HMI Functional Requirements

Deliverable D1.5 – WP1 – Public

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 814735.

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Work package 1, Deliverable D1.5

Please refer to this report as follows:

Grondelle, E.D. van, Zeumeren, I. van, Bjorneseth F., Borowsky, A., Chandran, T., Cleij, D., … Christoph, M. (2021). HMI Functional Requirements, D1.5 of the H2020 project MEDIATOR.

Project details:	
Project start date:	01/05/2019
Duration:	48 months
Project name:	MEDIATOR – MEdiating between Driver and Intelligent Automated Transport systems on Our Roads
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	This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 814735.

Deliverable details:	
Version:	Final
Dissemination level:	Public (PU)
Due date:	31/08/2020
Submission date:	31/03/2021

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Revision history

Date	Version	Reviewer	Description
14/12/2020	Preliminary draft 1	Professor Tal Oron-Gilad - Ben-Gurion University of the Negev, Israel	Internal review
20/12/2020	Revised draft	Elmer van Grondelle (Task Leader), Michiel Christoph (WP Leader), Ilse van Zeumeren (Researcher), Nicole van Nes (coordinator)	Processing internal review resutls and check of revised draft
08/01/2021	Preliminary draft 2	Professor John D. Lee - Department of Industrial and Systems Engineering, University of Wisconsin-Madison	External review
31/03/2021	Final draft	Michiel Christoph (WP Leader), Ingrid van Schagen (QA Officer), Ernst Verschragen (Administrative Manager)	Final checks
31/03/2021	Final deliverable	Nicole van Nes (Project coordinator)	Approved

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Foreword

This is D1.5 Functional Requirements of the MEDIATOR project. We are as proud to present this deliverable, regardless of the difficult circumstances under which the task was performed, and we are equally proud because of the difficult circumstances under which this task was performed. Despite this crisis, well beyond our influence and vastly affecting all staff and processes in time and resource unavailability, we have almost naturally maintained our enthusiasm and drive. A crucial success factor for that, is that we have rapidly transformed our once new consortium into a spirited alliance. Credit for that goes to our partners but certainly also to consortium leader SWOV.

This deliverable forms the basis for the HMI design task. A design task that has already started in overlap with this task, through its Research by Design strategy. The starting point for this task was formed by a set of identified knowledge gaps. Regardless of the aforementioned, unprecedented circumstances that limited experimentation possibilities for some partners, or even made experimentation impossible altogether for others, we are confident in our closing of the knowledge gaps. The few minor gaps that remain will be efficiently closed throughout the design process.

Credits are due to all who ran this gauntlet, who are duly noted and listed as authors. For lack of a specific section in the document format we have also included the talented designers of the first three HMI concepts that facilitated the research, Wang, Grazian and Mallon. Additional important contributors to the process are reviewer Prof. Tal Oron-Gilad (Ben-Gurion University of the Negev, Israel) and the core team at SWOV, led by WP leader Michiel Christoph.

Elmer van Grondelle

Task Leader

About MEDIATOR

MEDIATOR is a 4-year project led by SWOV. It started in May 2019. MEDIATOR will develop a mediating system for drivers in semi-automated and highly automated vehicles, resulting in safe, real-time switching between the human driver and automated system based on who is most fit to drive. MEDIATOR pursues a paradigm shift away from a view that prioritises either the driver or the automation, instead integrating the best of both.

Vision

Automated transport technology is developing rapidly for all transport modes, with huge safety potential. The transition to full automation, however, brings new risks, such as mode confusion, overreliance, reduced situational awareness and misuse. The driving task changes to a more supervisory role, reducing the task load and potentially leading to degraded human performance. Similarly, the automated system may not (yet) function in all situations. The objective of the Mediator system is 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.

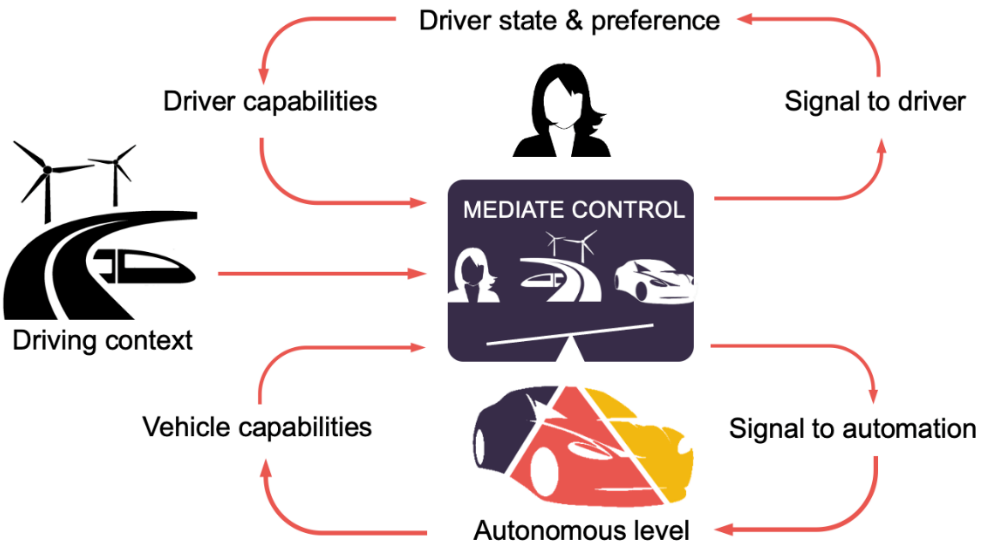


Figure 1 The MEDIATOR system will constantly weigh driving context, driver state and vehicle automation status, while personalising its technology to the drivers' general competence, characteristics, and preferences.

MEDIATOR will optimise the safety potential of vehicle automation during the transition to full (level 5) automation. It will reduce risks, such as those caused by driver fatigue or inattention, or on the automation side imperfect automated driving technology. MEDIATOR will facilitate market exploitation by actively involving the automotive industry during the development process.

To accomplish the development of this support system MEDIATOR 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.

Partners

MEDIATOR will be carried out by a consortium of highly qualified research and industry experts, representing a balanced mix of top universities and research organisations as well as several OEMs and suppliers. The consortium, supported by an international Industrial Advisory Board and a Scientific Advisory Board, will also represent all transport modes, maximising input from, and transferring results to, aviation, maritime and rail (with mode-specific adaptations.

Executive summary

The goal of the activities described in this deliverable, is to determine the **Functional Requirements** for the design of a Human Machine Interface (HMI) for vehicles that offer (partially) autonomous driving functionality. The MEDIATOR project is working towards a system that mediates, in real time, between the driver and the automated functions, ensuring that autonomous driving is always executed by combining the best of either's performance. The strategy by which this is done is research-by-design i.e., HMI design projects facilitate the research into a number of knowledge gaps, that were determined in our initial literature studies.

Despite of the severe impact of the Covid19 pandemic and the research limitations because of that, we have been able to make pivotal steps in closing the knowledge gaps and establish a starting position for HMI design.

Functional requirements form the bases for the Design Requirements by which the final HMI will be designed. This holistic HMI will be tested and evaluated in driving simulators as well as in on-road tests. The scope of these research-by-design projects is determined by non-functional requirements, use-cases to construct all relevant driving scenarios, and design requirements to ensure HMI design with raison d'être.

In a preliminary study we investigated the **Complexity of Mediation** i.e., the role of Human, Automation and Mediator by enactment, in order to obtain an understanding of how a Mediator system should work. In this study, in an experimental set-up, participants were given the role of the human driver and the automation, each with its own world view, and that of the mediator. The decisions of a Mediator system are based on the different views of the world between a Human driver and the Automation. This study yielded that the decisions of a Mediator system are mostly conservative because of these different views of the world on which it has to base its decisions. In addition, the results show that knowledge over time builds up trust and influences a Mediator's decisioning for future events.

Closing the knowledge gaps

The first knowledge gap **Transfer of Control** was researched in three studies from different perspectives; the control transfer from higher automation level to the driver, driver input towards automation preference, and the control transfer by means of specific potential technologies.

The first study on Transfer of Control introduces experiments for the transfer of control during a Time to Sleep (TtS) scenario within high automation. The experiments focus on the way of communication towards the driver during takeover transition in order to enhance the driver's situation awareness. Literature research and the experiments revealed that different (design)guidelines per stage of the take-over process are required. A first HMI concept was designed to perform physical and digital experiments in which the driver is guided step-by-step through the stages of takeover by means of signals by A-pillar light strips and a head-up-display.

Results of the experiments are translated into functional requirements, in related to the stages of a takeover experience (before a wakeup call, during a wakeup call, before a takeover request, during a takeover request) in order to improve driver's situation awareness. A key finding is the fact that in order to improve driver's situation awareness, drivers need to be guided step-by-step through all stages of takeover (before a wakeup call, during a wakeup call, before a takeover request, during a takeover request).

The second study on Transfer of Control builds on the first. After a literature and design study, its scope was narrowed down to driver input i.e., how drivers are to express their preference towards an autonomous level, for the control transfer ritual. This shift of control can give control to the automation to relieve the human driver of some, if not all driving tasks and vice versa.

Literature and user research showed that, in order to assure a smooth control transfer ritual, important requirements are the *simplification of automation levels*, frequent feedback, and a balance between user autonomy and automation-initiated actions. After a study into the positioning of the HMI elements, a third HMI concept was developed, which distinguishes three driving modes (manual, assisted and piloted driving) to communicate Mediator's four driving modes (conventional driving, Continuous Mediation CM, Driver Stand SB, and Time to Sleep TtS) to the driver.

Three concepts were tested by means of low-fidelity prototypes, after which a high-fidelity prototype of the chosen concept was built. The chosen concept, based on existing affordances, is a *redesigned automatic gearbox lever*, expanded with the three driving modes.

The third study on Transfer of Control addresses Control Transfers as a process during which a driver-automation system changes from one state to another involving reallocation of the longitudinal and lateral control task between the driver and the automation. The failure of effective communication regarding transitions such as take over request, takeover time, activated mode, time budget etc., could lead to safety-critical situations.

In this third study, a novel HMI interface (LED bar on steering wheel) was used to communicate transition related information to drivers. Two HMI concepts were made available, using the LED bar on a steering wheel, which were differed in color and illumination patterns. The two HMI concepts were compared with a baseline concept (without the LED bar on steering wheel) on subjective measures (trust, user experience and user acceptance). Results indicated that the two HMI concepts scored higher in all three metrics compared to baseline. Subjects also preferred to have the steering with LED bar for communicating transition related information.

The second knowledge gap concerns **Transparency and Information Overload**. One of the challenges in driving with higher levels of automation is to create mode awareness and appropriate reliance on the system. Transparency of the system is generally thought to improve both, as the driver can then understand the system and anticipate future system functioning. However, more transparency generally implies providing more information to the driver, which in turn can cause information overload. The research looks into this tradeoff between transparency and information overload, especially while driving with higher levels of automation. Literature research and several experiments, with different groups of participants were performed to provide insights into relevant types of information for the driver while driving with higher levels of automation.

The second HMI concept design in this research, conveyed specific information to the driver, as well as a subtle sense of the activated autonomous level by ambient lighting. The research concluded that the HMI should unobtrusively *communicate time budgets* such as minimum takeover time and the remaining time for which the current level of automation will be available, as well as information on *reasons for automation fitness to change*. The aim should be to create an ambience that reflects the current driver responsibility, which can also be perceived while NDRT's are performed. For long term planning of NDRT's also information on *route progress* and available automation levels along the route should be communicated. Finally, to improve the driver's understanding of the system, the HMI should also communicate information on *upcoming manoeuvres* and *automation perception*, such as other road users and traffic signs.

Research into the knowledge gap **Keeping the Driver in the Loop** i.e., countermeasures for Inattention, Distraction and Fatigue, was done through extensive literature studies and design inventory of existing solutions, either in production or concept vehicles, and available technologies in both the automotive as the aviation domain. Although a set of functional requirements on *countermeasures for HMI design*, was derived from the research, some caution towards the conclusions about their effectiveness is in order. Most of the investigated studies were done under specific conditions and did not include user acceptance perspectives such as the driver intention to use the system, perceived usefulness and usability of the system as well as personal differences.

The recommendations from this research, for HMI design, consist of the adaptation of Mediator intervention to the *dynamic situation of the triangle: driver, vehicle and context*. An imperative condition is that the driver should *understand the automation system*, fully and intuitively. For the visual inputs, the HMI designer has to use appropriate and effective colours, referring to established techniques in graphical HMI. The frequency of the interaction and the number of modalities for intervention depend on the immediacy of the situation. Another principle to be considered is the content of the information that should encourage the driver to adopt a behaviour that may decrease the risk of accident.

The knowledge gap **negotiating conflicts** i.e., when a human driver and the automation don't agree on the preferred automation level, was researched though a literature study which included other mobility domains with suspected experience in the negotiation between human and machine. Furthermore, an extensive inventory of potential conflicts in each autonomous level was composed. A main conclusion is that there is no single reply to the full spread of potential conflicts.

Each holistic situation must be analysed and assessed, such that a driver feels comfortable and in control, regardless of location or task, which can be achieved through research and testing. Disagreements about the automation's decisions will depend on the Human's attitude to, experience with and trust in Automated Driving Systems. Mediator *should be adaptable to different Human preferences*, selected by different experience modes or levels. To meet the individual driver's expectations to ADS, Mediator can be helpful in reducing potential conflicts. These findings, the aforementioned inventory on potential conflicts, and earlier ideas on HMI design for the negotiations between driver ad automation, frame our further research by the design of an HMI concept.

Conclusion

In conclusion, in this this report four out of five primary knowledge gaps have been researched. The fifth, OEM Design Space, can be addressed when the HMI design matures. Secondary knowledge gaps, Learning and Skill Degradation (unlearning) will also gain implicit attention in the further design process.

The collected functional requirements of the individual studies have been translated into one coherent set of functional requirements, through a number of cross checks, such as into the spread of investigated use-cases, and the identification of conflicting functional requirements.

In parallel with this process, additional HMI concept designs will further close the knowledge gaps, such as that of Negotiating Conflicts. Three HMI concepts have been designed, each in a number of redesign iterations. All HMI design concepts together, with the final set of functional requirements, translate into design requirements in an iterative process.

Readers' guide

Figure 2 provides an overview of this deliverable's structure in one glance. Icons depict if literature research and/or experiments have been conducted, and in which studies HMI Concept Designs have been developed.

Three framing chapters are depicted in red. In the introduction chapter we introduce our goals and objectives, scope and strategy. In chapter two we address the complexity of mediation. The collected functional requirements, collected from the various studies, are listed in the final Conclusions chapter.

Chapters which describe the nine studies in which the specific knowledge gaps are being researched are in between, in the order in which the knowledge gaps are being explained.

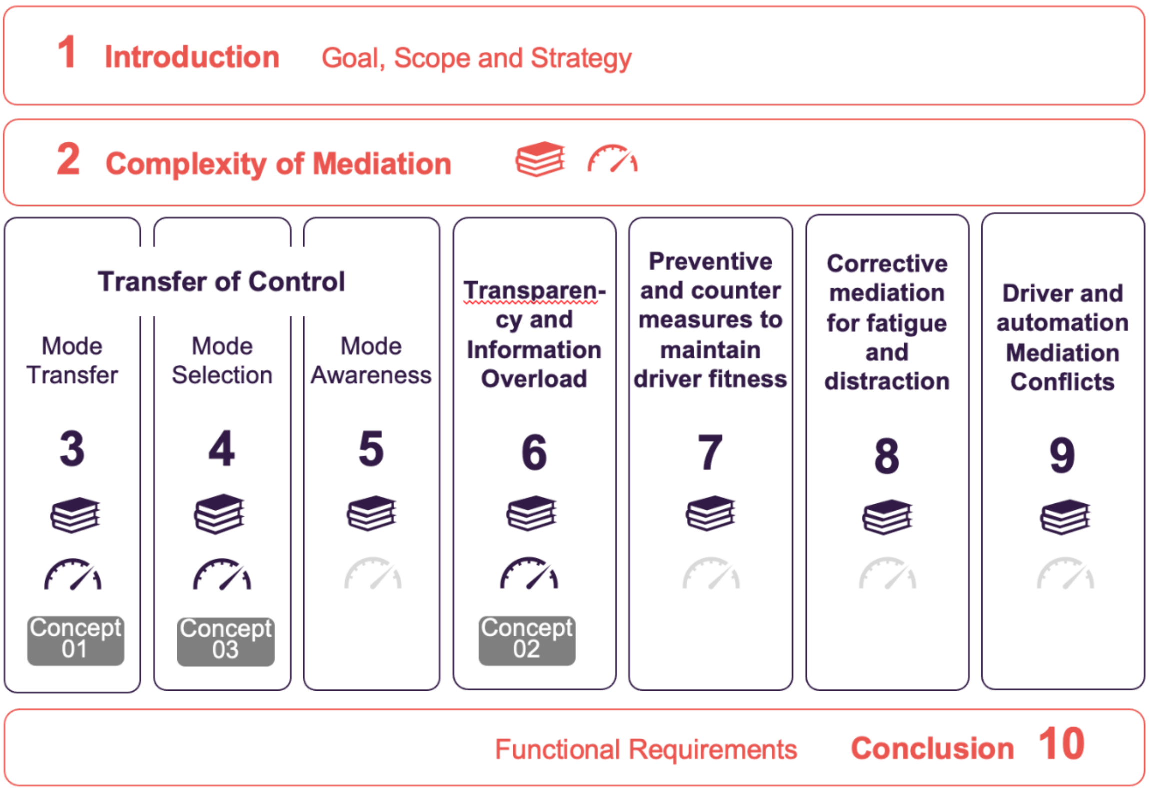


Figure 2 structure of this deliverable

1. Introduction

This document describes the first research phase in the development of the Mediator system's Human Machine Interface (HMI) i.e., the set of all interfaces that enables humans to engage and interact with the vehicle and its systems. The Mediator system (Figure 1.) is being designed modular and distinguishes, next to HMI, the modules Human Factors, Automation and Decision Logic (including Context), the latter of which is the central module to which the HMI has its only information gateway.

The main HMI functions are:

- Conventional driving tasks
- Guiding control transfers between driver and assisting or automated systems (take-overs).
- Perform negotiations between driver and automation regarding take-overs
- Execute preventive measures to maintain driver fitness
- Execute corrective actions to increase driver fitness
- Inform the driver appropriately on all of the above

The MEDIATOR project is working towards a system that mediates, in real time, between the automated functions of a vehicle and the driver, ensuring that autonomous driving modes are always made available with regards to automation fitness and driver fitness.

The HMI must ensure that the driver and the automation vehicle have a safe and acceptable exchange of roles and, as such, adhere to several non-functional requirements such as having high usability and transparency towards situational awareness (passive) and operating the system (active), and improving implicit conditions for that such as driver comfort and safety.

Continuously maintaining situational awareness (which is actually responsibility awareness) i.e., preventing mode confusion, is a key HMI design challenge with respect to information overload and underload, trust and overreliance, all of which are explained in more detail D1.1 (Christoph et al., 2019) and in this document.

1.1. Goal and scope of this deliverable

Next to the aforementioned unquantified non-functional requirements, described extensively in chapter 7 of D1.1 (Christoph et al., 2019), the goal of the studies described in this deliverable is to **deduce its functional requirements** by means of developing HMI design concepts. After identifying the important theoretical HMI principles, we define the prerequisites (e.g., correct type and detail of information, minimum takeover times) which will most successfully result in the required actions by drivers.

The project scope is set by:

- Aforementioned unquantified non-functional requirements
- MEDIATOR Use cases
- Design guidelines

1.1.1. MEDIATOR Use cases

Based on SAE levels 0 - 4 automation, three ‘general or ‘high level’ use cases were identified, to develop and evaluate the Mediator system (Christoph et al., 2019):

- **Continuous Mediation (CM) – Driver in the Loop** describes ‘assisted driving’. Drivers are responsible but supported by the automation. The automation generally performs the active control tasks, while the driver has a monitoring task. Challenges in this level of automation are *creating mode awareness* and supporting the driver with their part of the driving task by *creating an optimal task load*.
- **Driver Standby (SB) – Short Out of the Loop** describes ‘conditional automation’. Drivers can be out of the loop for a short time but must remain ‘on standby’ to take back control when needed. Challenges here are related to *regaining driver fitness* and balancing the time until the automation or driver becomes unfit, making sure always one is fit enough for the driving task. This challenge extends to the HMI challenges *of communicating these time budgets* and mediating *comfortable and safe takeovers* over a relatively short time span
- **Time to Sleep (TtS) – Long Out of the Loop** describes ‘highly level automation’. Drivers can be out of the loop for long periods of time and truly immerse themselves in non-driving related tasks and even fall asleep. Challenges in this level of automation are to *bring the driver back in the loop after full disengagement* and to predict when this will be required long enough in advance.

These ‘high-level’ use-cases focus on HMI challenges within driving modes and do not yet include the actual control transfers between driver and automation. Nor are they specific enough to design research. Therefore, ten ‘narrowed down’ use cases were constructed, a combination of which may be composed into a scenario for experimentation, as the example in the lower part of Figure 3 .

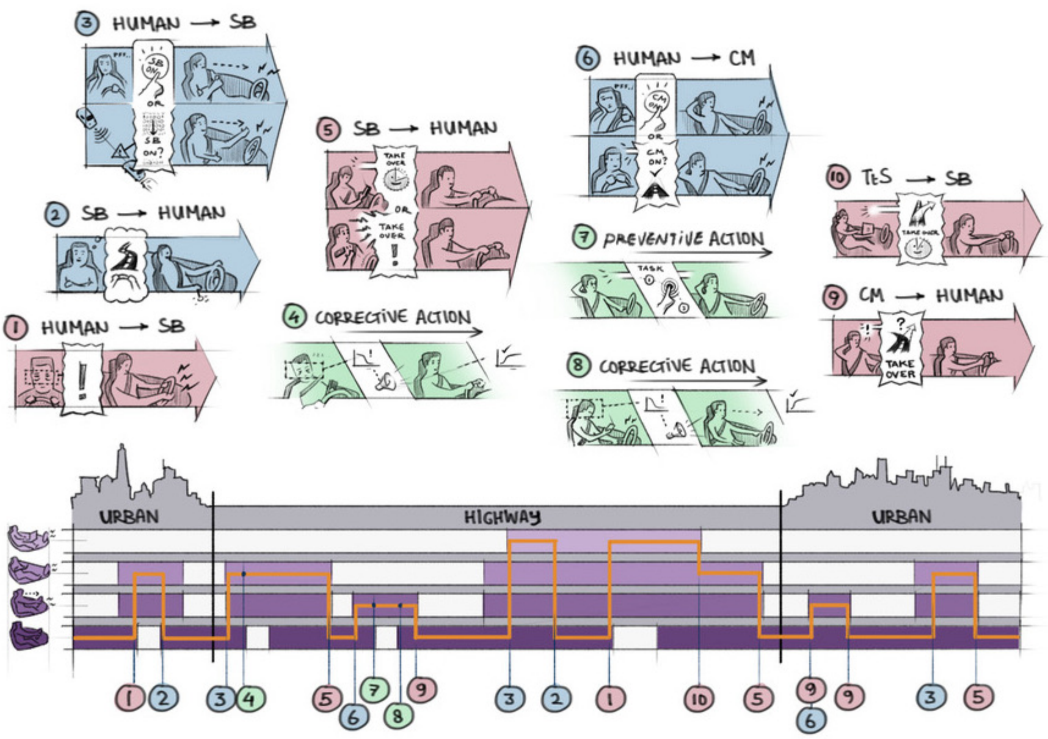


Figure 3 Mediator use cases (upper half) and an example of a scenario (lower half).

In the upper half of Figure 3, use cases are either labelled as mainly safety related (red or green) or comfort related (blue). A distinction is also made between safety related use cases that describe control transfers between automation levels (red) and those that describe driving within one level of automation (green). In the latter type there is also the important distinction between "preventive" actions that Mediator will take and "corrective" actions, both related to human performance.

1. Mediator system initiates takeover (human to automation): Degraded human fitness, caused by either drowsiness (a) or distraction (b), is detected by the Mediator system. The system reacts by initiating a forced takeover to automation.
2. Driver takes back control: The driver uses the HMI to indicate a desire to take back. The Mediator system reacts by confirming that the driver is fit enough to drive and guiding the takeover.
3. Comfort takeover (human to automation): Either the driver (a) or the Mediator system (b) initiates a takeover from human to automation.
    a) The driver indicates via the HMI that he/she is not motivated to drive. The Mediator system reacts by confirming the automation fitness and guiding the takeover.
    b) The Mediator system detects an event, such as receiving a text message or an upcoming traffic jam, from which it concludes that the driver comfort could be improved. The system reacts by suggesting a takeover to automation.
4. Corrective Action (SB): While driving in SB the human driver becomes drowsy. The Mediator system reacts by initiating an action to improve the driver fitness and monitors the effect.
5. Mediator initiated takeover (automation to human): A planned (a) or an unplanned (b) takeover from automation to human is initiated by the Mediator system.
    a) The automation indicates that the current route leads to automation unfitness as it will leave its operational design domain. The Mediator system reacts by preparing the driver for and guiding the driver through a non-urgent takeover.
    b) The automation indicates that its fitness is rapidly degrading and can soon no longer perform the driving task. The Mediator system reacts by informing the human driver and guiding the urgent takeover.
6. Comfort CM switch on: Either the driver (a) or the Mediator system (b) switches on driving in CM.
    a) The driver indicates via the HMI that he/she is not motivated to drive. The Mediator system reacts by confirming the automation fitness and switches on CM.
    b) The Mediator system detects sufficient fitness for driving in CM from which it concludes that the driver comfort could be improved, and reacts by suggesting switching to CM.
7. Preventive Action (CM): While driving in CM, the driver is supported by the Mediator system in performing the monitoring task. The system does this by trying to prevent underload and keeping the driver in the loop.
8. Corrective Action (CM): While driving in CM, degraded driver fitness is detected by the Mediator system. The system reacts by initiating a corrective action to improve driver fitness.
9. CM shuts off instantly: While driving in CM, the automation fitness degrades, and automation can no longer perform its driving task. The Mediator system reacts by communicating to the driver that CM is switching off.
10. Smooth transition from TtS to SB: while driving in TtS the driver is fully disengaged from the driving task when the automation indicates that the current route will leave the operational

design domain. The Mediator system detects sufficient automation fitness for driving in SB and reacts by informing the driver that SB will be switched on and subsequently monitors the required driver fitness.

1.1.2. Design guidelines

In order to assure a successful project outcome, in addition to the non-functional requirements that are inherit to the domain of (partially) autonomous driving, five design guidelines have been determined to frame the HMI research and design (Christoph et al., 2019):

Embracing a holistic approach

In order to design the vast complexity of an HMI for partially autonomous vehicles while securing (intuitive) usability i.e., simplicity for humans, the MEDIATOR 's HMI design guidelines state a holistic approach (Christoph et al., 2019). The complexity is twofold:

Firstly, because the HMI should take into consideration several demands that need to be evaluated and balanced: driver needs, and available technology in the project timeline. Related challenges include trust, mode awareness, fatigue and distraction, information load, user acceptance, industry acceptance, as well as learning and unlearning. Quite a few studies have been identified dealing with each of these challenges, both in the road transport section as in maritime and aviation. However, while a lot of knowledge exists, studies generally focus on individual challenges. Knowledge on dealing with multiple challenges simultaneously is largely missing. This is specifically relevant because a solution for one challenge may have negative side-effects with regard to dealing with other challenges, requiring evidence-based trade-offs.

Secondly, the Mediator system's overall schematic design (Figure 1) and that of its modules like HMI (*Figure 8*), suggest logical integration of all interactions between the vehicle and the driver, as well as the interaction with other sources through a central information gateway. In reality, the driver interacts with all sources independently, adding substantially to the overall cognitive load, either actively or passively.

The implication is that MEDIATOR HMI facilitates and manages all interaction components between human and vehicle for both primary, driving related tasks as well as for most secondary tasks like climate control or entertainment. We aim to carry this holistic approach throughout the project on the 'storytelling level' and carry its richness into dissemination and exploration (WP 4 and 5).

Design for user acceptance

A common assumption in autonomous driving research and design projects, is that a driver's suitability to control the vehicle is being determined by the system, based on a complexity of parameters that are either known about the driver or measured in real-time. In this line of thought the system decides unilaterally who has control over the vehicle, driver or automation. This disqualification of driver autonomy is in sharp contrast with the acquired status-quo in which driving ability is tested once in a lifetime, and only reassessed in special circumstances (e.g., alcohol abuse, high age). While the HMI plays a crucial role in avoiding misunderstandings, misuse, overreliance, reduced situational awareness and mode confusion, its success depends on its ability to facilitate driver autonomy, specifically towards chosen driving-modes, as they are primary components for achieving user acceptance (Christoph et al., 2019). The level of driver autonomy is foreseen to be larger towards the middle of the scenario spectrum in Figure 4.

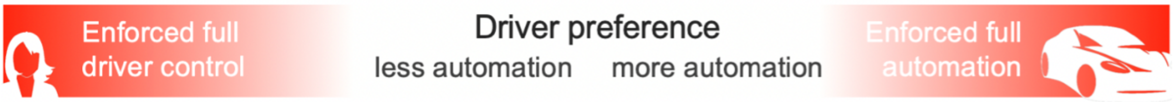


Figure 4 Spectrum of scenarios, with situational urgency towards the left and right ends of the scale (enforced control by either party), and identification of driver autonomy in between.

Design for industry acceptance

The automotive industry, which is structured by, and built upon deeply rooted emotional automobility values. While autonomous driving technology is a short-term business opportunity to create strategic advantage, in the long-term this rationalization of automobilism poses a risk towards the aforementioned automotive merits and structure because its rational parameters do, in principle, not inspire variation. For industry acceptance though, diversification in brand identity i.e., brand specific design of the human-product interaction, and manifestation of the HMI system (look and feel) are crucial. Brand identity i.e., brand specific design of the HMI is crucial for market penetration (Fiorentino et al., 2020).

In the MEDIATOR design process this means that we must identify design space, identify applicable value ranges and variation in visual, auditory and tactile design, rather than single values. As a restriction, variation in design is perceived to be unwanted in urgent or emergency scenarios.

In the scope of control transfer scenarios that will be initiated, monitored and managed by the Mediator system, variation in design is unwanted in scenarios in which driver preference is not a factor because of safety reasons (driver state) or vehicle performance (autonomous ability). See Figure 5, which builds on the scale of Figure 4. In all other situations however, design space may be identified in which consecutive OEMs have design freedom to create brand specific variation. Design freedom is likely to be the biggest in the middle of the scope where there is no Mediator system preference towards the level of control by either driver or vehicle.

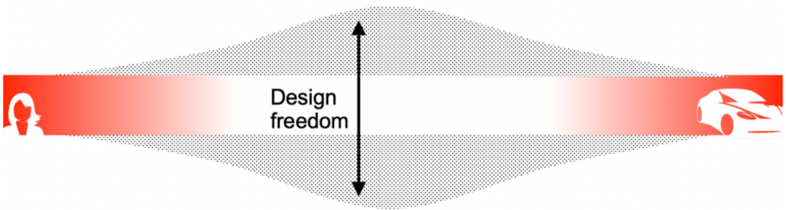


Figure 5 OEM design space for brand identity, crucial for industry acceptance.

Design a generic transfer ritual

The underlying principle for the design of HMI should be to elicit safe and sustainable behaviour of the driver in his/her interaction with the vehicle. In the interaction between the Mediator system and the driver, the information provided to the driver must be tailored to each transfer scenario, to evoke adequate driver fitness and actions within the available timeframe. Driving scenarios are composed out of the ten use-cases in the previous paragraph.

Decision Logic (DL) can request take-overs from the human driver (hereafter: driver) to automation or vice versa (e.g., use cases 3, 5 and 6, paragraph 1.1.1). The take-over procedure follows in which the driver is timely informed on, and guided through, the take-over, including measures to increase driver fitness if appropriate. Other interactions like increasing driver fitness, follow the same process. Despite this vast variety in interactions with the HMI in these scenarios, all interactions are constructed from the same components, similar to the standard model of human cognitive process. A standard sequence within control transfers between human and vehicle, either full or partial, serves as a template. Structural application and consistent visualization of the template in use cases, design processes and experimentation assure comparability, thus minimizes the risk of bias.

The control transfer ritual, Figure 6, foresees signals at specific time intervals, and required driver responses. Time intervals, the number, multi-modality and intensity of signals are all variable, depending on time budget and driver response, as indicated by Decision Logic.

Figure 6 Generic control transfer ritual

While the template of this transfer ritual and its components are fixed, the values of each component vary. The transfer ritual consists of the following components (Figure 5):

- S1, S2... Sn are signals of the HMI to the driver. Signals may trigger different senses or a combination thereof, while intensity and intrusiveness are likely to be determined by the urgency of the situation, i.e., the driver's required response time. Components of each signal that must be designed (auditory, visual, vibration, ...) are their intensity and duration, and if and how they are combined (multimodal).
- t1, t2... tn are time intervals from one signal to the next. Time intervals are being determined by the anticipated moment of the actual (partial) control transfer and the driver's response, i.e., changing state of alertness or driver fitness.
- Transfer is the actual control transfer of (partial) control from driver to automation or from automation to driver. While rituals are to be designed from the same HMI component-set, processes may differ.

Design for learned affordances

It is also important that the HMI design is compatible with current and future standards for HMIs for ADS and in line with users' intuitive expectations, as well as understandable for all drivers, independent of, for example, linguistic and IT abilities (Fiorentino et al., 2020). Thus, the design should be such that any licensed driver is able to use the HMI effectively and safely in any vehicle.

Timing of alerts is a major parameter in (autonomous) driving vehicles. It must be adapted to the emergency of the situation. Messages should be provided early enough for the driver to be able to react in the proper way. Timing is also essential in addressing the challenge of potential conflicts i.e., when driver and decision logic disagree on the preferred driving mode. This may occur because of mere driver preference or because the driver and the mediator system interpret the context differently.

Figure 7 Generic control transfer ritual with cognitive process -SPA (Signal – Processing – Action).

In the interaction ritual, introduced in the previous paragraph, the human cognitive process throughput time, depicted as SPA (Signal – Processing – Action), adds to the overall interaction time. This cognitive process can be skill-based, rule-based or knowledge-based, have different throughput times. A skill-based response (intuitive) is the fastest, not unlike an instinctive or intuitive reaction.

Familiar affordances (standardisation) are essential to overcome issues related to learning new (driving) skills while conventional driving skills remain. Familiar affordances are also essential to process the complexity of information and reduce cognitive response time.

Given that the MEDIATOR HMI will combine conventional driving skills with new driving skills, new functionalities, unfamiliar to the conventional automotive HMI, will be added. In that case the design directive would be to build on general known affordances in such a way, that they do not conflict with long-time learned affordances, like the form of a stick-shift or the location of blinker controls.

1.1.3. Knowledge gaps

At the beginning of the MEDIATOR project, after an initial literature study, knowledge gaps have been identified and prioritized for further research. In the prioritization five of those knowledge gaps out of eight have been earmarked as primary. With respect to expertise and allocated resources, those have been assigned to leading partners, while the remaining 'secondary' three have been earmarked to be researched within the primary knowledge gaps, upon opportunity and appropriateness (Christoph et al., 2019).

Knowledge gap 1, transfer of control

A generic transfer ritual has been described at a conceptual level, but knowledge is missing on how to best operationalize this ritual into a concrete transfer protocol for the Mediator system. With each take-over request a level of necessity, and a timeline, are provided, which together indicate the level of urgency. The way in which a take-over request is communicated to the driver and how the actual take-over ritual is executed, therefore differs depending on level of necessity.

Knowledge gap 2, transparency and information overload

A recommendation to prevent overreliance is to inform the driver about the operational design domain of the automation. Care should be taken not to overload the driver with too much information. How to elicit the optimal balance between transparency and information load, as to prevent mode confusion i.e., responsibility awareness?

- Mode confusion: informing the drivers on their task might be clearer but avoids the development of a mental model of automation behaviour and therewith restricts anticipation possibilities.
- Overreliance: transparency and making the limits of the automation clear can prevent overreliance but can also increase workload when processing this information.

Knowledge gap 3, keeping the driver in the loop

How to keep the driver in the loop i.e., elicit continuous monitoring and prevent distraction in CM (use cases 4, 7 and 8, Par. 1.1.1)

- Which task will we focus on in CM: e.g., haptic shared control or Active monitoring?
- How do we design, implement and test this task?

Knowledge gap 4, conflicts negotiating

Maintaining driver autonomy over driving mode decisions is crucial for trust and user acceptance. User acceptance has been framed in terms of preferences with regard to who is in control: driver or automation i.e., driver autonomy. Conflicts may arise when the Mediator system tries to improve driver fitness (e.g., a wake-up call, direction attention to the road), or when the Mediator system enforces manual driving to prevent de-skilling while the driver prefers to delegate control to the vehicle. Knowledge is missing, on how to predict the occurrence of such conflicts, and how to resolve them. In case the driver indicates a different preference than DLs preferred autonomous level, the HMI must negotiate with the driver. For low necessity levels a seductive negotiation between automation and human is applied, while for higher levels a persuasive negotiation is applied, or even a forced take-over (no negotiation).

Knowledge gap 5, OEM design space

The design requirement Design for Industry Acceptance implies an HMI design in which for components and parameters so-called design space or design freedom must be anticipated. An important question is, which aspects of the HMI are not safety critical and thus allow for design freedom, and which aspects of the HMI should be standardized and follow existing standards for safety reasons?

While preliminary indications may be derived from the research into other knowledge gaps, the research into this knowledge gap requires a full HMI to be completed. This research is anticipated to be conducted during WP2, and continuously in WP3.

Knowledge gap 6, intuitive learning

While the design guidelines foresee in an HMI, which builds on known affordances, new functionality indicates that some learning functionalities in the HMI may be in order. Affordances may be derived from the automotive domain or from other domains in case of functionality that is new to the automotive domain.

- How to implement learning (for novice users) and re-learning in an HMI design?
- How to detect skill degradation?

Knowledge gap 7, long term effect i.e., skill degradation and compliancy

Knowledge gaps 6 and 7 were initially identified as separate knowledge gaps, they address respectively learning and unlearning. Early design ideas indicate that it is to be expected that in HMI design the relevant tasks will be performed by the same algorithms and components.

Knowledge gap 8, human driver characteristics

General recommendations have been given with regard to learning how to use the Mediator system and how to deal with mode confusion. Knowledge is missing though, on if and how differences between users should be reflected in the chosen approach. For example, a skilled pilot may be able to interpret detailed information on automation.

1.2. Strategy

The goal of the activities described in this deliverable is to deduce the HMI functional requirements. Our strategy is **Research by Design** i.e., by means of developing HMI design concepts. Those concept designs initially serve to determine the research scope, identify thinking areas and inspire holistic thinking in the consortium. The aforementioned knowledge gaps are the starting point for subsequent research and experimentation. In the research by design method, the purpose of these

HMI design concepts is to inspire research questions and to provide all partners with design concepts with the objective to:

- Conduct (small-scale) laboratory and simulator studies to test theoretical concepts for their practical value, usability and user acceptance.
- Deduce the functional requirements for the MEDIATOR HMI from the studies conducted, with technical feasibility as a limiting condition.

Because the dynamic of concept design projects is different than that of a research project such as MEDIATOR, the research staff in MEDIATOR is enforced with graduation projects. A number of concept designs are rapidly being generated to research specific issues in the knowledge gaps, each time combining acquired research insight with newly generated design insight. Whenever appropriate, these projects are carried out in cooperation with or under assignment form one of the partners. To ensure scientific quality, each graduation project is being mentored by research staff as well as design staff. In the chapters on the knowledge gaps a number of those projects are being shared. In this iterative process, that is also fed by MEDIATOR's research phases, the final HMI concept design is developed.

1.2.1. Diverging applied HMI components

Figure 8 shows the interrelationship between HMI software and hardware components and the HMI Component Gateway to Decision Logic. Hardware components are grouped per technology domain. There are no a priori limitations to HMI design solutions. To increase innovation potential, it is important not to disqualify ideas, research subjects or technologies too early in the project. All different modalities, including visual, auditory and haptic, will be considered. As initially proposed in the Mediator project and confirmed in MEDIATOR's exploitation strategy (Fiorentino et al., 2020) developed design and technologies must be feasible within the MEDIATOR time frame. The development, integration, and research of HMI components are speeding up and emerging technologies are becoming accessible in the near future. For example, the potential of head-up displays and speech recognition technologies is improving in maturity and thus to be considered in HMI design, while windshield dimming is not expected to mature within the timeframe.

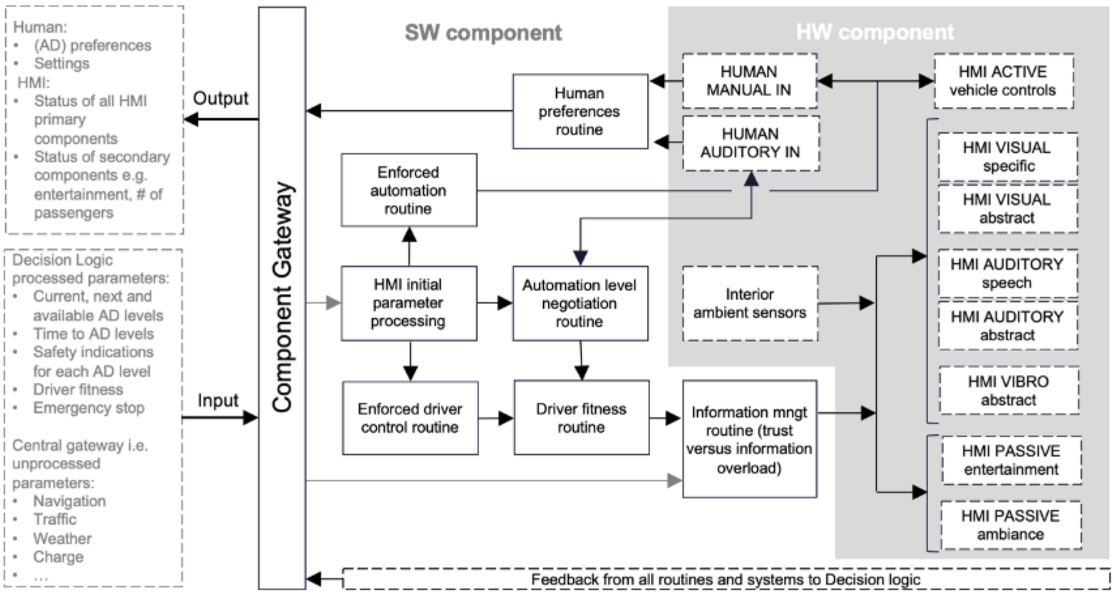


Figure 8 HMI main software and hardware components.

To facilitate rapid concept design projects a comprehensive table of possible technologies and components has been made available to partners. Even the kinaesthetic effect of a vehicle's longitudinal and lateral control is identified as a possible means, derived from conventional driving. Components or technologies in the table, may be grouped by the human senses which they trigger, specific or abstract. An indication of a component's physical position in the vehicle's interior is also given. Potential usage is also identified in terms of application in human machine interaction (output / input). Humans may be the driver, a passenger, or other traffic outside of the vehicle.

Concerning the latter, note that while the external HMI is out of the scope of MEDIATOR it must be acknowledged because it may add to HMI design complexity as it may require manual control, like blinkers and warning signals.

Assessment of the list will reveal that the majority of the listed technologies and components may be considered mature technologies or even embedded in contemporary vehicles. Note, however, that avoiding mode confusion i.e., elicit awareness on a driver's momentary responsibility (operational design domain ODD), is a task that will most likely benefit most from MEDIATOR's holistic design approach because that implies control over the overall interior of a vehicle beyond mere isolated controls. The HMI prototyping and manufacturing challenge lies in this holistic approach, which dictates a full integration of all HMI components. This is not the case in contemporary vehicles, nor does it comply with the automotive industry's organisational structure with its several layers of many suppliers (Fiorentino et al., 2020).

2. Complexity of mediation

One of the essential aspects in the MEDIATOR project is the actual mediation that has to take place between the way technology perceives the world and how a human perceives the world. In Van Egmond, de Ridder & Bakker (2019) — analogous to Parasuraman, Sheridan & Wickens (2000) — the processing of the information from the environment has been described as similar processes, these are: Human Information Processing (HIP) and Technology Information Processing (TIP). Both processes end up with their own “view” (Umwelt, Jakob von Uexküll) on the world (Umgebung), which can be similar or contradicting. In case of the latter questions arise like “Who to follow?” or how to exchange information in such a way that a satisfying decision can be taken for both parties. This should be the task of a Mediator system, which takes into account the stages of the proposed transfer of control ritual (that is intended to give weight to the decision made by HIP and TIP). In this chapter we will explore how decisions made by HIP and TIP are processed by a simulated Mediator using an enacting paradigm. The use of such a paradigm is often used in projects in which an automated system has to be developed and ideas need to be generated of how such a system would work and what is needed for such a system (see, e.g., Strömberg, Petterson & Ju, 2018).

2.1. Experimentation design

In this experiment a Mediating system was investigated using enactment. The experiment was performed with three acting roles *Automation, Human and Mediator*. *Automation* and *Human* were shown three different *Situations* consisting each of four scenes that appeared in consecutive order. The context of the Situation (Umgebung) was the same, but the actual imagery was designed to create a different Umwelt to mimic the processing of *Human* and *Automation*.

Participants

Eighteen participants volunteered. The participants were all members of the MEDIATOR consortium.

Stimuli

Two sets of four sequential screens were designed that mimicked human and technological processing of three environmental situations: *Traffic Light*, *Cyclist* and *Fog*. The screens are depicted under Figure 14, Figure 15 and Figure 16 in the Results section, respectively. Each situation was preceded with a screen announcing the start of the situation with a number, not with the actual topic.

Apparatus

To enable a more realistic imagination of the actors we used the CMMN car (ref?) in which the Human and the Automation actors sat on the front seats of the car and the Mediator actor in the back. Figure 9 depicts three photos of different events in the experimental procedure. A curtain was used such that the Automation actor and the Human actor could not see each other’s screen. The Mediator actor was positioned in the back and could not see the screens in front of the car. The images of the situation were presented manually using PowerPoint with the presentation divided over two screens to avoid timing differences. On the left Screen the Human slides were shown and on the right screen the Automation slides. Specially designed answer cards were used for the Human and the Automation (see Figure 10).

Figure 9 Photographs of the experimental set-up. Left photo: the CMMN car with driver and automation screens and a curtain in between. In the middle photo a driver is looking at the start screen of the experiment. The Right photo shows a participant (ic., Automation) handing a decision card to the Mediator.

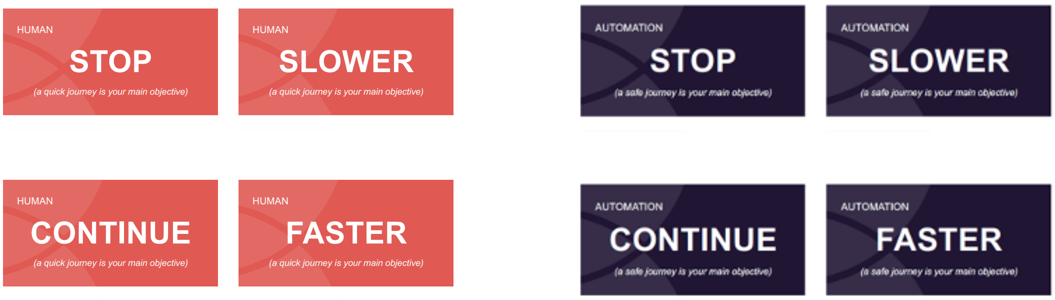


Figure 10 Instruction cards for the Human and Automation actor. The Human cards contained the instruction "a quick journey is your main objective". The Automation card contained the instruction "a safe journey is your main objective". The four choices were the same for Automation and Human.

Procedure

Participants were selected and instructed during a formal dinner of a Mediator joint task meeting at the Delft University of Technology on February 20, 2020 (Figure 11). This was just before the COVID-19 crisis and it enabled us to set-up an experiment to test the Mediator system with enactment and let Mediator members experience a Mediator system.

Figure 11 Participants at TU Delft

All participants were MEDIATOR consortium members; thus, they could imagine how a mediating system should function. Each session consisted of one group of three participants that could choose a role: *Automation*, *Human* or *Mediator*. In total six groups of three participants were formed. Each individual actor of a group was instructed separately concerning his or her role. The *Automation* and the *Human* had to choose the speed matching the scene they saw from the instruction cards shown in Figure 10. They were allowed only to choose one of the four speeds (ic. cards) presented (Stop, Slower, Continue and Faster).

The *Automation* received the additional instruction “a safe journey is your main objective “(because ADAS systems are often designed for safety) and the *Human* “a quick journey is your main objective” in order for them to envision the objective of the journey. Different instructions were given that would be similar to implementations in the car system (most technology systems, e.g., are introduced to improve safety, while a human may be in a hurry) *Automation* and *Human* had to hand their cards to the *Mediator* in the back, no discussion among the three participants in a group was allowed. The *Mediator* notated the answers on a response sheet (see Figure 12) and received the instruction “Mediator system: the vehicle’s battery charge is low. So, a steady journey is your main objective”. In addition, the *Mediator* had to make its own decision by filling in the speed (Stop, Slower, Continue and Faster) based on the decisions of *Automation* and *Human*. In addition, the *Mediator* had to indicate how difficult the choice of speed was. Thus, the Mediator was the only one who saw all the answers and filled them in. The order of the situations ((Traffic Light–>Cyclist–>Fog) was fixed for the groups. The experiment was self-paced in such a way that the Mediator indicated to the experimenter outside the car to proceed to the next scene.

Situation 1: Traffic lights

	Human				MEDIATOR				Difficulty	Automation			
Screen 1	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 2	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 3	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 4	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster

Situation 2: Cyclist

	Human				MEDIATOR				Difficulty	Automation			
Screen 1	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 2	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 3	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 4	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster

Situation 3: Fog

	Human				MEDIATOR				Difficulty	Automation			
Screen 1	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 2	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 3	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster
Screen 4	stop	slower	continue	faster	stop	slower	continue	faster	1 2 3 4 5	stop	slower	continue	faster

MEDIATOR: your battery charge is low. So, a steady journey is your main objective

Figure 12 Example of the answering sheet that the Mediator actor used. This sheet comprised the answers of the three Actors: Human, Automation, and Mediator. The Mediator actor also assessed the level of difficulty while making a decision.

2.2. Results

The data was analysed with a 3-way repeated measures analysis with *Actor* as between factor and *Situation* and *Screen* as within factors. The dependent variables were *Speed* (4-point scale) and *Difficulty* (6-point scale, only measured in the *Mediator* condition). Mauchly's test for Sphericity showed that sphericity had not been violated for the *Situation* $(X^2(2) = 1.80. p = .41)$ but yielded significance for *Screen* $(X^2(5) = 12.35. p = .03)$ and the interaction *Situation* * *Screen* $(X^2(20) = 38.13. p = .01)$. For the effects that violated sphericity a Greenhouse-Geisser correction on the degrees of freedom is used. Cohen (1988) has provided benchmarks to define small (η^2 = 0.01), medium (η^2 = 0.06), and large (η^2 = 0.14) effects. The partial eta squared are also indicated. The effect for *Actor* was not significant (*F*(2,15)=.78., *MSE*=.96, η^2 =..09, *p*=.48). Significant main effects were found for *Situation* (*F*(2,30)=32.51, *MSE*=16.95, *p*<.001, η^2 =.68) and *Screen* (*F*(1.98, 29.75)=62.02, *MSE*=22.12, *p*<.001, η^2 =.81). Significant two-way interactions were found for *Situation* * *Actor* (*F*(4,30)=11.49, *MSE*=5.99, *p*<.001, η^2 =.61), *Situation* * *Screen* (*F*((3.25,48.80)=22.81, *MSE*=11.44, *p*<.001, η^2 =.60), and *Actor* * *Screen* (*F*(3.97,29.75)=2.720, *MSE*=.97, *p*=.049, η^2 =.27). The latter interaction effect being the smallest. A three-way interaction effect was found *Situation* * *Actor* * *Screen*, *F*(6.51,48.80)=2.91, *MSE*=1.46, p<.015, η^2 =.28, indicating that different decisions are made for the three contexts for each actor and dependent of the position of the vehicle in the context.

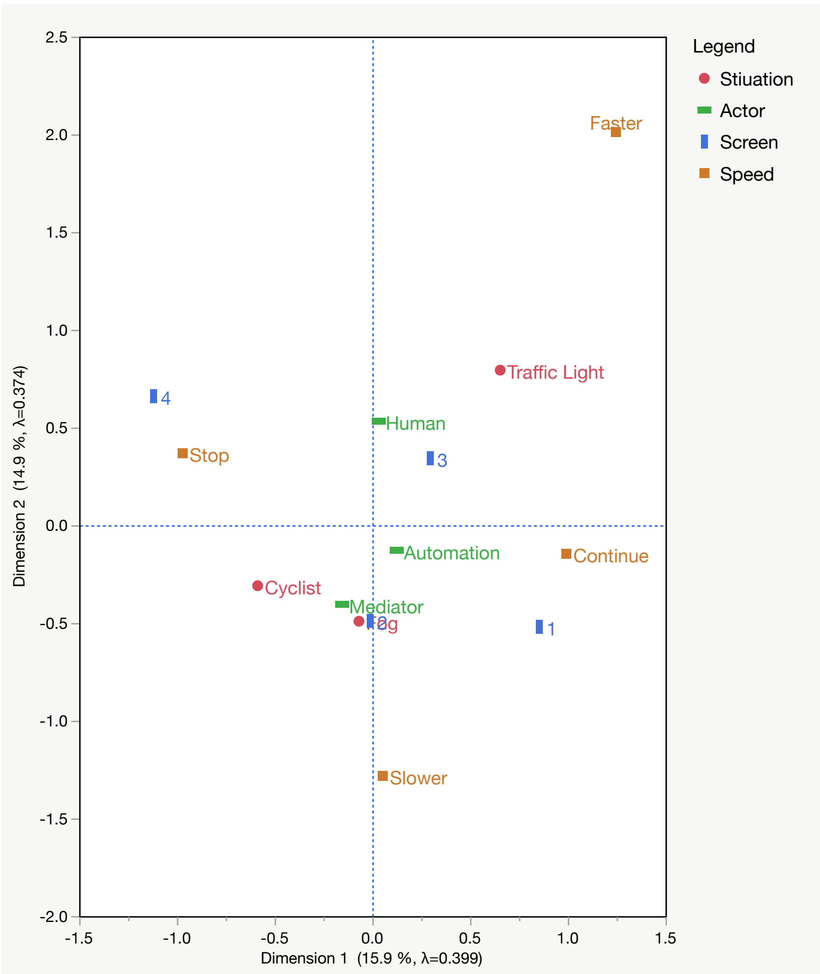


Figure 13 Display of the first two dimensions of a Multiple Correspondence Analysis, with Situation, Actor, Screen and Speed as multivariate factors.

A Multiple Correspondence Analysis was performed with Situation, Actor, Screen and Speed as multivariate factors in order to obtain a visual interpretation of how the factors are associated with each other. In Figure 13 two dimensions of the correspondence solution are displayed explaining 30.8% of the variance. It can be seen that *Mediator* is associated with *Cyclist* and *Fog* and is attracted by *Slower* and that *Human* Behaviour is more associated with *Faster* and *Traffic Light*. It can be that Mediator receives conflicting messages from *Human* and *Automation* and is therefore more precautious (uncertain) in making decisions. What is also apparent is that the overall judgment is *Stop* for *Screen4*. To obtain more insights into the behaviour of all parties involved, we analysed the rating scores for each situation.

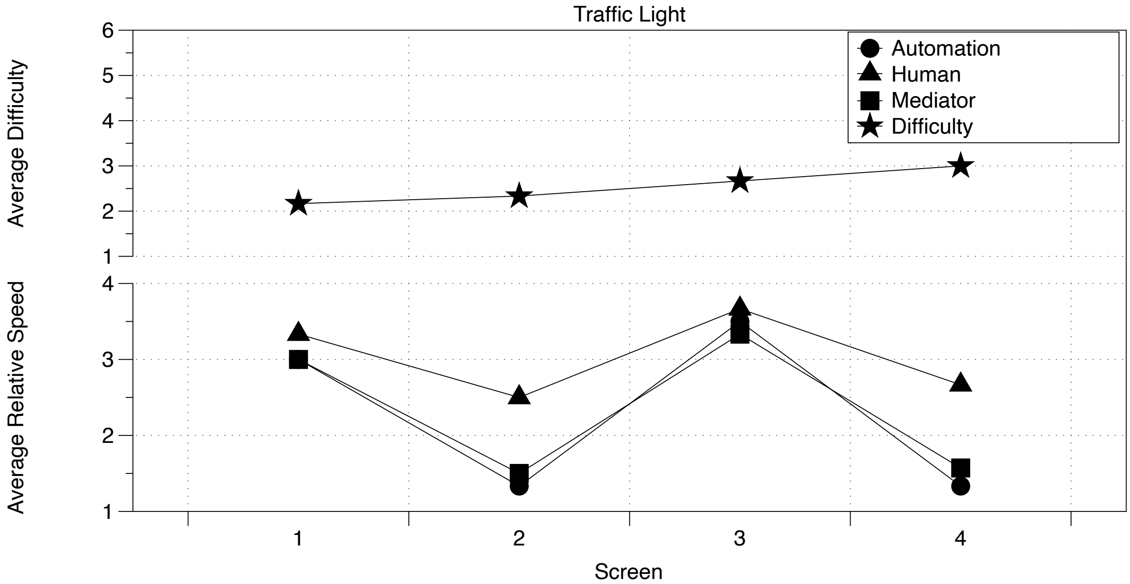


Figure 14 Average Speed Ratings as a function of Screen and Actor, Top panel lower half for the ***Traffic Light Situation****. Average Difficulty ratings for Mediator in Top Panel upper half.   Below line plots, the Screens for the Automation and Driver are presented.*

In Figure 14 the Average Speed Ratings as a function of *Screen* and *Actor* are depicted (Top panel lower half) for the *Traffic Light Situation*. As can be seen the Human is the upper line whereas the Automation and Mediator show very similar lower ratings over *Screen* order. It can be seen that for *Screen3* the three *Actors* increase their speed. However, in *Screen 4* the *Human* shows that it wants to continue to go through the orange light (something that can be seen in Figure 13 where *Faster* is a kind of outlier for *Human* and *Traffic light*), whereas *Mediator* and *Automation* want to stop. The Average Difficulty ratings for Mediator show that overall, this rating is low (thus not difficult to make decisions), although there is a slight increase for Screen 4 in which the *Human* response is different from *Automation*. Consequently, *Mediator* has more difficulty to decide.

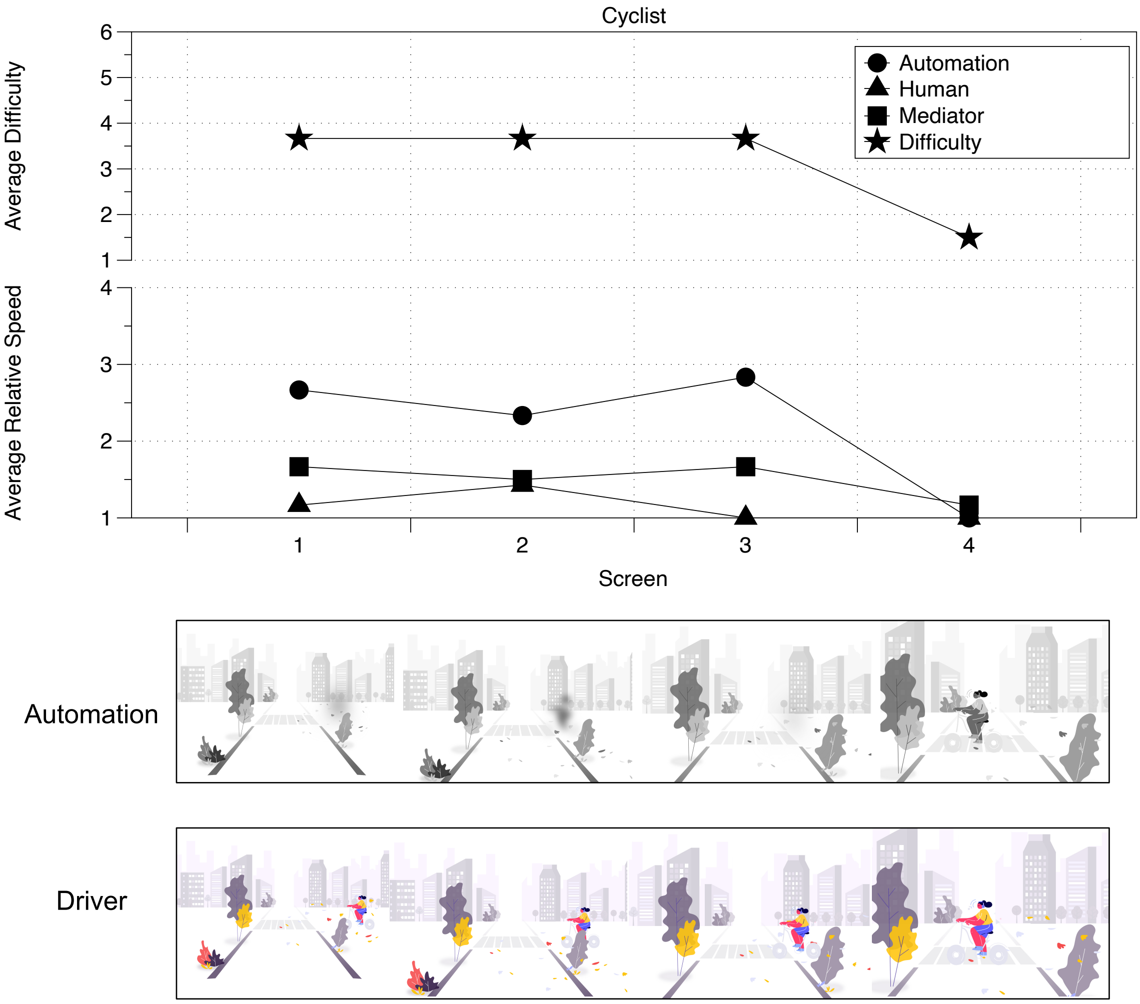


Figure 15 Average Speed Ratings as a function of Screen and Actor, Top panel lower half for the ***Cyclist Situation****. Average Difficulty ratings for Mediator in Top Panel upper half. Below line plots, the Screens for the Automation and Driver are presented.*

In Figure 15 the Average Speed Ratings as a function of *Screen* and *Actor* for the *Cyclist* Situation are depicted. If one compares this figure with Figure 14 one can readily see that the *Mediator* now follows the *Human* decision the most. This is probably due to the fact that the *Human* decisions are mostly around 1 (Stop), the *Automation* has in this case problems recognizing the cyclist due to occlusion of the cyclist by vegetation. The *Automation* only recognizes the Cyclist in the last screen and then decides to Stop. It is also worthwhile to note that the decision for the Mediator is more difficult because of the more deviating decisions of *Human* and *Automation*.

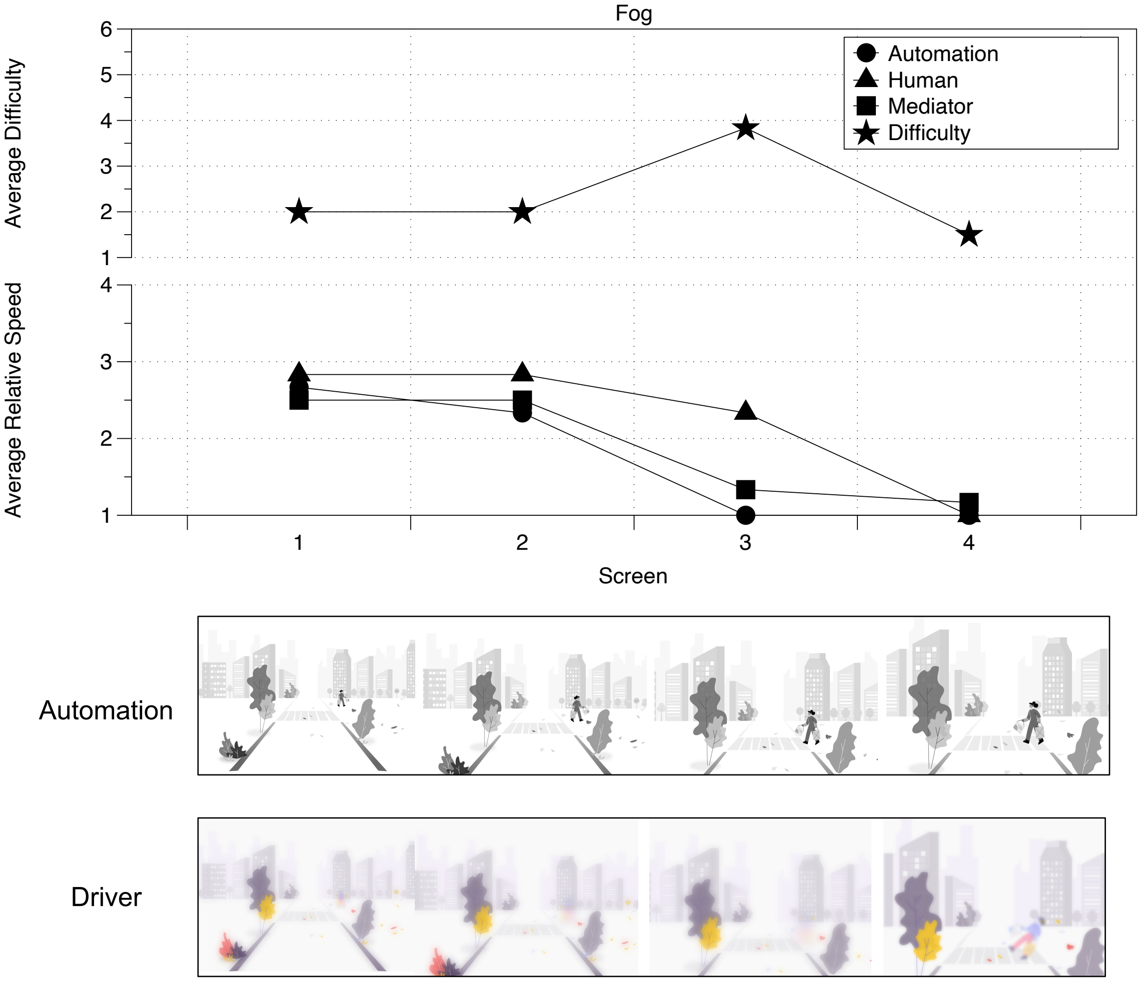


Figure 16 Average Speed Ratings as a function of Screen and Actor, Top panel lower half for Fog Situation. Average Difficulty ratings for Mediator in Top Panel upper half. Below line plots, the Screens for the Automation and Driver are presented.

In Figure 16 Average Speed Ratings are depicted as a function of *Screen* and *Actor* for *Fog* Situation. It can be seen that the decisions of all three actors largely coincide but that for Screen3 the decision of the *Human* differs from that of the *Automation* and the *Mediator*, in such way that the *Human* continues to drive where the *Mediator* follows the *Automation* to slow down or stop. One can see that this decision is more difficult (higher difficulty rating) for the *Mediator* because the decisions of the *Human* and *Automation* differ at *Screen3*.

Another important aspect that can be derived from Figure 14, Figure 15 and Figure 16 is that the *Mediator*'s decisions show a trend in following all four decisions of that actor (either *Human* or *Automation*) that has yielded the lowest speed at the initial screen, thus providing the safest choice. This can be considered as a build-up of trust of the *Mediator* system over time, taking both *Human* and *Automation* seriously.

2.3. Conclusions

It can be concluded that the actors showed that they understood the instructions and therefore fulfilled their enacted role properly. Consequently, it shows that the use of enactment is a proper way to mimic the behaviour of a system. It means that the outcomes from this paradigm are valid and consequently can be used to develop the concept of the mediator system. Our main finding is that in order for a Mediator (system) to function properly it needs to be able to handle (active) decisions from the Human Information Processing (HIP) and from the Technological Information Processing (TIP), which have been based on their own imagery (*Umwelt*) of the same world (*Umgebung*). Consequently, this has important implications for the design of the human UI, given that the input of TIP is directly handled by the AI in such a way that the interface should be able to allow active input of how a human interprets the world.

A completely free form of interaction could be handled by speech, but this system should be perfect under all circumstances (think of masking effects by other sounds or when the speaker is not very articulative) or instructions should be limited to a list of simple commands that a user has to know. If this limited list of commands is needed, one could also think of other input devices than speech. Important to note here, is that we mean other input than input that allows the human to perform tasks (fit to drive principle), which is captured from sensing the human on basic characteristics like fatigue (if possible, at all).

Another point that can be noticed in observing the response timeline of the *Mediator* is the hesitation of the actors over time. The *Mediator* is not always sure and sometimes follows the *Automation* and sometimes the *Human*. If one interprets this behaviour, one could state that there is room for negotiation if one extrapolates these findings into the real-life situation.

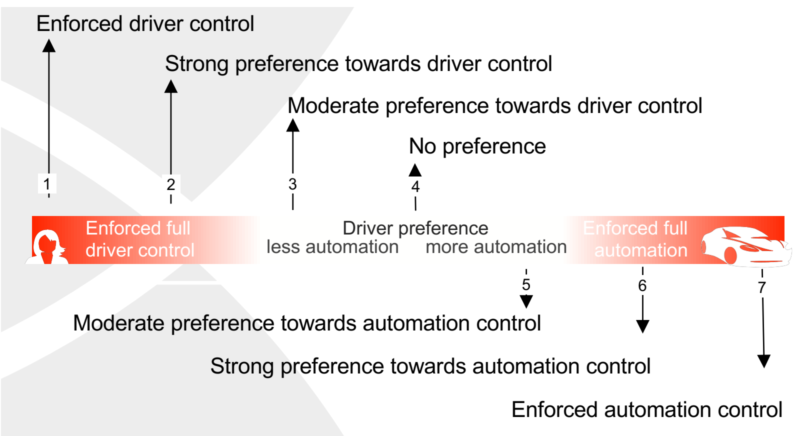


Figure 17 An overview of the responsibilities of who is in control of an automatic vehicle. At both end points of this scale there is full control of the driver or the automation. In between there is a possibility of negotiation.

In Figure 17 a conceptual framework is presented in which the possibilities (degrees of freedom) are presented of a driver (*Human* in the present study) and the *Automation*. The results found in this study fit these proposed possibilities of control nicely. We have shown that there is a need for humans to communicate their decisions based on their own view of the world to the mediator. In current automated vehicles, only the car gives input to the AI module and a human's intention is derived from sensor data that only makes a guess of the conditional state of a human. To build up trust and acceptance in highly automated vehicles, a driver's individual judgment should also play an important role.

3. Transfer of control, ritual

3.1. Strategy

This chapter presents experiments for the **transfer of control** during a **Time to Sleep (TtS) scenario in SAE level 4.** In order to gain knowledge within this domain, literature research has been conducted. To effectively prioritize gained knowledge, several automated driving specialists were interviewed. This analysis resulted in the uncovering of pain points from specialists' point of view. Subsequently, user research was conducted with Tesla autopilot users. Therefore, these users filled in an online questionnaire which resulted in insights regarding usability issues of the autopilot. The findings of the literature and user research were used to design an HMI concept, which is evaluated in a test set-up with participants with different levels of driving experience. The results of this experiment were used to redesign the concept, which thereafter was evaluated online. Finally, the concept is evaluated from two perspectives: the perspective of (MEDIATOR) experts and the perspective of (future) users.

3.2. Literature Research

The focus of the literature research is derived from the following research questions:

1. When is it needed to communicate what kind of information and how to communicate the information with the driver during takeover transition?
2. How to enhance driver's situation awareness before takeover?

Regarding the 1st research question, research showed that while drivers are doing secondary tasks, their visual attention is very likely to be off the road (Banks et al., 2018) which is one of the major problems that is needed to be considered while designing for the autonomous driving experience.

In the field of user interfaces, projecting texting output using HUDs on the windshield was found to improve driving performance while HUDs were also found to increase clutter and visual complexity (Villalobos-Zúñiga, et al., 2016). This is in line with the fact that visual messages require more time to be noticed than audio and haptic messages. However, if signals are too abstract their function is often not known and more information is needed to induce adequate behaviour (e.g., Heydra, Jansen and Van Egmond, 2014). In a take-over situation the time required to process a visual message (and therefore ignoring the road) could be a bottleneck (Sadeghian, 2018).

Regarding the 2nd research question, when referring to drivers' situational awareness, three aspects are of importance. Firstly, drivers should be aware of their current status, current mode and actions of the car; secondly, drivers need to be clear about their current tasks and understand the reasons behind the actions of the car; and lastly, after understanding systems' actions, they could predict the future intentions of the automation system When a driver is performing non-driving related tasks, a lower situation awareness is very likely, resulting in worse take-over performance (Endsley, 2011). Furthermore, situational awareness helps to promote trust in automated driving since it becomes easier for the driver to predict future actions, like decision making in avoiding hazards, planning routes and maintaining safe travel (Sirkin et al., 2017), which again could lead to better transition performance. Low situational awareness can also surprise the driver in a negative sense, since the driver is not aware of the reasoning of the actions of the car which could result in poor user experience (Norman, 2009) and even rejection of the technology (Lee and See, 2004).

3.3. User Research

The knowledge gained from the literature study was used to conduct user research in which the interaction and experience with automated driving is analysed. An online questionnaire is used to interview users of the Tesla autopilot. 26 users with more than 10 years of driving experience filled in the questionnaire. Overall, five problems emerged (summarized in the upper part of Figure 18), but two analysed problems are out of scope, since they relate to the passenger. Therefore, user research is proceeded regarding three desired effects (bottom part of Figure 18).

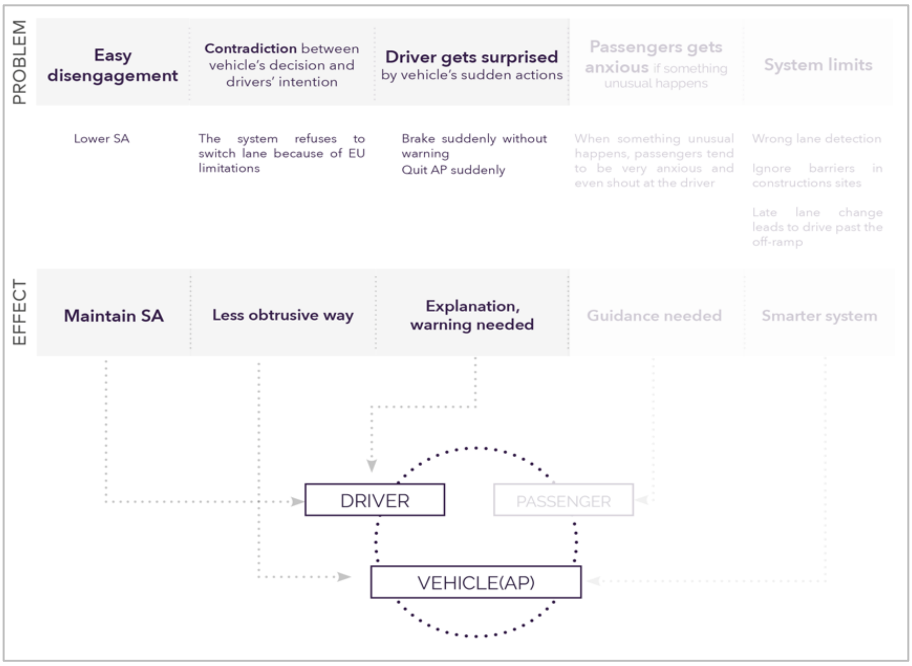


Figure 18 Takeaways from an online questionnaire with Tesla autopilot users (passengers are out-of-scope of MEDIATOR).

To verify the results of the questionnaire with Tesla autopilot users; four experts in the field of human factors related to automated driving were interviewed. The interviews were transcribed and analysed using the context mapping method (Sanders & Stappers, 2012) These interviews yielded 4 problems:

- Level 3 takeover is risky and controversial.
- Conflict might occur when the system decides the driver's state is not appropriate to takeover.
- It is risky to give the control back when a driver is not fit.
- Drivers need to get used to steering after being Time to Sleep.

To summarize the findings of the research, a visual representation of the key findings is constructed by means of a journey map capturing the takeover experience in AD (Figure 19). The journey map gives an overview in the actions of the vehicle and the driver together with the change in situational awareness throughout the takeover experience. The dynamic change of situational awareness is shown by the red line.

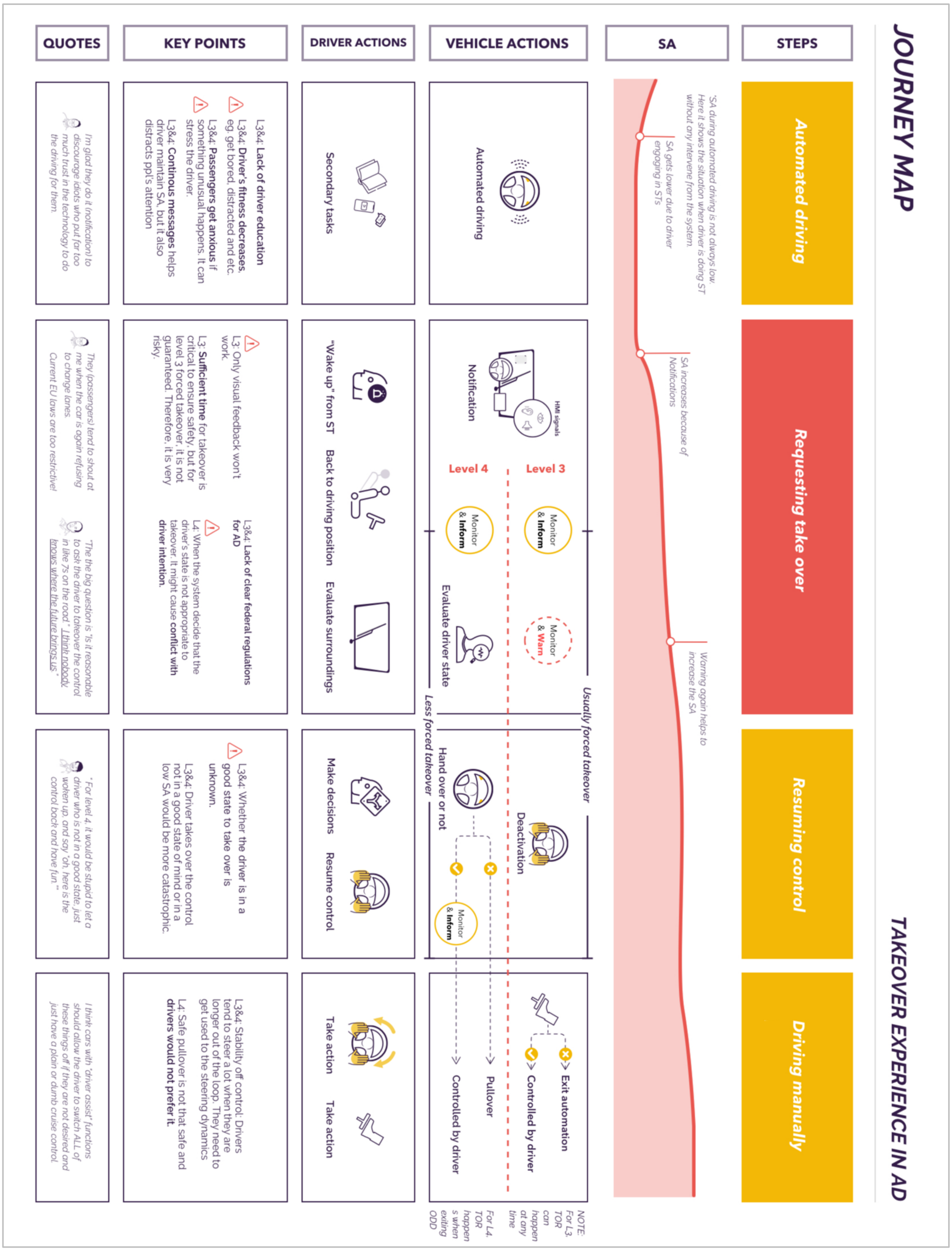


Figure 19 Takeover journey map: mapping out the results of user research related to the stages of takeover

The journey map emphasizes the fact that each of the 4 stages that make up the takeover requires feedback, that adapts to the stage in order to be understandable, supportive and effective. Therefore, guidelines for experimentation design are composed per stage of the takeover experience:

During Automated driving:

- **Help maintain driver's SA** but do not disturb driver too much.
- Provide clear information to enhance understandability.
- What the automation is doing should be clear.
- Reasons for the automation's actions should be explicit.
- Intentions of the automation should be predictable.
- Indicate TOR in advance and support drivers in getting prepared.
- Notify TOR in advance, leave sufficient time for drivers to get prepared.
- Give support/guidance to help driver know what he/she needs to prepare to become fit for takeover.
- Evoke driver's SA effectively before take-over.

During take-over:

- Effective take-over request.
- Take-over request should be clear, effective and take-over actions should be easy and intuitive.

After resuming control:

- Explicit feedback.
- Give explicit feedback when exiting the AD.

Overall

- Clear information.
- The limitation and capability of the automation should be clear.
- Universal Visual, auditory cues.
- All the visual, auditory messages should be universally used in the automotive HMI design, intuitive and will not cause ambiguity.
- The driver's eye should be off the road as less as possible.

In short, during TtS the HMI system should be designed in such a way that it adapts to each transition stage in order to be understandable, supportive and effective. In the next paragraphs we will address these aspects in a conceptual user interface design.

3.4. Design & experimentation of HMI concept

The design process started off with a creative session in which several creative thinking techniques (Tassoul, 2012) were brought into practice. Four people participated in this session, which resulted in 3 ideas. The ideas were all focused on nudging the driver to get into a reliable state before takeover (Wang, 2020). Afterwards, the ideas were presented to 13 MEDIATOR partners, all from different knowledge domains. During this evaluation, the efficiency of the wakeup-call (to wake up the driver from secondary tasks) and core values of the ideas are discussed. This evaluation was the reason for further development of one of the concepts. The concept focusses on communication through light strip signals (located at both A-pillars) in combination with a head-up display. Figure 20 displays communication through light-strip signals. The mode distinctions are conveyed by means of distinct mode vibes; for instance, the vibe that the light strips convey during automated driving is very calm, although when takeover-request approaches, the light strips start to convey an exciting vibe in which the lights slowly blink. This changes to rapid blinking when the message becomes more urgent (takeover is coming up). In the meanwhile, the light-strips count-down towards the takeover by decreasing the length of the light-strips.

Figure 20 CONCEPT 01 with HUD and light strip signals mounted on the vehicle's A-pillars.

Next to the light strip signals, a head up display informs the driver about the upcoming takeover and context information (Figure 21)

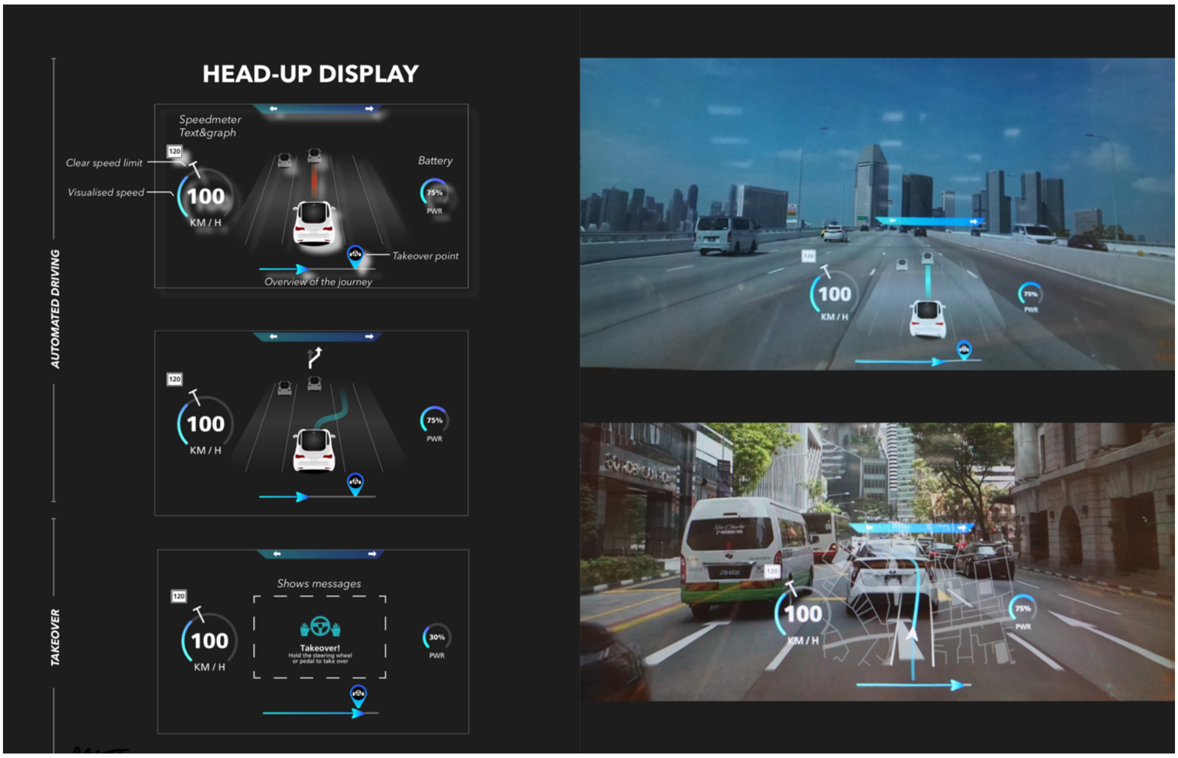


Figure 21 five HUD projections for CONCEPT 01

3.4.1. User Test

A test set-up with a low/medium fidelity prototype in combination with a car model is used to evaluate the concept. The prototype consists of light strips attached to the A-pillars on top of a windshield and a display outside of the cockpit (Figure 22). A microcontroller board (Arduino shield) contains code that controls the light strips. The display simulates the real road scene and head up messages by means of a video.

Figure 22 user test set-up

Six participants with different driving experiences experienced the takeover experience in Level 4 by means of the prototype set-up. They conducted secondary tasks during (the experience of) autonomous driving in order to distract their attention from driving tasks. After 2,5 minutes the wake-up mode was activated in which the light-strips and HUD convey messages (). Afterwards, the participants filled in a quantitative evaluation form and they were interviewed regarding their experiences with the prototype.

Further specifications of the experiment can be found in the experiment template TUD-light strips & HUD (Appendix 4).

3.4.2. Evaluation

The evaluation showed that during 3 stages of the takeover experience, most issues occurred: Before wakeup call, during the wakeup call and during the takeover request, which are separately addressed below.

Before wakeup call / autonomous driving

Participants found the HUD hard to understand (understandability was rated with a 2, out of a scale of 0 to 5). The distinguishment between one's own vehicle and other vehicles was not made since the cars did not differentiate in appearance. The HUD also shows an indication bar when takeover is due, although this indication was appreciated, the participants emphasized that they would value an addition of a time indication and ETA as well.

During the wakeup

The light-strips intuitively attracted the participant’s attention in order to bring them back into the loop (intuitiveness was rated with a 3.2 out of a scale of 0 to 5), without them knowing the actual meaning. It resulted in more awareness of the driving situation, regaining their situational awareness. The rhythm and colour of the light-strips were perceived as comfortable. Some of the participants regained their NDRT in between the wakeup call and TOR, since they did not know the priority of things to focus on. Besides the need for more guidance in preparation for take-over, the participants pointed out that they want to give input to confirm their regained attention.

During the takeover request

Most participants took over without checking the driving situation first, although this can be a result of how the experiment was set up. There was nothing to be seen in the mirrors. Thus, this can be a result of the lower fidelity of the prototype. Furthermore, the mode change through light signals from wakeup to takeover (the LED bar count-down) was not clear, although the fact that the light-strips started blinking during TOR clearly conveyed the urgency of that certain moment (overall the urgency of the takeover was rated with a 3.7 out of a scale of 0 to 5). After take-over took place, some participants missed clear confirmation that they successfully took over control.

3.4.3. Conclusions

In what degree the design guidelines, as stated in Par. 1.1.2., meet the concept-design is been evaluated by means of a prototype-experiment. This showed that there are some points of improvement in order to let users experience an understandable, supportive and effective takeover.

During autonomous driving/before wakeup call it was still unclear for the participants why the car decided to change lanes, therefore the reasoning of actions during automated driving should be clarified and more predictable.

The wakeup call is validated as efficient in catching the drivers’ attention and waking them up from secondary tasks. At the same time, the wakeup call is perceived as not too urgent, but rather exciting, which is in line with not disturbing the driver too much. However, in between the wakeup and takeover request, drivers should be stimulated to remain attentive until the actual takeover.

The takeover request is conveyed as efficiently and perceived as urgent, and all participants took over control in time. The takeover light signal -blinking to indicate the countdown- is not clear for drivers. Changing these signals, and the tint colour (which did not convey an urgent situation) is needed.

Concluding, the concept-design should be further optimised and therefore the following redesign targets are proposed:

- The intention of the vehicle should be clearly communicated in order for users to be able to predict the next move.
- The HMI should support the driver to remain attentive after the wakeup call.
- The HMI should support the driver to get prepared before take-over.
- The takeover request by means of a light pattern should be more obvious.

3.5. Optimisation and redesign

The user test showed that in between the wakeup call and the takeover, the driver needs to remain attentive. Therefore, the concept is optimized with an additional stage in which the driver gets step-by-step guidance (preparation stage) until take-over takes place. Thus, the takeover-journey consists of 5 stages: the driver conducts secondary tasks, the driver is alarmed by the wakeup call, gets prepared, is then requested to take-over after which the driver actually resumes control. The concept-design is redesigned according to these steps.

Stage 1: the driver is conducting secondary tasks
The HUD layout is redesigned to improve communication with the driver. In order to emphasize the difference of one's own vehicle in relation to other vehicles, the own vehicle is highlighted. It is also associated by explanatory text in order to give the driver a feeling of being prepared for the next action of the vehicle (Figure 23).

Figure 23 Redesign HUD layout - During stage 1, introducing the next action, which is a lane change to avoid slower traffic. Other vehicles are silhouettes only, while the own vehicle is fully depicted.

Stage 2: The wakeup-call
The wakeup-call to inform the driver that a take-over will take place shortly is assisted by notifications that appear at the place where attention is drawn at that moment. For instance, if the driver is using his/her phone, the cameras that monitor the driver's state will identify the phone as focus point and send a wakeup call via notifications (Figure 24). If the driver is not alarmed by the wakeup call, the colour of the light bars (located at the A-pillars) will change to a more alarming colour (orange) in order to show the urgency. At the same time, the HMI will give notifications via single tone audio reminders and simultaneously, the seat will vibrate.

Figure 24 Wakeup call: combination of HUD, (A-pillar) light-strip signal and a notification on the device where the driver's attention is.

Stage 3: Step-by-step preparation

The driver's attention is maintained by design interventions (e.g., a vibrating seat) and step-by-step guidance by means of feedback on the HUD (Figure 25).

Figure 25 The HUD displays step-by-step step messages like 'Stand-by'

Stage 4 + 5: Takeover request & the driver resumes control

In case the driver is not alarmed by the wakeup call, several stimuli (addressing different senses) are used in order to let the driver resume control in time; the light strips will change colour to increase the feeling of urgency. At the same time, single tone audio reminders, seat-vibration and HUD messages are displayed (Figure 26).

Figure 26 The HUD & light-strip signals during takeover request

3.5.1. Evaluation

This evaluation was executed digitally by means of an animation that simulated the takeover experience. Because of pandemic restrictions it was inevitable to conduct this experiment digitally. There are some limitations attached to this online method. Participants will have to evaluate the concept from a screen at home, asking a lot of their imagination. For this reason, and since the effectiveness of the light strips is already validated during the test of Concept 01, solely the HUD is evaluated during this online evaluation. However, the experience of the HUD differs amongst participants, since it relies on the equipment of every single participant. Also, an entire car interior cannot be simulated in an immersive way by means of the participants' screens. Also, all haptic elements cannot be tested (like seat vibrations).

The evaluation of the HUD was conducted amongst potential users and validated by experts in the field of autonomous driving. The evaluation focused on the usability of the system and whether the design follows the guidelines appropriately (understandability, effectiveness and level of support).

The participants were occupied in a secondary task while they were informed about the takeover that was coming up. After the test they were questioned about the understandability and support of the HUD design.

3.5.2. Results

The test showed that people feel well informed about the planned actions of the vehicle, which adds to the design guideline of transparency of the automation system, however some participants experienced the step-by-step guidance of the HUD as too informative, a more intuitive and simple guidance would be more fitting to the design guidelines. Participants do feel supported by the system and feel guided when returning back into the loop and resuming control.

Because of the on-line nature of the experiment to test Concept 02, additional testing to validate results in a future Work Package is foreseen. To conclude, the concept enhances the mutual understanding between drivers and the automation system by step-by-step guidance and it helps regain SA effectively before takeover. Therefore, the design meets the guidelines in terms of understandability, effectiveness and supportiveness.

As an overview, a journey map (related to the 5 stages of takeover) is presented in Figure 27. This illustrates the step-by-step guidance and the change of SA during all stimuli regarding the 5 stages of the takeover experience.

3.5.3. Functional requirements of this study

- In the case of the driver being out of the loop (use case 4) WHILE the driver is occupied in a secondary task, the HUD SHOULD present essential info only, like what the automation is doing, why it is doing so and the intention/next manoeuvre of the automation.
- In case the human has to take control after TtS (use case 10) WHILE awakening the driver to prepare for the transfer, non-intrusive (design) interventions should be used.
  - A non-intrusive design intervention might be ambient lighting.
- In case the human has to take control after TtS (use case 10) WHILE the SA is regained, the SA must remain, and the human should be guided in order to get prepared for takeover.
  - Guidance on what to prepare for, could be communicated by a HUD.
- In case the human has to take control (use case 5 & 9) WHEN the urgency level is high, the takeover request must be by means of intrusive communication stimulating multiple senses.
  - A multimodal request could be messaging through HUD in combination with audio warning sounds and count-down ambient light-strips.
- In case the human resumed control (use case 2) WHILE the transfer is executed, the HMI should remain giving feedback regarding mode change and duration.
  - The feedback could be given by a HUD.

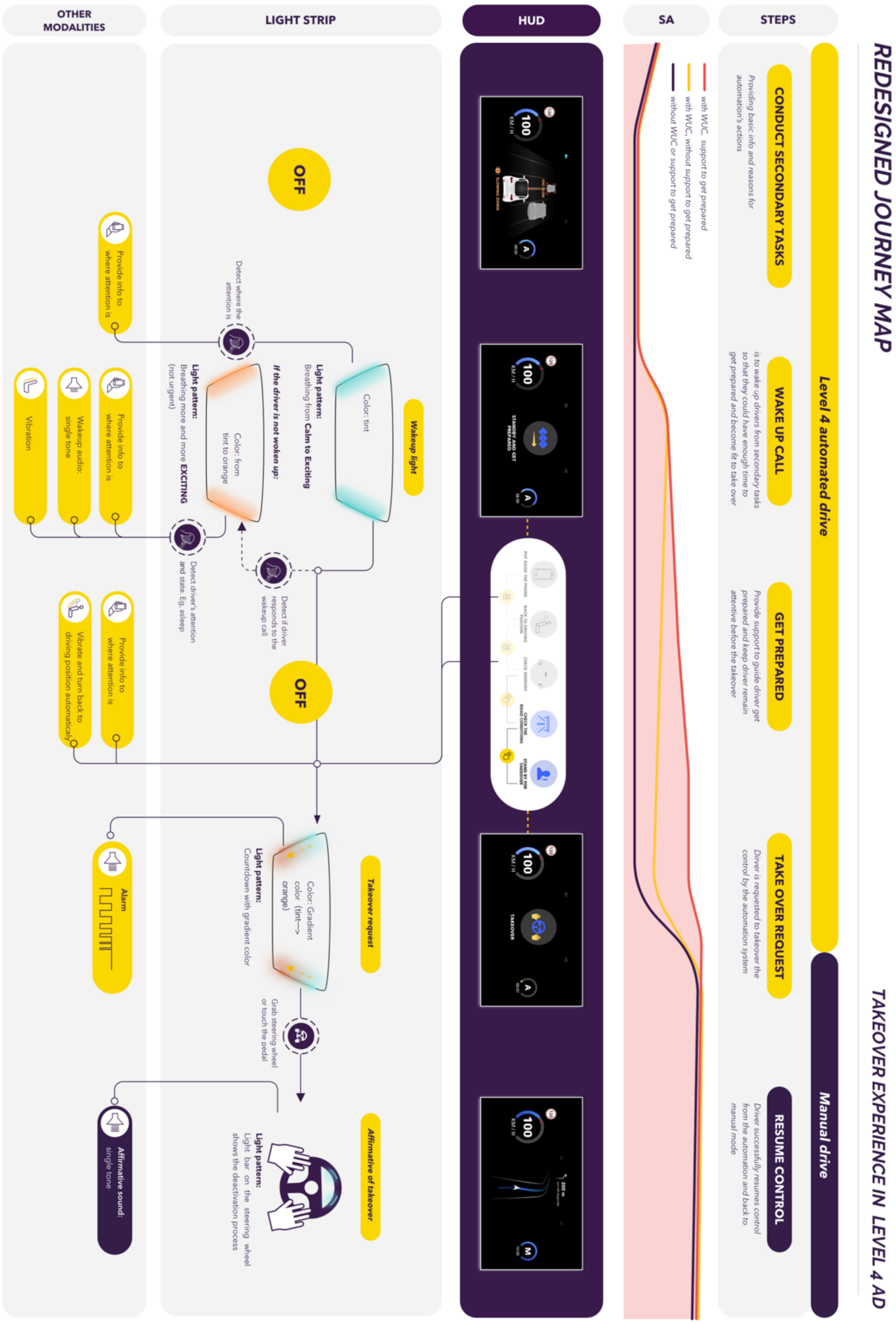


Figure 27 Concept for takeover experience explained by means of Journey map: the parts of the concept (HUD, light strips & other modalities) are explained by means of the stages of the control transfer ritual together with the increase in SA.

4. Transfer of control, mode selection

4.1. Strategy

The HMI is the connecting element between the user and the vehicle; therefore, it will serve as a communication tool during the switch of control between automated driving levels. It is analysed which elements may affect a smooth transition of control by means of literature research and low fidelity prototype testing. Three concepts are the result of this research and a creative design process. A high-fidelity prototype of one of these concepts is programmed and built in a vehicle simulator in order to test it in a later stage. Functional requirements are stated as a result of this process.

4.2. Literature research

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 Generic Control Transfer Ritual (Par. 1.1.2) illustrates the sequence of signals and time intervals in order to prepare the driver for the eventual transfer of control. This sequence differs per use case scenario since every use case relies on either different timing interval, amount of signal, duration, urgency-level and triggered senses.

In order to ensure a smooth transition of control, several factors should be taken into account. This literature research focusses on the following factors: the type and amount of feedback; the complexity of automation levels; the balance between user autonomy and dictated automated actions and the placement of HMI elements in the cabin.

Complexity of automation levels

Six technology-based levels of automation are defined in SAE J3016 by the Society of Automotive Engineers (SAE International, 2016), from which level 0 to level 4 are within the scope of the MEDIATOR Project. The switch between the levels will be referred to as a flow in automation. In theory, with SAE's 5 levels, there would be the ability to switch to 4 other levels, meaning 20 possible mode switches between one automation level to another (Figure 28).

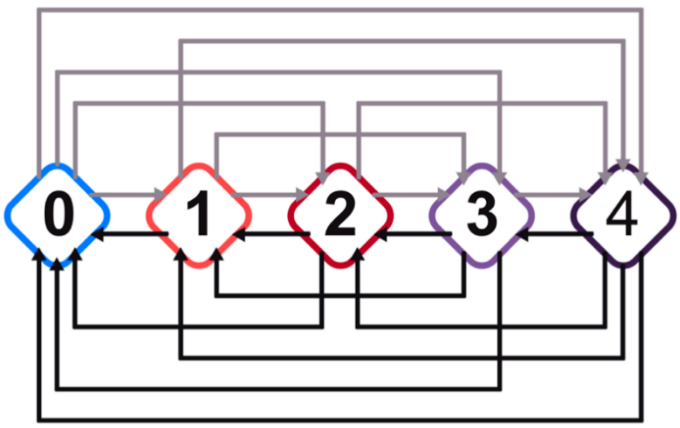


Figure 28 Theoretical mode switches (arrows) regarding 5 levels of automation (SAE level 0 to 4)

Concerns exist regarding the possibility for drivers to switch freely between the levels of automation, since the attention of drivers may be too attracted to the transfer of control instead of the current road conditions and/or driving tasks. This raises the question of whether a simplification of the levels of automation is needed and/or restrictions on mode switches should be enforced.

Some systems refer to a combination of automation levels instead of separately, such as the Advanced Driver Assistance Systems (ADAS). Kala (2016) defined ADAS as “intelligent systems that reside inside the vehicle and assist he main driver in a variety of ways. These systems can take-over control from the human on assessing any threat, perform easy tasks (like cruise control) or difficult manoeuvres (like overtaking and parking)” (p.59-82). ADAS refer to the SAE levels L0-L2, since in all these levels of automation, the human driver serves as fallback and is responsible for monitoring the environment and maintaining mode awareness. Pilot Assist is another example of a system that can take-over control in case of a possible threat, comparable to SAE level 1 (drivers need to keep their hands at the steering wheel). The system is optional for Polestar cars and newer Volvo models. It assists in regulating speed and keeping the vehicle in its lane by means of steering assistance (“Pilot Assist”, 2020).

The U.S. Department of Administration classifies the SAE levels based on the responsibility of either human or automation to monitor the driving environment (DOT, 2016). The distinction is drawn between Levels 0-2 and 3-5. Related to this policy, SAE levels 3-5 are represented by the term “Highly automated vehicle” (HAV), which relate to automated systems that are capable of monitoring the driving environment.

SAE	0	1	2	3	4	5
	Driver supported			Automated driving		
Automation responsibilities	warnings and momentary assistance	steering or brake/ acceleration support to the driver	steering and brake / acceleration support to the driver	Automated driving features will take care of driving under limited conditions when all required conditions are met.		It is taken care of driving under all conditions
Human responsibilities	driver must constantly supervise			When requested, driver needs to drive	It is not required to take over driving	
Euro NCAP		Assisted		Automated		Autonomous
		Shared control		Vehicle in control		
Automation responsibilities		OEDR and other supportive task.		OEDR & driving. Vehicle has full responsibility.		Full control
Human responsibilities		OEDR & driving. Driver is fully responsible. No ST.		Driver can do ST, but needs to be available for a safe transfer of control.		driver is a passenger.
Mediator		CM		SB	Tts	
		(Driver in the loop) "assisted driving". Drivers are responsible but supported by the automation. Driver has monitoring task		(Short out of the loop) "conditional automation". Driver needs to take back control when needed.	(Long out of the loop) "high level of automation" Drivers can immerse themselves in NDRT	

Figure 29 SAE, EuroNCAP and MEDIATOR automation levels, and their corresponding human responsibilities

Euro NCAP introduced a simplification for the general public in order to enhance the understandability of the limitations and usage of levels. They have simplified the SAE levels into only 3 levels, called Driving Modes (Euro NCAP, n.d.). The Modes are distinguished as follows: Assisted driving mode, Automated Driving Mode and Autonomous Driving Mode. In combination with Operational Domains, a systematic manner of testing can be pursued in order the verify autonomous functions and therefore provide comparative consumer information. Like EuroNCAP, MEDIATOR envisions three automation levels (1.1.1), adding up to four if one counts SAE’s Level 0 i.e., no automation (Figure 29).

Feedback

A smooth transfer of control is highly dependent on the clarity of the feedback to the user. Since user understanding creates trust, it will lead to user acceptance (Lilis et al., 2019). Trust can naturally develop with time and experience. Hoff and Bashir (2013) identify two types of trust; trust based on pre-existing knowledge (static trust) and trust by experience (dynamic trust). Designing for trust when there is no understanding yet is different, Hoff and Bashir identified transparency, ease-of-use and appearance as key factors to elicit trust in automation. For this reason, information about the decisions of the automation should be given timely, concisely and clearly and should be available at all times when the driver desires it.

Five phases of feedback during a Control Transfer Ritual can be determined: Set-up, Motivate, Guide, Confirm and Evaluate. Though they are not all applicable for all take-over scenarios. The driver needs to be prepared for take-over and therefore be clearly informed on time. In such case a Take Over Request (TOR) will be communicated in which the urgency should be properly emphasized in order to allow the driver to respond accordingly. Within the context of HMI, unimodal feedback usually lacks to convey information both quantitively and qualitatively, where multimodality feedback increases reaction time and allows a better understanding of the feedback (Naujoks,F. et al., 2019).

Driver override

Another key element to achieve user acceptance is finding a balance between actual autonomy and automation dictated actions. There are several approaches to find this balance, which are discussed below.

When looking at Tesla, the human driver can take back control from Autopilot or from Lane Change Assist by either steering beyond a threshold, braking or pushing the autopilot lever up. The user is always informed about the upcoming shift of control. Equal interaction is required in the theorized pilot control of Mercedes-Benz in which a button has to be pressed or either braking, accelerating or steering is needed to take back control (Daimler, 2019). Another possibility lies in shared control, in which a promising concept is tested by Guo et al. (2019) by letting the driver have the possibility to initiate a lane change while lane change assist is activated. The driver will be in control for a frequent moment and after the imitated lane change, the lane change assist will be activated again.

To conclude, in order to create a set of effective control transfer rituals the following has to be kept in mind:

- the complexity of automation levels,
- the balance between autonomy and automated actions,
- the frequency (and type) of feedback of the above.

4.3. Design analysis

4.3.1. Existing HMI designs

Above, the information stream from the Decision Logic to the human driver has been assessed. However, the user needs to be able to communicate information towards the decision logic as well. The HMI components for user input are explored by means of existing HMI designs (this does not include sensors for factors such as fatigue, stress or distraction).

Currently vehicles with up to SAE level 2 are available; a combination of ACC and LKA. Three distinct models can be categorized regarding interaction design:

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

Conceptual HMIs that have been developed for up to level 3 and 4 automation are schematized (Appendix 5) in order to make them comparable. There is a large variety of design choices that influence the interaction and placement of HMI elements like buttons, switches, levers and screens that are not yet seen in current vehicle designs. Furthermore, there are two different interpretations to user interaction with onboard technology: one is prompted by switches, levers, gestures or touchscreens and the other is based on communication with an Artificial Intelligence (AI) companion. Questions raise whether companion AI is a viable, wanted technology or that people prefer not to talk to their vehicle. In a car there is environmental noise that may cause speech to be masked and therefore difficult to interpret by the AI. Furthermore, we know from other voice activated devices (Siri, Alexia) that they need some training in recognizing a voice or need a specific set of commands as input. 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. It could increase complexity as well, since users have to remember commands over physical controls, which are less arbitrary, and that a dialogue would take more time than pressing a button. 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, (2009) with the adapter categories during a product lifecycle. Adapting to a high automation vehicle requires credibility.

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.

In order to compare the complexity of the HMIs (Appendix 5) from the user point of view, the interaction is rated on a scale of use. 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 is split into 8 (automation related) key factors that are of influence to usability:

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

The level of interaction complexity concept- and existing vehicles/systems is included. Therefore, the graph shown in Figure 28 includes 5 automation levels. 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 being negligible.

The y-axis stands for the level of interaction complexity, concerning the 8 key factors. At the upper limits of this 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. Ideally, the interaction complexity is considered as proper, meaning that all fundamentals are taken into account and allow a driver to operate the vehicle in a safe, controlled manner whilst being informed in the processes that the automation undertakes. In the lower limit, the complexity of the interaction drops to an extent that is impossible as added features will add more interaction. However, as the level of automation advances past SAE level 2, the required number of controls dwindle, especially between SAE level 4 and level 5. Because the functionalities are largely taken over by automation and the mandatory number of controls can be lowered.

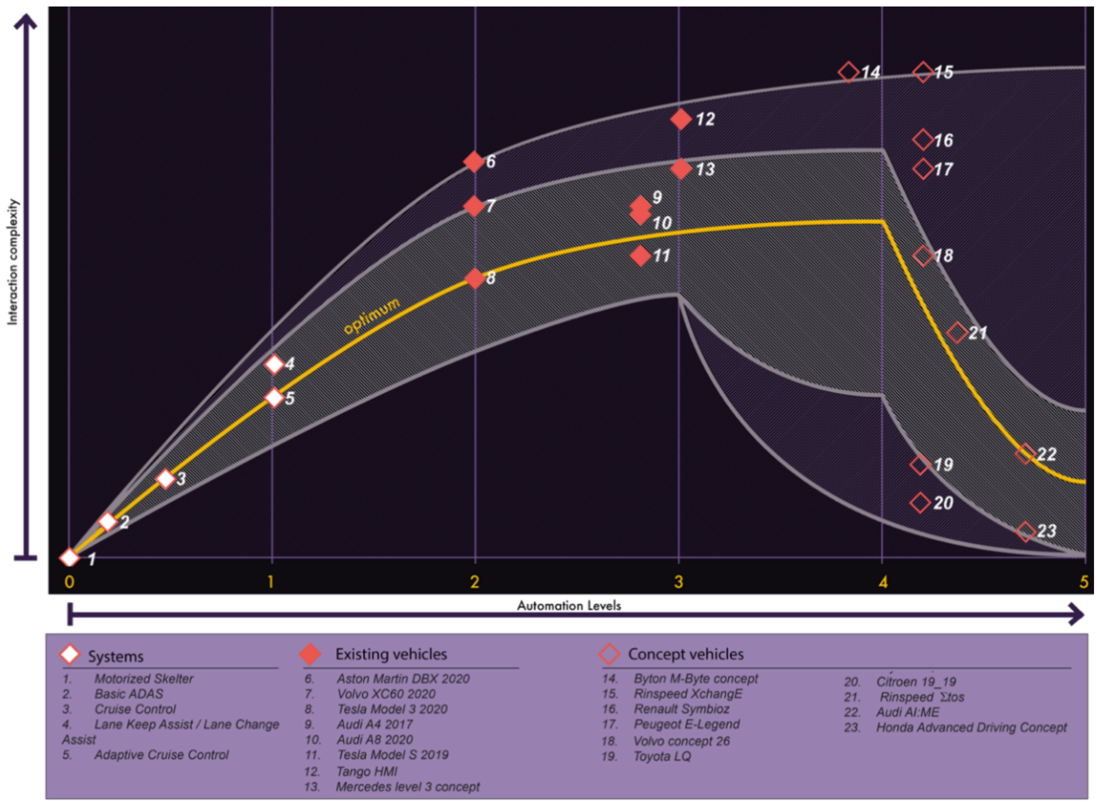


Figure 30 HMIs of different vehicles & systems (Appendix 5) plotted in Interaction complexity graph

4.3.2. Ergonomics analysis

Within the driver's 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 drastically up to level 4 automation, as can be observed from the concept vehicles (Appendix 5). A schematic interior of a 2019 Honda Civic is used 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).

Figure 29 illustrates the optimal placement for visual stimuli, based on Henry Dreyfuss (1993) research about the ability of the human eye. The human eye can observe an area of 62 degrees to each side, 50 degrees upwards and 35 degrees downwards. These envelopes are reduced when colour has to be distinguished: 37 degrees sideways and 20 degrees up-and downwards. Obviously, by turning one's head, the field of view is widened. Comfortably turning one's head can be done up to 45 degrees sidewards and 30 degrees up-and downwards.

Figure 30 illustrates the limitation of the reach area. In relation to the driver's centreline the inboard envelope is 600mm and the outboard envelope 400mm (both for horizontal as vertical movement) (Macey et al, 2014). The general rule is that reachability declines with the distance from the driver (so the steering wheel is the easiest to reach), nonetheless some close-by areas are also hard to reach, like areas close to the shoulder joints and areas behind the driver. Six reachable 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.

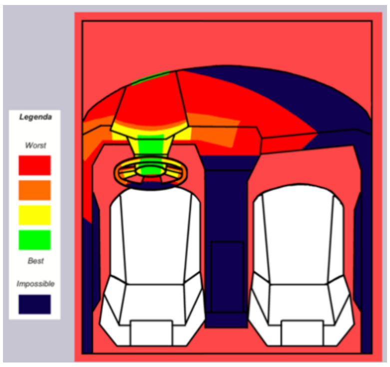


Figure 31 Heatmap of optimal placement for visual stimuli (Mallon,2020)

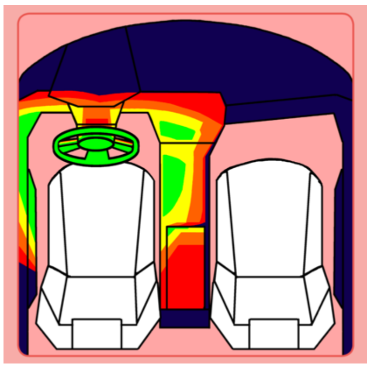


Figure 32 - Heatmap of drivers reach (Mallon, 2020)

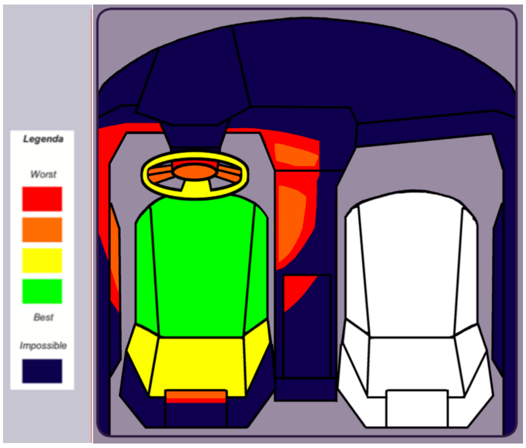


Figure 33 Heatmap of promising haptic areas (Mallon, 2020)

Vibrotactile mechanics will only be used as feedback mechanism, therefore the seat is also included as a promising haptic area (Figure 31) 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.

To summarize the findings of the analysis, a list of boundaries and/or guidelines for the HMI is compiled (Table 1). The list is split up into 3 categories: feedback (machine to human communication), input (human to machine communication) and a general category.

Table 1 Preliminary Design Requirements

Feedback	Input	General
Overall • 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	• 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	• 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 situations except those that are safety critical. • The Control Transfer Rituals must include design of MRMs and Error messages

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	• Steps to communicate intent must be minimized • Design of the input controls must communicate their functionality	• EMs 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 complexity.

4.4. Driver input, HMI concept 03

As stated in the design-guidelines, the automation levels should clearly communicate what is expected from the driver. Therefore 3 driving modes are introduced that represent (groups of) SAE levels. Furthermore, the analysis showed that for optimal functionality of different HMI elements, the placement of each element, that addresses different types of senses, should be considered separately. For this reason, 4 promising locations are defined for the control transfer input device. This input (and output) device is the result of a design process related to the guidelines. It is meant to smoothen the Control Transfer Ritual.

4.4.1. Driving modes

Within MEDIATOR the distinction between use cases is made by a 4 stage-group of driving modes, but another simplification could be made towards the communication to, and involvement of, the human driver: manual driving (SAE level 0), assisted driving (SAE levels 1 and 2, or CM) and piloted driving (SAE levels 3 and 4, respectively SB and TtS). By communicating only these three driving modes (Figure 34), a driver would only have to deal with 6, instead of 20 (SAE), mode switches and therefore there is a lower chance of mode confusion.

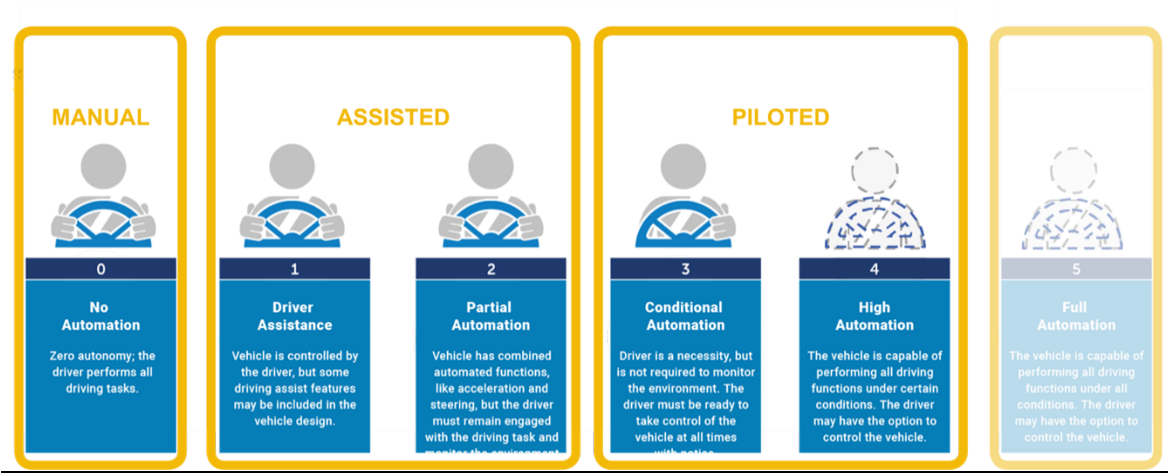


Figure 34 three identified driving modes (adapted SAE levels) in order to narrow down the amount of mode switches

Manual driving (SAE level 0) refers to driving without automation in which the driver is in full control. In **Assisted driving** or CM, the driver maintains some responsibilities and therefore is not fully out of the loop, with proper feedback the driver could have a monitoring task. Pilot Assist and ADAS would be covered by this driving mode. In **Piloted driving** mode (SB and TtS) the vehicle performs most or almost all driving tasks.

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 control in reach at all times and can visually determine its status, whether by line-of-sight or via a display. Furthermore, controls 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 35). These areas are suggested with in mind the shift from fossil fuelled vehicles to electric vehicles, which makes the centre console superfluous and so it is removed in this case. Furthermore, 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. Nonetheless moving the steering wheel would move the controls attached, making it even harder to focus on that control.

![Mediator logo]

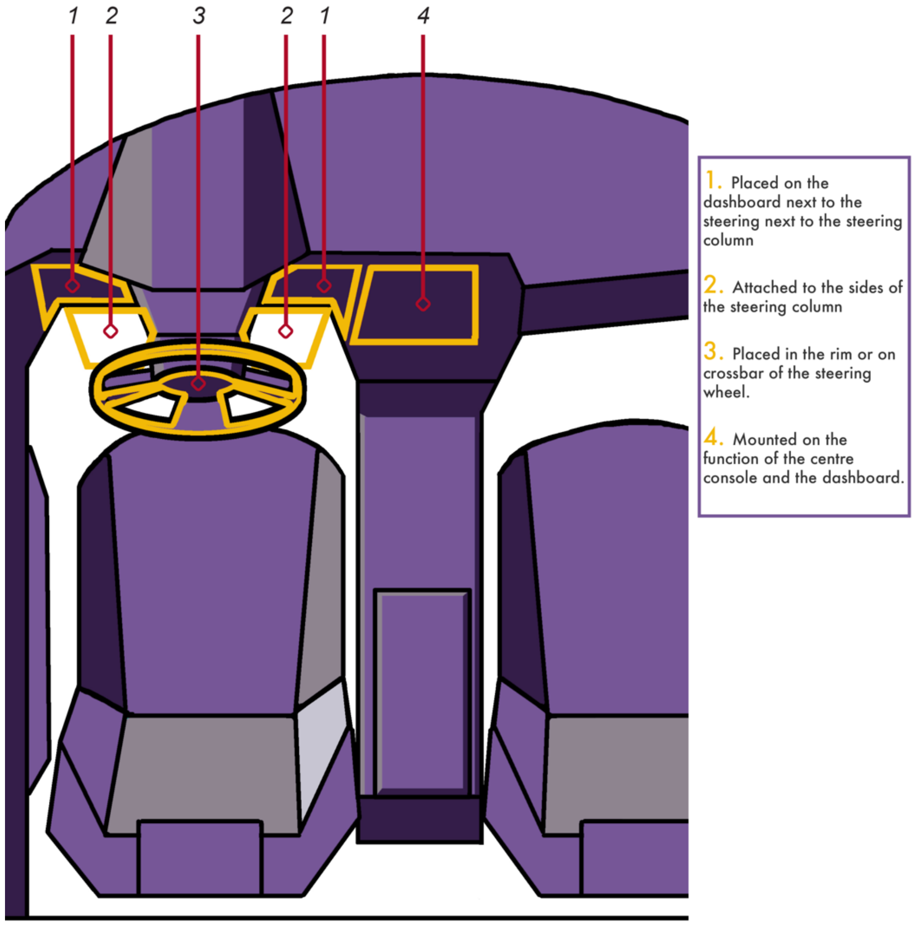


Figure 35 Recommended placement of input device

4.5. HMI Design Concepts

Various ideation methods are used to design the input device for the Control Transfer Ritual (in a representative environment) (Appendix 6). This ideation, with specifically the guidelines 'Design for Learned Affordances, Par. 1.1.2) kept in mind, lead to several concepts that uses affordances that can be found in contemporary 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 al. (2009) to pick up the technology as it is new and exciting. The majority, both early and late, will adapt to the technology relatively fast as the interaction remains familiar. Furthermore, trust is built 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. For this reason, the concepts that came forward out of the ideation phase do not force the user to learn a vastly different interaction, but they extend the current controls (and therefore build on the previously learned affordances).

First, the three concepts are explained, thereafter the evaluation of the concepts by means of a low fidelity prototype is explained.

Button concept

This concept consists of 2 separate rotary menus. The upper part of the button is meant for navigating and controlling features such as entertainment systems and cruise control speed, whereas the lower part is meant to control driving modes (Manual, Assisted and Piloted) (Figure 36). The coloured LED strip around this ring is meant to communicate with the driver by indicating the selected driving mode. The driving modes coloured in white are the ones available, the mode coloured in either cyan, red or magenta is the currently engaged driving mode. The LED blinks when the decision logic is processing the driver's input. A pending transfer is communicated by blinking two colours; the colour related to the current driving mode and the colour related to the planned driving mode). When human input should be restricted, the button will retract into the dashboard and therefore it limits the input of the driver (but it can still convey information).

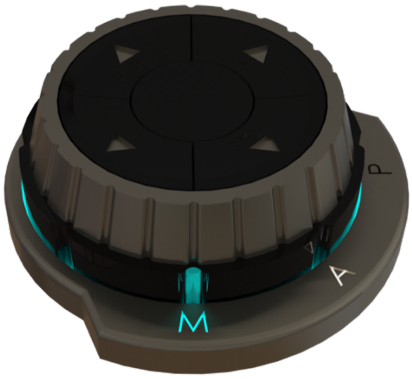


Figure 36 The button concept as a control transfer input device

Lever concept

Rain detectors will make the lever that controls the windscreen wipers in current cars redundant in the future. The available space (and the fact that people are familiar with the usage of this kind of controller) is used for the positioning and the overall looks of the lever concept (Figure 37). A sliding mechanism indicates which driving mode is selected (the used colours and abbreviations related to the driving modes are similar to the button concept). The communication of the driving modes will be done by means of other HMI elements as well, since the size and position of driving modes at the lever are not suitable as sole indicators for clear communication.

Next to the sliding mechanism, the lever can move horizontally and vertically. Therefore, drivers are able to navigate menus in the same way as blinkers are used (but on the other side of the steering column). Horizontal movement allows the driver to quickly (de)activate the selected driving mode. By rotating the lever, the driver is able to increase or decrease specific settings like cruise control speed or distance to the car ahead.

Figure 37 The stick concept as a control transfer input device

Stick concept

Manual gearboxes will become obsolete with the uprising of electric vehicles. Nonetheless drivers will continue to select either ‘park’, ‘neutral’ or ‘reverse’, therefore it makes sense to expand on the Automatic Gearbox lever expanded with **Manual** driving modes with **Assisted** and **Piloted** driving mode using the same mechanism (Figure 38). In terms of visual feedback and mode availability, the concept is comparable to the button concept.

Removal of the centre console was stated to be very likely in the future, therefore the lever will either move to the dashboard (as can be seen in transport vans) or in the steering column (as can be seen in American trucks).

It is chosen to focus on a lever attached to the dashboard, which makes it a very visible and an easy communication tool. A nudge of the lever indicates that the Decision Logic wants to change from one driving mode to another, which can be accompanied by visual and auditory prompt from both the control as other elements of the HMI. This concept is based on force feedback since user input can be counteracted, as well as the decisions of the Decision Logic, by means of resistance in movement of the stick.

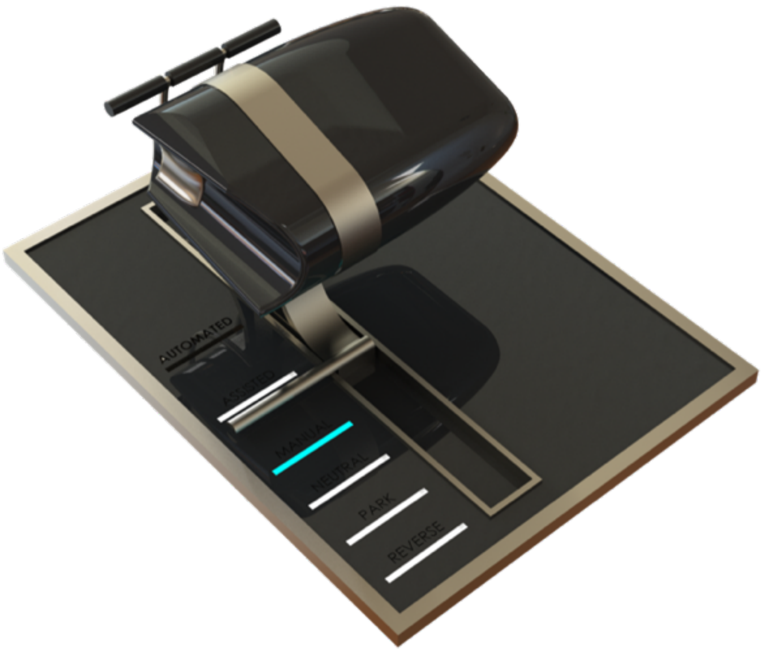


Figure 38 The lever concept as a control transfer input device

4.5.1. Initial testing and concept choice

A low fidelity prototype is used to evaluate the aforementioned HMI Design Concepts. Initially, it was not possible to set-up the test because of which first testing was set-up in a simplified setting. Three low fidelity prototypes of the concepts were attached to an installation including a steering wheel and pedal-box, and a screen that displayed a driving scenario (Figure 39).

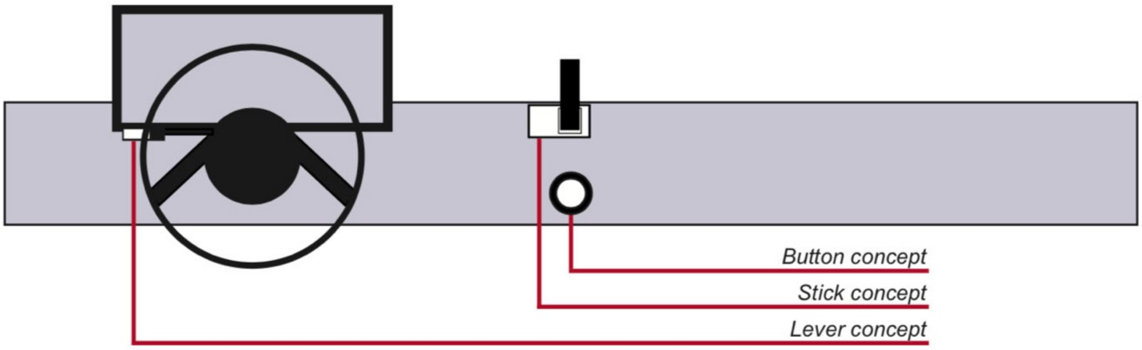


Figure 39 Concept evaluation set-up

Four participants used all three concepts in a driving scenario, after which they were asked to fill in a self-developed questionnaire (Mallon, 2020). This revealed that all concepts are deemed realistic and viable, but the preferred concept is the stick concept. The preference lies in the fact that users do not have to consistently go through an entire menu, like with the other two concepts. Although the stick concept does not give explicit information like the other two concepts, the force feedback does allow for meaningful and implicit communication.

Moreover, in the sequence of the driving modes of the stick concept, there was confusion about the driving mode Piloted, since P has its place for "Park" as well. Therefore, a new keyword for the Pilot function is chosen: "Handsfree", which also communicates that one is allowed to take of their hands of the steering wheel (and indirectly it also emphasizes the fact that in the Assisted driving mode, the hands should be on the steering wheel).

4.5.2. Experiment set-up

In order to test if the stick concept enhances the Control Transfer Ritual, a prototype is built inside a simulator vehicle, the CMMN. A virtual driving environment (a screen in front of the windshield), a dummy Decision Logic and functional steering wheel and pedals are integrated (Figure 39).

The prototype

A vehicle prototype is used to build in the dashboard and the stick-concept. A virtual environment is built by means of the Unity programming language that is programmed to a microcontroller board (in this case Arduino is used). The stick consists of two main components; a component visible to the user (the handle) and a component that is not visible for the user, which is a box that contains the components to deliver force feedback. The driving modes are separated by 18 degrees intervals and the new driving modes (Manual, Assisted and Handsfree) are separated from the traditional driving modes (Park, Reverse, Neutral) by a sloping segment that pushes the lever sideways.

The stick prototype is aimed to have no recognizable OEM design elements, to fit in the test-environment and to avoid brand associative judgement.

The prototype uses three methods to convey feedback: visual, auditory and tactile. First of all, visual feedback is given by movement of the handle, the indicator LED lighting of the driving modes and a Head up Display (HUD). Secondly, auditory feedback is given by means of an alert when a status change has occurred or when a mistake was made. Finally, tactile feedback is given by means of the spring in between the stick prototype.

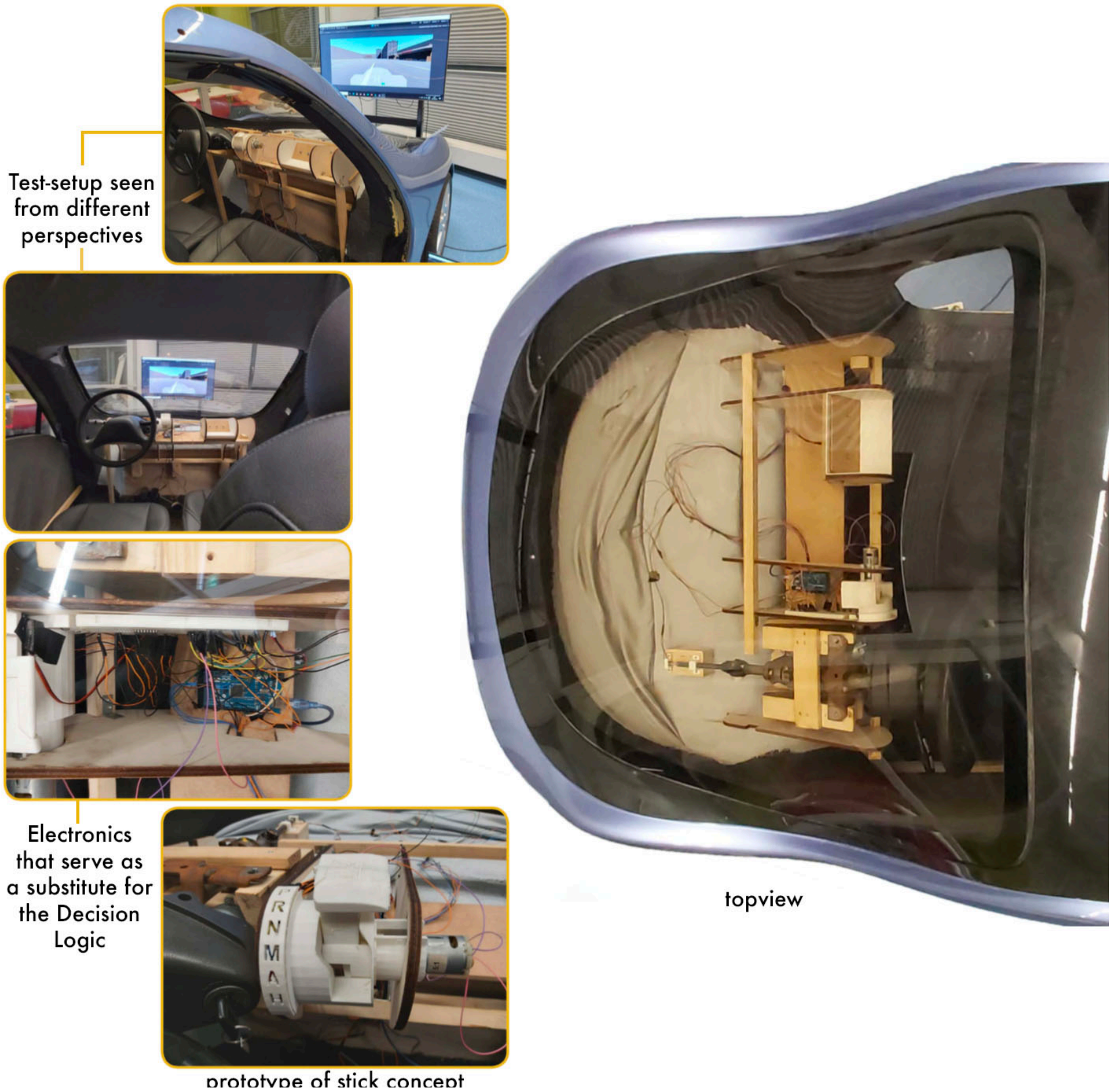


Figure 40 Experiment set-up of the Transfer of control input device concept

The immersion into a scenario of a Control Transfer Ritual is enhanced by the design of a virtual environment. Within this environment, different scenes are represented. These scenes are Inner city, mid-speedway and highway. A vehicle is modelled within this virtual environment to interact with its surroundings. It is adjustable in handling, driving-modes, speed and acceleration. Further development and testing are planned for WP2, when laboratory facilities are expected to be widened.

4.6. Functional requirements of this study

- In case of a transfer of control (use case 1, 2, 3, 5, 6, 9 or 10, Par. 1.1.1), mode confusion could be avoided WHEN the number of possible mode switches is limited by communicating no more than 3 overarching driving modes to the human.
- In case of a transfer of control, from either automation to the driver or from the driver to automation (use cases 1, 2, 3, 5, 6, 9 or 10), WHEN the DL disagrees with the transfer it should communicate this by means of forced feedback.

5. Transfer of control, mode awareness

5.1. Approach

The knowledge gap Transfer of Control was addressed by conducting a literature review to understand the key components involved in the transition process and also the underlying safety concerns. Following the literature review, an experimental study was carried out to investigate to how safety concerns could be addressed using an HMI component integrated on the steering wheel (Autoliv's zForce Steering wheel concept). The results from the study contribute to defining the functional requirement for the HMI in MEDIATOR project. For the future work, another study is being planned to investigate the steering wheel concept in comparison with other visual displays in the interior assisting drivers during transitions. The results from the future study will contribute to the MEDIATOR deliverable 2.5.

5.2. Transfer of control or Transitions

Transfer of control or Transition can be defined as a process during which driver-automation system changes from one state to another involving reallocation of the longitudinal and lateral control task between the driver and the automation (Lu & de Winter, 2015). According to Martens et.al, there are four possible ways where the transition could occur,

- Driver-initiated, from the driver to the automation
- Automation-initiated, from the driver to the automation
- Driver-initiated, from the automation to driver
- Automation-initiated, from the automation to the driver

The automation-initiated transition (from automation to the driver) which mainly occurs when the system fails to manage the driving task and try to reallocate it to the driver, termed as 'take-over'. The take-over process consists of complex information processing stages: perception (visual, auditory, tactile cues) processing the information, response selection (decision making) and resuming motor readiness (eyes on road, hands on steering wheel and feet on pedals) to manage the driving task (Gold et al., 2016; Petermeijer et al., 2016). Son & Park, 2017 proposed a framework that classifies the transitions based on transition initiator, control after transition and situation awareness (Figure 41 and Figure 42).

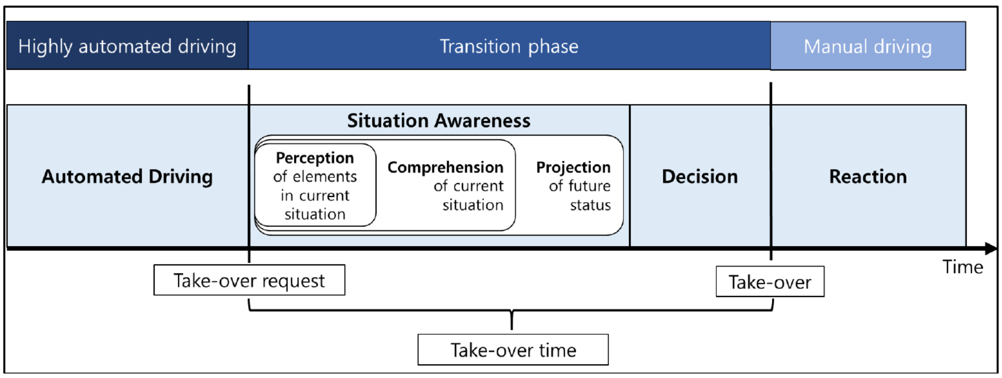


Figure 41 Take-over process from highly automated driving,(Son & Park, 2017)

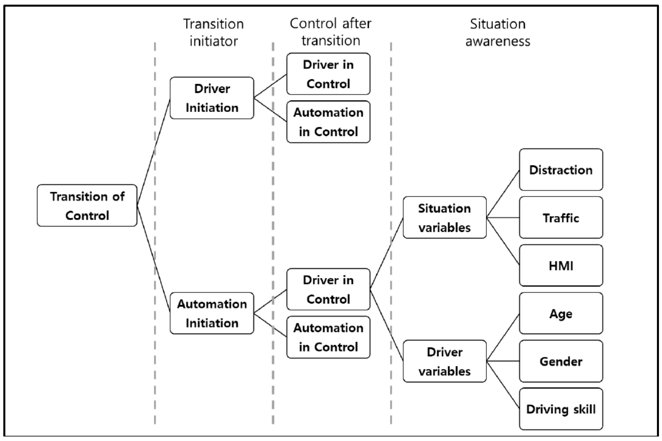


Figure 42 Classification tree of transitions in highly automated driving (Son & Park, 2017)

Take-over time

Take-over time (TOT), defined as the time that the drivers take to resume control from automated driving after a critical event in the environment or after having received a take-over request (Zhang et al., 2019). Besides take-over time, there exists different response time measures such as: gaze response time, eyes-on-road time, hands-on wheel time (Gold et al., 2013). Zhang et al., 2019 investigated the TOT of 129 experimental studies with SAE level 2 or higher using three meta-analysis methods to understand the effect of driver's ability, motivation to take-over, role of urgency prior take-over experience. Key findings include:

- Urgency of the situation (time budget to collision, time budget to reach system boundaries) is highly associated with TOT. Drivers use more take-over time if more time is available.
- Engaging in visual non-driving related tasks (NDRT) increases the TOT.
- In SAE level 3 and above, the availability of a longer time budget, lower urgency and engagement in NDRT showed higher TOT.
- Prior experience with the take-over process affects the TOT. Repeated trials could contribute to a shorter TOT.
- HMI: visual-only take-over showed longer TOT compared to auditory or vibrotactile take-overs

Partial automation (SAE L2) requires drivers to monitor the road and intervene with immediate action in case of critical events. At higher levels of automation (SAE L3 and L4) drivers are allowed to engage in Non-driving related tasks (NDRT), while the system performs monitoring task and issues take-over request (TOR) during intervention. The distribution of the driving task between the driver and automation could yield to new types of safety concerns such as mode errors and out-of-the-loop.

Mode awareness

The Society of Automotive Engineers (SAE) defines mode awareness, built on the definition of Situation Awareness by Endsley (1995) as "*The user's comprehension of the current operating mode of the driving automation system <u>and</u> its ability to transition to another mode, <u>as well as understanding of the subtasks</u> (or actions) that they as the driver are required to perform (if any) versus those the driving automation system is performing*" (Driving Automation Systems Committee, 2016, p. 6) From the SAE standard (2018), the key difference between the automation levels lies in who, the human or system, is responsible for the dynamic driving task and the readiness or receptivity of the human driver to assume control of the vehicle either themselves (user-initiated) or when the system alerts the driver (system initiated). In level 2, the driver is responsible for monitoring and to know when the system is about to exceed its ODD, whereas in levels 3 and 4, the system is fully responsible to know its limits.

Seppelt and Victor (2016) identify the following key human factors challenges with level 2 systems:

"*provision of sufficient feedback to ensure appropriate reliance on system control, to minimize secondary task involvement, to prevent mode confusion where the driver assumes the automation is more capable than it actually is*" (pp. 137–138); for level 3 the ability of the driver to resume control and what is considered "*sufficient time for a typical person to respond appropriately"* (On-Road Automated Driving (ORAD) committee, 2018, p. 24).

Transitions between levels 3, 4 and 5 do not constitute a mode increase as the dynamic driving task (DDT) responsibilities lie with the system. The system must assist the driver's understanding of the current mode, anticipate the performance of the engaged mode and possible mode transitions from the current mode (Driving Automation Systems Committee, 2016). In level 2 automation, the user may not be able to distinguish between a system failure and performance limitation (Driving Automation Systems Committee, 2016; Seppelt & Victor, 2016). To assist drivers in understanding the systems' intentions and limits during different automation levels, an HMI component is a mandate.

Mode confusion or mode error

Mode confusion is a kind of automation surprise, where the system fails to behave according to user expectations, consequently users lose track of the currently active system (Kurpiers et al., 2020). Mode error could lead users towards a safety critical situation if they weren't addressed effectively. Multiple modes in a device could contribute to mode confusion or mode errors (Sarter & Woods, 1995). Implementing multiple levels of automation in one vehicle could increase the complexity as drivers have to remember which tasks are taken care of by the system, and for which tasks they are responsible (Feldhütter et al., 2019). In conclusion, for each automation levels, the drivers have to exhibit a high level of awareness on system functionalities and its expected behaviour, consequently resulting in the need to have an adequate HMI that could support drivers with appropriate information.

Out-of-the-Loop

At L2 and L3 automation levels, when drivers shift from dynamic driving tasks to supervision, it could worsen their situation awareness, and make them incompetent during unscheduled interventions, caused by out-of-the-loop problem (Louw et al., 2017). Engagement in NDRT could further deteriorate the driver's performance during manual interventions. Drivers engaged in mobile phone conversation had reduced brake reactions time compared to drivers who weren't involved in mobile phone conversations (Neubauer et al., 2012). Removing drivers from the driving task would eventually lead to engaging in secondary tasks due to boredom. So, the system should assist drivers to remain in the loop and also support them to bring back their attention quickly when they are out-of-the-loop.

The results from the literature study showcased the necessity of providing drivers with relevant information that could reduce or eliminate the safety concerns related to transfer of control in automotive driving context. Besides that, it also highlights the need to have a competent HMI that could provide drivers with relevant information (approaching transition, intervention required, scheduled and unscheduled take-over request, currently activated automation level or mode, system behaviour, expected user behaviours, reduce out-of-the-loop) efficiently.

5.3. Human Machine Interface (HMI)

Human Machine Interfaces (HMI) in vehicles provide drivers with large amounts of information communicated via visual, auditory and haptic modalities. Automation brings in the necessity to provide drivers with new types of information such as take-over requests, control authority, time budget emergency take-over, transitions etc. that are challenging to communicate via traditional interface alone. An HMI interface that communicates the hand over information via pure tone and flashing icon reported shorter handover times compared to icon alone (Naujoks et al., 2014). An interface providing multimodality warnings is perceived as a more urgent cue compared to unimodality (van Erp et al., 2015). Multimodality also evokes faster reaction time compared to unimodal, however it could be detrimental if incongruence (semantically, temporarily or spatially) exists between the different source cues (S.M. Petermeijer et al., 2017).

Many research studies started to investigate the need for additional interactive interfaces that could effectively communicate the automation related information to drivers. Visual interfaces, especially the ambient lighting in the interiors, have been tested for communicating the automated vehicle's intentions with the driver. An ambient light concept using LED strip positioned on the foot of the windshield with configurable lighting sequence to communicate the automated system's intentions and boundaries to the user, was found to enhance user's trust and reliance towards the system (Yang et al., 2018b).

Figure 43 BMW HMI's Level 3 ADS, BMW (2020)

A dedicated visual interface that communicates safety-critical information to drivers at regular intervals would be beneficial. The steering wheel is one of the primary interfaces situated in the front of drivers and has potential benefits in terms of visibility (Meschtscherjakov, 2017). The integration of visual cues on the steering wheel (to communicate safety-critical information) could enhance its significance. Visual interface on steering wheels is implemented in production vehicles like the BMW Level 3 ADS (Figure 43), the Cadillac Super Cruise (Figure 44) and Autoliv's zForce steering wheel (Figure 45).

Figure 44 Cadillac CT6, Super Cruise on the left, Michael Wayaland (2019).
Figure 45 Intuitive Steering wheel on the right, Autoliv (2016).

5.4. Research study

The following section will focus on a research study (Muthumani et al., 2020) carried out at Autoliv to investigate the HMI component that assists drivers during automated transitions. This study was not a part of the MEDIATOR project; however, it investigated a similar use case used in the MEDIATOR that could be beneficial in defining the HMI functional requirements. The study investigated the transitions from manual driving to automated driving to assisted driving then back to manual driving. In this study, *Automated driving (AD)* defined as the driver is not required to pay attention to road and enough time is provided for any transitions (SAE, L3) and *Assisted Driving (ASD)* mode where the driver has the responsibility to monitor the driving task and to handle the unscheduled transitions during system boundaries are reached (SAE, L2). The transitions investigated in this study is similar to MEDIATOR use-case number 1, 5a and 5b. The key research questions are:

- How transition related information should be communicated?
- How to enhance mode awareness and reduce mode confusion and errors?
- How to reduce drivers' out-of-the-loop behaviour?
- Is HMI on the steering wheel beneficial in conveying information related to transitions?

The HMI designs were defined based on the input collected from HMI experts from different OEMS in a workshop session. In total three different HMI designs were tested in study. The baseline HMI design uses only auditory and visual cues (icons on instrument cluster) to inform drivers about the transition and system related information. The other two HMI designs, Concept A and Concept B used the Autoliv zForce steering wheel with 64 multi-coloured LEDs in addition to auditory and visual cues on instrument cluster. The LED's were illuminated with appropriate colours and patterns to convey events on mode availability, mode activation and unscheduled transitions. The colour blue was chosen to represent AD mode in concept A, HMI design was based on the reference from a few research studies including BMW L3 HMI ADS concept vehicle. The colour turquoise was chosen to represent AD mode in concept B was based on the reference from a research study that reported the user preference of turquoise colour for external HMI.

The touch pad interface positioned on the left and right side of the steering wheel spoke is used for driver's physical interaction (thumb press to confirm and trigger relevant function) with the automated system. AD is activated via thumb press on the left touch pad on the steering wheel, while ASD is activated via synchronized thumb press on both left and right touch pad surface.

Baseline HMI design

In the baseline design, LED illuminations on the steering wheel were not included. The availability of AD mode is conveyed via a "gong" sound and a voice message synchronized with relevant icon and a text stating "*Automation available*" (in German language), is displayed on the cluster (

Figure 46a).

The successful activation of AD mode is feedback to the driver through a voice message confirming the activation, along with display of "*hands off*" icon and a text "*Automation activated"* (in German Language)" is displayed on the cluster (

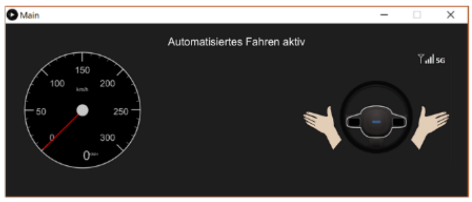
Figure 46b).

The availability of ASD mode is conveyed to drivers through a computerized voice message describing the process to activate ASD mode. The successful activation of ASD mode is feedback to the driver through a voice message confirming the activation and reminding drivers of their responsibility in this mode. The instrument cluster displays "*hands off*" and "*eyes on-road"* icon including the text "*Assisted driving activated"* (

Figure 46c). In the event of unscheduled transition (due to system failure) the system informs via a continuous "gong" sound along with cluster displaying "*hands back on wheel"* icon (

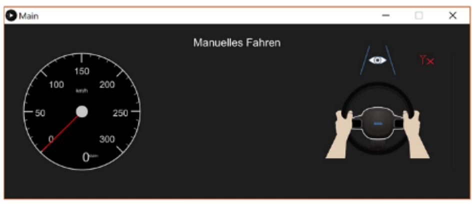
Figure 46d). After the driver takes overcontrol, the cluster starts to display conventional vehicle-related information until another system-initiated request is made.

a



b

c



d

Figure 46 Baseline HMI design

Concept A HMI design

The availability of AD mode is conveyed by the top 14 LED's starts to illuminate in blue colour (Figure 47a). On activation, the 14 LED's start to grow on both sides creating a flow to form a blue-coloured ring illuminating the entire 64 LEDs on the wheel. The availability of ASD is conveyed by a colour change (blue to amber) of 14 LEDs on the top (Figure 47b). The pattern of illumination starts from the top most LEDs changing to amber from blue colour followed by adjacent LED (from both left and right side) changing to amber until all 14 LEDS were illuminated. The illuminating sequence creates a dynamic flow pattern that enhances drivers' detection performance. On activation of ASD, the 14 LEDs stop the dynamic flow and turn amber coloured (Figure 47c). In case of sudden system failure, all the 64 LED's starts to pulsate in red at 1Hz to get driver attention (Figure 47d). After the driver take-over, all the mode related cues were switched off.

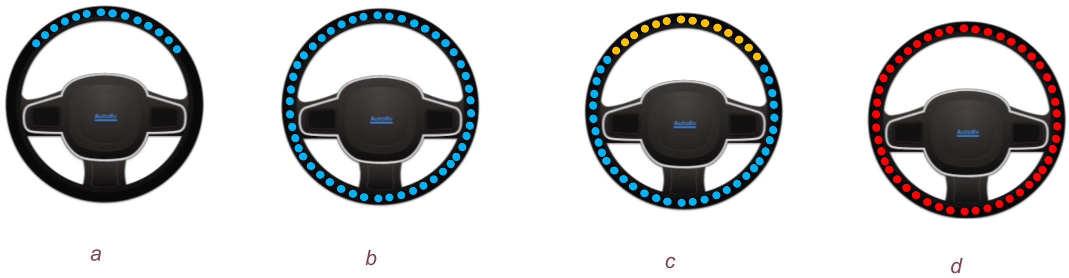


Figure 47 Concept A HMI design

Concept B HMI design

The availability of AD is conveyed via 14 LED's positioned on the right and left quadrant of the steering wheel starts to illuminate in pulsing Turquoise (Figure 48a). On activation, the adjacent LEDs positioned on the right and left quadrant of 14 LEDs start to illuminate gradually creating flow to form a circular ring bridging from left and right side of the wheel (Figure 48b). In AD mode, all the 64 LEDs are illuminated in Turquoise colour. The availability of ASD is communicated by switching of the top and bottom 14 LEDs simultaneously on the creating dynamic flow pattern to attract driver's attention. This sequence is repeated until the driver activates ASD mode. On activation of ASD, top 14 LEDs remains switched off the 50 LEDs start to light up in amber and the (Figure 48c). In the event of sudden failure, the 46 LEDs (18 on top and 28 in the bottom) starts to illuminate in a pulsating red colour (Figure 48d). The intent to switch off the remaining 18 LEDs (9 on left and 9 on right) is to nudge the drivers to grab the steering wheel at 10 o'clock and 2 'o' clock positions which is consider providing the best manoeuvrability during take-over situation. The moment when the driver grabbed the steering wheel, all LEDs were switched off conveying the manual control of the vehicle.

Figure 48 Concept B HMI design

5.4.1. Method

The study was conducted in a static driving simulator. The driver`s activities were recorded using USB web camera fixed in the interior of the vehicle mock-up. The steering wheel interface has built-in infra-red sensors that detect the drivers' hand position on the wheel. A 9-inch tablet mounted on the centre stack of the interiors is used by subjects to perform the Surrogate Reference Task (ISO, 2019) standardized by during AD and ASD mode. Thirty-eight subjects participated in the study. All subjects were recruited through word-of-mouth and also from the database of subjects who were previously participated in other research studies. The data from five subjects were omitted for technical reasons; the remaining 33 consist of 18 female (55 %) and 15 male (45 %) drivers, between 25 and 61 years old (mean = 39.2 years; SD = 12.0 years).

Procedure and data collection

After receiving the informed consent forms, subjects were briefed about the objectives of the study, automation levels, take-over process, surrogate reference task (SuRT) and data collection. Following the practice session for 5 mins, the experiment drive was started with subjects which lasted for approximately 18 minutes. The driving scenario (Figure 49) consists of first exiting a parking space and then merging onto a European two-lane highway (speed limit 130 km/h). A few seconds later, the vehicle gets connected to the 5G network and initiates an automation availability request. After activation of the AD mode, subjects performed the non-driving related task (NDRT) using the centre stack display. The SuRT was carried out in the centre stack display, where the subjects are presented with a number of circles of the same size and one with a larger circle than others. The subjects have to point out the larger circle compared to others circles (Petzoldt et al., 2014). Less than a minute the vehicle loses the network connection and initiates an ASD mode request. In this mode, subjects are requested to monitor the vehicle while they are performing the SuRT task. Within a minute of driving in this mode, a system failure occurs along a curved section of the road in one of six possible locations, which were predefined—but unknown to the subjects (Figure 49). Failure to respond to the take-over request results in a collision with the guardrail at the side of the road. All subjects drove the test scenario twice for each of the three HMI design concepts, so each participant drove six times. The trial order was randomized. The experiment was a within-subject design; the independent variables were the HMI design (Concept A, Concept B, and Baseline).

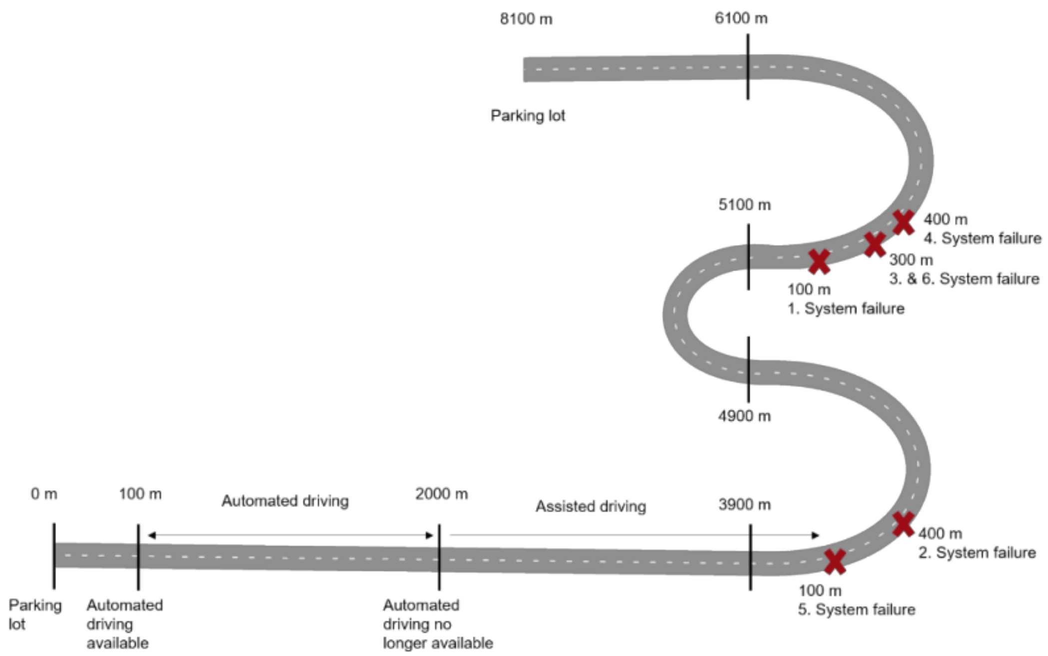


Figure 49 Driving scenario showing the AD and ASD mode activations and six possible system failure locations (red x's)

The dependent variables were the subjective questionnaire results with Likert scale metrics. For measuring user experience, a standard questionnaire UEQ was used which considers the aspects of pragmatic and hedonic quality (Schrepp et al., 2014). The UEQ scales include items on:

- Attractiveness: Overall impression of the product. Do users like or dislike is?
- Perspicuity: Is it easy to get familiar with the product?
- Efficiency: Can users solve their tasks with the product without unnecessary effort?
- Dependability: Does the user feel in control of the interaction?
- Stimulation: Is it exciting and motivating to use the product?
- Novelty: Is the product innovative and creative?

Questionnaires related to trust and acceptance were also measured. The collected data was tested for normality. For analysing parametric datasets, ANOVA and Bonferroni-adjusted post-hoc analysis with t-test were used. For non-parametric datasets, Friedman T-test and Bonferroni-adjusted post-hoc analysis with Wilcoxon test were used.

5.4.2. Results

The self-reported measure of *trust* used a two items Likert scale (Figure 50). For the question, the concept reliably indicates the automation level: $X^2(2) = 9.418$, $p = 0.009$, Concept A vs Baseline, $p = 0.042$, Concept B vs Baseline, $p = 0.006$, Concept A vs Concept B, $p = 0.819$. For the question: I trust the concept: $X^2(2) = 11.821$, $p = 0.003$, Concept A vs Baseline, $p = 0.009$, Concept B vs Baseline, $p = 0.060$, Concept A vs Concept B, $p = 1.000$. visual cues in the steering wheel increased trust in automation. The Baseline was significantly less trusted than either Concept A or Concept B.

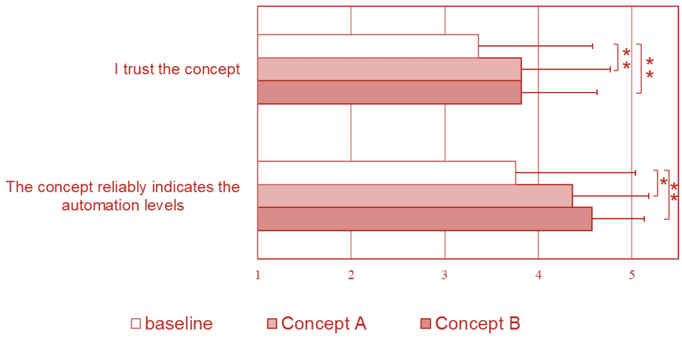


*Figure 50 Subjective responses: Trust in automation (***p <0.001,**p <0.05)*

The user experience questionnaire which consisted of six items (attractiveness, efficiency, perspicuity, dependability, simulation, novelty) were used for the evaluation (Figure 51). For the category attractiveness Concept A and Concept B both scored higher than baseline $F(1{,}41;45{,}12) = 19.733$, $p < 0.001$, $\eta^2 = 0.381$ ($p < 0.001$ for both) : for the item, efficiency no difference was found between Concept A and Baseline, but Concept B scored higher than Baseline ($p = 0.170$ and $p = 0.002$, respectively) $F(2{,}64) = 5.991$, $p = 0.004$, $\eta^2 = 0.158$; for the item perspicuity, Concept A and Concept B both scored higher than baseline (Concept A: $p = 0.056$ and Concept B: $p = 0.006$) $F(1{,}40;44{,}73) = 8.218$, $p = 0.003$, $\eta^2 = 0.204$; for the item dependability, both Concept A and Concept B scored higher than Baseline (Concept A: $p = 0.006$ and Concept B: $p = 0.001$) $F(1{,}48;47{,}41) = 11.681$, $p < 0.001$, $\eta^2 = 0.267$. For stimulation, Concept A and Concept

B scored higher than baseline $F(2,64) = 16.241$, $p < 0.001$, $\eta^2 = 0.336$; and for novelty, Concept A and Concept B scored higher than baseline ($F(1,38; 44,09) = 20.904$, $p < 0.001$, $\eta^2 = 0.395$).

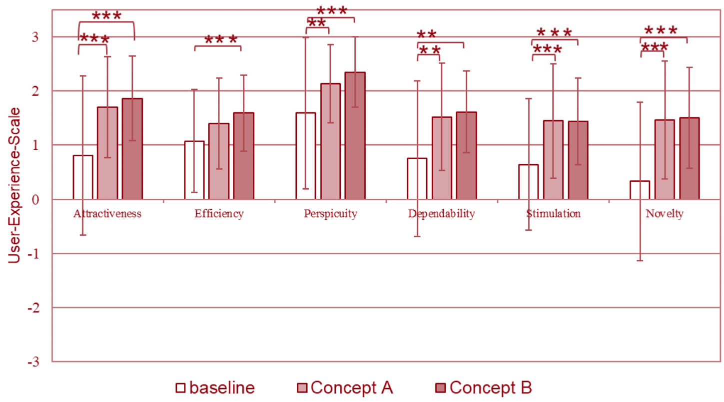


*Figure 51 Subjective responses: User experience (***p <0.001,**p <0.05)*

Results from the *user acceptance* scales show (Figure 52) that Concept A and Concept B scored significantly higher than Baseline ($p < 0.027$ and $p = 0.001$). Concept B also scored significantly higher than Concept A ($p = 0.003$) (□²(2)17.924, $p = 1.000$).

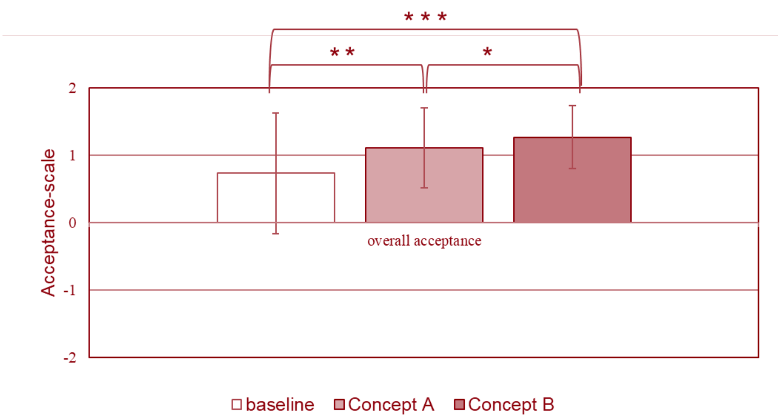


*Figure 52 Subjective responses: Acceptance (***p <0.001,**p <0.05)*

During the interview session, nearly 85% of subjects preferred a steering wheel with visual cues, in which 52% preferred concept B and remaining preferred Concept A. Many participants preferred Concept B as it was clearly communicating the activated ASD mode via different colour code than in Concept A. Subjects also highlighted the importance of having LEDs on the steering wheel's circumference, that it helped them to continuously check the steering wheel in their peripheral vision when their attention was directed towards the centre stack display engaging in SuRT task. These findings showcase that visual cues on steering wheel assist drivers in vehicle mode and also to stay in the loop despite of engaging in NDRT.

5.4.3. Conclusions

In this study, three HMI designs were investigated that convey transition related information to drivers. In general, there was a positive attitude towards the visual cues on steering wheels. When the subjects were asked about the reasoning behind their preference of HMI design, it was found that LEDs on the steering wheel communicate the vehicle mode with more clarity compared to baseline condition without LEDs. The higher rating of concept B was mainly due to the fact that it clearly discriminates the automation modes (AD and ASD) using different colours which symbolize the importance of visual cues in reducing mode confusions. This further emphasizes how the transparency of automation could affect the user perception and acceptance of the system.

Based on the results from trust scale, it was evident that visual cues on steering wheel increase drivers trust towards automated system. The user experience measure indicated that Concept B matched drivers' expectations on attractiveness, efficiency, perspicuity, and dependability.

Based on these above findings, the Concept A and Concept B HMI designs using Autoliv's zForce's steering wheel were effective in

- Communicating transition related information
- Reduce mode confusion and enhance mode awareness
- Allow users to stay in the loop in spite of engaging in NDRT.

5.4.4. Key findings

- Visuals interface on steering wheel is effective in communicating automation related information to drivers.
- Use colour codes with dynamic pattern for request messages such as automation available, activating automation, AD is activated etc as it enhances user perception and responses.
- Use distinct colour code to convey the vehicle mode or level related information.
- Take-over request design must encourage users to take-over the steering wheel using both hands for safety reasons.
- Emergency take-over request should always be conveyed using multimodality cues.

The key findings were translated into functional requirements in the proposed MEDIATOR template.

5.5. Functional requirements of this study

- In use case 1, when driver hand over to system Controller triggering the Visual cues on steering wheel (LED bar) Must deliver confirmation feedback via LED bar illumination (Blue or Turquoise)
- In use case 5a, while driver engage in NDRT, Controller triggering the Visual cues on steering wheel (LED bar) Must deliver which mode is currently activated (Amber)
- In use case 5a, when driver receive emergency take-over request Controller triggering the Visual cues on steering wheel (LED bar) Must deliver the importance of immediate driver action is required (Pulsating effect of red colour)

6. Transparency and information overload in conditional and highly automated driving

6.1. Strategy

Conditional and highly automated driving requires the human driver to be a backup for the automation. This is not a role that comes easily, and challenges related to overreliance and mode confusion will need to be overcome before a safe implementation of such systems is possible. In this chapter we address the trade-off between transparency and information overload in the HMI design during the use cases Driver in Stand By (SB) and Driver Time to Sleep (TtS), i.e., those related to conditional and highly automated driving. In these automation scenarios the driver is allowed to take his or her hands off the steering wheel and engage in a non-related driving task (NDRT). However, the driver can be requested to be on standby in order to be able to take-over from the automation within a reasonable time window.

Transparency in these situations refers to how well the driver can understand the automation system functioning, while information overload refers to the workload associated with processing information that is presented while driving in the relevant automation scenarios. While presenting more information can increase transparency, too much information can instead lead to information overload, which reduces driver comfort and can have an adverse effect on transparency.

In order to gain insight into *what* should be communicated to the driver, at *what time*, and *how* this should be communicated to obtain the appropriate level of transparency without creating information overload, first a literature review of existing knowledge on the subject was performed and is described in paragraph 6.2. Literature is explored on driver's information needs and preferences, driver's capabilities and limitations, and what available information about the automation can support those needs, preferences, capabilities and limitations. This overview gives insight into the type of information that is relevant to communicate and when to communicate it. Additionally, current and researched HMI implementations are considered, which provides more insight into how to communicate the relevant information. Building on this knowledge, specific HMI elements and concepts are proposed that could be valuable for preventing mode confusion and overreliance through transparency while maintaining proper information load during SB and TtS. In addition, relevant knowledge gaps are revealed, which form the basis for further experimentation. The set-up of these experiments is described in paragraph 6.3 and their corresponding results in paragraph 6.4. The experiments address different aspects of HMI designs and are therefore subdivided in two parts: 1) Experiments related to *exploration* of important aspects in HMI design and exploration of specific HMI elements; and 2) experiments to evaluate *full* HMI concepts. Full HMI concepts are defined as concepts that incorporate a combination of elements that are integrated into one concept. The full HMI concepts are aimed at answering the main questions of interest to the current work. Part 1 consists of interviews with experts and users of automated vehicles and exploratory experiments testing the interpretation of and experience of directions of HMI design and specific HMI elements. Part 2 consists of experiments testing full HMI concepts through questionnaires and the think aloud method. The conclusions drawn from these experiments, together with the corresponding limitations and directions for future work, are discussed in paragraph 6.5. Finally, based on the outcomes of the research functional requirements for HMI design for communicating information during SB and TtS are presented in paragraph 6.6. Throughout the document findings relevant for composing the preliminary function requirements are emphasized using italic font.

6.2. Literature research

Literature research was performed to obtain a clear understanding of what is already known about good HMI design for providing information during SB and TtS. First the driver's information needs and preferences for these use cases are discussed, which gives information on what type of information should be communicated. Additionally, the capabilities and limitations of the driver are explored, to get more inside into what can cause information overload. To better understand the feasibility of possible HMI solutions a short overview of the available information from the automation is provided. An overview of researched HMI designs and a brief discussion of HMI implementations currently applied in industry is presented in order to gain insight into current solutions on how relevant information can be communicated and to identify gaps in the literature. The chapter is concluded with an overview of the most important HMI requirements emerging from literature and with setting out the direction of research focused on resolving gaps in literature which will be presented in the following sections.

6.2.1. Driver's information needs and preferences

When people are being asked about expected benefits of automated driving, people indicate the possibility to engage in non-driving related tasks (NDRTs) as one of their most valued expected benefits (König & Neumayr, 2017). As engaging in NDRTs is considered to be of importance to drivers, automation transparency should support engaging in NDRTs. Moreover, providing transparency on the automation system has shown to be important, as an HMI that does not provide any transparency induces discomfort in the driver (Pokam Meguia et al., 2019). The literature points towards two types of information in particular when it comes to automation transparency, namely 1) information on *current automation status* (e.g. Beggiato et al., 2015; Feierle, Danner, Steininger, & Bengler, 2020; Hecht et al., 2019) and 2) *time available in current automation status/time to next automation status* (e.g. Pokam Meguia et al,, 2015; Beggiato et al., 2015; Hecht Darlagiannis & Bengler, 2019; Hecht, Kratzert & Bengler, 2020a; Wandtner, Schömig & Schmidt, 2018).

In order to plan engagement and disengagement in NDRTs, drivers need information about the available time in current and time to next automation status, in additionally to being informed about reliability and system status (Hecht et al., 2019, Hecht et al., 2020b). The types of non-driving tasks that people anticipate in automated vehicles (Pfleging, Rang, & Broy, 2016) or have already been observed in naturalistic driving studies (Dingus et al., 2016, Klauer et al., 2014) range from using phones, to talking and interacting with other passengers, to taking care of personal hygiene. And drivers are likely to increase their NDRT-engagement with higher levels of automation (Naujoks, Purucker, & Neukum, 2016), with highly automated driving being associated with an increase of NDRT-engagement of 261% in respect to manual driving (de Winter, Happee, Martens & Stanton, 2014). Based on experimental data Hecht et al. (2020a) demonstrated that drivers also adjust their NDRT to the frequency of take-overs. In addition, drivers avoid task engagement prior to predictable take-over situations (Wandtner, 2018). That information on time in current and time to next automation status is important for planning NDRTs additionally becomes clear from an experimental study by Danner, Pfromm, Limbacher and Bengler (2020). Danner et al. (2020) had participants drive in a driving simulator with transitions between L3 automation to manual driving and vice versa while having the chance to watch a video as NDRT. Based on interview data after the drives in the simulator, Danner et al. (2020) concluded that participants desired information about time or distance of automation availability before activating the automation in order to be able to assess whether the planned NDRT was feasible during the time the automation would be active. Additionally, participants indicated a display of the anticipated time until automation availability to be helpful.

Another related aspect that is important for the HMI design is the *minimum useful time* to offer a certain automation state. Hecht, Darlagiannis and Bengler (2019) asked people to state the minimum uninterrupted time they expected to need for different NDRTs. Average indicated minimum times ranged from about 8 minutes for watching the surroundings and 10 minutes for smartphone use to about 76 minutes for sleeping. Similarly, a questionnaire by Hecht, Kratzert and Bengler (2020a) indicated that the average preferred minimum time in automation should be 4.48 minutes and that drivers accept longer time in manual mode for less take-overs. In a new study (Hecht et.al. 2020b) Hecht et. al. investigated user requirements for a trip planning HMI for automated driving and found that drivers would like to be able to indicate their preference for a minimum continuous span of time that a trip segment offering a certain automation level.

Hecht et.al. (2020b) also found that such HMI should aid the drivers in planning their trip by providing *complete trip information*, rather than just the current or near future automation status. They provide several functional requirements for such HMI as choosing from a customizable selection of standard travel priority settings and providing the user with a reliable prediction on the available levels of driving automation throughout the trip.

In addition to supporting planning of NDRTs, the information should also *support the supervisory role* of the driver. Displaying the current system status, the fallback level and the remaining time until an expected or required change in automation level can help the driver understand whether the automation will be able to execute the driving task safely (Beggiato et al., 2015).

Providing more insight into automation behaviour can also support the supervisory role by improving the driver's understanding of and trust in the system. For example, *reasons for ongoing manoeuvres* and *previews of next manoeuvres* of the automation and *information on detected surrounding vehicles* were considered to be important (Beggiato et al., 2015). In a study by Diels & Thompson (2017) participants with no experience also indicated to prefer a visualization of *detection and identification of hazards* by the automation in addition to receiving information on *speed limits*.

The *level of detail* of the needed information, however, can vary and depends on several factors, namely 1) expectation on automation capabilities (Ulahannan et al., 2020), 2) driving context, 3) type of NDRT.

First of all, when the driver expects the automation to perform well, information needs generally decrease. Beggiato et al. (2015) and Diels and Thompson (2017) concluded that there is great variance in drivers' information needs which can change between different levels of automation (L2 versus L3 [Begiatto et al., 2015] and L3 versus L5 [Diels & Thomson, 2017]) and which are expected to decrease with more experience with the automation and with higher trust in the automation. Drivers who generally do not trust automation often also have a "High Information Preference" and prefer to get detailed information about the system's status and driving, while drivers who have high trust in automation generally have "Low Information Preference" and prefer to get no detailed information about the vehicle although this information might be required for safe use (Ulahannan et al., 2020). Information that is communicated by the automation can in turn impact the driver's trust in the automation, with appropriate information being able to lead in calibrated trust that matches the system's capabilities leading to the driver behaving appropriately (Lee & See, 2004) and eventually also leading to a decreased information need.

Second, what information is deemed as appropriate for facilitating an understanding of the automation can differ between different driving situations as demonstrated by Feierle et al., (2020).

Feierle et al., (2020) found that especially in situations where several manoeuvres were possible, drivers expressed a need to get information on the planned automation manoeuvre, presumably to be able to update their mental model of the automation decision making. It is possible that only information that helps to update the mental model of automation is deemed needed.

And third, information needs are thought to change when people perform a cognitively demanding and important NDRT such as engaging in working on a laptop. In this case, only high priority information is deemed needed, while lower priority information should be withheld as to not interfere with the NDRT. Hecht et al. (2019) concluded based on questionnaire data asking drivers about their information needs that information about current and upcoming manoeuvres, surrounding traffic and current speed become less important during such cognitively demanding NDRTs. The remaining time in current automation mode was considered important information irrespective of the cognitive demands of the NDRT. During an experimental study in a simulator by Feierle et al. (2020), however, watching a movie as NDRT did not influence drivers' self-reported information needs. This suggests that the importance of the NDRT and the cognitive load induced by the NDRT could influence information needs. Specifically, when an NDRT needs to be performed, the priority of receiving information about the automation is reduced to keep an appropriate level of cognitive load.

The above discussed work on driver's information needs and preferences suggest that an HMI should, as a first priority, provide information on *current automation status* and *time available in current automation status*/time to next automation status. It also suggests that the *minimum useful time being in SB* is about 4 minutes and drivers would like to be able to set this value themselves. *Complete trip information* regarding the expected automation functioning was also found to be useful. Additional information on system transparency such as on *current and upcoming manoeuvres* and on *surrounding traffic* appears also to be of importance. Drivers who are inexperienced with automation also requested information on *detection and identification of hazards* and detected *speed limits*. The exact information needs, however, can vary with different expectations of and trust in automation, the driving context and the priority level of the NDRT that is performed.

6.2.2. Driver's capabilities and limitations

While it is important to consider the driver's information-needs in HMI design, it is also important to consider what the driver *can* and *should* do, i.e., the driver's capabilities and limitations should be taken into account when designing an HMI. Generally, the HMI while driving with highly automated vehicles should create *mode awareness,* so that the driver is aware of their responsibilities and can act accordingly and should instil appropriate *trust* in the system so that *overreliance* is avoided, and appropriate driver behaviour is facilitated.

One way of attaining *mode awareness* is by making sure that the driver has a good understanding of the automation and the vehicle and its actions, in other words: a driver should have a good situation awareness – a picture of the state of the driver's surroundings (Endsley, 1995). Yet, the implementation of different levels of automation makes a vehicle increasingly complex for the driver to understand, with the risk of confusing the driver about the activated automation mode and its associated functional capability. This confusion is called *mode confusion*. This can, in turn, lead to incorrect behaviour of the driver, which is called a *mode error* (Sarter & Woods, 1995). As discussed in D1.1, two general approaches exist to avoid mode errors:

1. Ensuring the user is aware of the *system mode* and its behaviours; and
2. Avoiding the necessity of knowing the system mode by making the driver aware of the *driver responsibilities*.

Any such information about the system or driver responsibilities should be provided appropriately by taking into account the driver's mental workload (de Waard, 1996). In order for the driver to be able to process information, enough cognitive resources must be available. On the other hand, information induces mental workload which takes up cognitive resources. When too much information is presented to the driver in an inappropriate way *information overload* can occur which negatively affects the capability of the driver to respond to the demands of the driving task.

An important factor that influences the availability of the driver's cognitive resources to process driving relevant information is engagement in NDRTs. The NDRT can be considered as a sequential task with L3 and L4 automation, as the driver switches between the NDRT and the driving task (Marberger et al., 2018). Particularly visual-manual (handheld) tasks and tasks that impose high mental demands compared to auditory-vocal tasks have detrimental effects on take-over time and quality (Wandtner, 2018). Adaptive warnings providing extra notifications when needed have been reported to be useful in counteracting a larger time to react with visual-manual tasks (Wandtner, 2018). Not only engaging in a too demanding NDRT can be detrimental, disengagement from driving related activities can cause passive fatigue especially when there is no NDRT available to maintain a suitable arousal level (Naujoks, Befelein, Wiedemann, & Neukum, 2017). Ensuring engagement in a type of NDRT inducing mental demands fitting to the time in which the driver needs to be able to take-over could be a viable approach to prevent poor take-overs and unsafe situations.

The mental workload of processing the information related to the system or driver responsibilities in part depends on the sensory modality through which information is communicated. Appropriate sensory modalities should therefore be chosen for each type of information that needs to be conveyed. Information can be communicated to the driver through different sensory modalities by using visual, auditory, haptic and/or olfactory stimuli. Yang et al (2017) present an overview of how the different sensory modalities were rated by two ergonomic experts on suitability for interaction between a vehicle and a driver. This overview can be found below in Table 2 (from Yang et al., 2017).

Table 2 Overview of ratings of different sensory modalities in suitability for interaction between a vehicle and driver adopted from Yang et al. (2017). See text for further details

	Modality				
Category	**Visual**	**Auditory**	**Haptic**	**Thermal**	**Olfactory**
Content of Information	++	++	o	-	o
Coverage Rate	+	+	-	--	o
Forgiveness Rate	o	--	+	+	+
Perceptibility	+	++	o	o	+
Interpretability	++	+	o	--	-
Limitability	++	++	+	--	--
Interference Capability	+	-	o	+	o
Localisability	+	+	o	-	-

[++] very good [+] good [o] neutral [-] bad [--] very bad

To exemplify how the overview above should be interpreted: The visual modality was rated as being very good on “content of information”, as through visual stimuli very detailed and various information can be presented at once. “Coverage rate” was considered to be good overall, but visual attention might be limited. Regarding “forgiveness rate”, false alarms are not as intrusive as other modalities, yet most visual stimuli could even be seen on the periphery and will be perceived, therefore this was rated neutral. Although visual information can be perceived most of the times, in some cases the periphery is ignored and therefore “perceptibility” was rated to be good. “Interpretability” is rated very good, as visual stimuli are modifiable in a lot of ways and therefore can be designed with a high interpretability. “Limitability” is also rated very good as the timing as well as the location of the stimuli can be very precise (note for example that this is not possible with olfactory and thermal stimuli). As visual stimuli are detected most of the time, while drivers can decide to not look or ignore the stimuli, there is ‘interference capability’ to some degree. Visual information can be linked to where an event is happening most of the time, therefore “localizability” was considered to be good.

As visual and auditory stimuli are both able to convey detailed information very well to the driver, it is no surprise that these stimuli are most often implemented in automated vehicles. Sometimes haptic communication is added as well. In the European project HAVEit (Hoeger et al., 2011) that ran from 2008 to 2011 focusing on developing an HMI as a joint system in automated vehicles it was concluded that this combination of visual, auditory and haptic information worked best. Visual information was considered to be suited to continuously inform the driver about the current automation level and all relevant information related to automated driving (such as warnings and take-over requests). Auditory information was only used to communicate warnings through tones, because auditory stimuli are already fairly used in today’s cars and might be annoying to the driver. This fits the ratings as presented in the overview of Yang et al. (2017) indicating that auditory stimuli are quite intrusive (as it has a very bad forgiveness rate and a very high perceptibility). Yet, in the HAVEit project it was indicated that sounds might help supporting mode awareness by indicating downward and upward transitions. Regarding the haptic channel, the HAVEit project concluded that it is an important channel to include during the primary driving task (e.g., providing haptic warnings, providing force-feedback from the steering wheel and accelerator pedal). Based on these findings, it appears to be best to mainly focus on the visual modality when communicating information during SB and TtS, as auditory information will probably be already used for warnings (therefore including them to convey a substantial amount of information during SB and TtS will probably cause confusion) and the haptic, olfactory and thermal modalities are less suitable to convey content information.

As mentioned before, not only an understanding of the automation, but also an appropriate level of trust of the driver in the automation influences whether a driver will behave in the right way when using the automation. Trust in automation is defined by Carsten & Martens (2019) as “having confidence that the system will act according to what the driver expects it to do with additional benefits of this system for the driver”. The aspect of additional benefits for the driver is an important aspect of the definition, as trust does not develop when a driver correctly expects the system to not work well. A minimum level of trust is required for the driver to have any benefit from the automation (Carsten & Martens 2019); a low level of trust (i.e., under-trust) can lead to under-utilization of the system with functions being overruled by the driver when the system could actually have coped with the situation which could negatively affect acceptance, comfort and possibly even safety. Yet, a high level of trust (i.e., over-trust) is more dangerous and may certainly lead to unsafe situations. Over-trust can lead to overreliance with the driver trusting the system too much and expecting the automation to be able to handle situations which the automation would in fact not be able to handle (Stanton & Young, 2000). It has been demonstrated that overreliance can develop in a relatively short time span (i.e., within 45 minutes) and can even persist under explicit instructions that the automation is not able to handle the situation (Victor et al., 2018). Additionally, drivers often believe they could sleep when automation is active even though they are aware of the fact that they have to act as a fallback (Danneret al., 2020) and, similarly, it has been demonstrated that drivers still get drowsy and fall asleep despite being warned that the automation may fail (Omae, Hashimoto, Sugamoto, & Shimizu, 2005). It is therefore of importance that an HMI encourages an appropriate level of trust to ensure that overreliance does not occur.

An approach to tackling overreliance while preventing information overload is following cognitive systems engineering in which the human is involved in decision making, planning, collaborating and managing (Borst, Flach, & Ellerbroek, 2015). Here one would rely on the driver, finding his/her own solutions within set boundaries that are communicated to the driver, who can in turn use his/her ability to apply knowledge-based behaviour in a wide range of (new) situations. This framework has already been applied in driver assistance systems and has been demonstrated to be effective for enhancing lane change support systems (Lee, Nam, & Myung, 2008), to increase time to collision (Mendoza, Angelelli & Lindgren, 2011) and to promote appropriate reliance and improve take-over performance (Seppelt & Lee, 2007). In communicating the boundaries of what a driver can and cannot do it might be that the goals of the automation and the goals of the driver do not align. An HMI would need to facilitate the cooperation and interaction between the driver and the automation and should make sure that actions and subgoals do not interfere (Hoc, 2001; Hoc, Young & Blosseville, 2009).

The most important takeaway from the above discussion of driver's capabilities and limitations and the discussion of driver's information needs and preferences is summarized in Figure 53. It is important to provide a safe driving experience while maintaining driver comfort by creating mode awareness, an appropriate information load, and an appropriate reliance in the driver (in purple in Figure). Potential issues that should be prevented are mode confusion, information overload and overreliance (in red in Figure 53). These effects are, amongst others, influenced by transparency (i.e., informing on system functioning) and trust (which can be supported by experience and appropriate information) (in yellow in Figure 53).

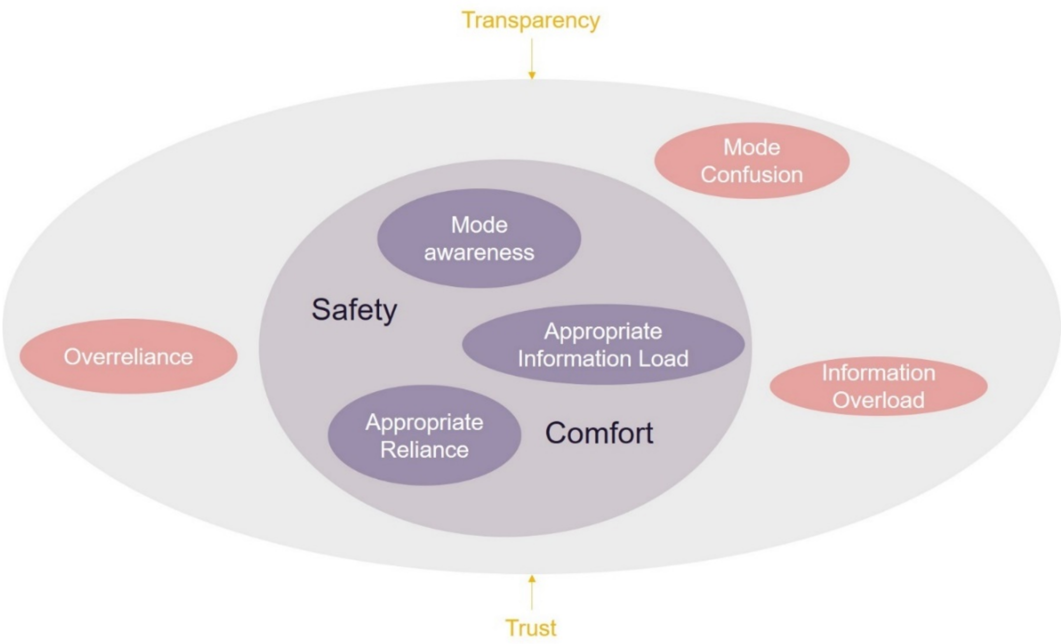


Figure 53 Important constructs for HMI design in automated vehicles. The figure shows what to achieve (purple), what to avoid (red) and important constructs that influence both (yellow).

More practically speaking, the information load can be minimized by providing only the most important information using easily processable interface elements that together creates sufficient transparency to inform the driver of the automation mode and their responsibilities and helps them plan their NDRT's. The literature overview showed that this important information includes information on current automation mode, next automation mode and time till next mode. Some information regarding upcoming manoeuvres and automation perception is especially relevant when the driver is expected to get back in the loop within a short time (SB) and for drivers with a high information preference, but less important during TtS and for drivers with a low information preference.

6.2.3. Available information from automation

It should be considered whether the type of information that has been identified to be of importance for the driver is actually available inside the vehicle. The previous sections showed that information related to the current automation status, time available in current automation status/time to next automation status and information related to automation behaviour or automation status (such as current and upcoming manoeuvres) and information on surrounding traffic, is of importance.

Information on current activated automation status will be available at each moment in time, yet estimating the remaining time in the current automation status and time to the next automation status is somewhat more complex. This time left/time to next can also be referred to as the *time budget*. The feasibility of communicating time budgets depends in large part on what the automation can estimate. To gain more insight into this, a general framework describing time budgets in relation to the automation parameters that would be informative for the driver was developed through several group discussions among experts on human factors in vehicle automation. The resulting framework is depicted in Figure 54.

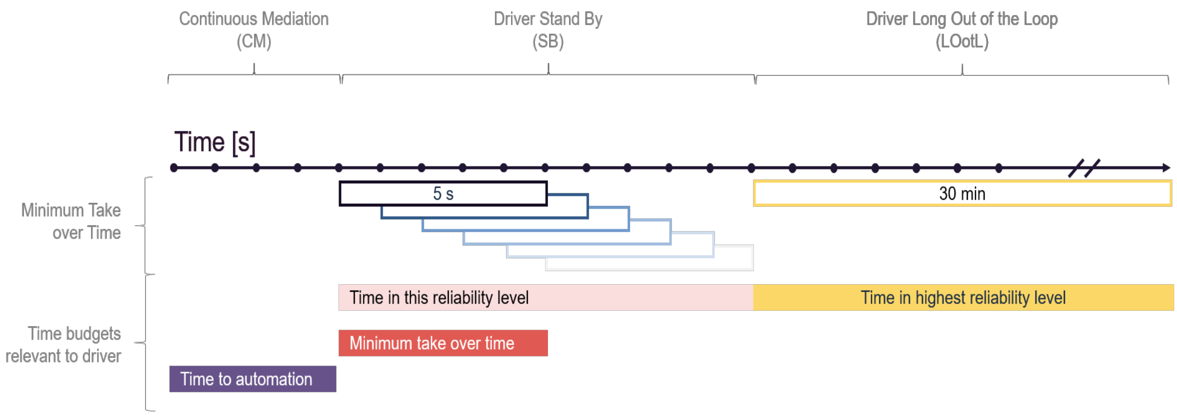


Figure 54 A general framework describing the time left in current level/time to next level of automation, also called 'time budgets', in relation to the automation parameters that would be informative for the driver informative. See text for further details

When driving in the automation scenario of Continuous Mediation (CM), where both manual driving and SAE level 1 and 2 automation are available, the relevant time budget for the driver is the time until full automation becomes available. The automation probably can give an indication of this duration based on its defined operational design domain (ODD) in combination with relevant route information. As described in D.1.1 the ODD is defined as 'the specific conditions under which a given driving automation system or feature thereof is designed to function. An ODD can include geographic, roadways, environmental, traffic, speed, land/or temporal limitations. The ODD is limited in all levels of automation, except for full automation. In some situations, reaching the end of the ODD can be foreseen for a longer time with sufficient input of data (for example: the time at which the end of the highway will be reached can be predicted by coupling navigational data with map data).

When driving in the automation scenario of SB, the driver will need to maintain some level of alertness as the human is considered to be the fallback when an issue occurs with the automation and, depending on the time that this automation level is available, can perform different NDRTs. In this scenario there are two relevant time budgets: 1) the minimum take-over time which dictates the required alertness level of the driver, and 2) the total time available in this level which can be used by drivers to plan their NDRT. The minimum take-over time is also used as input for the automation system to determine its reliability and can almost-directly be output to the HMI. This value is based on onboard sensor ranges and reduces when sensor quality is degraded. Here the time budget in which automation is available during SB can vary due to an unexpected incident that was not previously foreseen. In this case, therefor only a *likely* time budget can be communicated to the driver. As the driver would like to perform a (short) NDRT if possible, this likely time budget can still aid with planning a suitable NDRT accordingly.

In the scenario TtS the driver has a long time before a take-over will take place and can therefore perform NDRTs for a longer duration. The automation is expected to be able to handle any situation, or at least safely park the car in case the end of its operational design domain is reached. For this situation therefore the relevant time budget refers to how long this mode will be active. This information can be based on the expected time until the end of the ODD is reached, which can likely be outputted directly by the automated system. In this case, a certain or *fixed*, instead of a *likely*, time budget can be communicated to the driver. The driver should also understand that in this mode any take-over request will likely occur well in advance and that in case such request is ignored, the automation can still park the car safely.

Other information needs such as upcoming manoeuvres and automation perception should be possible to fulfil as this information will be available. Yet, providing this sometimes, complex information in an appropriate way through HMI design will present a challenge.

6.2.4. Current HMI implementations

This section will explore how researched HMI designs deal with the above discussed driver's information needs and preferences and driver's capabilities and limitations. Additionally, it is briefly discussed what HMI implementations are currently applied in industry. This will provide insight into current solutions and gaps in literature.

The findings are divided into which *type of information* is communicated to the driver and which *HMI elements* were used. An overview of the 22 scientific studies on which these findings were based is presented in Appendix 8.

Regarding the type of information communicated to the driver, the majority of studies communicated automation state, with only a single study communicating NDRT affordance (i.e., the driver task/responsibilities). Concerning automation state, some studies specifically focused on communicating how reliable or certain/confident the automation is (Beller, Heesen & Vollrath, 2013; Helldin, Falkman, Riveiro and Davidsson, 2013; Large, Burnett, Morris, Mathumani & Matthias, 2017; Ruijten, Terken & Chandamouli, 2018; Yang et al., 2017; Yang, Karakaya, Dominioni, Kawabe, Bengler, 2018). Findings on the effects of communicating automation state are mixed, with studies showing improvements on take-overs and interventions (Beller et al., 2013), improvements in mode awareness (Hoeger et al., 2011), and improvements in trust (Helldin et al., 2013; Yang et al., 2018), but with studies also showing no improvements on mode confusion (Feldhütter, Härtwig, Kurpiers, Hernandez & Bengler, 2018) or demonstrating that people do not often look at this information (Large et al., 2017). Concerning NDRT affordance, Schartmüller, Wintersberger, Frison and Riener (2019) presented participants with a keyboard in the steering wheel that changed its angle when it was allowed to use the keyboard. Compared to a baseline in which a standard laptop was used on the lap, the keyboard integrated in the steering wheel improved take-over times, gaze reaction, typing performance and subjective ratings compared to a baseline. Four studies (Hecht et al., 2020, Hoeger et al., 2011; Lu et al., 2019; and Wandtner et al., 2018) displayed automation availability, with this being well received by participants, however participants indicated that they missed information on the available time in the automation mode before activation (Hecht et al., 2020). This confirms the work discussed above, indicating that predictive information is indeed considered to be important. Yet only a single study (Wandtner et al., 2018) communicated predictive information on the time left in automation mode. In this study by Wandtner and colleagues (2018) the time until a take-over was visualized, and this was experienced well by participants. Participants also preferred having information on the reason for an upcoming take-over (for example indicating that roadworks are coming up).

Only 2 studies (Pokam Meguia et al., 2019; Yang et al., 2018) supported the driver in gaining an understanding of the automation behaviour, yet this was also identified as an important need in the work discussed above. Information on (upcoming) manoeuvres was presented in 5 studies (Cramer & Klohr, 2019; Naujoks, Foster, Wiedemann, & Neukum, 2017; Niu, Terken & Eggen, 2018; Pokam Meguia et al., 2019; Yang et al., 2017). Communicating what the automation is currently doing is considered as important for maintaining situation awareness (Pokam Meguia et al., 2019). The amount of information that needs to be communicated on upcoming manoeuvres probably also depends on the level of automation with for example Naujoks and colleagues (2017) demonstrating that it decreases workload during SAE level 3 and Cramer & Klohr (2019) indicating that it improves situational awareness during SAE level 2, while Pokam Meguia and colleagues (2019) report that the intention of the automation (including planned manoeuvres) and the associated reasons do not need to be communicated during SAE level 4. These findings suggest that at higher levels of automation (level 4 and 5) providing information on upcoming manoeuvres might be less important than during lower levels of automation (level 2 and 3).

This overview of researched HMI designs reveals two knowledge gaps in particular. First of all, while the literature overview from sections 6.2.1 and 6.2.2 showed that current automation mode, time to next automation mode and information on system behaviour are all important types of information to be communicated during driving in SB and TtS, only one study examined the communication of time to next mode. Secondly, no clear conclusion could be drawn on the best way of communicating information on the current driving mode, i.e., providing information on automation mode or on driver responsibilities/task.

Regarding which HMI elements were used for communication of information, most studies make use of dashboard icons. The icons that are used vary a lot throughout the studies even when communicating similar information, reflecting that there currently is no standard for dashboard icons. Two studies demonstrate that anthropomorphistic icons might have value for understanding of the automation. The first study, by Beller and colleagues (2013) presented an uncertain emoticon to drivers of an automated vehicle when the automation was uncertain. The uncertain emoticon led to the minimum time to collision (TTC) getting larger. Additionally, with uncertain automation, drivers intervene when TTC was low but drivers did not brake too early or drove slower in general and solved fewer secondary tasks in critical situations but more in noncritical situations. In the second study, by Niu and colleagues (2018), communication on present and future actions of the vehicle was either done through symbols or through symbols in combination with anthropomorphic representations. The anthropomorphic representations facilitated trust in and liking of the system. These two studies thus provide evidence that *anthropomorphic icons* can facilitate trust and appropriate reliance.

Information was presented through a head-up display (HUD) in two studies (Naujoks et al., 2017; Pokam Meguia et al., 2019), although one (Naujoks et al., 2017) simply presented icons like the ones that would normally be presented on the dashboard in the windshield, which doesn't make use of the potential of an HUD to couple information to the external environment.

The identified studies also indicate that LED bars can be used to communicate a variety of information. LED bars were included in four studies to communicate a variety of information. Specifically, a LED bar was applied to communicate active automation status (Feierle et al., 2020; Feldhütter et al., 2018) and to communicate both automation reliability and take-over requests (TORs; Yang et al., 2017) and even to communicate 5 aspects through the same LED bar (Yang et al., 2018): 1) activation of automation; 2) intention of automation lane change; 3) potential external global hazards; 4) specific hazards; and 5) a TOR. These studies thus show that a *LED bar* is a potentially effective HMI element to communicate a range of information types.

Many of the explored HMI concepts in the identified studies make use of colours to communicate information. When multiple colours are used to communicate automation status generally colours either range from green to yellow/orange to red (e.g., Large et al., 2017) or blue is used for higher levels of automation with colours like green (e.g., Feldhütter et al., 2018) or different shades of blue (e.g., Hoeger et al., 2011) for lower levels of automation. When only one colour is used to indicate activation of the automation, the most frequently used colour is blue (e.g., Hecht et al., 2020; Helldin et al., 2013; Hoeger et al., 2011). It is unclear however, which colours would be best to communicate different automation states/driver tasks. An answer might be found in research examining the emotional connotation of colour. Clarke and Costall (2008) for example demonstrated that red orange and yellow provoke active feelings, with red being the most activating and yellow the least. Green and blue are comfortable and soothing, with blue being the most soothing. Purple is also considered as calming and passive, but blue is considered to be calming by more people than purple. These findings could potentially be helpful in determining how to use *colour* for communication in the HMI design.

An additional noteworthy HMI element that was applied in the identified studies were the changing of the steering wheel in order to facilitate NDRTs when they are allowed (Schartmüller et al., 2019) and to communicate the current automation mode with the steering wheel moving out of sight in highly automated driving mode (Kerschbaum, Lorenz & Bengler, 2015). These studies thus investigated limiting driver actions that were not allowed or not necessary in the active automation mode. Another noteworthy HMI element that was applied was motion feedback of the vehicle indicating upcoming manoeuvres (Cramer & Klohr, 2019).

Regarding implementations from industry, Mirnig et al., (2017) examined academic publications and industry patents on transition interface designs in automated vehicles. They also examined how these systems inform drivers of the system state (whether it is in manual or autonomous mode), which is an attribute that is not necessarily related to the transition as it is also communicated before and after a transition. Mirnig et al., (2017) concluded that information on the current mode is rarely included in industry patents. About half of all identified academic publications included methods of informing the driver on the mode, mostly through using symbols, often supplemented by colour coding, sometimes with additional texts. The most frequently identified implementation of informing drivers on the current driving mode, however, is in its essence a binary "on vs. off". This implementation does not, however, allow for anticipating changes in driving mode and planning and adjusting NDRTs accordingly.

This overview of researched HMI designs thus shows knowledge gaps on how to best communicate time to next automation mode and if automation mode or driver task information should be used to communicate the current driving mode. The overview also shows that anthropomorphic icons have the potential to instil appropriate trust and reliance and that LED bars and colours have the potential to communicate a range of information types, especially related to the automation mode.

6.2.5. Important HMI requirements and research direction

Based on the discussed literature above, it can be concluded that it is important to find the right amount of safety and comfort for the driver and to find a balance between the two in order to attain mode awareness, an appropriate information load, and an appropriate reliance in the driver. Potential issues that should be prevented are mode confusion, information overload and overreliance. These effects are affected, and issues can be prevented through transparency and trust. The following types of information are considered to be of importance to be communicated to the driver to create transparency with minimal information load: 1) *information on the current level of automation*; 2) *information on automation behaviour* and 3) *information on time to next level of automation*. For all three types of information, it appears to be most appropriate to communicate mainly through the *visual modality* during SB and TtS, as information needs to be communicated *continuously*, which can best be done through presenting visual information and visual information can communicate content information very well. However, while it is clear that the communication should require minimal processing load for the driver, what exactly is the best way to visually communicate information is yet unclear. It is, for example, still unclear whether it would be beneficial to provide more information to the driver communicating the desired task of the driver (e.g., paying attention to the road or allowing a specific NDRT) related to the level of automation, or whether primarily communicating the level of automation would be enough for drivers to decide on the action to perform. Regarding information on the upcoming level of automation and time to the next level of automation, these types of information allow for anticipating changes in driving mode and planning and adjusting NDRTs accordingly. Yet, most currently researched HMI implementations focus on communicating the current automation state without informing on upcoming changes (a noted exception is the study by Wandtner, 2018), it is therefore of importance to research the effect of communicating anticipatory information taking into account the desire for low information processing load.

In order to structure current HMI implementations and potential HMI concepts that could be researched further and to identify important additional knowledge gaps that need to be researched in more detail, three expert group brainstorm sessions were organized. As preparation for these sessions, four experts on human factors in vehicle automation read up on the literature described in the introduction. In session 1 the four experts brainstormed together for three hours to attain some first ideas for concepts. The primary focus in this session was to brainstorm about how to provide the driver with information on the current level of automation, the upcoming level of automation, and time to the next level of automation. The brainstorm was additionally focused on how to make sure that a driver understands what would be expected of him/her. In session 2 the ideas that were generated in session 1 were discussed and clustered in the concept groups. In preparation for session 3, each of the four experts individually thought out an HMI design for one (or two) of the concept groups. These HMI designs were discussed amongst the four experts and improved on in session 3.

Based on the brainstorms of the first 2 sessions, current researched and potential HMI solutions were structured along two dimensions: 1) how much information is presented on the automation state and 2) how much information is presented on the required driver task. When no information would be presented on either dimension this would lead to mode confusion as the driver would not know anything about the automation state and about the state which would be required of him/her as a driver. On the other hand, when a lot of information would be presented in both dimensions, this would lead to information overload as the driver would be presented with too much information to process properly. The aim of the current research is to find out which minimal amount of information is needed to avoid both mode confusion and information overload. When structuring potential HMI solutions along these two dimensions, 5 groups of concepts emerge. These 5 groups are presented in Figure 55.

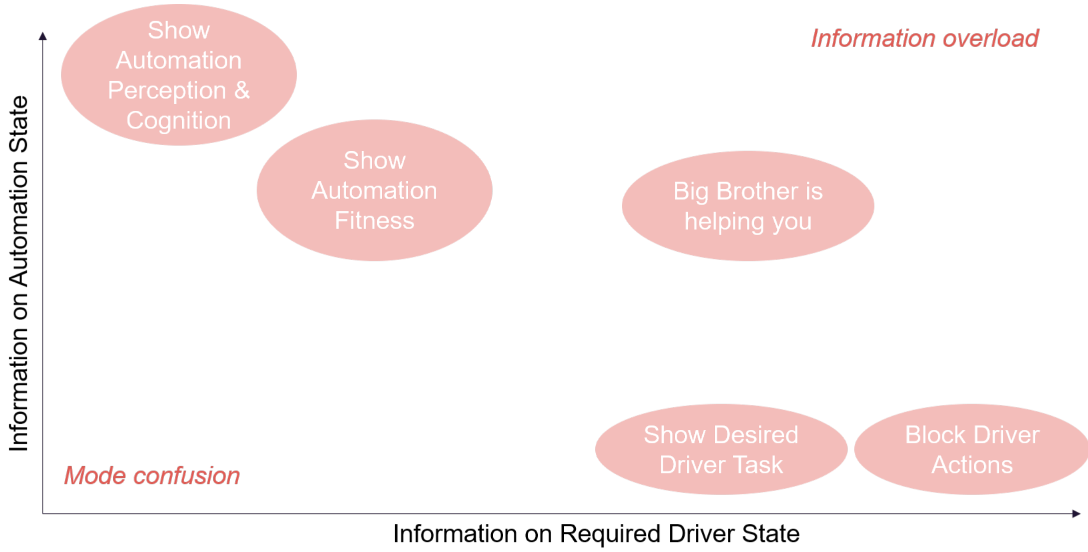


Figure 55 Overview of the 5 groups of concepts that emerge when structuring currently researched and potential HMI concepts along 2 dimensions: 1) how much information is presented on the automation state and 2) how much information is presented on the required driver task.

In the concept group on the upper left in the figure, the group 'show automation perception and cognition', focus is on providing information about automation behaviour. Concepts in this group would for example present the driver with information about what other road users, road characteristics and potential hazards the automation is detecting/perceiving. Concepts in this group could also provide the driver with information on the 'cognition' of the automation by for example presenting information on planned manoeuvres or navigation of the automation. The driver is expected to infer the fitness of the automation by him- or herself and regulate his/her behaviour accordingly. Examples of HMI implementations researched in the literature that communicates both on the perception and cognition of the automation is one of Naujoks et al. (2017) and one of Pokam Meguia et al. (2019). Examples that only focus on communication of cognition of the automation are the implementations researched by Cramer & Klohr (2019) and Niu et al. (2018)

The concept group 'show automation fitness' focuses on directly presenting the fitness of the automation to the driver. Therefore, this concept group does not require the driver to infer the fitness of the automation by him- or herself, which contrasts with the previously discussed concept group. Examples of concepts that would fall in this group could present the driver with information on the current level of automation fitness and/or the next level of automation fitness and the duration of these levels. The driver still must infer from the information on the automation fitness what behaviour as a driver would be appropriate. Examples of HMI implementations researched in the literature are the concepts of Beller et al. (2013), Helldin et al. (2013), Large et al. (2017), Ruijten et al. (2018), Yang et al. (2017), and Yang et al. (2018), which mainly focused on presenting current automation status.

When moving towards the lower right of the figure concepts here focus on presenting the driver with information on what state is required of him/her instead of presenting information on the automation state. The concept group 'show desired driver task' focusses on aiding the driver in performing the appropriate driving task by for example indicating where the driver should focus and which NDRTs are suitable to engage in. The study of Yang et al. (2018) provides an example of providing information when a driver needs to pay attention to the road, yet it does not provide any indication on allowed NDRTs.

The concept group ‘block driver actions’ includes concepts that prevent the driver from engaging in certain NDRTs and/or from performing certain driver tasks and is therefore more forceful than the concept group that shows or suggests the desired driving tasks. These concept groups that focus on presenting information on the state required of the driver without presenting information on the automation state might risk the mental model of what the automation can and cannot do becoming too weak and might lead to overreliance or under-reliance. Examples from the literature are the concept researched in Kerschbaum et al. (2015) in which the steering wheel moves out of sight when it does not need to be controlled and the concept researched in Schartmüller et al. (2019) in which a keyboard was either usable or unusable based on the allowed NDRT.

Another final group of concepts focusses on assisting the driver with every step, presenting the driver with information on automation state (changes) and information on what driving tasks to perform and NDRT suggestions. Therefore, we called this group ‘Big Brother is helping you’. As both information on automation state and required driver state are presented to the driver it is important to be careful not to induce information overload in the driver. None of the 22 identified studies test a concept that falls within the scope of this concept group.

Further research was performed along two approaches. The first approach focused directly on filling the identified knowledge gaps. Based on the outcomes of the expert brainstorm sessions, together with the identified literature, it was decided that it would be of importance to gain more insight into 1) whether providing information on automation fitness or the desired driver task would be most beneficial and 2) whether communicating anticipatory information on available time budgets would add to not communicating such information. Additionally, it was decided that 3 aspects of HMI concepts in the concept groups should be explored in more detail: 1) The inclusion of anthropomorphic icons to communicate the automation’s level of certainty; 2) the inclusion of icons to communicate the task that is desired of the driver; 3) coupling colours to different automation states/driver tasks. In parallel a second approach was adopted in the form of a master thesis (Grazian, 2020) where research was conducted with a focus on corroborating and potentially expanding the literature findings and examining promising directions of HMI design.

The experiments performed in both approaches first had a diverging nature and converged to a full HMI concept. The experiments are therefore subdivided into two parts: 1) an exploration of important HMI design aspects and specific HMI elements (diverging) and 2) an evaluation of full HMI concepts based on the outcomes of Part 1 (converging).

Part 1 starts with an interview with experts, an assessment of preferences and experiences of users of cars with automated functionalities, and brainstorm sessions in order to validate and/or expand on the identified knowledge gaps. Part 1 additionally consists of conceptualization experiments in order to broadly explore directions of HMI design. Finally, in Part 1 specific experiments are conducted in order to explore the 3 aspects of HMI concepts that were considered important to explore in more detail.

Part 2 consists of 2 extensive evaluation studies of full HMI concepts. The first experiment focuses specifically on examining whether providing information on automation fitness or the desired driver task would be most beneficial and on examining whether communicating the available time budget would be helpful compared to not providing this information. The second experiment focusses on the use of ambience adjustments for continuously and unobtrusively communicating different automation modes. Based on the literature and the outcomes of Part 1 and Part 2, functional requirements for HMI design for communicating information during SB and TtS will be presented in Paragraph 6.6.

6.2.6. Hypotheses

For the experiments in Part 1 the expectation is that the preferences and experiences of users of cars with automated functionalities and the conceptualization experiments will corroborate the findings from the literature. It is hypothesized that the experiments in Part 1 that will test specific aspects of HMI design will demonstrate that 1) the automation's level of certainty can be communicated well through anthropomorphic icons, 2) icons are able to communicate the desired driver task, and 3) colours are able to make the meaning of icons on automation's level of certainty and the desired driver task clearer.

For the experiments in Part 2 it is expected that the communication of time budgets will be beneficial for the driver for anticipating changes in automation reliability and for choosing an appropriate NDRT. The comparison between communicating on the desired driver task or on the automation reliability will have an exploratory focus, as it is yet unclear which of the two will be most beneficial. Furthermore, it is expected that changes to the in-vehicle ambience can be used to communicate driver responsibility in a nonintrusive way.

6.3. Design and experimentation of HMI concept 02

The goal of the experiments is to identify the functional requirements for HMI design to communicate information during SB and TtS to the driver. The HMI design should balance comfort and safety in order to attain mode awareness, an appropriate information load, and an appropriate reliance in the driver. Potential issues that should be prevented are mode confusion, information overload and overreliance. Trust and transparency are key to attaining these effects.

The experiments that were part of the design process are grouped into two parts. In Part 1 a diverging strategy was used where the focus was on the exploration of important aspects in HMI design and exploration of specific HMI elements. The first set of experiments in this part (1.1-1.3) was focused on extending and confirming the literature review results. A second set of experiments (2.1-2.3) evaluated conceptual designs from the ideation phase of the approach taken during the master thesis. A third set of experiments (3.1-3.4) focused on specific HMI elements that are used in the full HMI design resulting from the first approach which focused directly on filling the identified knowledge gaps. In Part 2 the results of Part 1 were used to converge to full HMI concepts and the focus was on the evaluation of these concepts.

An overview of the experiments in each of the two parts, their goal and methodology and the associated hypotheses is provided in Table 3. To create a concise overview of the many different experiments that were part of this work, this chapter is limited to only the most important information on the methodology and the results. Details on the methodology and the results for the experiments can be found in the master thesis of Benedetta Grazian (Grazian, 2020)) and in Appendix 2 and Appendix 3. For each experiment the table lists exactly where the details can be found for that specific experiment. This section continues with summarizing the most important information on the methodology of the experiments in part 1 and the experiments in part 2.

Table 3 Overview of experiments in part 1 (exploration of important HMI design aspects and specific HMI elements) and part 2 (evaluation of full HMI concepts)

Exp. #	Goal	Procedure	Participants	Analyses	Hypotheses	Details
Part 1: Exploration of important HMI design aspects and specific HMI elements						
1.1	Identifying important HMI design aspects based on experts' opinions	Online interviews	5 experts in the field of automation and in human factors	Thematic analysis and clustering of open-ended questions	Identified HMI design aspects will align with those identified from the literature study	Grazian, 2020: chapter 3
1.2	Identifying important HMI design aspects from preferences and experiences of drivers of cars with automated functionalities	Unsupervised online questionnaire	54 users of cars with automated functionalities	Thematic analysis and clustering of open-ended questions	Identified HMI design aspects will align with those identified from the literature study	Grazian, 2020: chapter 3
1.3	Identifying important HMI design aspects based on preferences and experiences of people in general	Online analogous context mapping; brainstorming procedure to identify needs in contexts similar to autonomous driving	9 non-experts	Thematic analysis and clustering	Identified HMI design aspects will align with those identified from the literature study	Grazian, 2020: chapter 3
2.1	Exploration of 3 concepts directions, to evaluate which HMI elements and directions of HMI design will be promising	Supervised online questionnaire with images of 3 concepts	8 users of cars with automated functionality	Exploration of subjective responses through clustering of responses	Identified HMI design aspects will align with those identified from the literature study	Grazian, 2020: chapter 5 – conceptualization 1
2.2	Exploration of 3 concepts directions, focusing specifically on ambience in the vehicle, to evaluate how ambience can be best included in HMI design	Supervised online questionnaire with videos of 3 concepts	10 users of cruise control	Exploration of subjective responses through clustering of responses	Identified HMI design aspects will align with those identified from the literature study	Grazian, 2020: chapter 5 – conceptualization 2
2.3	Exploration of 3 concepts directions, focusing specifically on a dashboard screen to evaluate how dashboard information can best be included in HMI design	Supervised online questionnaire with images of 3 concepts	6 experts in the automotive or design domain	Exploration of subjective responses through clustering of responses	Identified HMI design aspects will align with those identified from the literature study	Grazian, 2020: chapter 5 – conceptualization 3
3.1	Exploration of emoticons to communicate the automation's level of (un)certainty	Supervised online questionnaire: pair-wise comparison and rating of 5(+1) different emoticons	10 road safety researchers	Exploration of average ratings and ANOVA testing effect of emoticon on ratings	Emoticons are easily distinguishable and are able to communicate (un)certainty of the automation	Appendix 2

3.2	Exploration of icons to communicate the desired driver task	Unsupervised questionnaire: description and interpretation of 5 icons indicating the desired task, and an indication of which actions participants would perform with each icon	10 non-experts	Rating correctness of descriptions, correctness of interpretation of meaning and correctness of indicated actions	Icons of desired driver tasks are described and interpreted as intended and are able to communicate the desired driver task	Appendix 2
3.3	Exploration of coupling colours to different automation states/desired driver tasks	Online supervised questionnaires and watching 4 movies with HMIs with two different colour ranges while thinking aloud	3 non-experts	Exploration of interpretation of colours, based on think aloud descriptions of participants while watching video	Colours are able to make the meaning of icons on automation's level of certainty and the desired driver task clearer	Appendix 2
3.4	Exploration of coupling colours to different desired driver tasks	Unsupervised online questionnaire: description and interpretation of 5 icons indicating the desired task and indication of actions the participants would perform with each icon	6 non-experts	Rating correctness of descriptions, correctness of interpretation of meaning and correctness of indicated actions	Adding colours to icons of desired driver task will enhance the correctness of indicated actions	Appendix 2
<u>Part 2: Evaluation of full HMI concepts</u>						
4	Examination of effectiveness of full HMI concepts and examining whether providing information on automation fitness or the desired driver task would be most beneficial and whether communicating anticipatory information on available time budgets would add to not communicating such information	Online supervised questionnaire in which participants watched 4 movies of an automated drive with an HMI either presenting information on automation fitness or on the desired driver task with or without anticipatory information on available time budgets while participants thought out loud. And additional questionnaire items were presented	16 users of cars with automated functionalitie s	Coded think aloud data were primarily analysed using mixed effects zero-inflated regression model and questionnaire data were primarily analysed using linear mixed effects models. Data was additionally analysed in a more exploratory fashion	The communication of time budgets will be beneficial for the driver for anticipating changes in automation reliability and for choosing an appropriate NDRT. The comparison between communicating on the desired driver task or on the automation reliability could show either one would be most beneficial	Appendix 3
5	Evaluation of experiences and effectiveness of HMI elements in a full HMI concept with a specific focus on the	Online supervised questionnaire in which participants watched 2 movies of an automated drive. One movie	9 users of cars with and without automated	Exploration of subjective responses through clustering and	Ambient lighting effects and surrounding effects will support transparency	Grazian, 2020: chapter 6

	effect of ambient lighting effects and surrounding effects	included a full HMI concept with ambient lighting effects and surrounding effects and the other movie included the HMI concept without ambient lighting effects and surrounding effects	functionalities	averaging of responses	and mode awareness and will facilitate transitioning between SB and TtS while maintaining a proper information load	

6.3.1. Part 1: Exploration of important HMI design aspects and specific HMI elements

Experiment 1.1 – 1.3: Identifying important HMI design aspects based on experts' opinions, preferences and experiences of users of cars with automated functionalities and people in general

Details for experiment 1.1 – 1.3 are presented in Grazian's study (2020), in chapter 3. These experiments focused on identifying important HMI design aspects based on interviews with experts (experiment 1.1), preferences and experiences of users of cars with automated functionalities (experiment 1.2) and identifying needs of people in contexts similar to autonomous driving (experiment 1.3). To this aim, 5 experts, 54 users of cars with automated functionalities and 9 non-experts/non-users for the three experiments, respectively, participated in an online session and/or filled in an online questionnaire. Regarding online questionnaires, questions focused on current experiences, but also on expectations about autonomous cars of the future that would be highly automated. Regarding the session in which people's needs in context similar to autonomous driving were examined, analogous context mapping (Sanders & Stappers, 2012) was applied, in which a generative tool is used in order to let people express their experiences in a playful way and at the same time become more aware of their experiences. The answers to the (mainly open-ended) questions and ideas and thoughts raised by participants were clustered and a thematic analysis approach was applied for the analyses in order to identify aspects that would be important to HMI design.

Experiments 2.1 – 2.3: Exploration of directions for HMI design

Details for experiments 2.1 – 2.3 are presented in Grazian's study (2020). In these 3 experiments directions for HMI design were explored. The exploration was broader in experiment 2.1, while experiment 2.2 focused mainly on ambience in HMI design and experiment 2.3 focused mainly on dashboard information. For this exploration 8, 10 and 6 participants for the three experiments, respectively, participated in a supervised online questionnaire with either images or videos of HMI concepts. The answers to the (mainly open-ended) questions were clustered, and a thematic analysis approach was applied for the analyses in order to identify aspects that would be important to HMI design.

Experiments 3.1 – 3.4: Exploration of specific HMI elements

Details for experiments 3.1 – 3.4 are presented in Appendix 2. In these 4 experiments specific HMI elements were explored that needed further exploration as described in the introduction, namely: 1) The inclusion of anthropomorphic icons to communicate the automation's level of certainty; 2) the inclusion of icons to communicate the task that is desired of the driver; 3) coupling colours to different automation states/driver tasks. For this exploration respectively 10, 10, 3 and 6 participants were presented with images of HMI components and in experiment 3.3 with movies of a full HMI design and requested to fill in a questionnaire. The questionnaires either included a rating scale or an open question about the meaning of a component in order to assess how the component was interpreted. The responses to the questionnaires were analysed using ANOVAs (experiment 3.1) or by rating the correctness of the responses (experiments 3.2 and 3.4). The responses of participants to the videos were also rated on correctness.

6.3.2. Part 2: Evaluation of full HMI concepts

Experiment 4: The effect of communicating anticipatory information on available time budgets and a comparison of communicating on automation fitness or on the desired driver task

Details for experiment 4 are presented in Appendix 3. This experiment focused on examining whether providing information on automation fitness or the desired driver task would be most beneficial and on examining whether communicating the available time budget would be helpful compared to not providing this information. To this aim, 2 full HMI concepts were developed: 1) one that would fall within the concept group ‘show automation fitness’ and 2) one that would fall within the concept group ‘show desired driver task’. Baseline versions for each of the 2 full HMI concepts were also developed to evaluate the effect of providing anticipatory information in both concepts (i.e., in relation to the ‘full’ versions of each concept). The concepts were designed for low information processing load by combining ambient light effects with simple icons and intuitive bar-like representations of durations in a coherent fashion.

In the experiment 16 participants were presented with each of the 4 HMI conditions; 4 videos were shown of a drive in an autonomous vehicle with each video including one of the HMI conditions. The effectiveness of the different HMI conditions was tested using two different methods (details on these two different methods are described in Appendix 3), namely: 1) think aloud and 2) questionnaires.

For the first full HMI concept, that would fall within the concept group ‘show automation fitness’, the concept (Figure 56) included the emoticons researched in experiment 3.1 (specifically emoticons A, B, C, D, and E2; see Appendix 2) for communicating (un)certainty of the automation, as it was found that these emoticons were easily distinguishable in communicating un(certainty). The emoticons were coupled to colours that were demonstrated in experiment 3.3 to be suitable for this purpose (specifically colour range 2 from the lowest to highest level: red – orange – [bright] green – green – [darker] green; see Appendix 2). The emoticons were presented in the middle of the dashboard, with on the left the emoticon associated with the current reliability level being presented and being outlined in order to clearly communicate that this emoticon was currently applicable. On the right the emoticon associated with the upcoming reliability level was presented (without being outlined). An arrow from the left to the right emoticon was added to indicate that the current level will change to the level associated with the emoticon on the right.

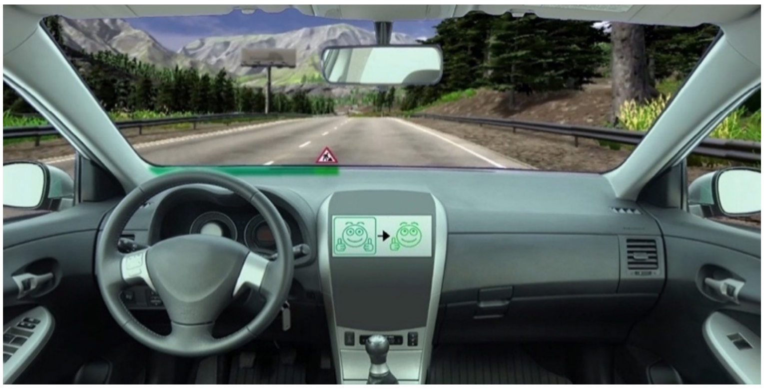


Figure 56 The full HMI-concept that would fall into the concept group 'show automation fitness'.

Time in current level and time to next level was communicated through a LED strip at the bottom of the windshield (the LED strip to communicate current level followed Feierle et al., 2020; Feldhütter et al., 2018; Yang et al., 2017; Yang et al., 2018 while depletion of the LED strip to indicate time in current/time to next level somewhat followed Wandtner et al., 2018). This strip would 'deplete' from right to left, with the size of the strip being reflective of remaining time in current level/time to next level of reliability. The (larger) part of the LED strip on the left indicated the current reliability level and had the same colour as the colour of the emoticon of the current level. The (smaller) part of the LED strip on the right indicated the next level of reliability and had the same colour as the emoticon of the next level. Additionally, a transition icon was included above the part of the LED strip on the right to indicate the reason for an upcoming change in reliability level (see Appendix 3 for further details on possible reasons for changes in reliability level).

In addition, ambient light in the car was simulated by overlaying the interior of the car with a transparent layer in the colour corresponding to the current reliability level. The intensity of the ambient light effect, here simulated with a changing transparency, was high when there was still a lot of time left in the current level and the intensity decreased with decreasing time left.

Figure 57 The full HMI concept for the concept group 'show desired driver task', showing a continuous transition from high automation fitness (top panel) to low automation fitness (bottom panel).

For the second full HMI concept (Figure 57), that would fall within the concept group 'show desired driver task', the concept included the icons communicating the desired driver task as researched in experiment 3.2 (see Appendix 2), as it was found that these icons were to a large degree suitable for communicating allowed and required driver actions. The icons were highlighted in the same colours as used for the final concept in the group 'show automation fitness', as it was demonstrated that these colours were suitable for this purpose in experiment 3.3 and experiment 3.4 (see Appendix 2). The icons were presented at the centre console.

Time in current level/time to next level was communicated by the colour in which the icon was highlighted. The highlighted area 'depleted' with less time remaining in the current level. When the next level was lower, the highlighted area depleted downwards. When the current level would be one of the two lowest levels communicating a required action, and the next level would be higher, the highlighted area depleted upwards. To make the direction of change clearer, an arrow pointing upwards or downwards was added for an upcoming change to a higher or lower level respectively. In addition, a transition icon indicating the reason for an upcoming change in reliability level was presented next to the icon communicating a desired action. This way of communicating time in current level/time to next level was somewhat similar to the way this was done for the concept group 'show automation fitness', but here the time left in current/time to next level and the reason for an upcoming change in level was visualized at the location of the different icons communicating different desired driver tasks. When the current level would be higher than the lowest two levels and thus communicating an allowed action, there would be no communication of time remaining in the current level when the next level would be higher. This implementation was incorporated as a higher level here would mean that the driver is allowed to perform an additional type of NDRT and there would be no need to terminate the current NDRT.

In addition, ambient light in the car was simulated by overlaying the interior of the car with a layer in the highlighted colour of the icon that was currently applicable. The radius of the ambient light effect/colour became smaller, focusing on the steering wheel, with decreasing time left in the current level. The ambient light effect/colour was somewhat similar to the one in the concept group 'show automation fitness', but here the time left was communicated through the radius of the light instead of through the intensity of the light. The ambient light effect was centred around the steering wheel to nudge drivers' attention towards the steering wheel with a decreasing reliability level. Again, reasons for the upcoming change were added through an icon placed next to the upcoming icon.

For each of the two full HMI concepts described above a baseline version was developed. In the baseline conditions, only basic information was presented without any information that allows for anticipating an upcoming change in automation level. For the baseline of the HMI concept that would fall into the concept group 'show automation fitness' only one emoticon was presented at a time that communicated the current level of reliability of the automation. The baseline versions included the same transition icons presenting the reason for a change in the reliability level. In the 'automation fitness' concept, the icon was presented for 5 seconds next to the emotion on the mid console at the moment a transition towards another reliability level occurred. In the 'driver task' concept, the icon was presented at the same location in the baseline and the full version of the concept, but rather than presenting the icon in advance of a change in reliability level, the icon was only present for 5 seconds at the onset of such a change (in line with the 'automation fitness' concept).Thus, experiment 4 included 4 different HMI conditions:

1. A baseline version of a show automation fitness concept (AF baseline).
2. A full version of a show automation fitness concept (AF full).
3. A baseline version of a show desired driver task concept (DT baseline).
4. A full version of a show desired driver task concept (DT full).

In Table 4 an overview is given of the different elements included in each HMI concept, where the yellow highlighted elements are the only elements, present in the baseline versions of these concepts.

Table 4 Elements of the HMI concepts evaluated in Experiment 4. Only the yellow highlighted elements were used for the baseline versions of each concept.

Information	HMI element	
	Automation State	**Driver Task**
Current automation status	Emoticon type and color in box	Driver task icon highlight color
	Ambient light effect color	Ambient light effect color
	LED bar color (left)	Center console highlight color
Next automation level	LED bar color (right)	Center console highlight color
	Arrow pointing to next emoticon	Arrow pointing towards next level
	Emoticon without box	
Time to next automation level	Length of LED bar	Length of center console highlights
	Transparency of ambient light effect	Radius of ambient light effect
Reason for level change	Transition icon above LED bar (next to emoticon for baseline)	Transition icon on center console

Regarding the think aloud method, we used the concurrent think aloud procedure (Eccles & Arsal, 2017) which gives access to the information present in participant's working memory (Ericsson & Simon, 1980). The think aloud procedure involves participants' verbalizing their thoughts as they are performing a task and/or processing information. The advantage of this procedure in addition to questionnaires is that think aloud provides insight into cognitive processes online during the processing of information, while questionnaires provide insight offline after the information has already been processed and thus relies on memory. In this study this procedure was applied in order to gain insight into how participants perceived and understood the different HMI conditions while they were watching the different conditions' videos. Data processing and analyses of the think aloud data followed Rose, Bearman, Naweed and Dorrian (2019). Statements of participants were coded based on Endsley's (1988) three levels of situational awareness: 1) perception (i.e., statement referring to a signal), 2) comprehension (i.e., statement about the meaning of the current implications of the communicated information), and 3) projection (i.e., statement referring to something or an action coming up in the future). Additionally, for each relevant statement it was determined whether the statement was correct or incorrect, and, when applicable, whether a statement was focused on the driver's own actions, the automation status and/or the environment (i.e., this exploration examined the referents in the statements). If a statement was specific to a component of the HMI it was also coded to which component the statement referred to. In this way, the think aloud statements of the participant could be explored in depth. Coded think aloud data was converted to data on counts of each combination of applicable coded variables. These data were analysed using mixed effects zero-inflated regression models.

Regarding the questionnaires, after each video participants answered questions on their experienced task load/information load, the usability of the HMI system, and on potential overreliance. After being presented with all 4 HMI conditions, participants answered questions on constructs such as trust in technology, trust in automation, spatial presence and driving enjoyment. Additionally, questions were presented that aimed at gaining insight into the understanding of each HMI system and into preferences regarding the presented systems. The questionnaire data with closed answers were analysed using linear mixed-effects models. Answers to open-ended questions were examined in an exploratory fashion.

Experiment 5: The effect of ambient lighting effects and surrounding effects

Details for experiment 5 are presented in chapter 6, a study conducted by Grazian (2020). This experiment focused on examining experiences and effectiveness of HMI elements in a full HMI concept with a specific focus on the effect of ambient lighting effects and surrounding effects. To this aim 1 full HMI concept was developed primarily based on the outcomes of experiments 2.1 – 2.3 that explored directions for HMI design. A baseline version of this full HMI concept was also developed in order to allow for comparisons between the baseline and the full concept.

In the experiment 9 users of cars with automated functionalities participated in a supervised online experiment. The 9 participants were presented with two videos: 1 of the baseline HMI-concept, and 1 of the full HMI-concept. The participants provided feedback on each concept while viewing the video and answered questions about each concept after viewing the video. The focus of the questions was mainly on gaining insight into the participants' understanding of and experiences with the concepts. These subjective responses of participants were explored through clustering and averaging of responses.

The full concept (Figure 58) included three main aspects: 1) ambient light effects, 2) surrounding effects, and 3) central display. The first aspect, ambient light effects, was presented behind the steering wheel and the center control screen to continuously inform the driver about the status of the automation. The light was purple during TtS and light blue during SB. This effect was evaluated well by participants in experiment 2. The second aspect, surrounding effects, included masking the windows and highlighting other road users. The windows are masked when the driver does not need to pay attention to the road. This effect was included to facilitate engagement in secondary tasks and to enhance the noticeability of the ambient lighting effect. The windows were less transparent during TtS than during SB, as drivers would be required to pay more attention to the road during SB. Highlighting of other road users was included to support automation transparency and to make the driver aware of the most important elements in the surroundings. The central display as a third aspect informed on desired driver tasks and allowed for personalization on the left (i.e., driver section) and informed on the automation on the right (i.e., automation section) (Figure 59). The bar above has the same colour as the ambient light effect, and gradually turned into a different colour when transitioning between SB and TtS. In the driver section on the left NDRTs were suggested through the 'activity wheel' and the estimated duration in which the activity can be safely performed was indicated below this activity wheel (in green). It also indicated when the activity needs to be changed (in orange), or when the current activity was not safe and needed to be changed immediately (in red). In the driver section on the right a 'settings wheel' was presented which allowed the user to adjust the degree to which the windows were masked. Regarding the automation section of the central display on the right, this section detailed the time and distance to the destination at the top, in addition to a vertical route progress bar on which the current location of the car on the route was indicated. This route progress bar also indicated when a change in desired NDRT was coming up. For both the driver section and the automation section a bar with settings that can be changed is presented. Note, however, that in the current tested version there was no interaction possible in order to change settings. The concept also included sounds that were presented together with a transition in automation level, and that were presented before a transition from TtS to SB occurred in order to prepare/alert the driver for this transition.

Figure 58 The full HMI concept tested in experiment 5, including 1) ambient light effects (purple area below steering wheel and central display), 2) surrounding effects (highlighting of other road users in yellow), and a 3) central display (tablet with information for the driver).

A baseline of the full HMI concept was additionally developed. In this baseline version ambient light effects and surrounding effects were removed. Thus, the baseline version only included the central display presented in Figure 59.

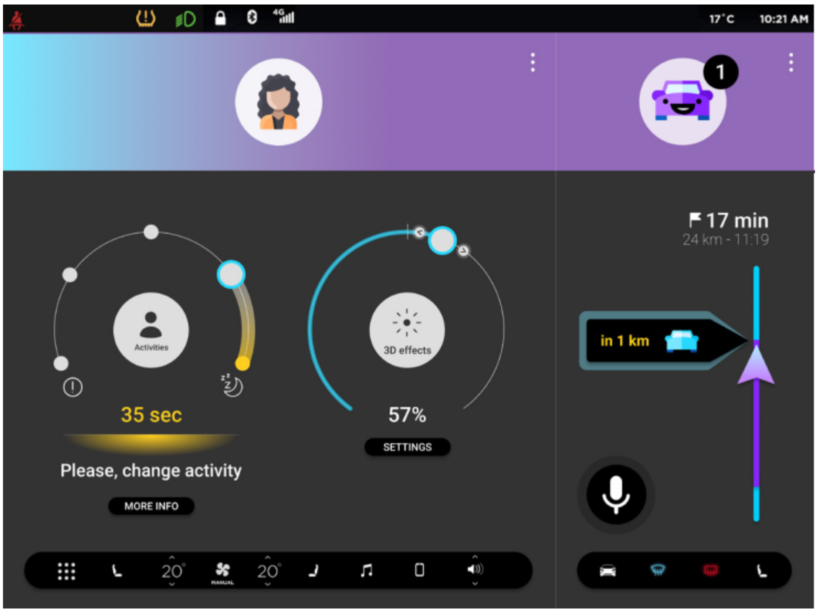


Figure 59 The central display of the HMI concept that was tested in experiment 5. The central display informed on desired driver tasks and allowed for personalization on the left (i.e., driver section) and informed on the automation on the right (i.e., automation section). The bar above has the same colour as the ambient light effect, and gradually turned into a different colour when transitioning between SB and TtS.

6.4. Results

6.4.1. Part 1: Exploration of important HMI design aspects and specific HMI elements

Experiment 1.1 – 1.3: Identifying important HMI design aspects based on experts' opinions, preferences and experiences of users of cars with automated functionalities and people in general

Detailed results for experiment 1.1 – 1.3 are presented in Grazian's study (2020) in chapter 3. The outcomes of the experiments supported the findings from the literature. It was demonstrated that people can be divided into 2 groups: 1) people with high information preference (HIP), and 2) people with low information preference (LIP), of which the HIP group prefers to have more information about the automation and their own role and of which the LIP group prefers to have less information about the automation and their own role. Experts indicated that it is important to *adjust the amount of information* based on whether someone falls in the LIP or the HIP group. Additionally, experts clearly indicated that important information to communicate is the *driver responsibilities*, *time estimated on current level*, *time before change in level*, and *next level availability*. Information on driver responsibility was indicated to be most important during continuous mediation, while all other aspects where of importance in SB and TtS, and especially during TtS. The current mode, the driver's responsibility, and time before change in mode should be communicated *continuously*. Additionally, *information should not be intrusive and annoying*, colours and lighting are promising means to create a non-intrusive ambience to guide the driver in what to do.

Users of cars with automated functionality consider bad experiences with partially automated driving when the reason of an action of the automation is unclear and/or when an action is unexpected and/or when actions and information are inconsistent. Users indicated to prefer receiving information about *time in current level/time to next level of automation*. Additionally, users preferred information being communicated visually or auditorily. Regarding differences between SB and TtS driving scenarios, users are more likely to perform an NDRT with longer periods of automated driving. Information on the *automation status* appeared to be especially preferred in SB by users, while information on *progression on the route* was especially preferred in TtS.

In contexts similar to automated driving, people indicate that they want to be *unconsciously aware* of the situation and they do not want intrusive signals. They also indicated that facilitating time management and experience with the system are important in performing a task well. Finally, the participant remarks suggested that *emotional attachment to the task* increases attentiveness. For example, for the context of watching your child while calling on the phone, emotional attachment to the object of your attention, your child, will increase your attentiveness. Also, in a situation where one is cooking on the stove while baking a cake in the oven, the emotional attachment to the final goal of making nice food for a cosy evening increases attentiveness to the tasks a hand.

Experiments 2.1 – 2.3: Exploration of directions for HMI design

The outcomes of these 3 experiments demonstrated that participants liked concepts that created an *ambience that nudges* the driver in what to do, for example through ambient light effects in the car. *Ambient light* effects were shown to be able to attain situation awareness, awareness about the automation and about the driver's responsibility (Grazian, 2020) Ambient light effects have the potential to also guide the driver's attention. Yet, participants raised doubts about whether they would understand clearly what would be expected of them as a driver, as the ambience doesn't specifically tell the driver what to do. A solution is to supplement the ambience by presenting additional information on the dashboard, which can communicate more specific information. For this more specific information, information on current automation status, time left to the next driving mode and the driver's responsibility appeared to be helpful. Additionally, an *overview of the route* with indications of confidence levels of the automation along the route was appreciated by many participants, who indicated that this could assist in choosing an NDRT. Some participants indicated that a virtual assistant which you could ask questions to and provides you with specific updates would be quite helpful in understanding the automation status, driving mode and responsibilities of the driver. Yet, some other participants mentioned that such a virtual assistant could be annoying and intrusive. From the 3 experiments combined it became clear that there are marked individual differences between participants in their preferences, with some people indicating specifically to like a specific element of the design while other people indicate specifically not to like the same specific element. Participants indicated that *personalization* options would be appreciated.

Experiments 3.1 – 3.4: Exploration of specific HMI elements

Detailed results for experiments 3.1 – 3.4 are presented in Appendix 2. The outcomes of these 4 experiments focused on exploring specific HMI elements demonstrated that *emoticons* are suitable to communicate the (un)certainty of the automation (experiment 3.1). Additionally, it was demonstrated that icons are suitable to communicate the desired driver task, including what a driver is required to do (pay attention, take-over control) and what a driver is allowed to do (sleep, work on laptop, use phone). Yet, for icons communicating the allowed tasks it became clear that some knowledge of autonomous cars and/or more information on contexts would be necessary in order for participants to interpret the icon's meaning and intended task (experiment 3.2). Interpretation was facilitated by presenting the icons communicating required tasks in red/orange and icons communicating allowed tasks in green (experiment 3.3 and experiment 3.4). However, again some knowledge of autonomous cars and/or more information on context appeared to be necessary, as some icons were still being interpreted in the context of a 'standard' non-self-driving car. It was also demonstrated that the colours red, orange and green were also suitable to be coupled to emoticons communicating the (un)certainty of the automation (experiment 3.3).

6.4.2. Part 2: Evaluation of full HMI concepts

Experiment 4: The effect of communicating anticipatory information on available time budgets and a comparison of communicating on automation fitness or on the desired driver task

Regarding the detailed outcomes of experiment 4, focused on testing the effect of communicating information on available time budgets and comparing providing information on automation fitness or on the desired driver task in users of cars with automated features, details can be found in Appendix 3.

For the think aloud data the results demonstrated that more correct statements on a projection level occurred in the AF conditions compared to the DT conditions, suggesting that participants were better in foreseeing future changes in automation mode or their own responsibilities when providing information on the automation status rather than on the driver task. When comparing baseline to full, the full conditions led to a smaller number of correct statements on a comprehension level, but to a larger number of correct statements on a projection level and in total on all SA levels combined. This finding suggests that with the full concepts, where information on *future automation mode* was provided, participants had a better SA in general and that they were specifically better able to foresee future changes compared to the baseline. More incorrect statements on a comprehension level and in total were uttered by participants in the DT conditions compared to the AF conditions, suggesting better understanding when presenting *automation status* than driver task information.

On a comprehension level, statements relatively included a lot of references to a HMI *transition icon* and included frequently a reference to a DT icon and an emoticon (i.e., referring to the driver task and the status of the automation respectively), suggesting that these HMI elements supported comprehension. On a projection level, statements referred relatively often to a transition icon, and somewhat often to the LED strip, suggesting that these HMI elements supported projection.

Incorrect statements were explored in order to gain more insight into what HMI information is not perceived or understood correctly. On a perception and comprehension level, most incorrect statements were uttered with the DT concept, were either confusion existed about the presented information or misinterpretation of an icon. Confusion also occurred, although to a lesser degree, with the AF concept, which was then often related to misinterpretation of an emoticon. Most incorrect statements on a projection level were made during the full versions of each concept but note that information that facilitated projection was only presented during the full versions. Participants often thought that they had to be more involved with the driving task than intended, or they did not understand a transition icon that was meant to prepare the participants for an upcoming change in the environment.

Statements involving an evaluation of the presented HMI were also explored in order to gain further insight into how the HMI concepts and aspects of these concepts were experienced. The most frequently recurring theme in these statements concerned participants longing for information that was not presented by the HMI, such as *navigation information*, *detection of traffic signs*, and *speed (limit) information*. The latter was uttered in the context of a future take-over situation for which participants indicated that we like to know how fast they would be allowed to drive when the need to drive themselves again. Additionally, some participants liked the idea of having ambient light effects in the car. Others, however, considered the ambient light effects to be annoying or uncomfortable. Additionally, several participants expressed a liking for the full versions of the AF and DT concepts, because these versions allowed them to anticipate upcoming events. When presented with the LED bar, some participants stated that they would not additionally need information on automation status from the emoticons, because this would be communicated through the LED bar's colour and also because having a single information display would negate the necessity to continuously look at two physical locations. Many participants expected that there would be *sounds* informing them of changes in the system state, especially when transitioning towards a lower level of automation fitness.

Overall, relatively few incorrect statements were made by the participants, while they got little to no information on the HMI functioning at forehand. This suggests that the current design choices to obtain low information processing load, where ambient light effects are combined with icons and bar-like visuals, can indeed be easily interpreted.

Regarding the results of the quantitative analyses on the questionnaire data, comparing the baseline to the full versions, the full version was supporting participant's understanding about when to look at the road and about when an event will take place more than the baseline.

Comparing AF to DT, AF was rated as having a higher usability than DT. Additionally, carefully watching DT was indicated as taking more time away from other tasks than AF. Yet, DT made the currently desired task and when to take-over clearer than AF.

From the ranking of the HMI conditions, it became clear that user preference differed strongly; none of the HMIs was clearly preferred the most or the least by participants. Yet, the characteristics of participants were related to HMI preference. To be precise, participants who scored high on sensation seeking were more likely to prefer AF base. Participants who scored high on perceived driving enjoyment for self-driving vehicles were more likely to prefer AF full the most and to prefer DT the least. With a higher trust in technology participants were more likely to prefer DT base less than DT full.

Participants who preferred DT indicated that the DT concept induced higher mental demand than for participants who preferred AF. Participants who preferred AF full, were more inclined to watch this HMI carefully even when they would have a lot to do. And participants who preferred AF in general indicated that this system helped them to understand when to look at the road. For participants that preferred DT full, it was demonstrated that they indicated that this system helped them understand which NDRT they could perform.

When the difference between the most preferred and least preferred systems were compared, a system that was most preferred had a relatively high usability score, helped the driver understand when to look at the road, when an NDRT is allowed, when an event would take place and when the automation would give back control. It appeared that rank was mainly influenced by whether a system helped to understand timing, rather than whether it helped to support understanding of what and how often. A system that was preferred the least was related to thinking that that HMI required careful watching which would take time away from performing other tasks.

Regarding the results of the qualitative analyses on open-ended questions, some recurring themes were identified in participants' answers. Participants that preferred a baseline system over a full system seemed to do so because of the minimalistic way of presenting information or because they did not like certain elements of the full version. Those that preferred the full version of the DT and AF designs often mentioned to appreciate the LED bar and the ambient light effects. The remarks seem to reveal that participants liked those HMI elements because it relieved them from the task of constant monitoring of the system by either telling them the time until something comes up, or by relying on the change of the ambient light effect as an indicator of any relevant events.

Experiment 5: The effect of ambient lighting effects and surrounding effects

Details for the outcomes of experiment 5 can be found in MTBG chapter 6. The full HMI concept (including ambient light effects, surrounding effects, and a central display) was rated more positively by participants than the baseline HMI concept (only including a central display). Specifically, on average participants indicated understanding of the status of the automation, the driver's tasks and responsibilities and the road context to be easier with the full HMI concept. In general, the usability of the full HMI concept was rated relatively high, especially by participants that had experience with automated functionalities in cars. Participants without such experience indicated they *needed technical support* (in the beginning) in order to be able to use this system. Participants indicated they would take-over the driving task more than was necessary, especially when they did not have any experience with cars with automated features. Both the *ambient light effects* and the *surrounding effects* were rated positively by participants, indicating that these features that were only available in the full HMI concept were appreciated. When the colour of the ambient light effect changed indicating a transition from TtS to SB this was immediately noticed by participants and they understood that it was not allowed anymore at that point to continue their current NDRT. The *highlighting of other road users* led to a realization in participants that the automation was able to detect other road users, which could support trust in the system, and which could enhance awareness about surrounding traffic even when engaged in an NDRT. Yet, for the specific surrounding effect of masking the windows participants indicated to prefer the masking to be less intense during SB in order to support gaining awareness of the surrounding traffic again.

Regarding the central display that was presented to participants in both the full and baseline HMI conditions, the information on desired activities was relatively unclear to participants. For example, some participants interpreted the information as reflecting the current activity that the participant would be engaged in, with two participants for example asking: "Am I sleeping now?" when sleeping was communicating as a desired activity. Three participants indicated that there were too many desired activities being communicated. Additionally, the visual feedback on dangerous activities was sometimes unnoticed. In general, it appeared that participants were not able to read all messages that were presented, possibly because participants were unprepared for a message coming up. The information on *route progress* on the display, however, did contribute to the activity planning action of drivers and their understanding of the time budget,

6.5. Conclusions

6.5.1. Main conclusions

The goal of the work described in this chapter was to determine functional requirements for an HMI that is active while driving in SB and TtS. The main challenge to be addressed during these driving modes is providing appropriate transparency to prevent mode confusion and overreliance, while maintaining proper information load. To this aim, the research described in this chapter consisted of two parts: 1) exploration of important aspects in HMI design and exploration of specific HMI elements; and 2) evaluation of full HMI concepts (consisting of a combination of elements). Part 1 consisted of interviews with experts and (potential) users of automated vehicles and explorative experiments testing the interpretation of and experience of directions of HMI design and specific HMI elements. Part 2 consisted of experiments testing full HMI concepts through questionnaires and the think aloud method.

Generally, it was found that sufficient transparency could be achieved with minimal information load by providing the driver with the most important information in such a way that it is easily interpretable by the driver. The following paragraphs describe these different types of important information and ways to communicate it.

From the literature and interviews with experts and (potential) users it became clear that the *current automation mode* should be communicated to the driver at all time because a driver should continuously be aware of his/her responsibilities and choose their NDRTs accordingly. Yet, it was still unclear whether communicating on the automation mode or directly on the desired driver task would be more valuable. The current work demonstrates that people understood HMI concepts that communicated on the *automation status* better compared to concepts that communicated on the desired driver task. Additionally, people preferred concepts in which an ambience is created that *nudges drivers* in what to do instead of concepts that present too much detailed information on desired tasks. These findings fit the approach of cognitive systems engineering (Borst, Flach, & Ellerbroek, 2015) in which one would indicate boundaries within which a driver can chose his/her own actions.

The current work also demonstrates that creating *subliminal awareness of the driving mode* is appreciated and that ambient light has the potential to make the driver aware of the automation mode in such a nonintrusive way. Yet especially when people are still learning the meaning of the information presented by the HMI, only presenting ambient light might not be enough for drivers to fully understand to mode and understand what actions are expected from them. More specific additional information can potentially be presented through icons which are easily interpreted by people.

From literature it was found that *anthropomorphistic icons* which include emotional expressions, might have value for understanding of the automation, creating trust and reducing overreliance. The results from Experiment 4 corroborated the value of such icons for understanding the automaton. Furthermore, results from the generative sessions suggested that emotional attachment to the task makes one feel more attentive. The anthropomorphistic icons could be a way to increase emotional attachment to the automation and consequently improve human-automation collaboration. Using such icons for conveying automation status information could then not only reduce mode confusion but might also improve attentiveness distribution between automation and driver and reduce overreliance. The true effect and best design of such icons, however, should be tested in future studies.

In addition to communicating on automation mode, the literature also indicated communication of *time budgets* (i.e., time left in current mode/time to next mode) to be potentially beneficial for the driver in anticipating changes in automation reliability and for planning appropriate NDRTs. The current work examined the effect of communicating time budgets and demonstrated that it indeed supported drivers in understanding what will happen in the future and that it could assist in planning NDRTs. Information on time left in current mode was also appreciated by people. When a change in automation mode will occur, drivers additionally appreciate it to know the *reason* for this change. Specifically, experiment 4 showed that conveying information on current automation state and time within this state, next automation state and reasons for changing the state can be effectively communicated, especially via an LED bar with changing length and colour combined with a simple icon. In this experiment many participants also indicated they expected a sound to be used to at least communicate switching down in automation level. Both the literature review and results from Experiment 5 additionally showed that providing information on *route progress* in combination with the time budget is very helpful for drivers for planning their trip.

Related to the information on time budgets is the *minimum useful time being in SB* which literature showed to be in the order of a few minutes. Driver's might have different preferences regarding this minimum time, and literature also showed that drivers would like to be able to set this value themselves through the HMI. Many current systems in automated vehicles do not provide information on time budgets that can be communicated to the driver. The expectation is, however, that this information will be available within the MEDIATOR project and that it will be possible to provide information on time budgets to the driver.

The current work also highlights that drivers want to understand the reasons for and anticipate manoeuvres of the automation. This is clear from the literature, interviews with users, but also from participants indicating when being presented with a video of an HMI design that they wanted to have insight into *upcoming manoeuvres* initiated by the automation and the automation's corresponding *decisions*. This information aids drivers in developing a mental model of the automation and avoiding automation surprises. In addition, providing insight into *automation perception* can support the driver's situation awareness and their trust in the system. For example, it was shown that highlighting other road users was effective to that aim. Also, in Experiment 4 participants indicated they would like information on speed limits and detected traffic signs. Potentially other information on automation perception, such as highlighting hazards, can be presented to the driver as well. Yet, one should be careful not to present a driver with too much information in order to prevent information overload. One way to do this is to simplify the information on the perception of the automation and the total amount of information presented to the driver. The current work demonstrates that a promising way to approach this is to reduce the window transparency and to only highlight the traffic characteristics that are most important in the current mode, such as other road users. This shows the driver for example that the automation detected these road users, which can increase trust in the system. An additional benefit of the implementation is that it can be perceived with peripheral vision, giving a more subliminal sense of traffic density and automation functioning. Current HUD solutions present information overlaying the real world, which comes with the danger of inducing information overload in the driver as here additional information on top of all information from the outside world is being presented to the driver.

Yet, the current work indicates that there are marked individual differences in the amount of information a driver would like to receive. Generally, two groups of people emerge: those with a high information preference and those with a low information preference. The high information preference group prefers to have more information about the automation and their own role while the low information preference group prefers to have less information about the automation and their own role. A way to deal with these different information preference groups, and with information load, is to implement *personalization*. In this way, not all information will always be shown, but the driver can adjust which information s/he wants to see. Of course, here the most essential information for the current mode should be presented at any time and it should not be possible for the driver to turn this information off.

Another finding of the current work is that people can learn the meaning of a HMI concept relatively fast. For example, in experiment 4 no training with and only little information was provided about an HMI concept. Yet, there were relatively little incorrect statements uttered by people during think aloud while viewing the HMI concepts, which suggests a good understanding of the concepts without training and/or an extensive explanation of the concept. The current work also demonstrates, however, that expectations about the automation can be of importance. For example, in experiment 5 people indicated they would take-over the driving task more than was necessary, especially when they did not have any experience with cars with automated features. Some explanation and a bit more context that *guides the driver through the automation functioning* can facilitate understanding of the information presented by the HMI. It seems that most faulty interpretations of people that were identified in the current work can be easily resolved in this way.

6.5.2. Limitations and recommendations for future work

The current work focused on presenting visual information to the driver through HMI design, as visual information was considered to be most suited to continuously inform the driver during SB and TtS. Also, content information is best conveyed using visual information. Yet, the value of presenting information additionally to other sensory modalities has been highlighted in the literature and the current experimental work demonstrated that information presented to other modalities such as auditory information could be essential for getting the attention of the driver when necessary. This might, for example, be necessary when a change of driving mode occurs and especially when the driver needs to disengage from his/her current NDRT.

Another limitation of the current work is that for some analyses only a limited number of participants was included. Additionally, several analyses on incorrect statements during think aloud were not possible due to the low occurrence of incorrect statements. Yet, increasing the number of participants would likely not solve this issue as everyone participant will probably utter relatively few incorrect statements. To have a larger number of incorrect statements per participant one would need to have longer periods of think aloud. However, it has also been indicated that people are not able to think aloud for too long. Although variation in the data is induced by the fact that there are marked individual differences between people regarding their information preferences, the patterns as evidenced by the main findings of this current work will probably remain even when testing larger groups of participants.

A very important aspect to keep in mind when interpreting the current findings is that the current work made use of online experiments in which images and videos were presented to people. This set-up of experiments is less engaging and less naturalistic. Also, the perspective that was presented to the participants was different from the perspective one would normally have when seated on the driver's seat. For example, in experiment 4 the viewer's perspective in the drives was on eye height (vertical position) of someone sitting in the middle of the vehicle in between the driver's seat and the front passenger's seat (lateral position), moved slightly towards the back of the car from the driver's seat (longitudinal position). Note however, that we examined spatial presence in experiment 4 and that the obtained scores were comparable to scores in earlier experiments in which participants passively viewed a 360º video in the lab (Tjon, Tinga, Alimardani, & Louwerse, 2019). This suggests that although experiments were executed online in the current work and presented a different view than one would normally have during actual driving, the feeling of presence in the presented scenarios was actually sufficient. Yet, ambient light will for example look and feel different when being immersed in an environment in which the ambient light affects the complete environment instead of only a part of an image on the screen being highlighted in a colour as in the currently applied ambient light effects. Therefore, findings should be replicated in a more immersive setting in future work.

The current work placed an emphasis on examining what information should be presented during SB and TtS to a driver and through what HMI element. As a next step future research could emphasize simplifying HMI information in order to determine how to present the right amount of information with the right degree of simplification. This is especially interesting as the current work highlighted that people prefer to receive nonintrusive information and that people prefer information to nudge them in the right direction without telling them explicitly what to do at each moment in time.

In addition, in the current work the effectiveness of full HMI designs for communicating information during SB and TtS was tested in experiment 4 and 5. Yet, it is not completely clear from the results what the effect is of (specific combinations of) each included specific HMI element. This could be examined in further detail in future work. Also, future work should examine the HMI designs for communicating information during SB and TtS combined with HMI designs for communicating other essential information to the driver, for example for corrective and preventative mediation. It is of importance to determine whether the current researched HMI design does not interfere or conflict with HMI design fulfilling another aim.

Another important aspect for future work is to examine long-term effects of the current researched HMI designs. It is yet unclear how the designs will be experienced by the driver on the long-term. It is also yet unclear what the (long term) effects will be for passengers. For example, does ambient light induce eyestrain when presented for longer periods of time both in the driver and in passengers? And how to adapt the amount of more specific information (such as icons) being presented over time in order to deal with changing information needs? Also, an order effect was found in experiment 4, suggesting that experience with one design might influence the effectiveness of another design. This could be of importance to examine further, especially when considering that different car brands might incorporate different HMI designs which could influence the effectiveness of the HMI design when a driver has experience with another HMI design.

Finally, when communicating time budgets in the current work no distinction was made between likely and certain or fixed time budgets. Drivers will probably have more difficulty with dealing correctly with likely than with fixed communicated time budgets. It is yet unclear how a likely time budget should be communicated to ensure that drivers will understand it and respond to it correctly. Of course, it depends on the available information from the automation whether likely time budgets can also be communicated to the driver. Yet, findings might be different when focusing on communicating likely compared to fixed time budgets.

6.5.3. Conclusions in short

Although there are still some remaining questions that need to be researched in future work, the current work provides important insights into HMI design for communicating information to the driver during SB and TtS with the aim of facilitating sufficient transparency without creating information overload, namely: 1) the automation mode and time budgets should be communicated continuously; 2) reasons for changes in automation mode should be clear; 3) an ambience should be created that nudge the driver in what to do in a nonintrusive way; 4) reasons for manoeuvres of the automation should be clear and information that allows on anticipating manoeuvres should be available; 5) information on automation perception should be available but information overload should be prevented; 6) personalization should be possible in order to deal with individual differences such as people having a high or a low information preference; and 7) expectations of the automation and the HMI should ideally be correct in order to facilitate interpretation and correct actions of the driver.

6.6. Functional requirements of this study

The conclusions discussed above result in certain functional requirements for HMI design for communicating information to the driver during SB and TtS. Therefore, the functional requirements are applicable to all use cases which include SB and/or TtS. These functional requirements are listed below. The necessity for implementation of each functional requirement is indicated based on three levels ranging from most to least important: 1) 'Must' indicates that implementation is mandatory, 2) 'should' indicates that implementation is desired, and 3) 'will' indicates that implementation is somewhat desired. Each functional requirement specifies what the system must do and not how to. Possible HMI components and their settings in order to achieve each functional requirement are detailed below each functional requirement.

- While driving in SB or TtS the HMI *must* communicate the current mode continuously.
    - This requirement can be attained through providing an ambience in the car which non-invasively communicates the current mode, for example through ambient light. Especially in the beginning of driving with the HMI system it is desirable to additionally present more specific information on the mode, for example through anthropomorphic icons. Such specific information should reflect the automation status rather than driver task.
- While driving in SB or TtS the HMI *must* communicate the time left in current/time to next mode continuously while still clearly communicating the current mode.
    - This requirement can for example be attained through communicating the time in a number, or, through a LED bar depleting over time with decreasing time in the mode.
- While driving in SB or TtS the HMI *should* communicate what the next mode will be
    - It is possible that if this next mode is far in the future, e.g., hours, that an HMI element such as the LED bar in experiment 4, will not communicate this mode as it is not immediately relevant. However, in this case the next mode should still be communicated through an HMI element that shows route progress.
- While driving the option to switch on SB or TtS *will* only be offered if it is likely that it will be available for at least 4.5 minutes
    - This requirement related to NDRT planning mostly, but it is possible that some drivers also would like to use SB or TtS for shorter periods of time. It is therefore advised to offer the option to the driver to set this minimum time through the HMI. The 4.5 minutes limit is based on questionnaire results from literature. However, it is possible that in certain circumstances, such as when a message arrives to which the driver quickly wants to reply, shorter times are also acceptable.
- When the current mode will change to another mode the HMI *should* communicate the reason for this change in advance.

- This requirement can be attained by for example using icons for an event that will occur in the environment, for example indicating that roadworks are coming up or that the car will leave the city.

- While driving in SB or TtS the HMI *should* nudge the driver in what to do.
  - This requirement can be attained ideally by not directly communicating to the driver what to do but by for example providing the right ambience in which the driver can choose the right task within the boundaries of the current mode.
- While driving in SB or TtS the HMI *should* communicate the foreseen automation status throughout the route.
  - This requirement can for example be attained through visualizing the complete route the car is planning on taking on a map and indicating the highest applicable automation status on parts of this route.
- While driving in SB or TtS the HMI *should* communicate manoeuvres that the car will perform in the near future.
  - This requirement can for example be attained through visualizing through icons whether the car will go left, right, or straight. Or when the car will change lanes, this can also be indicated through an icon for example.
- While driving in SB or TtS the HMI *will* communicate reasons for manoeuvres that the car will perform in the near future.
  - This requirement can for example be attained through visualizing through icons the reason for actions such as overtaking and changing lanes.
- While driving in SB or TtS the HMI *should* communicate on automation perception.
  - This requirement can for example be attained through highlighting traffic aspects that are of importance in the current mode. For example, detected other road users can be highlighted.
- While driving in SB or TtS and if the current mode allows for a setting on presented information to be changed the HMI *should* provide the option to have its settings on presented information changed.
  - This requirement can for example be attained through allowing the driver to set a user profile. A user profile for people with a low and a user profile for people with a high information preference can for example be desirable.
- If a driver has never used the HMI before the HMI *will* guide the driver through all its functionalities and how these functionalities relate to the capabilities of the automation.
  - This requirement can for example be attained by highlighting and explaining each element of the HMI before the driver will drive with the HMI for the first time.

7. Preventive measures to maintain driver fitness

7.1. Strategy

Partial automated driving requires the human driver to constantly monitor the driving situation. In order to be able to fulfil this requirement the human driver needs to maintain optimal vigilance. In this chapter we address this issue and examine how optimal vigilance could be maintained through HMI design during the use case Continuous Mediation (CM). Preventive measures that are aimed at maintaining driver fitness, and in this case especially at preventing vigilance deterioration, will be referred to as *preventive mediation* solutions.

First, we explain the (underlying mechanisms of the) challenges during CM and the concept of preventive mediation in order to support identifying directions for solutions for preventing vigilance deterioration. Second, we present the results of a literature review on how vigilance decrements could be prevented during CM. Third, based on this literature review we present functional requirements for HMI design for maintaining optimal vigilance during CM.

7.2. Challenges during Continuous Mediation

As described in D1.1, important challenges arise during CM. During partial automated driving the human driver has to both monitor the system and needs to be able to take over driving immediately if necessary. This requires the driver to stay involved in the driving task continuously to maintain adequate situational awareness at all times. This requirement presents two main challenges: 1) Mode awareness should be attained, and mode confusion and mode errors should be prevented; and 2) an optimal vigilance should be maintained, and vigilance deterioration needs to be prevented.

The first challenge is not unique to CM and is also present during SB and TtS. Ways in which HMI design can support mode awareness and prevent mode confusion and mode errors are discussed in chapter 6.

The second challenge is one that is rather unique to CM, as only during partial automated driving the driver needs to constantly monitor the driving situation while being partly involved in the driving task. This task is highly monotonous and requires sustained attention for the detection of unpredictable instances of automation failure. For this task it is of utmost importance to maintain optimal vigilance. Vigilance refers to the ability to maintain alert and maintain focus of attention over prolonged periods of time (Warm et al., 2089). Deteriorated vigilance causes monitoring performance to decrease, and it can potentially lead to overdependence on the automation (Matthews et al., 2019).

In order to be able to find a solution for the challenge of maintaining an optimal vigilance it can be helpful to understand why constant monitoring can lead to deteriorated vigilance. The literature provides three different but complementary explanations (Matthews et al., 2019): The first is based on the resource theory of vigilance decrement (e.g., Warm et al., 1996 & Warm et al., 2008), which states that persistent signal detection under high workload leads to depletion of resources and loss of vigilance. If partial automated driving would induce high workload in the driver a potential solution could be to reduce the driver's demands. The second explanation concerns the idea that a repetitive task that provides little positive reinforcement affects neural systems related to energy and vigilance, contributing to boredom and mind-wandering (Cummings et al., 2016 & Scerbo, 2001). This issue could be relevant to partial automated driving where the driver receives little positive reinforcement for a repetitive effort, which suggests that solutions could be aimed at providing positive reinforcement. The third explanation comes from the perspective of the transactional model of stress and emotion (Lazarus, 1999) which states that vigilance reflects the appraisal and coping processes of the operator's interaction with the task environment. Therefore, low challenge appraisal and low use of task-focused coping are thought to be associated with loss of task engagement. Vigilance can easily deteriorate when effort commitment is perceived as unrewarding (when the task is boring) or when effort commitment is perceived as ineffective. These issues are thought to increase when agency is transferred to automation as work becomes more limited and repetitive and as it induces reluctance to exert effort since striving to maintain vigilance tends to be subjectively aversive (Matthews, et al. 2019). Again, this suggests that solutions could be aimed at making the partial automated driving task more rewarding. Additionally, solutions could potentially be aimed at making the task less limited and less repetitive. Another direction could be to directly intervene on the reluctance to exert effort by making sure the driver understands the importance of remaining vigilant and/or by making the task more enjoyable.

Another way to look at existing explanations for vigilance deterioration during monitoring is to divide the explanations in the *underload* and *overload* explanations (Greenlee et al., 2019). A monitoring task could lead to underload, as monitoring is passive and does not require active input which can lead to under-stimulation and boredom. When the driver is underloaded, vigilance can greatly deteriorate. This is supported by research on partial automated driving demonstrating that underload (as reflected in subjective ratings and brain activity) already occurs within less than 5 minutes and increases with increasing time on task (Solís-Marcos et al., 2017). This would suggest that solutions could be aimed at increasing load in the human driver. Alternatively, a monitoring task could lead to overload, as monitoring is thought to be extremely demanding causing resources required for maintaining vigilance to deplete. This is supported by research indicating that indicates that vigilance decrements during partial automated driving occur due to the driver being overloaded (Greenlee et al., 2018 & 2019). To date, the exact underlying causes of vigilance decrements during monitoring remain unclear. This makes it more challenging to find a solution for maintaining optimal vigilance.

Additional complexity is introduced by findings demonstrating that drivers can underestimate the actual load induced by attentive monitoring during partial automated driving as exemplified by the fact that subjective workload measures can be low while objective measures indicate that workload is actually high (Stapel et al., 2019). Therefore, both subjective and objective measures of workload should be considered. Moreover, individual differences can greatly influence experienced workload during monitoring (Guastello et al., 2014).

Although having insight into the underlying causes and the role of individual differences would greatly benefit finding a solution for maintaining vigilance during partial automated driving, solutions could be aimed at changing the monitoring task in such a way that vigilance decrements are prevented irrespective of the exact underlying mechanisms. Such solutions could be referred to as *preventive mediation* solutions.

7.3. Preventive mediation

Preventive mediation is introduced as a term to refer to measures that are aimed at maintaining driver fitness. Preventive mediation can be distinguished from *corrective mediation* which refers to measures that are applied as a response to deteriorated driver fitness. Thus, while preventive mediation *prevents* driver fitness from deteriorating, corrective mediation *corrects* driver fitness when it is already deteriorated. This also implies that for applying corrective mediation the driver needs to be monitored in order to detect deteriorated driver fitness and that no such monitoring is needed for preventive mediation as it is a continuous intervention or design solution which prevents a state of deteriorated fitness.[1]

7.4. Preventing vigilance deterioration by changing the driver's task

Preventive mediation during CM should primarily be focused on preventing vigilance deterioration, because, as explained above, this is one of the main challenges during CM. This section explores solutions for preventing vigilance deterioration by changing the driver's task during partial automated driving and their effectiveness as proposed and researched in the MEDIATOR project and in the scientific literature. To identify relevant scientific literature a search was conducted in the Google Scholar and Web of Science databases in February 2021 using a combination of the search term 'partial automat*' with terms such as 'underload', 'vigilance', 'fatigue', 'mind-wandering', and 'bored*'. In addition, references in and references to relevant articles identified through this search were assessed and were included when relevant. Articles were considered to be relevant that focused on preventive measures during partial automated driving. An overview of the solutions aimed at changing the driver's task can be found in Table 5.

A solution that has been explored in the MEDIATOR project is described in D1.2. This solution presented an additional active task during partial automated driving. The task concerned the so-called *Simon Game*. In this task a display with 4 colored squares was presented. The colored squares were selected in a certain order and the participant had to repeat the sequence by touching the colored squares in the same order. In the first and easiest level, the sequence included one color. Each time the participant repeated the sequence correctly, an additional color was added to the sequence. Therefore, the second level included a sequence of two, colored squares, the third level a sequence of three colored squares and so on. If an error was made or if a response took longer than 2 seconds, the game was restarted at the first level. The opportunity to play the Simon game was triggered after 9, 24 and 37 minutes from the beginning of the experiment, for 2 minutes each time. Each correctly repeated sequence entitled the participant with points corresponding to the sequence's length at that level (e.g., 3 points for a sequence of 3 colors). Points were accumulated which resulted in a final score at the end of the experiment. Participants were stimulated to perform well as they were instructed that the three participants with the highest scores would win a monetary prize. This solution is therefore thought to make partial automated driving more rewarding and more enjoyable and making it less repetitive. The results of the evaluation of this solution demonstrated that the Simon Game (compared to not having such a task) reduced subjective sleepiness and increased heart rate variability (which could be indicative of a reduction in arousal or stress or cognitive load in participants, see for example Tinga et al. 2019 and 2020) while leaving the number of glances to hazards unaffected.

When presenting a visual secondary task during partially automated driving, it might be beneficial to present the task using a head-up display (HUD) compared to a display presented at the center console as suggested by Hensch et al. (2020). In their study two different visual secondary tasks (the surrogate reference task and text reading) and two different display positions (HUD and center console) were presented to participants during partially automated driving. More tasks were solved on the center console than on the HUD. Yet, participants spent more time looking at the HUD than the center console and looking at the text reading task than the surrogate reference task. Participants preferred the HUD as a display position compared to the center console, indicating that they thought that the spatial proximity of the HUD to the driving scene was advantageous. Yet,

[1] Note, however, that techniques for driving monitoring might be valuable for evaluating the effectiveness for preventive mediation for example in a pretest before widescale implementation.

about half of the participants also indicated that the HUD was distracting, and some participants even indicated that shifting attention from the HUD to the driving scene was effortful. The authors interpret the findings as that a HUD might enable faster identification of and reaction to critical situations. However, the current study only examined subjective experiences and glance behavior and therefore the effects of presenting a secondary task on a HUD on actual performance remain unclear. Based on the subjective experiences of participants the HUD could potentially also have a negative impact on vigilance and performance.

Based on other findings in the literature, it might be best to not present drivers with a visual secondary task, but with a secondary task that stimulates another sensory modality. A study by Lassmann et al. (2020) tested four different secondary tasks during partial automated driving: An auditory n-back task (either 1- or 2-back), a surrogate reference task, activating stretching exercises and watching a video. These conditions were compared to manual driving without secondary task and partial automated driving without secondary task. When no secondary task was presented, the participants got fatigued. With activating exercises subjective sleepiness decreased, but response times to events increased. These increased response times were potentially caused by the head being turned during the stretching exercises causing gaze to be not focused on relevant events. The addition of the auditory n-back task led to response times that were comparable to manual and partial automated driving without secondary task. Yet, the audition of visual secondary task (surrogate reference task and watching a video) increased response times. These findings suggest that a secondary task can mitigate subjective sleepiness, but that a secondary task can also increase response times to events. Only the auditory secondary task mitigated subjective sleepiness while not increasing response times, suggesting that stimulation of the auditory instead of the visual modality might be preferable when presenting a secondary task during partial automated driving. This idea is also supported by the Multiple Resource Model (Wickens, 2002) which suggests that two tasks can be executed at the same time without decrements in performance when they are depending on different modalities. Therefore, adding a visual secondary task in addition to the driver's monitoring task that heavily depends on the visual modality can lead to visual overload and therefore to monitoring performance impairment. To prevent this issue a secondary task can be presented to another modality, for example the auditory modality.

The effects of two different types of auditory secondary tasks were examined by Neubauer et al. (2014) during manual, partial automated and total automated driving. These tasks concerned a trivia game and a hands-free cell phone conversation. During the trivia game participants had to answer to questions from one of five categories (e.g., sports, movies, food, general knowledge, current events) for 10-minute periods at two times during the drive. During the cell phone conversation participants were required to engage in a conversation focused on memories of a personal event during the same two 10-minute periods. A secondary task improved subjective task engagement and objective vehicle control compared to driving without a secondary task. There was one difference between the two types of secondary tasks; during the cell phone conversation subjective distress was the lowest without increasing subjective workload. Yet, the secondary tasks did not counteract slowed braking to an emergency event during automated driving.

Hirano et al. (2018) and Lee et al. (2019 & 2020) conducted studies also testing the effects of being involved in a conversation during partial automated driving. In contrast to the previous study, however, participants were conversating with a passenger being present in the car in these studies. Hirano et al. (2018) compared the effects of conversating with a passenger to listening to music and to a baseline without any auditory secondary task. While talking with a passenger, drivers looked more to the lane center, had their eyes closed for more than 80% less frequently, yawned less, were subjectively less bored and had shorter time to collisions compared to while listening to music and while driving in the baseline condition. However, response times to a hazardous event were highest while conversating with a passenger compared to the other two conditions. Lee et al. (2019) compared conversating with a passenger in the car to conversating with a verbal communication system. Additionally, these conversations did or did not include information about upcoming driving situations. Responses to critical events after 10 and 20 minutes in the drive were tested in these different conditions and in a baseline without any conversation. Responses to the first critical event were delayed with the conversation with the passenger without information about the upcoming driving situation. And there were participants that were not able to deal with the event in the conditions in which they conversated with the system. Moreover, subjective sleepiness and boredom were higher in the baseline than in the conversating conditions. When conversating while receiving information about upcoming driving situations, participants thought it was less difficult to drive. No significant differences in responses to the second event were demonstrated and the conditions also did not affect subjective workload, distraction and concentration. Lee et al. (2020) examined whether there would be a difference in conversating with an experimenter that participants had either met before or had not met before. Compared to a baseline drive without a conversating partner in the car, subjective sleepiness decreased, subjective boredom decreased, subjective distraction decreased, and subjective workload decreased while participants found it also easier to drive with a conversating partner. Moreover, participants yawned more frequently without the conversating partner being present in the car. However, out of the 22 participants 5 participants were not able to respond to hazardous events with a conversating partner, while only one participant was not able to respond to hazardous events without a conversating partner. The findings of these studies demonstrate that while conversations had positive effects, it negatively impacted objective safety outcome measures. Highlighting that it is necessary to consider multiple outcome measures and that one needs to be careful with implementing secondary tasks during partial automated driving.

In the solutions discussed until now the preventive measures were largely enforced; being presented at predetermined times or continuously and requiring a response when presented. In contrast to these enforced measures Naujoks et al. (2018) examined the effects of letting participants engage in whatever activity they felt safe enough to do so during a partially or highly automated drive. Participants were informed about the limits of the automated systems and it was emphasized that constant monitoring was necessary during partial automated driving. During partial automated driving, most participants used their smartphone. After 60 or 120 minutes a hazardous event took place in which a lead vehicle performed a lane change to the participant’s lane and suddenly braked which would cause a collision after 3.73 s if the participant would not respond. Prior to the hazardous event about 70% of participants were engaged in a secondary task. Out of 32 participants that drove with partial automation, 7 participants collided with the vehicle that performed the cut-in. The study by Naujoks et al. (2018) also tried to predict the take-over performance of the participants, in which it was demonstrated that visual and mental workload and motivation to accomplish the secondary task in addition to fatigue (all as were rated by observers) during an interval of 15 s before the event were able to predict take-over reaction times with a higher workload leading to lower braking reaction times and a higher motivation and higher fatigue leading to higher braking reaction times. Minimum time to collision increased with higher motivation and higher fatigue and a higher mental workload increased minimum time to collision. Note, however, that all measures were observations from coders, while it is for example unclear whether experienced workload can validly be detected by an observer. As the authors indicate the rating scheme used in the study might not be highly sensitive to detecting workload. There was no difference in take-over performance between the 60 minutes’ drive, and the 120 minutes’ drive and fatigue was relatively low throughout the experiment, which the authors interpret as potentially demonstrating that the engagement in the secondary tasks might have helped the drivers to maintain vigilant. It could be that self-pacing of a secondary task can also be an effective preventive measure, yet no control condition in which secondary task engagement was not self-paced and/or in which there was no secondary task engagement was included which makes it unclear whether self-pacing provides additional benefits to enforcing a secondary task.

While the solutions discussed above mainly focus on changing the driver's task through secondary tasks, another way to change the driver's task is through the interaction with the automation. Research indicates that issues in automated driving can be prevented when the driver and the automation continuously interact and communicate (Abbink et al., 2012). One solution that is aimed at having a continuous interaction is haptic shared control. Abbink & Mulder (2010) define haptic shared control as a method of human-automation interaction that ''...allows both the human and the [automation] to exert forces on a control interface, of which its output (its position) remains the direct input to the controlled system." In the case of automated driving, haptic shared control lets the driver share the steering torque with the automation through a haptic guidance steering system (Abbink et al., 2012), enabling both the driver and the haptic guidance system to contribute to the steering input. In this way, the driver remains in-the-loop while they need to exert less control than during manual driving. Haptic shared control is an interesting solution for changing the driver's task during partial automation. However, technical implementation of haptic shared control is challenging as for example forces of the driver's steering and of the haptic guidance need to be appropriately balanced in order to prevent conflicts that would feel intrusive to the driver (Wang et al., 2019). Therefore, solutions aimed at haptic shared control are not included in the current overview as they fall outside the current project's scope. Haptic shared control solutions, however, also underscore that changing the driver's task might be beneficial.

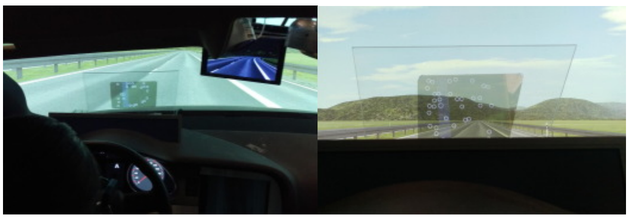
Research (e.g., van den Beukel et al., 2016) also points towards the potential of directing attention to the road when an event occurs that requires attention or intervention, for example through illumination of the sides of the windscreen intended to attract attention towards the road and away from any non-driving related tasks. This is an interesting approach, but for this to work the automation would need to be able to detect all potential hazards otherwise chances are high that the driver misses a hazard completely. Yet, current partial automation systems are not able to detect all hazards, making it impossible to implement reliable warnings directing attention towards the road when needed. Therefore, this type of solutions is also not included in the current overview.

Other preventive measures that have been proposed include enforcing breaks in which the driver should rest (e.g., Helton & Russell, 2017) and limiting the availability of partial automation to situations where the task demands will be manageable for the driver (Greenlee et al., 2019). Enforcing breaks and limiting the availability could then be an interesting option for when partial automation does not seem to be fitting after applying the most effective other preventive measures. Yet, to date few studies have been conducted on this type of solutions. It is recommended that future research explores this type of solutions in more detail by examining for example the optimal duration for partial automated driving and breaks, the effect of switching between ACC and LKS and the effect of type of situation on optimal durations and effects of switching. For now, we have also not included studies on enforcing breaks and limiting the availability of partial automation in the current overview.

In addition to preventive measures that change the driver's task, research (Llaneras et al., 2017; Seppelt & Lee, 2007; Zhou et al., 2020) has indicated that knowledge of the limitations associated with partial automation can have a positive impact. Zhou et al. (2020) demonstrated that this knowledge positively affects safety of interventions during partial automation. Specifically, knowledge about the limitations coupled to the conditions on the road (also called 'scenic knowledge') compared to functional knowledge is able to benefit safety of interventions the most. Knowledge coupled to conditions on the road in this case would be knowledge such as "the system no longer works because the visual field is poor due to deep fog or because highway lanes are closed due to objects on the road" while functional knowledge would be knowledge such as "the system no longer works because the system cannot sense traffic lines or because the system cannot recognize static objects on the road".

In addition to studies that focus specifically on (partial) automated driving, research conducted on monotonous manual driving might also point in interesting directions for preventive measures. For example, it has been demonstrated by Schmidt et al. (2011) that about 1 minute of verbal interaction every 20 minutes during a 4-hour monotonous manual drive improved vigilance during the verbal interaction, persisting for up to two minutes after the interaction. Suggesting that vigilance can be increased by a conversation, with effects maintaining only for a limited amount of time after the conversation has finished. Moreover, positive effects of an auditory trivia game in mitigating sleepiness and maintaining arousal and alertness have also been demonstrated during monotonous manual driving (Gershon et al., 2009). In a similar vein, gamification has also been suggested to be beneficial (Bier et al., 2019). As another example, research on monotonous manual driving also indicates that timing of a secondary task might be of importance; in a study by Atchley & Chan (2010) a verbal secondary task was most beneficial in improving driving performance when it was presented at the last time block of a 25-minutes' drive, instead of continuously during the complete duration of the drive.

Table 5 Overview of solutions aimed at preventing vigilance deterioration during partially automated driving by changing the driver's task

Study	Solution for maintaining vigilance	Main findings & image of solution, if available)
D1.2 MEDIATOR	A secondary task was presented during L2 driving, namely the 'Simon Game': 4 colored squares were selected in a certain order which needed to be repeated by touching the colored squares in the same order. This was compared to manual driving and L2 driving without a secondary task	KSS (sleepiness) scores were lower and heart rate variability increased during L2 driving with the secondary task compared to without. No effects of the secondary task on number of glances to hazards were found. 
Hensch et al. (2020)	Two different visual secondary tasks were presented during L2 driving: the surrogate reference task and text reading. These tasks were presented with two different display positions: HUD and center console.	More tasks were solved on the center console than on the HUD. Participants spent more time looking at the HUD than the center console and looking at the text reading task than the surrogate reference task. Participants preferred the HUD as a display position compared to the center console, indicating that they thought that the spatial proximity of the HUD to the driving scene was advantageous. Yet, about half of the participants also indicated that the HUD was distracting, and some participants even indicated that shifting attention from the HUD to the driving scene was effortful. 
Hirano et al. (2018)	Three conditions were presented: conversating with a passenger, listening	While talking with a passenger, drivers looked more to the lane center, had their eyes closed for more than 80% less frequently, yawned less, were subjectively less bored and had shorter time

Study	Solution for maintaining vigilance	Main findings & image of solution, if available)
	to music and a baseline without any auditory secondary task.	to collisions compared to while listening to music and while driving in the baseline condition. However, response times to a hazardous event were highest while conversating with a passenger compared to the other two conditions.
Lassmann et al. (2020)	Four different secondary tasks were tested as solutions during L2 driving: 1) Auditory n-back task (1- and 2-back); 2) surrogate reference task; 3) activating stretching exercises; 4) watching a video. These were compared to manual driving without secondary task and L2 driving without secondary task.	No secondary task induced fatigue; activating stretching exercises led to a decrease of subjective sleepiness but increased RTs (potentially because of the head being turned leading to a distraction of gaze). RTs were comparable with the baselines with the auditory n-back task, while they increased with visual secondary tasks.
Lee et al. (2019)	Participants were either conversating with a passenger in the car, conversating with a verbal communication system, or not conversating at all (baseline). Additionally, conversations did or did not include information about upcoming driving situations.	Responses to a critical event occurring after driving 10 minutes were delayed with the conversation with the passenger without information about the upcoming driving situation. And there were participants that were not able to deal with the event in the conditions in which they conversated with the system. Moreover, subjective sleepiness and boredom were higher in the baseline than in the conversating conditions. When conversating while receiving information about upcoming driving situations, participants thought it was less difficult to drive. No significant differences in responses to the second event were demonstrated and the conditions also did not affect subjective workload, distraction and concentration.
Lee et al. (2020)	Tested the effect of conversating with a passenger being present in the car (i.e., an experimenter that they had either met before or had not met before) during L2. This was compared to a baseline drive in which no conversating partner was present.	With a conversating partner, subjective sleepiness decreased, subjective boredom decreased, subjective distraction decreased, and subjective workload decreased while participants found it also easier to drive. Moreover, participants yawned less often. However, out of the 22 participants 5 participants were not able to respond to hazardous events with a conversating partner, while only one participant was not able to respond to hazardous events during the baseline.
Naujoks et al. (2018)	Examined the effects of letting participants engage in whatever activity they felt safe enough to do so during L2 and L3.	During L2 most participants used their smartphone. Prior to a hazardous event about 70% of participants were engaged in a secondary task. Out of 32 participants that drove with L2, 7 participants collided during the hazardous event. Visual and mental workload and motivation to accomplish the secondary task in addition to fatigue (all as were rated by observers) during an interval of 15 s before the event were able to predict take-over reaction times with a higher workload leading to lower braking reaction times and a higher motivation and higher fatigue leading to higher braking reaction times. Minimum time to collision increased with higher motivation and higher fatigue and a higher mental workload increased minimum time to collision. There was no difference in take-over performance between the 60 minutes', and 120 minutes' drives, and fatigue was relatively low throughout the experiment.
Neubauer et al. (2014)	The effect of the following two secondary tasks was tested during L2 and L5 and during manual driving: 1) Auditory trivia game; 2)	Subjective task engagement was lowest without a secondary task and highest with a secondary task. Additionally, a secondary task decreased the standard deviation of the lateral position (i.e., increased vehicle control). With the cell phone conversation subjective distress was the lowest without increasing subjective

Study	Solution for maintaining vigilance	Main findings & image of solution, if available)
	hands-free cell phone conversation. A condition without secondary task was also tested.	workload. Yet, the secondary tasks did not counteract slowed braking to an emergency event during automated driving.

7.5. Conclusions

The goal of the work described in this chapter was to determine functional requirements for HMI design for maintaining optimal vigilance in the human driver during partial automated driving in CM. To this aim, the current chapter focused on 1) exploring the challenges that arise during CM and their underlying mechanisms, 2) explaining the concept of preventive mediation, and 3) examining preventive solutions for maintaining vigilance based on a literature search.

From the exploration of the challenges that arise during CM and the underlying mechanisms associated with these challenges it became apparent that the continuous monitoring that is required of the driver is rather unique to partial automated driving. In order to be able to fulfil this requirement the driver needs to maintain optimal vigilance. Yet, research demonstrates that vigilance decrements occur easily and can occur already within a short period of partial automated driving, indicating that the driver needs to be supported in maintaining vigilance. The exact underlying causes of vigilance decrements during continuous monitoring are, however, unclear. As the underlying causes are unclear, finding a solution to maintain optimal vigilance is challenging.

Potential solutions could be aimed at changing the monitoring task in such a way that vigilance decrements are prevented; these solutions that are aimed at maintaining driver fitness are referred to as *preventive mediation* solutions.

Through literature search 8 studies were identified that examined preventive mediation solutions aimed at changing the monitoring task during partial automated driving by presenting drivers with a secondary task. Considering these studies altogether it seems that presenting a secondary task can have beneficial effects, especially for mitigating subjective sleepiness/boredom. It additionally appears that a secondary task presented to another sensory modality than the visual modality seems to be preferred as the monitoring task also heavily depends on the visual modality and in this way visual overload could be prevented. Yet, care should be taken with implementing a secondary task during partial automated driving, even if the task is not presented visually, as multiple studies demonstrated that objective safety outcome measures can be negatively affected by a secondary task. This is also supported by other scientific work in which it has been acknowledged that secondary task engagement during partial automated driving can have negative effects, by for example drivers paying less attention to objects in events if they are engaged in a secondary task (Llaneras et al., 2013). Therefore, one needs to be careful to not induce any negative effects by using a secondary task as a preventive measure. As also emphasized by Shupsky et al. (2021) it is of utmost importance to clarify what distinguishes unsafe from acceptable or even beneficial secondary task engagement. As long as this is unclear, this poses a considerable challenge for presenting a secondary task as a preventive measure. Therefore, future research should aim at identifying what secondary task at what times can prevent vigilance deterioration during partial automated driving.

Potential solutions to mitigate negative effects of a secondary task as a preventive measure during partial automated driving could be to not present the secondary task continuously, but only after a certain duration of driving at times when it would be expected that secondary task engagement would be most beneficial. Alternatively, one could let the driver decide when to engage in the secondary task. Yet, these potential directions need to be researched in more detail to determine their effectiveness.

One preventive measure that has been deemed as effective that is relatively easy to implement and which, to the best of our knowledge, is not related to any negative effects is to inform the driver about the limitations associated with partial automated driving. When providing the driver with such information it appears to be most beneficial to couple the limitations to the conditions on the road.

As long as preventive mediation is not fully able to ensure safety during partial automated driving, it is recommended to additionally employ corrective mediation solutions and/or to enforce breaks from or to limit the availability of partial automated driving.

7.6. Functional requirements of this study

From the conclusions above it is challenging to determine functional requirements for HMI design for maintaining optimal vigilance in the human driver during partial automated driving in CM. The functional requirements that are listed below should be read as a potentially promising direction that can be included in HMI design in order to examine its effectiveness in more detail. There is a need for additional research to establish the exact requirements, which is why most of these functional requirements are designated as SHOULD (Par. 10.1.1). Functional requirements specify what the system must do and not how this should be achieved. Possible HMI components and their settings in order to fulfil each functional requirement, are suggested below each functional requirement.

- While driving in CM the HMI *must* communicate the current mode continuously.
    - In line with the suggested implementation in chapter 6, this requirement can be attained through providing an ambience in the car which non-invasively communicates the current mode, for example through ambient light. Especially in the beginning of driving with the HMI system it is desirable to additionally present more specific information on the mode, for example through anthropomorphic icons. Such specific information should reflect the automation status rather than driver task.
- While driving in CM the HMI *should* support driver's vigilance through preventive mediation.
    - This requirement could potentially be attained by providing a secondary task to the human driver. This secondary task should preferably not be presented visually and not continuously. For example, an auditory secondary task could be presented about every 3-5 minutes for about 30 seconds (note, however, that the most beneficial timing is yet unclear). A conversation-style task could be beneficial, especially when this is coupled to events happening on the road to support situation awareness. Potentially, a conversation-style task that additionally reminds the driver of the importance of the monitoring task could be beneficial. Additionally, it could be helpful to make this task rewarding through for example gamification.
- While driving in CM the HMI *should* make the driver aware of the limitations of the current mode.
    - It appears to be most beneficial to communicate limitations by coupling the limitations to the conditions on the road. Such as “the system no longer works because the visual field is poor due to deep fog or because highway lanes are closed due to objects on the road”.

- While driving in CM the HMI *should* employ corrective measures and/or enforce breaks or limit the availability of partial automated driving when needed.
  - This is recommended as long as preventive mediation is not fully able to ensure safety during partial automated driving.
- If a driver has never used partial automation before, the HMI *should* inform the driver about the limitations of partial automation and about what is required of the driver.
  - This requirement can for example be attained by only making partial automated driving available after the driver has received the information. Information can for example be presented when the car is parked, through presenting an instruction video.

8. Corrective mediation- countermeasures for fatigue and distraction

8.1. Introduction

The goal of this chapter is to investigate if it is possible to deduce the functional requirements for MEDIATOR HMI intervention to prevent and correct fatigue and distraction at partially autonomous driving PAD   from the literature and experience.

This chapter presents a literature overview that was aimed at finding successful applications of existing technologies and countermeasures for keeping a driver in the loop or bringing the driver back safely into the loop during PAD, when the driver is under a state of distraction, fatigue, boredom or any other combination of these states. To succeed in doing this, a certain level of communication and interaction between the partially autonomous vehicle (PAV) and the human driver is required. There could be various types of interactions and the purpose is to focus on types of interactions that were found useful across many studies. In addition, the chapter distinguishes between corrective and preventive interventions that can help to achieve the MEDIATOR goal. Preventive mediation refers to existing technologies and countermeasures that can predict beforehand that the drive is entering an unwanted driver state (e.g., fatigue) and intervene before the driver's fitness to drive deteriorates. Corrective interventions refer to existing technologies and countermeasures that can detect that the driver is already in a certain unwanted state (the sooner the better) and to intervene in order to compensate for loss of driver fitness to drive.

8.1.1. Focus of the review

Our review deals with mitigation of (1) distraction, inattention, and (2) fatigue at continuous monitoring (CM) and Stand By (SB). For CM, the driving assistance of the PAD can lead the driver to do other things rather than pay attention to driving and monitoring as required, which may result in distraction. For SB, although the driver is not required to monitor the driving and can perform other tasks, this can decrease driver's situation awareness (SA) and affect their readiness to take control when needed. When it comes to fatigue, there is evidence that the CM, induces active fatigue and vigilance decrement (Warm, Parasuraman and Matthews, 2009). On the other hand, for SB, underload or boredom for long periods of driving may induce passive fatigue (Greenlee at al., 2018; Schömig et al., 2015).

The Time to Sleep (TtS) problem argues that during the automation, the driver is relieved from two independent control loops: cognitive control loop and physical control loop. The first is related to the decrease of driver's SA and the second to the situation in which the driver has little/no interaction with the vehicle's steering wheel and pedals (Louw et al., 2015; Cunningham & Regan, 2018). Keeping the driver in the loop refers to the ability of the system to provide the driver with appropriate mechanisms to maintain a sufficient level of vigilance and attention and physical contact to respond to dynamic situations under different levels of automation.

To prevent and correct possible dangerous situations of distraction and fatigue, technology-based and legislative countermeasures for mitigation, should be part of the HMI. These countermeasures aim to keep the driver in the loop as required in CM or to bring the driver back into the loop when needed for SB. Figure 60 illustrates the continuous process of the detection of fatigue and inattention and the countermeasures that mitigate their effects.

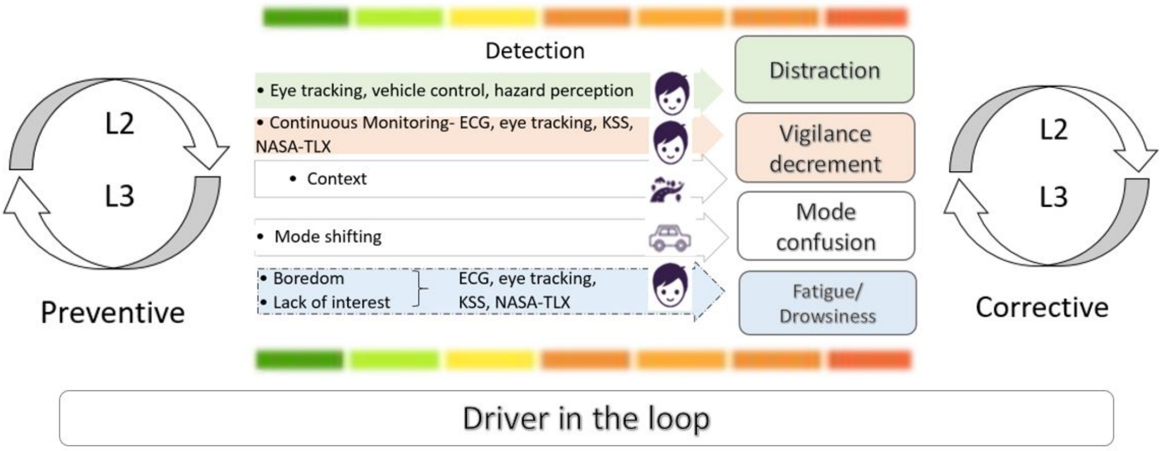


Figure 60 Keeping the driver in the loop or bringing the driver back to the loop, intervention (i.e., preventive or corrective mediation) by using countermeasures for distraction and fatigue at partial autonomous driving.

8.1.2. Preventive and corrective mediation

We have attempted to distinguish between two types of intervention: preventive mediation and corrective mediation. Although literature barely distinguishes between these two interventions, we believe that effective HMI should classify the countermeasures into these two mediations. Our proposed definitions for prevention and correction are: Preventive mediation refers to the ability of the system to predict when driver fitness is likely to degrade and apply certain actions that will increase or maintain driver fitness, and the chance that the driver will remain in the loop. Corrective mediation refers to the ability of identifying as soon as possible that the driver's fitness is deteriorating and applying certain actions that will mitigate the effect, despite the loss of fitness. These definitions cannot be separated from the level of automation of the PAV as the requirements from the driver and consequently the meaning of remaining in the loop is different. For CM the driving loop consists of continuous monitoring and intervention, hence the driver cannot be in an out-of-the-loop state at any time, whereas at SB there is more flexibility in a way, as most likely the driver is in standby form. Note that, how the detection of driver states occurs, is not in the focus of this review; however, common methods and tools are introduced in D1.2. In addition, the transition between preventive and corrective modes is not a clear cut. For example, if a human driver becomes sleepy, his alertness decreases gradually over a period of time where preventive actions can be applied until there is a performance decrement that requires corrective actions.

8.2. Method of literature survey

8.2.1. Eligibility Criteria

Consistent with the research aims and scope, we included studies that dealt with measurements and countermeasures for fatigue or distraction in partial autonomous driving CM or SB. In addition, relevant studies from other domains like aviation were collected for inspiration and are marked with -✈. Searches were performed in August-September 2020, using Google Scholar that adopts full-text search and has broad coverage (De Winter at al., 2014; Gehanno et al., 2013; Shariff et al., 2013). Literature in most cases does not explicitly define whether the countermeasure is used for prevention or correction nor for CM/SB and therefore we classify the items based on SAE and definitions as mentioned in Section 1.

8.2.2. Classification of papers and keywords

For this study, we searched for papers that deal with partial automation, driving, countermeasures, drowsiness, fatigue, distraction, and inattention. The key words of the papers included in the review were classified into five groups as summarized in Table 6.

Category	Words
Driver related	Countermeasures, fatigue, drowsiness, driver distraction, task induced fatigue, monotony, workload, underload, mind wandering, inattention
Vehicle related	Partially autonomous vehicle (PAV), partially autonomous driving (PAD), CM, SB
Driver-Vehicle interaction	HMI, transition time, take-over request (TOR), handover, shared control, Steering override, gamification
Warnings/symbols	Understanding, modality (text/symbol, audio, tactile), message style (advisory/informative), message type (navigation/drive related, general), priming cue, location cue (flight or fight)
Measurements	Haptics, physio, e.g., heart rate, gaze and eye tracking, vehicle dynamics, subjective

Table 6 Summary of the key words for each category

8.2.3. Distraction and Inattention in driving - definitions

"**Driver distraction**" is not a new problem in road safety (Regan et al., 2011) and it is likely that the problem will increase as more technologies find their way into vehicles (Olson et al., 2009; Klauer et al., 2013). The terms driver distraction and driver inattention are frequently discussed in literature. However, they are inconsistently defined and the relationship between them is unclear. In an International Conference on Distracted Driving in Canada in 2005 (Hedlund et al., 2006) researchers discussed and suggested the following definition (page 6): "*a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes*". Additional definitions, which were taken from systematic literature reviews revealed the following common elements (Hoel at al., 2010; Pettitt at al., 2005):

- There is a diversion of attention away from driving, or safe driving.
- Attention is diverted toward a competing activity, inside or outside the vehicle, which may or may not be driving-related.
- The competing activity may compel or induce the driver to divert attention to it.
- There is an implicit, or explicit, assumption that safe driving is adversely affected.

Inattention on the other hand, has been defined as the "failure to pay attention or take notice". However, this definition is devoid of the driving context. There are only a few definitions of driver inattention exist in the literature that vary in their meaning. For example, Regan et al., (2008) define inattention as "***diminished attention to activities critical for safe driving in the absence of a competing activity***" (p 1772). This definition means that drivers can become inattentive to driving without the presence of a competing activity (i.e., a secondary task). Victor et al., (2008) define driver inattention as "improper selection of information, either a lack of selection or the selection of irrelevant information". Regan et al, (2011) suggested essentially two points of view in the consideration of the relationship between driver distraction and driver inattention.

- driver distraction is a form of driver inattention. For example, Victor et al., (2008) defined distraction as a subset of inattention, referring to all instances when attention is misallocated, but excluding cases when attention is not allocated at all.
- driver distraction is different from driver inattention; thus, the constructs can co-exist. Regan et al., (2008) argued that the critical factor distinguishing driver distraction from driver inattention is the absence (in the case of driver inattention) of a competing activity. Hoel et al. (2010) claimed that the critical difference is the nature of the competing activity—for inattention, it is preoccupation in internalised thought and for driver distraction it is any external (i.e., to the mind) non-driving related activity.

While distraction and inattention are different definition wise, the effects of not allocating attention to driving related information either due to distraction or inattention may be similar. Hence, it is argued that countermeasures for both inattention and distraction can be combined. There are variety of countermeasures for the detection of inattentive and distracted driver that in some cases may lead to take-over control in autonomous cars (Stanton & Young, 1998; Young & Stanton, 2002). The literature introduces physiological measurements, advanced eye tracking tools and methods, driving performance, haptic, auditory and contextual indicators. The existing methods and technologies that are used for detecting driver distraction appear in D1.2. Section 7.3.2 outlines countermeasures that have or may have the potential to prevent and mitigate the effects of inattention and distraction during automated driving.

8.3. Distraction in PAVs; Countermeasures for Intervention

PAD (CM and LSB) is likely to be accompanied by spare attentional capacity and drivers may in turn be more likely to be engaged in secondary tasks that are unrelated to driving. For this reason, there is a rapid development in technology-based countermeasures that are targeted at mitigating the effects of distraction in various ways. It is important to apply the countermeasures while addressing the Level of autonomy, as in CM the driver is not supposed to disengage from monitoring the drive at any term. The intervention is usually including presentation of information to drivers during the driving task, which is a challenging task. The central goal is to communicate essential and useful information in a timely fashion without creating distraction and without increasing the cognitive load. The modality in which this information is presented can be critical, especially given the limitations to what the human cognitive system is able to simultaneously perceive (Kern et. al., 2009).

The purpose of this section is to introduce the most promising countermeasures in the literature that were found useful at mitigating the effects of distraction on deterioration in partially autonomous driving safety. Although the literature defines distraction and inattention slightly different (as mentioned in paragraph 6.1), since the end results are similar (insufficient levels of attention to the road environment) the literature on the countermeasures that can mitigate distraction and inattention hardly ever distinguishes between them. We organized the countermeasures based on their documented relative efficiency and robustness as described in the literature. In most of the cases, the distinction between preventive and corrective mediations, was done by the authors of this report, based on the predefined principles as explained above (see section 8.2.1) and what we perceive can be within the scope of MEDIATOR. A summary of the reviewed countermeasures is presented in Table 6, with an indication for the countermeasures with the highest potential to be applied in MEDIATOR.

Adding Stimulation

Loss of Situation Awareness (LSA)- (recurring or by request)

Hazard perception is an indispensable skill for the human driver in partial automation, specifically at CM but as needed at SB as well, who needs to anticipate hazards and be able to intervene in critical situations. Inspired by the work of Tejero Gimeno et al., (2006) that suggested several methods for stimulations to maintain driver alertness, it is possible to adopt these principles to maintain driver SA. By using common measures (e.g., camera and eye tracking system, EEG) the system can recurrently provide a certain "artificial stimulus" in order to monitor the driver state in real time situations and maintain driver alertness. This intervention could be applied in two ways (as preventive or corrective mediation): as an occasional stimulation or as a response to the detection of distracted or inattentive driver. However, the interaction is an iterative process that adjusts the response to the situation. For example, if a recurring stimulation reveals that the driver is not distracted then no additional intervention is needed. On the other hand, if the system detects that the driver is already distracted, the next intervention will be according to the urgency of the situation. An alternative method is to passively monitor the driver and to intervene only if the system detects a deviation from acceptable driver behaviour (i.e., inattention or distraction).

A recent study examined the effects of warning signals in CM on the number of instances of driver inattention/distraction over time when drivers were operating an CM automated vehicle (Atwood et al., 2019). It focuses on the frequency of warning signals as an intervention for prevention and mitigation for the frequency of instances of inattention. In their study, participants (n=48) operated an CM vehicle on a test track with simulated highway driving conditions for three 60-minute sessions. The vehicles were operated with adaptive cruise control (ACC) and lane centring active. Participants were divided into three groups (16 in each group): those who received prompts (yellow flashing light) after 2 sec of inattention, those who received prompts after 7s of inattention, and those who did not receive prompts. The reason for 2sec is based on Klauer et al. (2006, 2010) who identified 2sec as a potential point at which inattention can lead to safety critical event risk. If the participant did not react within 5sec, the light would change to red and be accompanied by both a haptic and an audio alert for another 5sec. The results of this study suggest that drivers in an CM vehicle who are prompted to return focus to the road after instances of at least 2s of inattention may experience an overall change in driving behaviour as their experience with such a system increases. Specifically, the results suggest that drivers will adapt to the warning system of CM vehicles and alter their behaviour to avoid the warning trigger.

Driver Task Requirement to Maintain Engagement

A task requirement to maintain driver engagement could assume a variety of forms in terms of the action itself, time periods, and specific conditions. If the system detects that, the visual attention of a driver is inadequate while monitoring the driving (at CM) it should prompt for performing a secondary task to maintain driver engagement (Marinik et al., 2014).

Location Based Cues

In a previous wide research on an In-Vehicle Safety Advisory and Warning System (IVSAWS), the driver understanding of hazard warning and location symbols were examined (Hoekstra., 1993). Although this study was conducted in a traditional manual car, it has dealt with design questions that are relevant also for contemporary, partial driving: which hazards would be appropriate for warnings? What graphics best represent those hazards? By what methods can the relative location of the hazard be communicated to drivers, and how well they are understood. In an understandability test (n=20), drivers were shown with warnings and location cues while either driving a test route or parked. Ten hazard location symbol designs were tested (e.g., road construction ahead, out of order traffic light ahead, railroad crossing etc.). Three warning formats were examined: graphic, text, and mixed, with different location cue designs (e.g., straight ahead, cardinal left etc'.). Results showed that overall, the hazard symbols were understood adequately. The location cues, text ("on right," "behind," "ahead to left," etc.) was best understood and led to the best performance. The ability to identify hazards is made possible by the use of innovative technologies in automotive domain (e.g., vehicle-to-vehicle/infrastructure V2X, V2V,V2P,V2I) as shown in Figure 61, enable to display appropriated hazard warnings regarding the environment, other cars, infrastructure and other road users (e.g., Ahmed, & Gharavi, 2018; Hobert et al., 2015; Hussein et al., 2016; Ma et la., 2020; Rasouli, & Tsotsos, 2019). These innovative technologies can be potentially used for designing driver-warning applications to maintain SA, in general and specifically under distraction. The timing and the modality of the information/cues communicated to the driver might affect the ability of the driver to comprehend and react if needed.

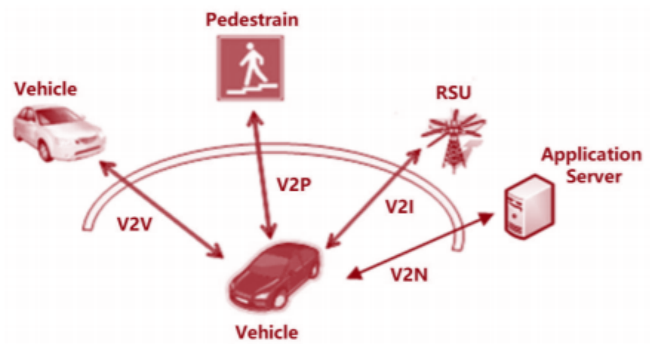


Figure 61 V2X defined in 3GPP (Ma et al., 2020)

As long as the hazards are latent, there is relatively more time to react compared to materialized hazards. Similarly, the modality of the interaction and the level of the message urgency. There is a rich body of literature on how to design differently urgent driver warnings, using different modalities (e.g., speech, audio, visual, tactile non-visual, and multi-modal). Recommendations regarding how and when to warn the driver depend on the situation criticality and the context (Politis et al., 2014; 2015; 2017).

- Inspiration from aviation- Traffic alert and collision avoidance system (TCAS)

Traffic alert and collision avoidance system (TCAS) is a system designed to *prevent* (and possibly *correct*) mid-air collisions between aircraft. When the TCAS system comes to the conclusion that the separation between two aircraft is insufficient, and a conflict is imminent, it can warn the pilots early (FAA, 2014). In modern aircraft, the electronic TCAS display may be integrated in the navigation display.

TCAS provides so-called Traffic Advisories (TA). These are alerts that only show the distance, altitude and an estimate of the direction of a potentially conflicting device. It is up to the pilot to decide how to avoid the possible collision. A second version of the TCAS (i.e., TCAS II) also provides so-called Resolution Advisories (RA). These are recommendations, on how to prevent a possible collision. In TCAS II these recommendations are limited to the advice to rise or fall. This is because the antenna system in TCAS II cannot determine the direction of the conflicting system with sufficient precision, but it can determine the exact height and distance. When both aircraft are equipped with TCAS II, these systems coordinate with each other to ensure that they do not both give the same advice to the pilots (one of the aircraft will receive an ascent advice, the other a descent advice). If only one aircraft is equipped with TCAS II, the system will give advice based on the current rate of the climb or descent of the conflicting aircraft. TCAS II can also coordinate with more than two aircraft if the conflict consists of more than two aircraft. There is a third version of the TCAS system (TCAS III) yet in development. In this version, the Resolution Advisories should also contain advice in the horizontal plane i.e., to deviate left or right (FAA, 2011).

TCAS II gives advice (visual and oral) to the pilots of the aircraft in several ways to prevent collision (FAA, 2011):

- At the moment of approaching an aircraft: warning of approaching aircraft (e.g., “Traffic. Traffic.”) and on TCAS display, the intruder is indicated in yellow.
- At the moment of getting so close that a collision becomes possible: vertical advice (which is reversed for the other aircraft e.g., “Descend.”) and on TCAS display, the intruder is indicated in red, and the required descent speed is displayed.
- At the moment of advice does not have the desired effect: advice is adjusted for a stronger movement (which is reversed for the other aircraft e.g., “Increase descend.”) and on TCAS display the greater descend speed is displayed.

Airbus (SKYbrary, 2019) offers the option of an autopilot/flight director TCAS for automatic avoidance manoeuvres. In such a way, the active TCAS system is corrective instead of preventive.

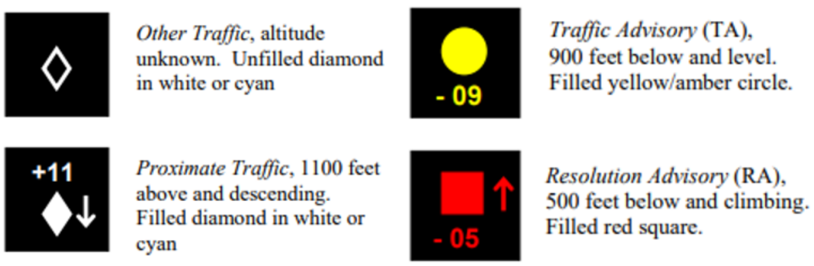


Figure 62 Standardized symbology for use on the traffic display

Driver Assistance System 360° LED strip

Pfromm et. al., 2013 have dealt with deficiencies in risk recognition. They proposed to draw the driver’s attention towards relevant traffic objects, which might be a safety hazard, by a LED strip which is mounted 360° around the interior of the car’s cabin (shown in Figure 63). In a simulator study (n=13), the effectiveness of the LED strip was examined in four critical traffic situations, using gaze attention, mental effort and acceptance. Without driver support, gaze attention time was shortened, and participants understand the information submitted mostly intuitively.

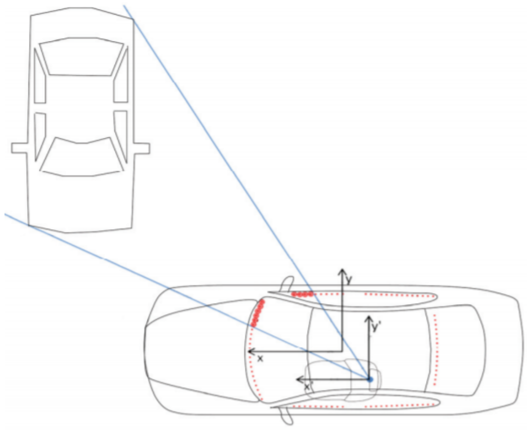


Figure 63 Projecting relevant traffic objects on the 360° LED strip

Cooperative automation mode

In a wide research project, a driver assistance system for collision avoidance and automated vehicle guidance based on a modular system architecture was proposed (Bauer et al., 2012). PRORETA 3 mode cooperative automation, a partial-automated, manoeuvre-based vehicle guidance concept that relieves the driver of the vehicle stabilization task in order to decrease the latent risk of the overall situation and to prevent a critical traffic configuration in its beginnings. For example, a blind spot warning system alerts the driver if a car is in the blind spot during a lane change but is not able to intervene while current emergency braking systems intervene without providing well-directed information in advance to avoid an impending accident. PRORETA3 integrates and expands different coexistent assistance functionalities into a combined system for intervening and preventive active safety approaches. The system provides relevant information, warnings, action recommendations and, finally, interventions. The system decisions are based on the context, which consists of: the environment of use given by the traffic situation, the driver's tasks, and possible driver errors. In order to provide this content to the driver, physical HMI devices are needed. This solution is relevant mainly for distracted and fatigued drivers at CM.

Haptic shared control (steering wheel)

Recent solutions proposed haptic interaction with the driver through the pedal or the steering wheel. Abbink & Mulder (2010) define haptic shared control as a method of human-automation interaction that ''...allows both the human and the[automation] to exert forces on a control interface, of which its output (its position) remains the direct input to the controlled system. They design force feedback based on human capabilities and essentially ''mirror the human''.

The study of Abbink et al., (2012) can be relevant to TOR or distraction in CM for the intervention in safety critical situations. They investigated how haptic interaction can be used in automation in more time-critical situations, in particular where multiple trajectories need to be considered. For example, how to deal with an object suddenly appearing in the reference trajectory of the automation system? In such cases, even if the sensors would accurately detect the object, an engineering problem remains to determine which way to avoid the object. They suggested leaving the choice to the driver, who may have better insight into the best solutions to avoid the situation. However, from the HMI perspective, instead of suddenly switching off automation or haptic-shared control in such complicated cases, they suggested a novel concept that is based on temporarily reducing the steering wheel stiffness around the steering angle that will steer straight into the object, thereby making it easier to steer away to avoid the crash (Della Penna et al., 2010). This leaves the authority of choice completely up to the driver, but once the choice is made, the driver is assisted in steering fast in the direction he chooses, where he will be guided on the redirected trajectory. As long as the driver does not make a choice, he will feel that the automation system communicates increasing criticality and wants the driver to make a choice. This approach was supported by experimental results in a driving simulator that showed that haptic shared control system allowed drivers to choose their preferred trajectory around the object and helped to quickly execute this choice without deteriorating overshoot that might result from excessive steering.

✈ Inspiration from aviation

Already for some decades, the aviation domain installed a stick (control yoke; sort of the steering wheel in an aircraft) in the cockpit, which can interact with the pilot by shaking when approaching a stall (i.e., condition wherein the angle of attack increases beyond a certain point such that the lift begins to decrease). This warning system acts as a preventive countermeasure for distraction that may lead to further escalation. Some stall warning systems also generate synthetic voice warnings ("Stall!") to indicate an approaching stall (SKYbrary, 2019; Mark, 2017; ATSB, 2013).

Ambient peripheral Light cues –illuminated LED

Borojeni et al., (2016) conducted an experiment that aimed to propose applying ambient TORs, which addresses the peripheral vision of a driver. The experiment included light cues that were presented via an illuminated LED strip located behind the steering wheel, the frame located on the dashboard. The research aimed to investigate whether contextual information can be encoded and conveyed through light cues and assist drivers to get back to the loop and be aware of the situation. Hence, the light cues informed the participants about an upcoming takeover situation (and were hidden when there was an obstacle on the way). They measured the reaction time that was defined as the time between the presentation of the TOR and the first steering action. The researchers conducted a pilot study and observed that, besides the situation of having a red colour (an indicator of danger or avoidance) the participants perceived the displayed direction, as the direction to steer to. They concluded that in order to create a process of disengagement from the non-driving task, which is highly required in some cases at SB, it can be achieved through salient sensory cues. Specifically, information can be provided to cue the appropriate action that the driver has to perform. The research included three cues (baseline and static vs. moving). The experiment included two cues, one was static and the other moving. Both cues provided information regarding the action that should be taken by the driver. The researchers concluded that the static cue is leading to the expectation of attracting overt attention. However, the moving cue led to attract attention to the operational context.

Pre-alert and early warning

In the domain of autonomous driving (relevant to SB), using alerts before handover of control has have received attention in the literature. However, the driver may not have the proper situational awareness to be able to immediately take the proper action. Therefore, an additional alert, namely "pre-alert" that commences well before the actual handover request (e.g., 20 sec) may improve the transition (van der Heiden et. al., 2017). The effects of early warnings were studied using a repeated burst audio pre-alert, and an increasing pulse audio pre-alert. Results showed that pre-alerts helped drivers prepare better for taking over control by increasing gaze on the road and earlier suspension of the phone task, followed by quicker reaction to traffic incidents compared to having no pre-alerts (van der Heiden et. al., 2017).

Vibro-tactile driver seat alerts

Vibrotactile stimuli can be effective as warning signals, but their effectiveness as directional take-over requests in automated driving is not fully settled yet. Petermeijer et al. 2016 investigated the correct response rate, reaction times as part of a take-over request, via vibrating motors in the driver seat. They conducted a within subject design (experiment (driving simulator) in order to evaluate the vibration type (static or dynamic). The vibration locations were varied. They concluded that the vibration patterns they used were effective as a warning to prompt drivers to quickly reclaim to manual control, nevertheless participants did not reliably detect the directional cue that was embedded in the stimulus. Furthermore, static patterns yielded faster reaction times than dynamic patterns. Thus, their results showed that a distinction can be made between four dimensions of coding of the vibrotactile information (amplitude, frequency, timing, and location), each of which can be static or dynamic. There is a consensus that frequency and amplitude are less suitable for coding information than location and timing. Petermeijer et al. 2016 concluded that vibrotactile feedback can be used to supplement auditory and visual displays, but they recommended that directional instructions in a take-over scenario should not be provided by means of a vibrotactile seat alone. In line with this, another study of Capallera et al. (2019) examined the SA in conditional automated driving with a haptic seat. ￼ In their experiment, they found it useful to use vibrations for increasing SA. Furthermore, participants preferred to use the pan to transmit information about lane marking. Cohen-Lazry et al. (2918; 2019) looked into the question of ipsilateral or contralateral vibrotactile alerts relative to the location of hazards at SB situations. Each participant experienced two TORs in which they were required to regain control and divert the vehicle away from an impending hazard, situated 4 seconds in front of them. The disengagement of the autonomous driver was signalled to drivers using a directional tactile alert. For half of the participants, the tactile alert was directed to the direction of the hazard (contralateral), for the other half, the alert was directed away from it (ipsilateral). Results showed that drivers in both groups made the same number of errors (initially steering the vehicle in the direction of the hazard before steering it away). However, when using ipsilateral alerts, drivers were faster to steer the vehicle away from the hazard.

✈ Inspiration from aviation

Another preventive countermeasure example from aviation are tactile sensation generators in vicinity of the pilot's legs (Vavra, 1984) for sensing an uncoordinated turn condition and indicating to the pilot the control adjustments required to correct the turn condition. The system controls activation of the tactile sensation generators that indicates to the pilot, which foot to depress on the rudder control to return to coordinated flight.

Salzer and Oron-Gilad (2011; 2014) used a tactile on-thigh display to improve TCAS conspicuity for rotorcraft pilots. Each vibrotactor conveyed a direction to take, in the vertical plane.

First (2011) looked at the compatibility of the vibrotactile direction to the hazard and found that the flight mode, that is, directing the way to escape from hazardous situations, was preferred. Second (2014) they looked at the contribution of the addition of the tactile functionality to the existing visual alerting cues and it was found that adding tactile alerts to visual ones may have.

Balancing Authority and Responsibility -adaptive automation [HUD]

In partial automation, the need for balance between appropriate degree of control authority and corresponding degree of responsibility lead Dijksterhuis et. al., (2012) to suggest an adaptive automation approach. The meaning of this concept is to support rather than automate the driving task in order to balance authority and responsibility and to keep the driver in the loop. Dijksterhuis et al., (2012) tested the implementation of an adaptive driver support system by providing support only when necessary. However, a crucial challenge is how to determine what defines the necessity for adapting task automation (i.e., triggers). Triggers for the intervention could be critical events in the environment, the operator's psychophysiological signals or operator behaviour or operator's mental workload. At CM, it is possible referring to the intervention as assistance, since most of the driving task is performed by the human driver and could include support types that are not readily included in the concept of automation, such as providing information, warnings, and advice. Dijksterhuis et al., (2012) examined the effects of adaptive automation support using three modes of lane-keeping support, showing the information on a head-up display projected on the windshield of the simulator car in order to increase gaze time toward the roadway environment (see Figure 64). The study was conducted using driving simulator (n=32). After using the HUD support, participants were asked to complete a technology acceptance questionnaire (Van Der Laan et al., 1997). Results showed that participants preferred the adaptive support mode mainly as a warning signal and tended to ignore non-adaptive feedback. A third of the participants indicated to have ignored the head-up display carrying lateral position information. Only adaptive support resulted in an improvement of lateral control.

Figure 64 Lane position information projected on the windshield (Dijksterhuis et al.,2012)

Another study supported the value of presenting information near the centre of the road to improve driver SA. It was demonstrated that a head-up display, not only encourages driver to gaze toward the road centre but also brings drivers back into the loop more efficiently, facilitating better situation awareness/hazard perception during the manual resumption of control (Louw et al., 2017; Louw & Merat., 2017).

✈ Inspiration from aviation

Berstis & Smith (2002) developed a method of alerting a pilot to the location of other aircrafts by calculating the aircraft's projected flight path in the sky. A given image (circle) is then projected on the aircraft's windshield at a calculated position.

Augmented Reality Cues

Highlighting the cues

Augmented reality (AR) technologies aim to optimize the visual attention of the driver by increasing the salience of high value elements (e.g., cues). Eyraud et al., (2015), examined the effects of AR videos of automobile driving situations (n=48). In these videos, some situational cues were graphically highlighted related to either the general driving task (e.g., road signs, pedestrians) or to a specific manoeuvre (e.g., look for overtaking cars before changing the lane). The results show that AR affects the allocation of visual attention more strongly during the decision-making phase. In another study, Lorenz et al (2014) investigated whether augmented reality information can positively influence the takeover process, using two AR scenarios. The first concept "AR red" displays a corridor on the road to be avoided by the driver in a takeover scenario. The second scenario, "AR green" suggests a corridor the driver can safely steer through. Results indicate that the type of augmented reality information does not influence take-over times, but considerably affects reaction type.

Pokémon Drive

An interesting approach was introduced by Schroeter et al., (2016), using augmented reality to design the application Pokémon DRIVE that aimed at increasing driver's voluntary attention to the outside world, highlighting that visual perception. Pokémon DRIVE designed around gamified AR on a windscreen display. The idea is to develop an application that places "AR hazards" into the driving scene to which drivers need to respond. The application was inspired by Pokimon GO, by implementing game design elements such as challenges, rewards, and narratives as a motivational tool. Figure 65 illustrates the concept of the application: Part 'A' on the left, depicts a common, driving situation, part 'B' in the centre depicts a faint yellow Pikachu, and on part 'C in the right the driver needs to react and perform an interaction. Pokimon Drive is suitable for CM and SB f to keep drivers in the loop and to encourage a proactive approach to increasing situational awareness through gamified AR.

Figure 65 Pokémon DRIVE concept (Schroeter et al., 2016)

Education and Training

In order to interact with PAD, the driver should understand the automation system including the role and responsibilities of each part. Cunningham & Regan (2018) presented an article with the aim of outline countermeasures that have or may have potential to prevent and mitigate the effects of inattention and distraction during automated driving. One of the potential countermeasures they emphasized was education, training, and licensing. They said that, for example, training programs can be used to inform and explain the driver of the capabilities and limitations of automated driving systems. Furthermore, they explained that education may be used to calibrate the driver's reliance and trust in the automation. Regarding licensing, they claimed that special licensing programs should run and focus on explaining how to respond safely to the challenging and potentially distressing tasks of automated vehicles.

Olfactory Notification

Olfactory stimulation is the most challenging communication channel to apply in the car (Dmitrenko et al., 2019). Contrary to visual and auditory notifications that are dominate in modern vehicles, olfactory notifications use separate and free channels that don't affect the visual or hearing abilities. For example, it is known that visual notification might increase visual load, and it may distract the driver's visual attention. Olfactory notifications have been proven to have a positive impact on the alertness and mood of the driver (Baron et al., 1998; Dmitrenko et al., 2019), drivers' braking performance (Martin et al., 2007), and on keeping drowsy drivers awake) Funato at al., 2009; Oshima et al., 2007; Yoshida et al., 2011). Past research indicates the odours of peppermint and cinnamon (1) enhance motivation, performance, and alertness, (2) decrease fatigue, and (3) serve as central nervous system stimulants (Raudenbush et al., 2009). Therefore, it can be reasonable to use scents to convey driving-relevant information. However, there is no framework to identify which scent is the most suitable for every application scenario. A recent driving study (n=21) proposes an approach for validating a mapping between scents and driving relevant notifications (Dmitrenko et al., 2019). Results showed multiple proofs of concepts demonstrating the effectiveness of olfactory stimulation in the automotive context. Tang et al., (2020) quantified the impact of olfactory stimulation and takeover modality on the performance of takeovers in conditionally automated driving (n=60). Results showed that the presence of peppermint odour did not influence the reaction time, but participants did show signs of being more alert afterwards.

Blocking Mobile Technologies

Mobile phone use while driving is a pervasive problem that continues to increase, although the large crash risk involving this behaviour (Oviedo-Trespalacios et al., 2016). At CM, the driver might feel that the automation system enables to do other things but monitoring the driving as required, which results in the driver distraction. Literature introduces locking strategies that prevent the driver from continuing the distracting task, showing that incorporating this strategy into the existing in-vehicle systems can mitigate the effects of distractions and improve driver performance (Donmez et la., 2008). In addition, smartphone applications designed to prevent phone use while driving show potential for playing a large role in a systemic intervention to prevent mobile phone distracted driving. However, a drawback of these applications is that it might not be attractive to drivers who view their phone as a necessity. As such, these drivers are unlikely to use these voluntary applications at all while driving (Oviedo-Trespalacios et al., 2016).

Design philosophy (environmental)

✈ Inspiration from aviation; Dark Cockpit as a new design philosophy.

In its most simplified form, the dark cockpit means that when everything's working, there are no blinking lights. Information is not displayed until a system condition warrants notifying the pilot about an abnormal condition. Usually, the annunciator panel includes a main warning lamp or audible signal to draw the attention of the air crew to the annunciator panel for such abnormalities. If an abnormal condition is detected, a prominently located caution or warning light illuminates, which draws the crew's attention to the annunciator panel. There, individually labelled, color-coded lights indicate the exact problem and its relative significance:

- Red warning lights: serious problem requiring immediate crew action.
- Amber-coloured caution lights: trouble of a less urgent sort that merely requires immediate crew awareness.
- White (or blue)-coloured advisory or agreement lights: something is working as it is supposed to (engine anti-ice or fuel cross feed valves, for example), and may also serve as a reminder to turn it off when no longer needed.
- Green-coloured lights: something is in use or ready for operation (such as landing gear down and locked).

More recently, the crew-alerting system (CAS) is used in place of the annunciator panel on older systems. Rather than signalling a system failure by turning on a light behind a translucent button, failures are shown as a list of messages in a software-driven electronic display. This system monitors hundreds of engine and aircraft-system parameters. Like master annunciator panels, it provides different levels of information to the crew: informational (blue/white, green and cyan lights), cautions (amber light), and warnings (red light). They only display the information needed for the current task. For instance, during the start-up the system display only presents engine information that is needed for the start-up task. During other times, such as cruise, it presents more information that must be monitored.

CAS first gets the crew's attention by illuminating the master caution or warning lights located on either side of the forward instrument panel. Depending upon the situation's urgency, CAS may also emit a beeping tone, sound a bell or siren, or generate a synthetic voice message to ensure that the crew is tuned in to the problem. (Hearing "Engine fail!" during the take-off roll is especially attention getting.). Although computer-generated voice warnings are used sparingly on the 777, manufacturers generally consider the tone, volume, and even apparent gender of computer voices, which may vary, depending on the nature of each warning.

Besides dark cockpits, another design philosophy also emerged to tackle the same problem, namely glass cockpits. NASA (Wiener, 1989) started a study in the 70s to replace the overload on instrumentations by a few electronic displays that presented information the pilot needed for the moment. The pilot could focus on the most essential information. The electronic displays had different modes for landing, cruise and take-off. According to Alm (2007), the automotive industry still uses a lot of static controls and instrumentation in a modern car. The driver has to search the area around his steering wheel to find the correct instrument for input. It forces the driver to look away from the road. Replacing the current instruments with electronic displays opens new opportunities. The information on the displays can be adjusted based on the driving conditions (Norén, 2008).

✈ Inspiration from aviation; attention colours

Besides the attention management in the cockpit as preventive countermeasure, the air traffic control working positions have a similar hierarchy (Bos et al., 2018) in using colours red and amber. The attention colours red and amber are only used for *urgent* attention management which are safety related.

- Red: Immediate action required. This attention colour disappears as the situation improves. It can be combined with flashing and/or a repeating sound.
- Amber: Attention is required, and possible action required. This attention colour disappears as the situation improves. It can be combined with flashing and/or a one-time sound.

The attention colour yellow is used for *non-urgent* attention management, which is non-safety related. Besides the attention colour, non-colour related visuals are also part of the non-urgent attention management:

- Yellow: Possible action needed. It disappears automatically when no more action is needed or when the air traffic controller has performed the action.
- Framed textbox: Status change that may affect task execution over time. The framework disappears automatically after some time.
- Asterisk (*): Change that affects task execution. It disappears as soon as the air traffic controller selects the flight.

Red and amber are also used in the cockpit for warnings and cautions. Blinking is more conspicuous in peripheral vision than a change of colour. The audio channel is reserved for radio communication, but the application of sound is possible in combination with a warning (red and amber). This could be applicable in places where the visual attention needs to be distributed, for example in the tower.

8.4. Fatigue (Active and Passive)

Drowsiness and fatigue are recognized as being involved in several types of accidents, especially for drivers and operators of equipment. Both fatigue and sleepiness induce hypo-vigilance, often called “drowsiness”, which consists in a decrease in reactivity to the environment, with hypo-vigilant subjects that are affected by a deficit in information processing and a slowing down of the reaction time which can both cause dramatic accidents.

Authors often loosely refer to the term “drowsiness” as “fatigue” and “sleepiness”, because all three impair the individual’s judgment and ability to execute a task correctly, but properly “fatigue” and “sleepiness” are two distinct physiologic phenomena. Correctly, drowsiness is an uncontrollable need to sleep that can occur at any time of the day and fatigue is a physiological state of reduced mental or physical performance capability resulting from extended workload. The words “drowsiness”, “sleepiness” and “fatigue” are usually used interchangeably in the automotive fields, but they differ significantly, with fatigue that refer to a feeling of tiredness or exhaustion due to mental or physical activity, while drowsiness refers specifically to the state related to high sleep propensity.

In fact, medically speaking, sleepiness refers to the inability to stay awake even in situations in which wakefulness is required, such as behind the wheel of a car and fatigue is a state of overwhelming sustained exhaustion and decreased capacity for physical and mental work that is, indeed, not relieved by rest. *(Krupp et Al, 1988, Maestri et Al, 2020)*

Fatigue is a complex phenomenon, captured by a number of conceptualizations and definitions, with a ‘gold standard’ for its measurement remaining elusive. For automotive research purposes, one of the best definitions is actually provided by the International Civil Aviation Organization *(ICAO, 2015)*:
“A physiological state of reduced mental or physical performance capability that can impair a crew member’s alertness and ability to safely operate an aircraft or perform safety related duties”.

Literature differentiates between two types of mental fatigue: active fatigue and passive fatigue. Under overload conditions, active fatigue is more likely to occur, whereas passive fatigue is more likely to appear under underload conditions (Desmond & Hancock, 2001). Active fatigue produced by sustained performance of a task that demands mobilising resources of attention. For example, at CM, there is an evidence that, when a driver adopts the role of the monitor within partial automated driving, the mental demand and the workload increases (Banks & Stanton, 2019; Körber at al., 2015; Helton at al., 2009). On the other hand, passive fatigue may result by prolonged and continued execution of undemanding tasks that hardly need the exertion of attentive resources. At higher automation levels (e.g., SB or TtS) the demands of driving are relatively low, thus in prolonged driving may need relatively little attention and the situation can lead to drowsiness or boredom. This is an example to fatigue that develops over a number of hours of doing what appears to be nothing at all (Desmond & Hancock, 2001).

A distinction proposed for the conditions that may lead to fatigue and vigilance decrement: endogenous and exogenous factors (Meuer et al., 2006):

- Exogenous: externally induced, stem from the individual's interactions with the road environment. (e.g., familiarity with the environment, traffic density, task complexity). Vibrations and sustained linear accelerations play a very notable role in fatigue and workload response, acting by a very complex phenomenon that depends on a range of structures and mechanisms that regulate transmission of vibrations through the body itself: bones, cartilage, synovial fluids, soft tissues, joint kinematics and muscular activity. Specifically, vibrations have significant implications in safety issues because prolonged exposure to vertical vibration, at some amplitudes and frequencies, has been shown to induce fatigue and to inhibit neuromuscular performance (Rittweger et al, 2003). Furthermore, in driving, not only periodic narrow band and sinusoidal vibrations occur, with but also vibration exposures with broadband signals to random characteristics are often encountered. These movements are also stochastic, and they contain transient events, with the human body that is known to be more sensitive for random, stochastic vibrations. (Mansfield et al., 2000)

- Endogenous factors affect the basic preparation state of the individual when performing the driving task and some of them are associated with internal fluctuations of alertness. . As for example, fatigue is related to circadian rhythm, with fatigability that could be enhanced by sleepiness, even if not necessarily somnolence and fatigue gets progressively worse with the duration and intensity of the task.

The reason for elaborating upon these definitions is that we believe that when using countermeasures for prevention or correction, it is important to understand the source and the conditions for the situation.

The objective is to maintain an optimal level of performance in the task, such that an optimal level of arousal/stress must be met (de Ward, 1996). Vigilance tasks require stamina and persistence; thus, the arousal level must be pertained on the optimal value or slightly higher (comfort zone). Relevant measurements for fatigue are discussed in D1.2. The next section deals with fatigue countermeasures for intervention for CM & SB.

Fatigue - Countermeasures for mediation

Given the number and nature of the factors that cause drowsiness or fatigue in drivers, and also taking into account the factors that modulate the effects of these states on the action of driving the vehicle, it is clear that various complementary strategies need to be used to tackle these problems in real traffic (Tejero Gimeno et al., 2006). In the following sub section, we introduce the existing countermeasures to mitigate fatigue.

8.4.1. Secondary Tasks (preventive mediation)

Advanced driver assistance systems may help the driver in remaining in optimal load during a potentially long, monotonous automated drive (at SB). Lassmann et al., (2020) assessed the impact of several secondary tasks, naturalistic as well as standardized, during partly automated driving, showing that secondary tasks differ in their effects on the driver performance. Visual secondary tasks lead to a decrease in drivers' monitoring performance (relevant to CM), but subjectively demanding auditory tasks did not lead to substantial monitoring lapses and induced positive effects in potentially monotonous automated driving situations such as drowsiness and Fatigue. For example, in a previous studies alertness maintenance was achieved by inviting drivers to perform a mental task such as communication and report tasks (Drory, 1985) or games based on measuring time, distance, and speed, or recording and playing back the driver's own voice (Verwey and Zaidel, 1999) while driving, see also Oron-Gilad et al. (2008) for a model and application.

Interactions between driver and vehicle through gamification can remedy under-challenged situations when driving monotonous journeys in autonomous car (Bier et al., 2019). In order to test the effectiveness of such interactions a driving simulator study (n=31) was conducted using driving performance and psycho-physiological parameters. The results provide clear indications of safer when driving with gamification and with a passenger. The tested interaction system prevents upcoming fatigue in a similar way to communication with a passenger (Bier et al.,2019).

In-vehicle natural language interfaces can be used as countermeasures for driver fatigue. Using a Wizard-of-Oz, Large et al. (2018) examined the effectiveness of engaging drivers in conversation with a digital assistant as an operational strategy to cope with the symptoms of passive task-related fatigue. In their study, 20 participants drove manually in a medium fidelity driving simulator such that it naturally reduced their alertness. During one of the counterbalanced drives, participants were engaged in conversation by a digital assistant ('Vid'). Results demonstrated that interacting with digital assistance (Vid) had a positive effect on driving performance and arousal, evidenced by better lane-keeping, earlier response to a potential hazard situation, larger pupil diameter, and an increased spread of attention to the road-scene.

Interesting results have been obtained using a secondary task that consisted of periodically modifying the vehicle speed. The activation level in drivers seems to be lower when travelling the route at a constant speed. Furthermore, modifying speed seems to be effective to avoid the progressive diminishing of the driver's level of activation, at least during the initial part of the route. Although more evidence is needed, these results suggest that this strategy may be a recommended countermeasure when driving becomes boring or monotonous (Tejero & Choliz, 2002).

✈ Inspiration from aviation; mental disengagement

Studies have shown that a particularly powerful recovery experience is mental disengagement, being occupied with varying things allows for physiological and psychological restorative processes to occur (Niks et al., 2020). This has been demonstrated by Fowler & Gustafson (2019) in an aviation setting: before work- video game play significantly increased perceived and physiological alertness in air traffic controllers for at least 30 min after they stopped playing, and during their work.

8.4.2. In-Car Media Use for Alertness Improvement

A recent study reviewed six studies to examine the influence of in-car media use as a countermeasure for fatigue (Matthews et al., 2019). The studies reviewed suggest that in-car media use may variously improve alertness but not subjective state. Further work is needed to identify the circumstances under which media use may benefit the fatigued driver.

8.4.3. Auditory Pre-Alert

Auditory pre-alerts have been shown to increase safety when task-induced driver fatigue takes place. Auditory collision warnings can reduce fatigue-related rear-end crashes, particularly among older drivers (Baldwin et al., 2015). Gaspar et al. (2017) showed that a combination of auditory–visual alerts reduce the frequency of drowsy lane departures in the context of relatively short drives. In the case of longer, multiple hour drives, these feedback warnings seem insufficient.

✈ Inspiration from aviation

In aviation, auditory alertness devices have also been tested. Wang et al. (2014) found that in an online pilot-study, an OCLDM System was able to continuously detect EEG signatures of fatigue, and deliver auditory arousing warning to subjects suffering momentary cognitive lapses. Wright et al. (2005) found that a wrist worn alertness device (worn by Air New Zealand pilots) could activate pilots after determination of sleepiness and sleep (validated through EEG and EOG), and that such an alertness device, using an auditory alarm, can awaken pilots effectively during flight.

8.4.4. Stimulus Intervention

Intervention during driving by giving the driver an extra stimulus such as light, sound or other form of stimulus in order to alert the driver and prevent sleepiness, fatigue or inattention are considered particularly appropriate for passive fatigue conditions (e.g., monotonous, familiar routes, lack of stimuli, night journeys or highly predictable surroundings). In this sense, it has been proven that drivers find that a simple tone, variable in frequency and length, has positive effects to keep them alert (Landstrom et al., 1999a). There is also evidence that suggests that music can have a positive influence on the speed of detecting changes in visual stimuli (Beh & Hirst, 1999).

8.4.5. Environmental Conditions (peripheral cooling and lighting)

Cold air to the face from the vehicle's air conditioning vents, seems to be quite poor (Reyner & Horne, 1998b). Another environmental condition is the right light that has demonstrated alerting effects, although some laboratory evidence suggests that this does not counter the effects of partial sleep deprivation (Akerstedt et al., 2003).

✈ Inspiration from aviation- Distal cooling /temperature

It is known that both high and low ambient temperatures can affect driving performance by at least 13% (Daanen et al., 2003). On the other hand, non-thermal circadian oscillation of core body temperature (TC) and skin temperature (TSk) is temporally related to both initiation and termination of sleep (Raymann et al., 2007). TC remains high and TSk remains low across the day, and vice versa at night. Attainment of warm (~35°C) limbs in the evening is important for rapid onset and improved sleep depth, as demonstrated previously (i.e., Raymann et al., 2007). Attaining high TSk in sleep-permissive settings appears to induce drowsiness separate from other sleep-inducing factors. Sixtus et al. (2017) therefore tested the concept of peripheral cooling to promote vigilance at a time of high sleep pressure. They found that mild or moderate cooling of the feet did not attenuate declines in vigilance of healthy young adults but that there was a small but transient sleepiness reduction effect. At the moment, distal cooling, for instance by means of cooling the steering wheel, seems only to have temporary fatigue mitigating effects.

8.4.6. Substance intake

A strong literature foundation deals with the effects of substances intake on fatigued drivers. Some evidence shows that the driver's alertness improves if they eat some food during the rest break (Lisper and Eriksson, 1980). Other studies showed that the effects of caffeine, alone or in `functional energy drinks', seem to be positive. Furthermore, the effects of caffeine after sleep privation can be sustained for longer than the effects of a short nap (De Valck et al., 2003). Another possible strategy to prolong alertness or to fight fatigue is to take certain stimulant drugs under medical supervision (Moolenaar et al.,1999). However, the diverse and complex effects produced by these drugs on human advise this strategy to be used restrictively and under medical control (Tejero Gimeno et al., 2006). The HMI design may suggest the driver to take a break and incorporating caffeine.

8.4.7. Activity Breaks

Short Rest Brake

Interrupting driving to rest is one of the most recommended countermeasures for drivers in general, based on the assumption that interruption allows drivers to rest and overcome fatigue caused by prolonged driving. However, the effects of these breaks have been evaluated with varying results. There is evidence that having a break does not imply significant effects on the quality of driving in a simulator. At most, it may relieve the subjective feeling of fatigue (Drory, 1985; Gillberg et al., 1996). Some evidence suggests that a driver's alertness improves if they eat some food during the rest break (Lisper & Eriksson, 1980), or drink coffee alone or `functional energy-drinks'. Figure 66 shows an alert and a 'Take a brake' message displayed by Mercedes-Benz. In general, these findings indicate that the recommendation of having a break from driving should be complemented by informing that a break alone may not be enough, and that they should take advantage of the break to have a short nap or have some food, caffeine or energy drink.

Figure 66 Take a brake alert for fatigued driver

Exercises and Activities Alternation

Several studies have shown that stimulation of light to moderate levels of exercise, and alternating between active (talking, navigating, getting up, stretching) and passive (reading, resting) activity, can affect cognitive performance by raising arousal levels (Rosekind et al., 1994). More strenuous, submaximal exercise however has been shown to have some short-term alerting effects in sleep deprived flight crew subjects. However, it does not seem to protect subjects from performance decrements (leDuc et al., 2000). Sammonds et al. (2017) showed that if a break after one hour of driving contained activity (walking), it reduced discomfort and increased performance in the subsequent hour of driving, in comparison with a break in which participants stayed seated. Phillips-Nelson et al. (2011) however, showed that during the night, although breaks temporarily ameliorate time-on-task fatigue of driving, they cannot attenuate sleepiness as a result of sleep deprivation.

Q Inspiration from aviation- Strategic Napping

Napping break can reduce fatigue and improve alertness although one needs to take sleep inertia into account, especially when naps take more than 20 (min) (Ruggiero et al., 2014). Longer naps are also less practical in comparison with short duration breaks (10- 15 min) that have been shown to attenuate fatigue during cruise flight, with an effect of up to 25 minutes (Neri et al. 2002). A nap of max 30 minutes has also been shown to significantly improve driving performance during the night (Philip et al., 2006; De Valck et al., 2003). Hilditch et al. (2015) however, argue that shorter, 10-minute naps are far less likely to produce sleep inertia and to provide more specific recommendations more extensive research is required to better understand the interactions between nap length, the time of the day/night and prior sleep/wake history. New research of Centofanti et al. (2020) shows that a possible way to overcome sleep inertia might be to take in coffee (200mg) before the nap.

8.4.8. Applied Technologies from the Automotive Industry

The sub-chapter reports benchmarking on the different technologies installed by different OEMs on concept cars or vehicles on market to monitor and detect fatigue. The benchmarking was made using as reference the web sources (also YouTube videos) for the vehicle on market and A2Mac1 (a tool for automotive benchmarking used by FCA) for the concept cars.

Haptics

Several are the attention assist systems based on haptic inputs, available on the market, and sometimes assessed by EuroNCAP as innovative solution within BeyondNCAP.

Mercedes (2009). The system creates an individual profile of the driver, recognizing behaviour while the driver is fully alert. That profile is used as the basis for comparison during the rest of the drive. Mercedes-Benz Attention Assist uses a highly sensitive sensor that monitors and records steering movement and speed (Mercedes-Benz USA (2013) ATTENTION ASSIST Vehicle Safety Technology -- Mercedes Benz 2013 ML-Class, https://www.youtube.com/watch?v=A66zgJ4Oj8o)

Audi (2012), The rest recommendation function analyses the driver's steering motions and gas pedal activity at speeds between 65 and 200 km/h. If the analysis reveals indications that the driver's attentiveness is declining, the system recommends a rest by illuminating an indicator in the driver information system and sounding an acoustic signal (Bosch Mobility Solutions - Driver drowsiness detection - https://www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/driver-assistance-systems/driver-drowsiness-detection/)

Nissan (2015) Nissan's Driver Attention Alert (DAA) monitors behaviour through steering wheel inputs, alerting a drowsy driver with an image of a coffee cup on the dashboard. DAA monitors steering input patterns (using steering angle sensors) during a period of driving to establish a baseline. It continuously compares subsequent driving patterns to a baseline using a statistical analysis of steering correction errors. (Nissan USA – Driver Attention Alert System - https://www.nissanusa.com/experience-nissan/news-and-events/drowsy-driver-attention-alert-car-feature.html..html)

Renault & Dacia (2016) Tiredness Detection Warning (TWD). The vehicle's path is constantly monitored by a Bosch-developed algorithm, providing both visual and audible warnings. It analyses driver behaviour and takes account of events to inform driver of any risk of fatigue, such as steering wheel movement, driver actions on other devices (indicators, windscreen washer, etc.), time spent driving without stopping. (Renault e-guide - FATIGUE DETECTION WARNING - https://ie.e-guide.renault.com/eng/Scenic-4/FATIGUE-DETECTION-WARNING)

Honda (2018) On highway and arterial roads the Driver Attention Monitor continually monitors and assesses driver behaviour behind the wheel to help determine if the driver is becoming inattentive – and then if so, warn the driver to take a break. The system uses input from the Electric Power Steering (EPS) to measure both the frequency and severity of the driver's steering inputs to gauge their level of awareness with four gradients. (Honda - How to Use the Driver Attention Monitor on the 2018 Honda Accord - https://www.youtube.com/watch?v=ITvVuNbPHyA)

Volkswagen & Skoda (2018). The Driver Fatigue Detection System (also called Rest Assist) is available on certain models of Volkswagen and Skoda range. This system automatically analyses the driving characteristics and if they indicate possible fatigue, recommends that the driver takes a break. The system continually evaluates steering wheel movements along with other signals in the vehicle on motorways and other roads at speeds in excess of 65 km/h, and calculates a fatigue estimate. If fatigue is detected, the driver is warned by information in the Multi-function Display (MFD Premium) and an acoustic signal. The warning is repeated after 15 minutes if the driver has not taken a break ((Drivetribe - škoda safety- ibuzz fatigue alert - https://drivetribe.com/p/skoda-safety-ibuzz-fatigue-alert-f43lX1BbTT2Mn-XhfC26jg?iid=E66Jo66vQlyCQpXLS9fKLg)

Kia (2019). Driver Attention Warning (DAW) monitors the driver steering and acceleration pattern to detect if you are losing concentration and alerts you with a warning sound and a coffee cup symbol in the cluster. (Kia User Manual – Driver Assistance - http://webmanual.kia.com/PREM_GEN5/AVNT/RJ/KOR/English/driverassistance001.html)

Eye tracking and gaze behaviour

There is a wide consensus that camera-based monitoring is one of the best approaches to infer driver's condition and such technologies, mainly based on detection of blink behavioural changes, has been extensively developed and often are implemented by OEMs.

Below there is a summary about the different attention assist systems based on the analysis of gaze behaviour, something supported by figures.

Volvo has installed cameras inside vehicles to monitor driver behaviour and intervene if the driver appears to drive inconsistently or is not watching the road or even has closed eyes (e.g., fall asleep, drunk, distracted etc'.) Driver alert control is intended to attract the drivers' attention and to present the driver with symbols and messages (as shown in Figure 67). If he does not respond, the car will slow and even stop (Marinik et la., 2014).

Audi A8 (2018). The technology is based on an **infrared camera sensor** in the car that monitors the driver inside the vehicle and prevents him from falling asleep at the wheel. If the camera detects his eyes closed for an extended period, or obscured by a newspaper or large device, it will ask him to take back the wheel. (TopSpeed - Audi A8 – SB autonomous driving - https://www.youtube.com/watch?v=oV4ee17Nf44)

Cadillac uses a small camera located on the top of the steering column that focuses exclusively on the driver and works with infrared lights to track head position to determine where the driver is looking whenever Super Cruise (CM) is in operation. If the system detects the driver has turned attention away from the road ahead for too long, it will prompt the driver to return their attention to the road ahead. If the driver does not immediately refocus on the road, Super Cruise will continue to safely steer until a further escalation of alerts prompts the driver to resume supervision. If the system determines continued inattentiveness, a steering wheel light bar guides the driver to look at the road or take back control of the wheel. Additional alerts can include visual indicators in the instrument cluster, tactile alerts in Cadillac's Safety Alert Seat and audible alerts, if required. In the limited event of an unresponsive driver, the Cadillac CT6 utilizes the full capability of on-board driver assistance technologies to bring the car to a controlled stop and contact OnStar to alert first responders, if necessary. (Cadillac - Designed to Take Your Hands and Breath Away - https://www.cadillac.com/ownership/vehicle-technology/super-cruise)

Figure 67 Cadillac CT6 – Driver Attention Assist

Similarly, the Subaru's Driver Focus technology, developed by Mitsubishi Electric, also uses an infrared LED and a camera, placed on the top of a secondary display above the multimedia system, to monitor the driver for signs of inattention or sleepiness. Once the camera has scanned the driver's face, the system tracks the driver's eye activity to calculate two stages of tiredness - drowsy and extremely drowsy. If the driver is recognized as being extremely drowsy or dozing off, a visual and audible warning will alert them. A dozing driver is detected based on the opening degree of the eyelids and the time during which the eyelids are closed. Subaru's Driver Focus system keeps a watchful eye also on distraction, by monitoring to see if his head is turned away from the road ahead (shown in Figure 68). If the system detects that the driver is not looking at the road ahead, a buzzer and display warning will remind him to bring his focus back to the front. The system can also recognize up to five individual drivers, memorizing their pre-set preferences and adjusting the cabin environment for both their safety and comfort. (Subaru Australia - Driver Monitoring System – Driver Focus (DMS) - https://www.subaru.com.au/driver-monitoring-system)

BMW X5 (2019), uses a suite of ultrasonic sensors, cameras and radar to drive semi-autonomously under certain conditions and it is equipped also with a driver-facing camera mounted in the instrument cluster that checks to see that the driver's eyes are open and facing the road. (Autonews - At BMW, a camera can now monitor X5 driver attention - https://www.autonews.com/article/20180927/OEM04/180929798/at-bmw-a-camera-can-now-monitor-x5-driver-attention)

Figure 68 On the left, the driver is facing cameras of Subaru DriverFocus.

Figure 69 On the right, BMW's driver attention system.

DS7. The DS Driver Attention Monitoring System, installed on DS7 model, is designed to detect any form of distraction or possible drowsiness and, if necessary, to alert the driver (see Figure 70). Using a camera above the windshield and an infra-red camera placed above the steering wheel, the car's trajectory (deviations or steering movements by the driver), the driver's eyes (blinking of eyelids), face (direction of gaze), and head movements are analysed. If the system detects an anomaly, a "take a break" pictogram appears on the instrument panel with a special alarm sound. (DS Automobiles UK - DS7 Crossback | Ds Driver Attention Monitoring - https://www.youtube.com/watch?v=PwrRT1HJrpo)

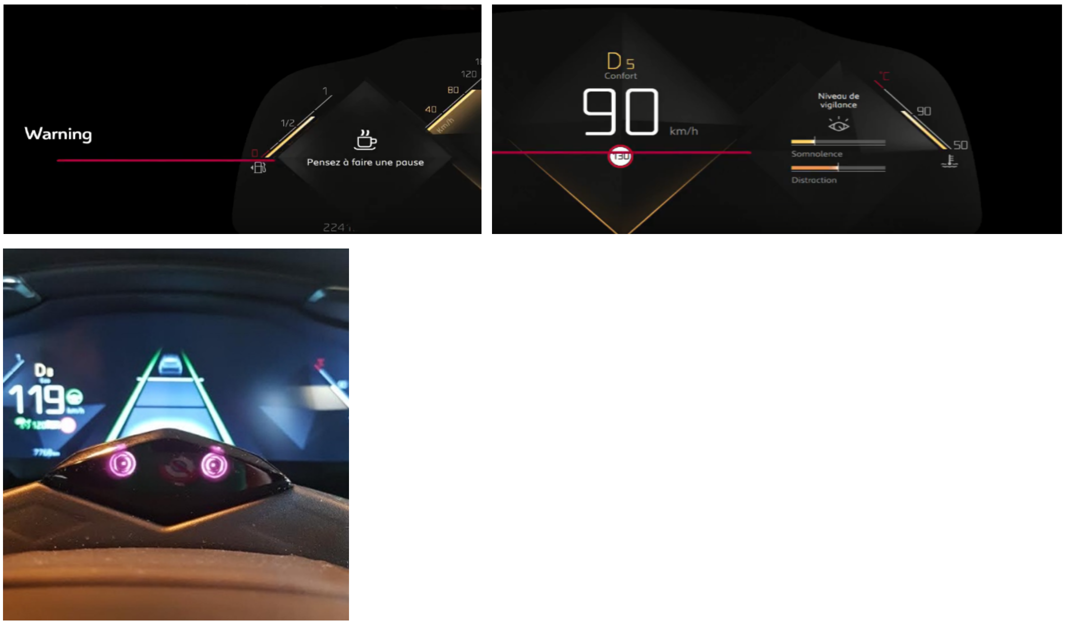


Figure 70 Details of the DS7 driver attention monitoring system

Physiological measures

The fatigue detection by physiologic measures is based on the bio signal analysis, the branch of biometry that studies human body measurement of the human individual that varies in such way to be representative of a physio-pathologic or homeostatic process. Most of these kinds of systems are cantered on an unobtrusive heart rate sensor and on an analysis of the Fluctuations in Inter Beat Interval (RRI) reflects activity of Autonomic Nervous System.

The following is an overview of different solutions implemented in production or concept vehicles.

Jaguar Land Rover is assessing how a vehicle could monitor the well-being of the driver using a medical-grade sensor embedded in the seat of a Jaguar XJ. The sensor, which was originally developed for use in hospitals, has been adapted for in-car use and detects vibrations from the driver's heartbeat and breathing, to detect that a driver is beginning to daydream, or feeling sleepy, whilst driving. (Land Rover USA - 2017 Range Rover | Driver Condition Monitor - https://www.youtube.com/watch?v=UuyFLE6yMxY)

Honda's HANA (Honda Automated Network Assistant) will learn from the driver by detecting the emotions behind the driver's judgements and then, based on the driver's past decisions, make new choices and recommendations. HANA can check on the driver's emotional well-being, make music recommendations based on mood, and support the owner's daily driving routine. Honda's NeuV can assess its driver's stress levels by analysing facial expressions and voice tones and provide suggestions for coping with different situations. (The Wheel Network - Honda Automated Network Assistant (Hana) Artificial Intelligence System - https://www.youtube.com/watch?v=Q1Br7meYrS4)

Ford has developed a car that can read emotions and display them on the vehicle. Working with Designworks, Ford has created the 'Buzz Car' - a customized Ford Focus RS incorporating wearable and AI technology. The driver wears two sensors on the wrists - one that monitors heart rate, and the other which measures the skin response. Every time the sensors detect a 'buzz moment' - when the driver is excited, and the heart rate increases - a dazzling light display appears across both the interior and exterior of the car. (Quattroruote - Ford Focus RS Buzz Car, l'auto che ti fa la radiografia! - https://www.youtube.com/watch?v=sySyFSpYESE)

Giorgetto Giugiaro's GFG Style (2018): The concept car Bandini Dora, a full electric four-wheel drive Barchetta car designed for outdoor leisure, is equipped with a special sensing technology embedded in seat, developed by Delta Kogyo, that make able to detect the Aortic Pulse Wave (APW), the vibration emanating from the cardiovascular system (shown in Figure 71). This allows to set a warning device to combat drowsy driving, the "Sleep Buster", that always monitors the drivers by assessing determines their condition every 18 seconds and warns of a risk to safety or the possibility of dozing off, in real-time. The "Quasi-Heart Sound Studio" displays waveforms of heart rate fluctuation in real time and makes the quasi-heart sound audible. It can capture daily fluctuations too, thus providing health care information that will allow to establish physical condition. (Gazzetta dello Sport – Arrivano i sedili che controllano la salute: per l'assistenza alla guida sulle hypercar - https://www.gazzetta.it/motori/la-mia-auto/17-03-2020/assistenza-guida-sedili-hypercar-controllano-salute-3601791655593.shtml)

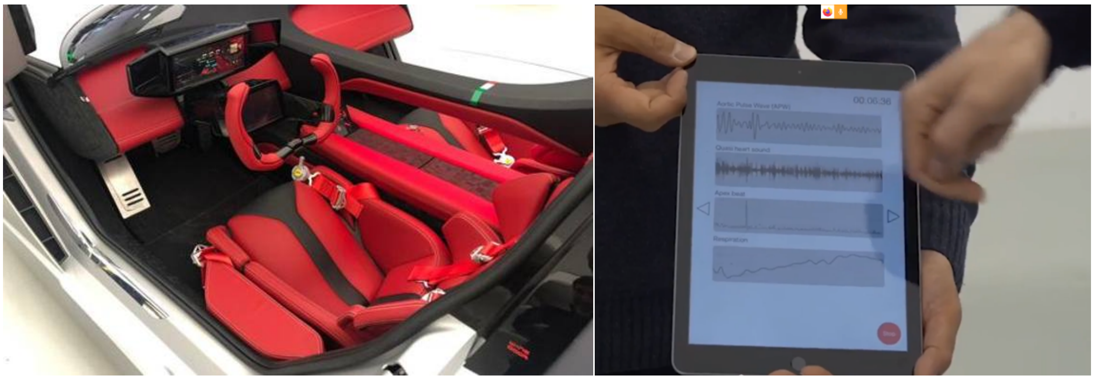


Figure 71 The GFG Style Bandini Dora equipped with APW sensing technology developed by Delta Kogyo

8.4.9. Regime Optimization

Driving regime optimisation seems to be particularly useful with professional drivers. Transport regulations generally prescribe the maximum length of shifts, the minimum duration of daily rest, and the length and distribution of breaks along the shift. These countermeasures, however, are less relevant to the Mediator (Tejero Gimeno et al., 2006).

8.5. Functional requirements of this study

In this section, we summarize the main countermeasures and functional requirements to mitigate driver distraction and fatigue under PAD.

8.5.1. Distraction – Functional Requirements

Based on the insights gained by the literature review, we phrase our guidelines as functional requirements for distraction preventive/corrective mediation:

Preventive mediation:

- If a driver at CM handles mobile or other apps than it is recommended to suggest, to block the apps that are considered distracted.
- If a TOR is upcoming and the driver is engaging with a non-driving task, the system should alert by using ambient peripheral cues with an indication for the desired steering direction.
- If a TOR is upcoming the system should provide an early/pre alert.

If a TOR is upcoming the alerts should be provided with different frequencies based on the immediacy (Time for TOR) of the situation.

Corrective mediation:

- If a driver is detected as distracted for at least 2 seconds at CM, the system should prompt by using coloured warning signals.
- If the system, at CM has already prompted (due to driver distraction) and the driver did not react within 5 seconds, the alert light would change to red and be accompanied by both a haptic and an audio alert for another 5 seconds.
- If a driver is detected as distracted at CM, the system should alert by using coloured warning signals.
- If the system provides an alert for a distracted driver, then the location of the alert should be in the driver's field of view (e.g., tablet or cellular screen).
- If a driver's visual attention to the driving scene has been detected as inadequate, the system may prompt the driver to perform a task in tandem with driver monitoring.

In addition, the suggested countermeasures for the Mediator system are organized in a descending order. At CM, whereas the driver is required to continuously monitor the driving, the distraction detection should lead to an intervention and an attempt of the system to bring attention back to the driving task. At SB, the driver can engage with non-driving tasks, but should be available if TOR is coming, so the system intervenes before take-over request (TOR).

Table 7 Suggested countermeasures for distraction for CM and SB

DISTRACTION					
Method	**Automation level**		**Intervention**		**Summary**
	2	**3**	**Preventive**	**corrective**	
Stimulation (Driver-based trigger)					
Recurring /Continues monitoring for preventive and corrective mediation Visual and audio alerts	x	x	x	x	A real time monitoring and distraction detection system is used as a trigger for intervention. Inspired by the work of Tejero Gimeno et al., 2006
Frequency of warning signals **Light, haptic and audio alerts**	x		x	X	The solution proposed warning signals on different frequencies, to mitigate the driver inattention. Atwood et al., 2019
Pre-alert		x	x		Audio pulse pre-alert that before the actual handover request van der Heiden et. al., 2017
Olfactory	x	x	x	X	Olfactory notifications have been proven to have a positive impact on the alertness and mood of the driver. For example, Baron et al., 1998; Dmitrenko et al., 2019

Hazards Warnings (Environment-based trigger)					
Location based cues for Latent /materialized hazards	x		x		Hazard location symbols were understood adequately (e.g., road, pedestrians) Hoekstra., 1993
Ambient peripheral light cues (LED)	X	X	X		Light cues were presented via an illuminated LED strip located on the dashboard Borojeni et al., 2016
Using Augmented Reality (AR) to display situational cues	X	X	X		Eyraud et al., 2015
		X	X		Lorenz et al., 2014 (TOR)
Gamification via AR	X	X	X	X	Pokémon DRIVE designed around gamified AR on a windscreen display. Schroeter et al., (2016)
360° LED strip display hazards	X	X	X	X	Display safety hazards by LED strip that is mounted 360° around the interior of the car's cabin. Pfromm et. al., 2013
Cooperative Automation PRORETA 3	X		X	X	Modular driver assistance system for collision avoidance Bauer et al., 2012
Vibro-tactile		X	X		Vibro-tactile stimuli for directional TOR, valuable supplement to auditory and visual displays. Petermeijer et al. (2016)
Adaptive automation support [HUD]	x		X	X	Adaptive driver support system provides support only when necessary Dijksterhuis et al., (2012)
TCAS,TCASII	Relevant	Relevant	X	X	Traffic alert and collision avoidance system, using visual display and haptic. FAA, 2011
TCAS,TCASII	Relevant	Relevant	X	X	Alerting a pilot to the location of other aircrafts path in the sky. Berstis & Smith (2002)
Haptic Shared Control					
Haptic interaction with driver through pedal or steering wheel	X	X	X		Deals with an object suddenly appearing in the reference trajectory. Abbink et al., 2012
Stall warning systems	Relevant	Relevant	X	X	Stick shaking when approaching a stall. Mark, 2017
Tactile (legs) sensation indicator	Relevant	Relevant	x		Tactile sensation generators in vicinity of the pilot's legs to correct the turn condition (Vavra, 1984)
Education and Training					
Education, training and licensing	X	X	X	X	informing and explaining the driver of the capabilities and limitations of automated driving systems Cunningham & Regan (2018)
Design Philosophy					
Dark Cockpit (CAS)			X		A new design philosophy that means that when everything is working, there are no blinking

8.5.2. Fatigue – Functional Requirements

This section summarizes the main countermeasures for mitigating fatigued and drowsy drivers under PAD. Figure 72 is organized in a descending order of the most appropriate countermeasure for Mediator system. At CM, whereas the driver is required to continuously monitoring the driving mainly on prolonged driving, detecting a fatigued driver or an upcoming fatigue should lead to an intervention and an attempt of the system to bring attention back to the driving task. At SB, the driver is allowed to engage in a non-driving task, and to be available if needed for upcoming TOR. Therefore, if the countermeasures are tasks (other than driving) then the nature of the task will be different depending on the level of automation. Based on the insights gained by the literature review, we phrase our guidelines as functional requirements for induced fatigue preventive/corrective mediation:

Preventive mediation

- If at CM, the driver is predicted to become drowsy/fatigued, the system will suggest the driver to engage with a relatively low demanding (secondary) task (audio task such as conversation with Vid) to mitigate fatigue.

If at SB, the driver is predicted to become drowsy/fatigued, the system will suggest the driver to engage with NDRT (such as game) to mitigate fatigue.

Corrective mediation

- If a driver is detected as drowsy/ fatigued at CM, the system should prompt by an audio alert and flashing up an unequivocal instruction on the display.
- If at CM or at SB the driver is detected as drowsy or fatigued, the system should suggest the driver to take a rest brake and to recommend her to drink coffee and perform light-intermediate physical activity.
- If a driver at CM or SB does not respond to an alert (detected as unresponsive) when detected as fatigued, the system will slow and eventually stop.

FATIGUE					
Method	Automation level		Intervention		Summary
	2	3	Preventive	corrective	
Non-driving Related Task					
Maintain alertness by inviting drivers to perform a mental task such as communication conversation, games and report tasks	X	X	X	X	A remedy for unchallenged situations when driving automation. Results provide clear indication for positive effect on safety (Bier et al., 2019; Lassmann et al., 2020; Drory, 1985). Task demanding should be adapted to the automation level.
Stimulation (vehicle)					
Auditory combined with visual alerts increase safety when task-induced fatigue takes place	x	x	x	x	It has been proven that even a simple tone, variable in frequency and length has positive effect to keep alertness (Baldwin et al., 2015; Landstrom et al., 1999a).
Interventions by a stimulus such as light, sound etc., prevent sleepiness and are		x	x	X	Landstrom et al., 1999a

particularly appropriate for passive fatigue conditions					
Stimulation –Driver					
In order to prolong alertness or to fight fatigue it is possible to intake caffeine alone or in functional energy drinks.	X	X	X	X	Caffeine intake is known to have positive effects on fatigue (De Valk et al., 2003; Gillberg et. al., 1996)
A short rest break (or nap) can relieve the subjective fatigue. However, combining it with caffeine intake or light to moderate levels of physical exercise (e.g., walking stretching) may increase arousal levels.	X	X	X	X	A short break alone does not necessarily affect significantly driver arousal, it can be improved if it contains also caffeine intake and physical activity (Lisper & Eriksson, 1980; Sammonds et al., 2017). Still, this countermeasure cannot mitigate sleepiness because of sleep deprivation.
In case the driver does not respond to the alert and detected as fatigued the emergency Stopping Assistant (developed by BMW) provides safe stopping.	X	X		X	Marinik et al., 2014

Figure 72 Summary of countermeasures for fatigue levels 2&3

8.5.3. Summary and Recommendations

The literature review introduces a variety of countermeasures for inattention, distraction, and fatigue under PAD at CM and SB. It seems that the high complexity of partial automation driving pose significant challenges to the interaction between the vehicle and the driver. Using countermeasures as part of the interaction requires adapting the intervention to a diverse set of variables including the driver state and the driving context that may change dynamically. For example, if the system at CM detects that the driver is unattended the frequency and the modality of the alert may change if the driver does not respond, or the hazard becomes materialized. This review provides a set of functional requirements (see section 8.5.2) that should be incorporated with the HMI design. However, we should be most cautious when drawing conclusions about the effectiveness of the countermeasures, for several reasons. Firstly, in most of the cases the countermeasures were studied under more or less constant specific conditions (e.g., environment, road, traffic, personality), therefore it limits the option for generalization of the results. Secondly, when evaluating countermeasure effectiveness, it is essential to control personal factors (e.g., age, experience, skills, and personality variables). In addition, we are not aware to studies that examined the long-term effects of the usage of the countermeasures and the implications of their combination. This review does not include user acceptance perspectives such as the driver intention to use the system, perceived usefulness and usability of the system as well as personal differences.

Our recommendations for HMI design consist of the adaptation of Mediator intervention to the dynamic situation of the triangle: driver, vehicle and context. An imperative condition is that the driver should *understand the automation system*, fully and intuitively. Specifically, the driver needs to understand the limits of the automation system and the human driver role. For this purpose, the Mediator may rely on a previous knowledge of the driver regarding the expected behaviour of the system and should display the driver the level of automation. Another important thing that emerged from the review is the need for the driver to report his/her own state (subjective), as this is found in the literature to be an valuable measure. Hence, the driver too should have a way to convey information to the Mediator actively.

In general, it is recommended that the interaction with the driver should be conducted via more than one modality, whereas audio channel seems to be more effective. For the visual inputs, the HMI designer has to use appropriate and effective colours, referring to established techniques in graphical HMI. For example, warning messages are usually shown in red (Naranjo et al., 2010; Yang et al., 2018). Mediator should show the information to the driver in a location that does not obstruct the line of sight of the driver and at the same time without disturbing to driver's vision. Furthermore, the location of an alert should be in the driver's field of view. The frequency of the interaction and the number of modalities for intervention depend on the immediacy of the situation (i.e., the time for TOR and time for TOC). Another principle to be considered is the content of the information that should encourage the driver to adopt a behaviour that may decrease the risk of accident. For example, using ambient peripheral cues with an indication for the desired steering direction, may lead the driver to take the right action.

An important aspect to be considered is the personalization of the HMI, using driver characteristics and preferences. For example, at CM, Mediator may suggest the driver to block apps that are considered distracting, thus the system behaviour will be according to the user preference. Another example is the use of NDRT at SB, in order to prevent or mitigate drowsiness or fatigue. In this case, Mediator may adapt the NDRT type to the driver preferences and areas of interest.

9. Mediation conflicts

9.1. Strategy

The first section is focusing on literature research on relevant issues about conflicts and disagreements in Automated systems in general and more specific for maritime control systems and partly from nuclear plant control rooms. 8.4.3 is comparing SAE Level of Automation with the use of Dynamic Positioning (DP) system in an offshore vessel where the transfer of control is gradually handed over from the Human to the Automation. The next chapters are focusing on the disagreement between MEDIATOR decisions and Human preferences when using Automated Driving Systems in cars. Disagreements and conflict at a little larger scope than can be covered in the MEDIATOR project are debated as well. These arguments were found based on design analysis of the topic. They were presented and discussed at the T1.5 Workshop at TUDelft in February 2020 and have then been further worked on.

9.2. Literature research – The sweet spot between human performance and automated systems – a discussion

Introduction

Looking back in time automation has been part of the development for decades, starting off with the transition to mass-producing industry where producing large amount of merchandise became possible with fewer humans involved. Accidents in dangerous factory environments were reduced and the safety of the workers improved. The trend has continued and worked its way towards automating everything from shops to cars, aeroplanes and ships to reduce costs and free humans from repetitive and dangerous tasks. However, with the increased pace of innovation and technology development, the motivation of increasing the level of automation has developed into different directions. One direction still concerns health and safety, while the other direction is more concerned about the possibility automation can give from a financial perspective. Still with aim of reducing the number of human operators, but now also adding the dimensions of comfort and convenience. It would be comfortable and convenient for automotive passengers to move driverless from A to B or with as little intervention as possible. It would be both comfortable and convenient for ship personnel to work from control centres rather than from onboard being away from family and friends for long periods of time. The visions of the future are optimistic and bright by including a high level of automation (LOA). However, time-to-time conflicts appear between the human as the operator of the system and the automated part of the system. How can this be solved? Where are the sweet spots between comfort and convenience, the human operator's performance, capabilities and the automated systems? There is a carefree optimism both in research environments and industry concerning the level of automation, there is also a growing scepticism towards it. In this article issues concerning the level of automation (LOA) and the capabilities of the human operator will be discussed, highlighting some of the crossing points where conflicts between them can appear from a maritime point of view.

Theory

When discussing the level of automation (LOA) another keyword, Human centred automation, appears with one single word in focus that binds it together, automation. The Cambridge dictionary (Cambridge Dictionary, 2020) defines automation as "the use of machines and computers that can operate without needing human control." Using the examples:

- Office or factory automation
- Automation and robotics have decreased the need for a large, highly skilled workforce.

Interpreted that the human operator is currently not needed. Digging deeper to look at the definition of the word automate: “to make a process in a factory or office to operate by machines or computers, in order to reduce the amount of work done by humans and the time taken to do the work.” Which leads us closer to our assumption that the level of automation must be implemented stepwise rather than a with binary 0 or 1 approach.

Level of Automation (LOA)

Fitts et al (Fitts, 1951), presented the LOA concept as the first researchers out, however the most commonly used model has been developed by Sheridan and Verplank (Sheridan & Verplank, 1978) in 1978, where 10 levels of automation were presented for a man-computer decision-making for a single elemental decisive step (Figure 73).

Level	Description
1	The computer offers no assistance, Human decides everything
2	The computer offers a complete set of decision/action alternatives
3	Narrows the selection down to a few
4	Suggests one alternative
5	Executes that suggestion if the human approves
6	Allows the human a restricted time to veto before automatic execution
7	Executes automatically, then necessarily informs the human
8	Informs the human only if asked
9	Informs the human only if it, the computer, decides to
10	The computer decides everything and acts autonomously

Figure 73 10 levels of automation by (Sheridan & Verplank, 1978).

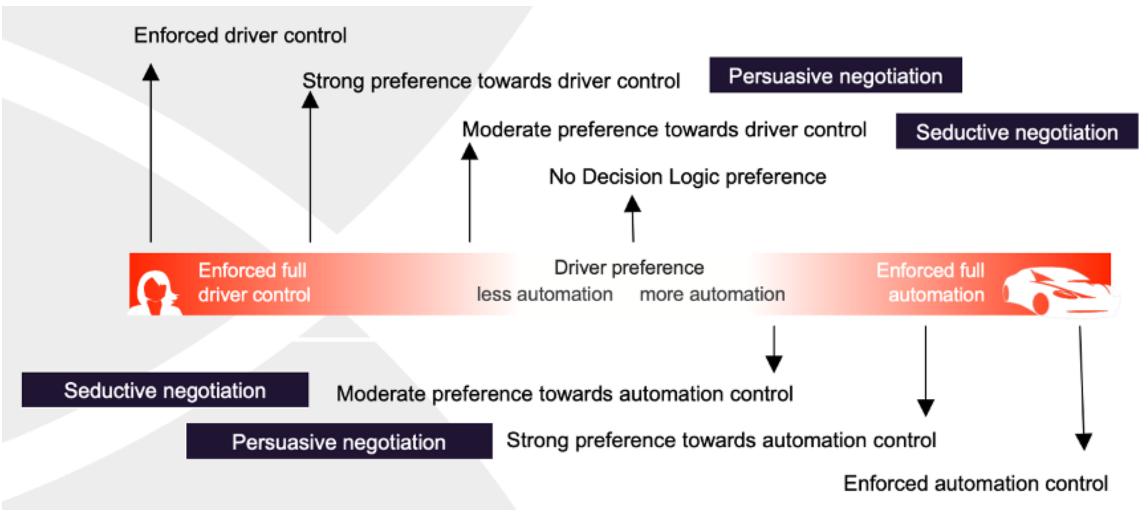


Figure 74 The negotiation options the MEDIATOR project is anticipating

The Level 1 and 10 in Sheridan & Verplank’s Level of Automation is comparable with the levels in MEDIATOR. The Levels in between can be compared, but is missing the mediating component and the sensors that evaluate the fitness of the Human:

- **No negotiation, driver's choice:** Enforced driver control – Level 1: The computer offers no assistance, Human decides everything.
- **Seductive negotiation:** Moderate preference towards driver control or automation control – Level 4-6.
- **Persuasive negotiation:** Strong preference towards driver control or automation control – Level 2-3 and 7-9.
- **No negotiation, automation decides**: Enforced automation control – Level 10: Computer decides everything and act autonomously.

The levels have developed with time and in the automotive industry the LOA is according to National Highway Traffic Safety Administration (NHTSA, 2020) within the United states Department of Transportation now down to six levels of automation. See Figure 75.

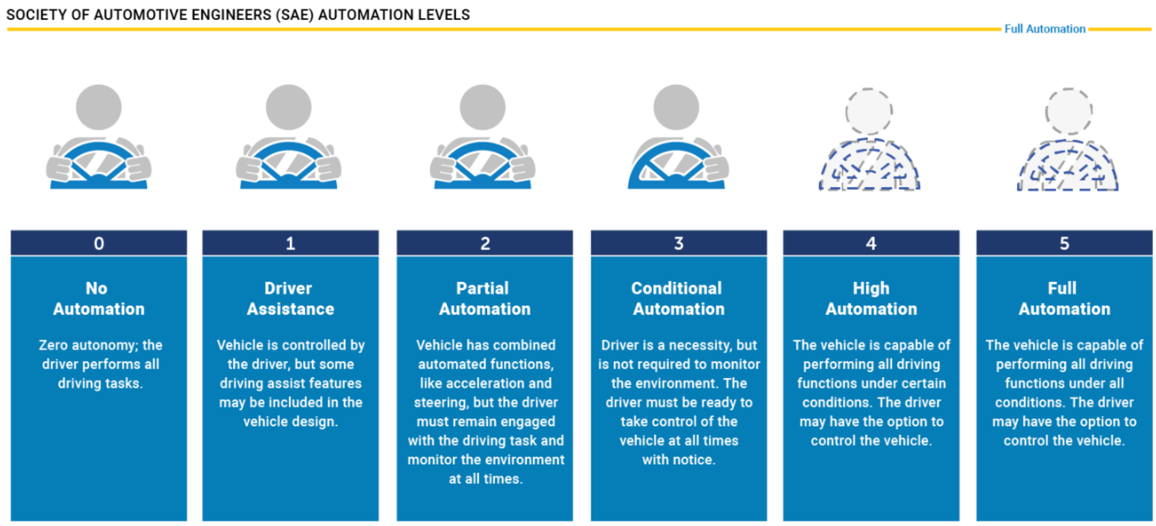


Figure 75 LOA in the automotive industry (NHTSA, 2020).

According to NHTSA the industry is now advancing into level 3, conditional automation. Conditional automation requires the driver to be present and ready to take control with notice. It also states that the driver is a necessity but is not required to monitor the environment. This raises questions concerning situation awareness that will be discussed in one of the next sections.

In the Halden report from 2017 (HPR-387) a large study carried out by the Institute for Energy Technology in Norway (IFE) as a part of the Halden Reactor Project (Skraaning & Jamieson, 2017), states that plant-wide procedure automation is tightly coupled to the operators' taskwork and can therefore easily alter the operational concept in unintended ways. In this case transparent automation, giving the operator insight into which functions were automated and the progress and status of the actions, attracted too much attention and made the operators less aware of the plant state. The plant is in this case a nuclear power plant. The Halden report further states that automation at the component level of the plant is probably working as local tools embedded in the technical system and are therefore less prone to confounding with the overall control of the plant. In this case parallels can be drawn to autonomous or automated driving automating features of the engine, steering, or braking systems (such as fuel injection, emission control, power steering, antilock braking, or traction control) may be less likely to interfere with the human operation of the vehicle than automation of the driving itself (adaptive cruise control, lane keeping, brake activation, autonomous navigation etc.). This finding is interesting as automatic gearshift feels like an aid to the operator rather than a task that interferes with the actual driving and where the operator can develop feelings concerning loss of control and being out-of-the-loop.

In the same report (Skraaning & Jamieson, 2017), further findings suggest that studying the level of automation (LOA) formed subjective impressions that their out-of-the loop performance and quality of cooperation with the computerized procedure system were poorest under the fully- automated condition. Using these findings and drawing parallels to other industries that are currently under pressure of being large scale automated, such as the maritime industry, the aviation industry and the automotive industry, a certain caution must be included to make sure the designs made, and the tests done are according to realistic preferences and not based on visionary thoughts. This is also reflected in the publications by Jamieson and Skraaning in 2018 and 2019. The topic by Jamieson and Skraaning (2020) has however caused some debate by Wickens et al (2020).

Human-Centred Automation

Designing interfaces and products for human utilization, a human-centred – design process is often used. In the perspective of automation, human -centred- automation is according to Mitchell (1996) a term used to characterize the use of automation technologies to enhance the capabilities and compensate for the limitations of human operators responsible for the safety and effectiveness of complex dynamic systems.

In the maritime industry this can be transferred to the vessel’s automation system (among many other systems available on a ship) where a range of sensors give the chief in the engine control room (ECR) notice of limit deviations such as oil temperatures, pressure, valves and similar. Making it possible to act before an incident occurs.

Mitchell (1996) states that automation does not have to be human centred. There is however an increased use of control automation that operates in the background without the operator even knowing about it. Drawing connections to the studies discussed above are done by (Skraaning & Jamieson, 2017), where there is a division between what interferes with the operational situation and what can be automated without the operator knowing. The latter, such as automatic gearshift in the automotive industry and silencing the positioning (GPS etc.) alerts when passing under a bridge or being in GPS shadow in a maritime context, is something that represents repetitive tasks that only occupies cognitive load, without giving any aid or benefit to the operator. Mitchell (1996) states that this type of automation operates purely autonomous, and the operator is not responsible for ensuring its successful operation.

Situational awareness (SA)

When discussing LOA and human centred automation, situational awareness is a common denominator. When increasing the LOA, there are no requirements for the operator to monitor the environment constantly. While connecting this with human-centred automation where the automation that can aid the operator without the operator being aware of it has the best effect, while the automation that interferes with operative control tasks needs careful design as it touches to disturbing the operator (Skraaning & Jamieson, 2017).

Literature referrers to situation awareness to the operator’s ability to be aware f or to assess the operating situation (Singh, 1997), but is formally defined by Endsley (Endsley, 1996) as *“… the perception of their meaning and projection of their status in the near future.”*

Looking at the above definition and then LOA in in terms of being present long enough to understand the situation in order to decide, both in a very short period of time, the level of complexity increases. In a maritime setting where the frequency of events is at a much slower pace than in the automotive industry, loss of situation awareness is often a cause of misunderstandings that can or will lead to accidents.

A range of questions appear:

- To what extent can we automate in the maritime domain without loss of SA?
- At what LOA should the system take-over?
- How should the automation system communicate with the operators?
- What if there is a conflict between the operator and the automated system? Who wins?

To simplify the above questions into one:

- Where is the sweet spot between the human performance and automated systems?

Discussion

It is clear from the above-mentioned research that when elements and functions of an operation is automated, operators can experience loss of SA for different reasons.

Boredom and repetitive tasks tower high on the list on a ship bridge or in the ECR, where an overactive automation system aggregates all alerts without taking operational context into account. The audible alerts being shelfed or acknowledged at rapid pace by the operator due to the noise level (constraining even more of the operator's mental capacity) and the overwhelming number of alerts being presented leaving little time to read and understand the codes and text presented.

On the other end, loss of SA can also be present when functions or elements of a process becomes digitalised or automated. A simple example is the task of navigation. Today paper charts are being removed from the vessels or placed in a drawer that is seldom opened after the introduction of ECDIS and electronic charts. A necessity and support to the operators on board but reducing their knowledge and understanding concerning how to actually navigate without electronic and automated aid. With the introduction of autopilots, auto crossing and auto docking, there is soon nothing left of the tasks assigned to the operator, returning the thoughts to boredom and repetitive tasks, as explained above. The operator's attention is elsewhere, either by instruction or by occasional daydreaming, leaving less time to react to a situation where human intervention is necessary.

In 2007 (Havarikommisjon, 2008) the vessel Bourbon Dolphin capsized and sank in the North Sea just off the coast of Shetland resulting in the loss of 8 lives. The vessel was working on towing an oil rig together with many other vessels when it capsized due to stabilization issues with the wires that were connected to the rig. The reasons of the accident were many, however one detail can be interesting in the current setting. On board a function previously called "quick release" of all chains and wires, now called emergency release, was present on the vessels bridge. The function's name indicated that this was something that released the tension of chains and wires quickly and to be utilized only in emergency situations. When the vessel started to heel, the captain pressed the quick release button, with the expectation and assumption that this might be able to return the vessel to a stable condition. The scenario when pressing this button, was not a full release of the drums as anticipated, but a much slower process which did not make any difference to the situation, due to the button being pressed too late. In the accident report it is indicated that this function could not have saved the vessel regardless of the time being pressed. It is however interesting to keep in mind what the expectation of an automated function can do to an operator's ability to make decisions.

Final words

Accidents keep happening, even though many functions have been automated and made so easy that operators expect them to be present. Automotive drivers expect to have power steering, while maritime operators expect to have electronic charts available for their disposal. Looking back to the question concerning the sweet spot between human performance and automated systems, it is difficult to answer with one single reply or conclusion. The holistic situation must be analysed and assessed, and that carefree and optimistic development must slowdown from a commercial and research point of view to have the ability to ask the correct questions. Although there are many benefits of automating functionality, to take a step back and ask: "Why should we automate this? Who does it benefit?" before eagerly automating every function possible automate. The sweet spot is where the operator feels comfortable and in control, regardless of location or tasks present, which can be achieved through research and testing.

9.3. Transfer of control on a vessel with Dynamic Positioning

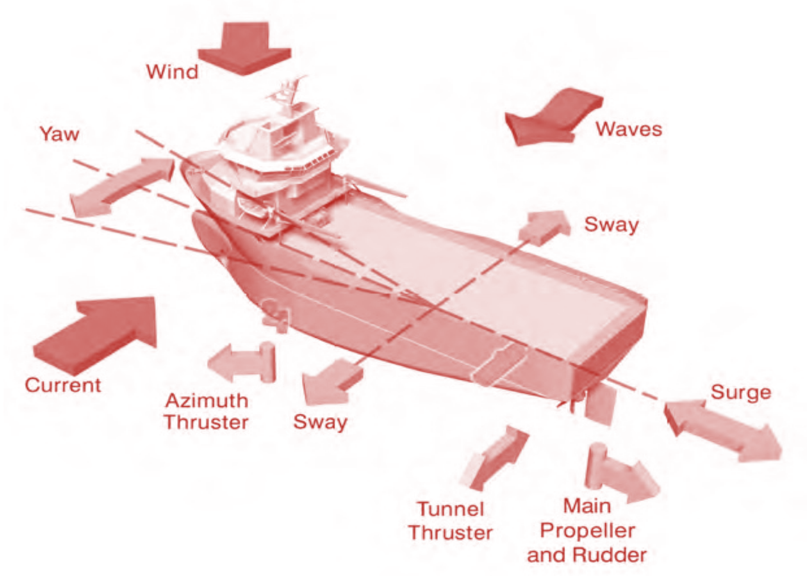


Figure 76 Control of vessel's three degrees of freedom: Surge, Sway and Yaw

The Levels of Automation used by SAE can be compared with how Dynamic Positioning (DP) systems is used. DP is widely used in offshore operations to keep the vessel in a defined position, to follow a track etc. The vessel can be manoeuvred manually by individual rudder-, tunnel-, propulsion- and azimuth- thruster levers. Alternatively, a joystick is used to adjust the engaged propeller, rudder and thrusters to give the force and direction given by the joystick position. In DP operations the vessel is mainly manoeuvred manually by a joystick. As an example, we can use a supply vessel entering the 500m safety zone around an oil rig. The DP system is activated and tested outside the zone, but the vessel is steered against the rig manually. As the vessel comes closer, the Heading (Yaw) can be set, and the control of Yaw is now done by the DP system. This can be compared to Level 1 – Driver Assistance. As the vessel gets nearer the Surge direction can be set and controlled by DP. Level 2 – Partly Automation. The Human now only control the Sway direction and can steer the vessel against the rig sideways while DP is controlling the Yaw and Surge. When the vessel is close to the rig, the Operator hand over the control of Sway to DP as well. The vessel position is now controlled and kept with a small deviation by the Automation. The Human have now a monitoring role like Level 3 – Conditional Automation. The Operator must be ready to take-over within short time. He/she cannot leave the workstation but can perform other tasks related to the vessel's operation. The DP system can keep the position for hours, for other vessel types the DP can be in control for several months. This can be compared with Level 4 – High Automation, but the Human cannot go to sleep, but need to monitor the DP system with is sensors and be ready to take-over if a failure occurs.

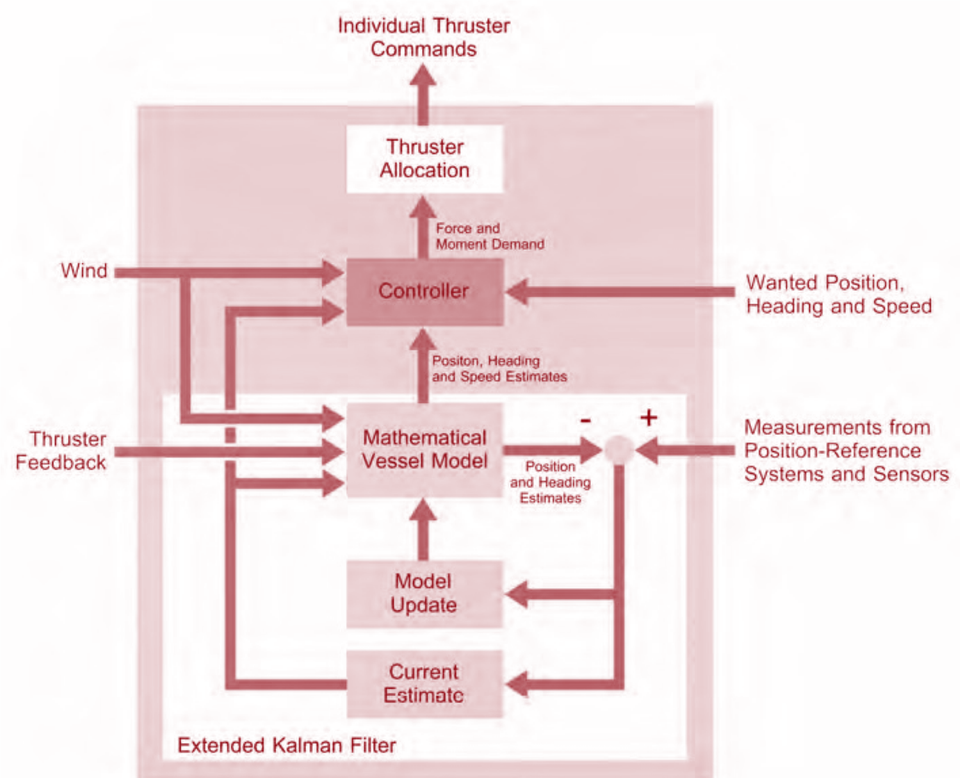


Figure 77 General DP theory

Position:

- Wanted position – Operator
- Estimated position – DP Model
- Measured position – Reference Systems

Vessel model:

- Drag coefficient (surge, sway, yaw)
- Mass (surge, sway, yaw)

Controller – Force demand:

- Setpoint deviation
- Wind force
- Current estimate
- Demand > Available Thrust = Insufficient

9.4. Disagreement between automation decisions and human preferences

The use cases 1 (Mediator initiated takeover – Human to Automation), 5 (Mediator initiated takeover – Automation to Human) and 9 (Continuous Mediation (CM) shuts of immediately) have been investigated regarding disagreements between the Mediator decisions and Human preferences. An overview of use case is to be found in Par. 1.1.1.

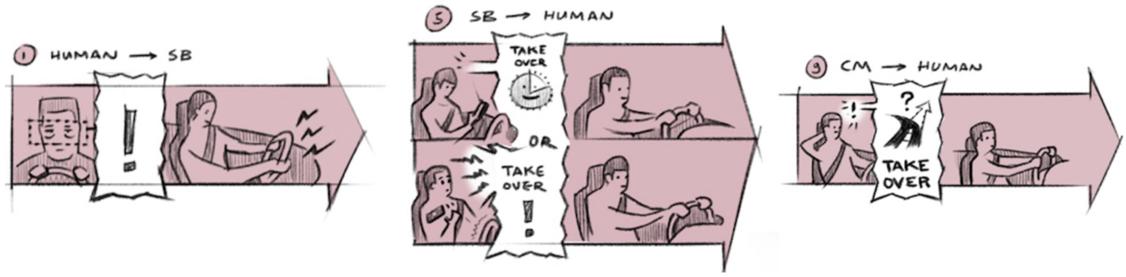


Figure 78 Use cases 1, 5 and 9

Un use case 1 Mediator detects degraded human fitness caused by drowsiness, or degraded human fitness caused by distraction, and initiates a forced take-over to automation.

In use case 5 the automation communicates according to plan that the current route will leave the ODD within the next seconds, or the automation communicates that its reliability is degrading rapidly, and the human should take-over within seconds. Mediator informs the human and guides an urgent take-over.

In use case 9, while driving in CM the road markings degrade and Mediator indicates CM will shut off immediately. The scope has however increased a little to cover more disagreement and conflict areas that may occur when driving cars with Automated Driving Systems (ADS). There are also some questions that need to be discussed that increase the complexity of potential disagreements and conflicts:

- Where will the mediator system be installed and utilized? Will it only be in future cars with SB and TtS automated driving capabilities, or in cars with lower automation capabilities that are already available? Mediator requires several sensors and means to observe the Human's condition. Will these be installed and made available in a car restricted to L1 or L2 driving?
- Will driving in a lower automation mode in a car with SAE L3 and L4 capability be different to drive in L1 or L2 than a car with only L1 capability or perhaps L2? A L3/L4 car will anyhow have more advanced ADAS systems, processors etc. available which also will be utilized in L1 and L2.
- Will there be a conflict if a Human used to drive a L3/L4 car switches to a car limited to L1 or L2 driving? Is there a risk he/she have more thrust in the Automation than he should?

The two following paragraphs are divided into cars limited to L1 and L2 driving (Continuous Mediation), and cars with L3 and L4 Automated Driving System (driver in Standby or driver Time to Sleep, SB or TtS).

9.4.1. Disagreement between MEDIATOR decisions and Human preferences – cars limited to L1 and L2 automated driving (CM)

Thrust conflict – Human sceptical about new technology – L1 and L2 or CM

Disagreements about Mediator decisions will depend on the Humans attitude to, experience with and thrust in Automated Driving Systems. Today several Humans prefer to drive manually at L0 and do not activate Advanced Driver Assistance Systems (ADAS) even if the car have these functions available and L1 and L2 driving is available. Should Mediator encourage sceptical drivers to use ADS to a large degree?

- Human is driving in L0. Mediator detects that the Human is partly distracted with other tasks leading to driving at a speed below the speed limit and is not keeping a steady lane position. MEDIATOR warns the Human that he/she must pay attention to the road. Human feels this is annoying and ignore the recommendation.
- Human is driving in L0. Mediator detects that the Human is drowsy. Mediator decides to activate CM and recommends driving to the nearest rest stop or similar to take a break or get a powernap. The Human disagrees and does not feel drowsy or see the need to stop for a rest.
- Human is driving in L0. Mediator detects that the Human does not access CM in areas where this could have been beneficial. Mediator offers to take-over the speed control and/or the steering. Maybe Mediator could evaluate the Human to be unexperienced with automated driving and offer to give support and guidance?

Thrust conflict – Human has too high expectations – L1 and L2

Some drivers believe more in new technology and exaggerate at which level the automation can perform. Cars with Adaptive Cruise Control (ACC) and Lane Assist Systems that can be driven in SAE levels L1 or L2 today have their limits and requires that the driver has a hand on the steering wheel and the eyes on the traffic situations. Still, Humans do things they should not and are distracted with their mobile phone etc. when driving in L2. They are not paying attention to unexpected road situations like road works, reduced speed limits, traffic accidents etc. that can occur and requires a sudden reaction by the Human. More and more accidents occur today when the Human was distracted while driving in L1 or L2.

- Human is driving in CM. Mediator detects that the Human is not in the loop and are distracted with other tasks. Mediator warns the Human that he/she must pay attention to the road. Human feels this is annoying and ignore the recommendation.
- Human is driving in CM. Mediator detects that the Human is distracted. Mediator decides to step down from to no automation and asks the Human to take-over.

9.4.2. Disagreement between MEDIATOR decisions and Human preferences in automation levels SB and TtS

Thrust conflict – Human sceptical about new technology – SB and TtS

A Human who buys a car with SB/TtS ADS will normally be keen to learn how to use the system and utilize it. Still there will be other Humans driving this car that has a more sceptical attitude to ADS. The complexity of having to choose between no automation, CM, SB or TtS and at which traffic situations and environment to activate what, must be overwhelming. Mediator may here have an important role in giving the Human confidence in the ADS and when to access which automation level. It is probably easier to accept SB and TtS where the vehicle is in charge of the driving for a shorter or longer time period, than to use CM in which there may be a split between which part is controlled by the automation and which by the Human.

- Human is driving with TtS activated. Mediator warns the Human and gets he/she back in the loop and prepare for take-over while in *no automation*.
- After take-over to *no automation* and driving manually Mediator recommend activating CM or SB, depending on what is recommendable at the given situation.
- Should there be a mode in Mediator where the degree of experience with ADS is selected?

Thrust conflict – Human experienced with new technology – SB and TtS

Humans used to and with interest in new technology may want to use the ADS more actively and select which level of automation depending on what Mediator recommend. Having a mode where high experience with ADS can be selected, can be like this.

- Human is driving in CM. Mediator informs the Human that in a distance like e.g., 500m SB or TtS can be activated. The Human decides if the recommendation and advice should be activated or not.
- Human is driving in TtS. Mediator gets the Human back in the loop when the period where TtS can be activated is coming to an end. Mediator decides to go to CM, and not to *no automation*, for the more experienced driver.
- Human is driving in CM. Mediator detects that the Human is distracted with other tasks. MEDIATOR decide to step down from CM to no automation (SAE L0) and asks the Human to take-over.
- Human is driving in CM. Mediator detects that the Human is drowsy. Mediator decides to activate TtS if this is available. The Human can then get a powernap. If TtS is not accessible MEDIATOR recommends driving to the nearest rest stop or similar to get a rest.

9.4.3. Other disagreements and conflicts between MEDIATOR and Human preferences

In this Chapter the term System is used mainly for the car's ADS (Automated Driving System) but also for the Mediator system. Some of these disagreements are linked to the performance of the ADS, some are outside the scope of the MEDIATOR project, but are still disagreements that will occur during Automated Driving (AD).

Disagreement about take-over (SB) – Human wants to extend AD

- Human in standby for shorter period of the trip.
- At the end of the period Mediator wants Human to take-over from L3 driving.
- Human is not finished with a task not related to driving and wants to extend the period a little to complete the task.
- ADS is on the limit of the timeframe and can no longer have control. The consequence can be Automation is forced to continue outside the available period and performs an unwanted stop. This may have traffic impact and can create critical and dangerous situations.

Disagreement about take-over (TtS) – Human not fit to take-over

- Driver is out of the loop; the Automation has full control of the driving. The Human wants to sleep during a longer part of the trip.

- At the end of this longer period, the Mediator starts to wake-up the Human, but struggle in making him/her fit.
- The ADS is on the limit of the timeframe and can no longer have control. The consequence can be the Automation is forced to continue outside the available period and performs an unwanted stop on the nearest road shoulder or rest stop. This may have traffic impact and can create critical and dangerous situations.

Disagreement about readiness to take-over (SB, TtS)

- During L4 or longer L3 automated driving Mediator is uncertain if the Human is ready to take-over or not.
- Should the System ask the Human to take-over in a non-critical situation, just for testing the readiness of the Human?
- This is a way of securing and training the Human, especially if he/her is unfamiliar with automated driving.
- For an experienced driver this test mode can be annoying and should perhaps be possible to deactivate.

Disagreement about obeying traffic rules

- One of the goals with automated driving is to increase road safety.
- Following the traffic regulations should help achieve this goal.
- In automated driving at level 3 and 4, the System will be in charge of following the traffic rules. In level 0, 1 and 2 the Human is responsible. Or is the driver always responsible?
- It is expected that the System will not bend the rules, nor have a too large safety margin. Both may create a disagreement.
- Risk taking should be low when driving partly or fully automated. Should the System give guidance when rules are override when driving in L0, L1 and L2?

Disagreement about speed above speed limit

- When driving manually the Human prefers to go with a higher speed than the speed limit.
- The speed limit is overrun with a margin the Human think is “safe” for not being caught or loose the driving license by speed cameras or in a speed control.
- The Human wants the System to use this margin when driving partly or fully automated.
- This is an ethical dilemma. Who is in charge of the speed limit at L3 and L4? Should it be possible to force the System to drive faster than the speed limits?

Disagreement about speed limit– warn or prevent

- Should the System warn the Human when driving over the speed limit (L0. L1 and L2)?
- Should the System prevent the Human from driving over the speed limit? Should it then be possible to fast override the speed limit in an emergency situation by pressing the accelerator pedal to maximum level or similar?
- Should the System educate the Human that the benefit of driving at this certain speed above the limit, the gain will be that many seconds? And if the speed limit is followed you will reduce the energy consumption with this amount?

Disagreement about legal speed limit

- In a future with many cars driving partly or fully automated, will the average speed be more consistent and closer to the speed limits? Few are driving too fast, and none are driving too slowly.
- On roads with speed cameras many drivers add a too large safety margin, resulting in a long queue of cars behind. With automated driving this could be eliminated. Or should the Human be able to overrule the System to drive more slowly than the speed limit even if the road conditions don’t require a reduced speed?
- Will the Humans in cars without possibility to drive automated get irritated when following behind automated cars? Cars that drive legal and do not take risks by overriding the speed limits?

Disagreement about too low speed

- The Human drives manually or in L1 and L2 at a speed level below the speed limit.
- The reason can be unfamiliar roads, lack of concentration on the speed, but focus on other traffic situations, but also lack of fitness.
- Should MEDIATOR warn the Human that he/she is driving under the recommended speed limit?
- Or should MEDIATOR offer to take-over control? If driving at a lower speed than the speed limit is resulting in cars following behind is queueing up, should Mediator then force to take-over and drive in L3 and L4 if this mode is available?

Disagreement about variable speed

- The Human drives manually with a speed that is not constant and varies so much that cars queue up behind.
- The reason may be distraction or lack of concentrations but can also be Human fitness.
- Should Mediator warn the Human that the driving speed is inconsistent?
- Or should Mediator offer to take-over speed control and drive in L1 or L2? And L3 or L4 if this is available?

Disagreement about speed in curves

- Automated driving in curves is too slow for the driver. Feel irritated and loose thrust in the ADS, do not believe in its capabilities and turns automated driving off.
- Automated driving in curves is legal, but too fast for the Human. He/she feels unwell and insecure.
- Possible solution: Different driving preferences or driving modes for automated driving (comfort, normal, sport etc.).

Disagreement about lane position

- The automated driving follows a curve that is too far out against the road shoulder or against the centre of the road compared to what the Human would choose.
- The Human may feel insecure and have less thrust in the ADS. This may force the Human to take control of the steering on curvy roads even if Mediator means he/she is un-fit now.

Disagreement about overtaking – different knowledge about traffic situation ahead

- As Mediator have more information about the traffic situation far ahead via traffic information systems, it can evaluate the current traffic situation differently than the Human.
- For instance, if the car in front drives at a slower speed than the speed limit, or at a slower speed than the Human prefers, or at a slower than needed to arrive at the destination in time (ETA), an overtaking would be evaluated when the traffic situation makes this possible.
- ADS/ Mediator would evaluate the situation differently than the Human if there is e.g., a traffic jam one km ahead. ADS/ Mediator would estimate and see that there is nothing to gain by doing the overtake. Automated driving at level 3 and 4 would just follow the car in front. This can lead to a disagreement if the Human is not informed about the reason why an overtaking is not performed.
- When driving at L1 and L2, and L0, the Human could be informed when a situation mentioned above occurs, that there is nothing to gain by doing an overtaking.

Disagreement about turn indicators and signalling

- Turn indicators should be used to inform other vehicles about change of lane, exit at crossroads, in roundabouts etc. Not all drivers are good at following these rules.
- Automated driving in L3 and L4 requires that ADS has control of both the turn indicators, the dim and full light, the window wipers etc.
- Should the ADS support the Human by using the turn indicators in L0, L1 and L2 as well? If the destination and route is known, this should be feasible.
- Or will this create disagreements of who is in control when? Should the use of lights be fully automated as it partly can be set to today? The car will need to have the technology for this available in a L3/L4 car, but should the Human be out of the loop for these tasks also? Or should the Human decide to have it automated or operated manually. Should Mediator then be used to supervise and give recommendations if correct use is not performed?

Disagreement about energy saving mode

- By driving economical with a more constant speed, this behaviour can create disagreements with other vehicles following behind.
- They may plan to do an overtake which may create dangerous traffic situations.
- The Human may see the risk in this situation and could override or change ADS parameters from economical to safe mode.
- Or ADS identify the risk and change mode by itself when in L3 or L4.

Disagreement about sharing information

- The System may have more information about the traffic situation far ahead via traffic information systems.
- Traffic jams, road works, accidents etc. is information that may influence the driving, whether it is manual, partly automated or fully automated.
- If the information has not been shared with the Human in advance, this is information which is not visible for the Human until the vehicle reaches the actual areas and situations.

- The traffic information is normally not shared with the Human before the System means it is relevant to be shared. The selection of what to share, how to share it and when to share it, may lead to disagreements. Too much information can be annoying, and too little may result in less situational awareness for the Human.

Disagreements about experience level – demanding traffic situations

- For complex and demanding traffic situations, an experienced driver will evaluate the situation differently than the System.
- The Human could then be more fit than the System, and this can lead to disagreements when driving partly or fully automated.
- The Human will wonder why the System reacted so slow or took decisions that differ from the Human preferences.
- The result may be lack in confidence in the System and the benefits that should be possible to achieve with automated driving, is not met.

9.5. Conclusions

Disagreements about Mediator decisions will depend on the Humans attitude to, experience with and trust in Automated Driving Systems. Mediator should be adaptable to different Human preferences, selected by different experience modes or levels. To meet the individual Humans expectations to ADS, Mediator can be helpful in reducing potential conflicts.

9.6. Functional requirements of this study

- In use case 1, WHEN the automation wants to take over control and the automation gives recommendations to the human (who is sceptical about new technology), Mediator SHOULD take into account that the human can ignore recommendations although distraction or fatigue is detected.

- In use case 9, WHEN a human, driving in L2, needs to take over, but has too high expectations of automation and therefore becomes distracted with other NDRTs, Mediator SHOULD take into account that the human can still ignore warning signals and/or take over requests.

- In use case 5, WHEN in SB a take-over is due but the human wants to extend AD, the automation MUST continue outside the available period and should perform an unwanted controlled stop (The type of stop depends on the situation to be out of danger for other traffic).

- In use case 5, WHEN in SB a take-over is due but the human seems unfit to take-over, the automation is forced to continue outside the available period and should perform an unwanted controlled stop (The type of stop depends on the situation to be out of danger for other traffic).

- In use case 4 & 5, WHEN driving in SB or Tts, the HMI WILL secure and train unexperienced drivers by asking to take-over in non-critical situations.

- In use case 3 & 5, IF there is disagreement about who's overtaking control driving manually or in CM, the HMI SHOULD inform about the traffic situation in order to proof that there is nothing to gain by overtaking.

- In all use cases, WHEN driving, Mediator SHOULD take into account disagreement of speed (limit) and both human drivers (as Mediator) SHOULD be able to give their preference during AD to point out (inconsistent) driving speed during manual driving.

- In all use cases, WHEN using ADS, Mediator SHOULD give the human confidence in the ADS and when to access which automation level in order to give guidance in the amount of automation levels related to the suiting traffic situations/environments.
  - It could be of importance to have a mode in Mediator where the degree of experience with ADS is selected.

10. Conclusion

10.1. Overview

The studies in this document have resulted in a comprehensive set of HMI functional requirements, which was the main objective. In addition, through our research by Design strategy in which a number of HMI design concepts have facilitated the studies, we have been able to test and confirm our original design guidelines, that have now translated in additional functional as well as non-functional requirements.

Non-functional requirements describe the performance characteristics of the Mediator system. Those passive requirements have guided the formulation of our design guidelines and in this chapter, they frame the functional requirements that actually describe what the system must do, how the system must behave as it relates to the system's functionality when specific conditions are met. In addition to the ones that were identified in the introduction of this document, as well as in D1.1 (Christoph et al., 2019) non-functional requirements are:

- The system shall make use of learned, familiar and generally known affordances to minimise learning effort.
- The system shall preserve human autonomy, as that is a pivotal comfort component and crucial in achieving user acceptance.
- The system shall have high usability, user acceptance and trust and provide a good user experience.

In paragraph 10.2 of this chapter the functional requirements as they are derived in the studies in the previous chapters, are compiled into one coherent set of functional requirements, organised per use case. The first assessment is to investigate if and how the set covers the knowledge gaps. Simultaneously, all use cases must be sufficiently and appropriately covered. From there, we are looking for cross-confirmation of findings between the knowledge gaps because all cases must be covered by one HMI, composed out of a limited number of technologies. At the same time, it is not unlikely that functional requirements conflict. If that is the case, and if conflicting functional requirements apply to the same use case, a hierarchy of hierarchy of importance must decide which functional requirement prevails. Lastly, another research iteration is necessary.

10.1.1. Functional requirements

To allow for the previously described processing of functional requirements, functional requirements that are determined by project partners must be comparable by applying a checklist that defines the attributes of a well written requirement. This checklist is provided in the form of a common syntax, which is based on industry standards and must be consistently applied, in the formulation of preliminary (per knowledge gap) and final (holistic HMI) functional requirements. The syntax foresees in three levels, ranging from most to least important:

1. MUST indicates that implementation is mandatory.
2. SHOULD indicates that implementation is desired.
3. WILL indicates that implementation is somewhat desired.

Each functional requirement specifies what the system must do and not how this should be achieved. Possible HMI components and their settings in order to achieve each functional requirement are detailed below each functional requirement.

Figure 79 shows the template which is composed for T1.5. In addition to common syntaxes for functional requirements, the appropriate use-cases, on the left, are required information.

#	IN THE USE CASE(S)	CONDITION	(SUB) SYSTEM WHICH PROVIDES THE FUNCTIONALITY	LIABILITY	QUALIFYING EXPRESSION	VALUE
		if (logical)		must (mandatory)		value
		or		*or*		*or*
		when (event)		should (desired)		value range
		or		*or*		*or*
		while (time period)		will (recommended)		combination
	Notes:					

Figure 79 mediator HMI functional requirements syntax

Literature dictates that good functional requirements must be complete, correct, concise, feasible, prioritized, unambiguous, consistent, verifiable and traceable. For the translation of functional requirements into design requirements they must also be quantifiable. For

10.1.2. Converging applied HMI components

As a first step in the design process, functional requirements, within the context of the MEDIATOR relevant use cases, are processed and translated into overall technical requirements, mapping them to the main components. Ultimately, functional requirements must translate into design requirements. From all experimentation we know which technologies and components, including their parameters have been applied. These form the starting point of process in which we diverge the number of components (Appendix 1) as they will be part of the holistic HMI, with respect to manageability in the design and development process as well future exploitation.

10.2. MEDIATOR HMI functional requirements

All functional requirements, each of which in principle applies to specific use-cases only (Par.1.1.1) are listed in this paragraph, sorted by the use case in which they are most relevant. Note that D1.1 (Christoph et al., 2019), in which the HMI knowledge gaps were determined, is also analysed for functional requirements that would be an addition for the HMI design.

In the next phase these functional requirements, as well the experiment templates which have been filled in by all partners (example in appendix 4), will be transformed into tables that can be cross-referenced in multiple ways (per use-case, per HMI components, etc.) so that overall HMI functional requirements steer the HMI design process.

General HMI functional requirements:

- The HMI module *must* perform all HMI functions of the original vehicle HMI
- The HMI *should* unambiguously make the driver aware of current automation levels, and therefore the driver's appropriate sense of responsibility, as consistently as possible thorugh its primary and secondary (ambient) look and feel.
- The HMI *must* as much as possible fulfil its interaction with the driver, within modes such as preventive and corrective actions, as well as in tall ransfers between modes, through a single, recognizable and predictable ritual, for quick and intuitive learning.

  Differences between the HMI – driver interactions may be in the application of HMI components and their parameters i.e., time intervals, uni-modal versus multi-modal signals, and the manifestation of signals.

- In case the driver indicates a different automation preference than that of DL, the HMI *should* negotiate with the driver. For low necessity levels a seductive negotiation between automation and human is applied, while for higher levels a persuasive negotiation is applied, or even a forced take-over (no negotiation).

  While seductive negotiation may be limited to informing the driver of possible consequences of an automation choice, persuasive negotiation may limit a driver's freedom (e.g., through a speed delimiter) in case of ill adviced automation choices.

Use case 1, forced handover to automation

- In use case 1, WHEN driver hand over to system Controller triggering the Visual cues on steering wheel (LED bar) MUST deliver confirmation feedback via LED bar illumination (Blue or Turquoise)
- In use case 1, during driving in CM or SB, WHEN the driver does not respond to an alert (detected as unresponsive) WHEN detected as fatigued, the system WILL slow and eventually stop.
- In use case 1, WHEN the automation wants to take over control and the automation gives recommendations to the human (who is sceptical about new technology), Mediator SHOULD take into account that the human can ignore recommendations although distraction or fatigue is detected.

Use case 2, driver indicates to take back control

- In case the human resumed control (use case 2) WHILE the transfer is executed, the HMI SHOULD remain giving feedback regarding mode change and duration.

  The feedback could be given on a HUD.

- In use case 2, WHEN the driver resumed manual control, the driver can be supported in tactical decision making IF the HMI WILL provide visual and vocal messages (this is effective for complex information) (retrieved from D1.1)

Use case 3 & 5, comfort and system initiated takeover

- In use case 3 & 5, IF there is disagreement about who's overtaking control driving manually or in CM, the HMI SHOULD inform about the traffic situation in order to proof that there is nothing to gain by overtaking.

Use case 4 & 5, corrective action and human takeover

- In use case 4 & 5, WHEN driving in SB or Tts, the HMI WILL secure and train unexperienced drivers by asking to take-over in non-critical situations.

Use case 4 & 8, corrective action in SB & CM

- In use case 8, If a driver is detected as distracted for at least 2 seconds at CM, the system should prompt by using coloured warning signals.
- In use case 8, If the system, at CM has already prompted (due to driver distraction) and the driver did not react within 5 seconds, the alert light would change to red and be accompanied by both a haptic and an audio alert for another 5 seconds.
- In use case 8, If a driver is detected as distracted at CM, the system should alert by using coloured warning signals.

- In use case 4 & 8, If the system provides an alert for a distracted driver, then the location of the alert should be in the driver's field of view (e.g., tablet or cellular screen).
- In use case 4 & 8, If a driver's visual attention to the driving scene has been detected as inadequate, the system may prompt the driver to perform a task in tandem with driver monitoring.
- In use case 8, If a driver is detected as drowsy/ fatigued at CM, the system should prompt by an audio alert and flashing up an unequivocal instruction on the display.
- In use case 4 & 8, If at CM or at SB the driver is detected as drowsy or fatigued, the system should suggest the driver to take a rest brake and to recommend her to drink coffee and perform light-intermediate physical activity.
- In use case 4 & 8, If a driver at CM or SB does not respond to an alert (detected as unresponsive) when detected as fatigued, the system will slow and eventually stop.

Use case 5 & 9, system initiated human takeover

- In case the human has to take control (use case 5) WHEN the urgency level is high, the takeover request MUST be by means of intrusive communication stimulating multiple senses.

  A multimodal request could be messaging through HUD in combination with audio warning sounds and count-down ambient light-strips.

- In use case 5a, WHILE driver engage in NDRT, Controller triggering the Visual cues on steering wheel (LED bar) MUST deliver which mode is currently activated (Amber)
- In use case 5a, WHEN driver receive emergency take-over request Controller triggering the Visual cues on steering wheel (LED bar) MUST deliver the importance of immediate driver action is required (Pulsating effect of red color)
- In use case 5, WHEN in SB a take-over is due, but the human wants to extend AD, the automation MUST continue outside the available period and should perform an unwanted controlled stop (The type of stop depends on the situation to be out of danger for other traffic).
- In use case 5, WHEN in SB a take-over is due, but the human seems unfit to take-over, the automation is forced to continue outside the available period and should perform an unwanted controlled stop (The type of stop depends on the situation to be out of danger for other traffic).
- In case there is a short time frame for take-over (use case 5&9), IF the HMI trains the driver (in order to gain experience with take-over situations), take-over time WILL be reduced. (retrieved from D1.1)
- In use case 9, WHEN a human, driving in L2, needs to take over, but has too high expectations of automation and therefore becomes distracted with other NDRTs, Mediator SHOULD take into account that the human can still ignore warning signals and/or take over requests.

Use case 7, preventive action

- In use case 7, If a driver at CM handles mobile or other apps than it is recommended to suggest blocking the apps that are considered a distraction.

- In use case 7, If a TOR is upcoming and the driver is engaging with a non-driving task, the system should alert by using ambient peripheral cues with an indication for the desired steering direction.
- In use case 7, If a TOR is upcoming the system should provide an early/pre alert.
- In use case 7, If a TOR is upcoming the alerts should be provided with different frequencies based on the immediacy (Time for TOR) of the situation.
- In use case 7, If at CM, the driver is predicted to become drowsy/fatigued, the system will suggest the driver to engage with a relatively low demanding (secondary) task (audio task such as conversation with Vid) to mitigate fatigue.
- In use case 7, If at SB, the driver is predicted to become drowsy/fatigued, the system will suggest the driver to engage with NDRT (such as game) to mitigate fatigue.
- In use case 7, While driving in CM the HMI *must* communicate the current mode continuously.

  In line with the suggested implementation in chapter 6, this requirement can be attained through providing an ambience in the car which non-invasively communicates the current mode, for example through ambient light. Especially in the beginning of driving with the HMI system it is desirable to additionally present more specific information on the mode, for example through anthropomorphic icons. Such specific information should reflect the automation status rather than driver task.

- In use case 7, While driving in CM the HMI *should* support driver's vigilance through preventive mediation.

  This requirement could potentially be attained by providing a secondary task to the human driver. This secondary task should preferably not be presented visually and not continuously. For example, an auditory secondary task could be presented about every 3-5 minutes for about 30 seconds (note, however, that the most beneficial timing is yet unclear). A conversation-style task could be beneficial, especially when this is coupled to events happening on the road to support situation awareness. Potentially, a conversation-style task that additionally reminds the driver of the importance of the monitoring task could be beneficial. Additionally, it could be helpful to make this task rewarding through for example gamification.

- In use case 7, While driving in CM the HMI *should* make the driver aware of the limitations of the current mode.

  It appears to be most beneficial to communicate limitations by coupling the limitations to the conditions on the road. Such as "the system no longer works because the visual field is poor due to deep fog or because highway lanes are closed due to objects on the road".

- In use case 7, While driving in CM the HMI *should* employ corrective measures and/or enforce breaks or limit the availability of partial automated driving when needed.

  This is recommended as long as preventive mediation is not fully able to ensure safety during partial automated driving.

- In use case 7, If a driver has never used partial automation before, the HMI *should* inform the driver about the limitations of partial automation and about what is required of the driver.

  This requirement can for example be attained by only making partial automated driving available after the driver has received the information. Information can for example be presented when the car is parked, through presenting an instruction video.

Use case 10, smooth transition TtS to SB

- In case the human has to take control after TtS (use case 10) WHILE awakening the driver to prepare for the transfer, non-intrusive (design) interventions should be used.

  A non-intrusive design intervention might be ambient lighting.

- In case the human has to take control after TtS (use case 10) WHILE the SA is regained, the SA must remain, and the human should be guided in order to get prepared for takeover.

  Guidance on what to prepare for, could be communicated through a HUD.

- If a TOR is upcoming and the driver is engaging with a non-driving task (use case 10), the system should alert by using ambient peripheral cues with an indication for the desired steering direction.
- If a TOR is upcoming (use case 10) the system should provide an early/pre alert.
- If a TOR is upcoming (use case 10) the alerts should be provided with different frequencies based on the immediacy (Time for TOR) of the situation.

Applicable to several use cases:

- In case of a transfer of control (use case 1, 2, 3, 5, 6, 9 or 10, Par. 1.1.1), mode confusion could be avoided WHEN the number of possible mode switches is limited by communicating no more than 3 overarching driving modes to the human.
- In case of a transfer of control, from either automation to the driver or from the driver to automation (use cases 1, 2, 3, 5, 6, 9 or 10), WHEN the DL disagrees with the transfer it should communicate this by means of forced feedback.
- In case the driver needs to be warned about upcoming take-over (use case 5,9 and 10), take over time can be reduced when the HMI will provide auditory and vibrotactile feedback (this is not effective though when conveying complex information). (retrieved from D1.1)
- In all use cases, WHEN driving, Mediator SHOULD take into account disagreement of speed (limit) and both human drivers (as Mediator) SHOULD be able to give their preference during AD to point out (inconsistent) driving speed during manual driving.
- In all use cases, WHEN using ADS, Mediator SHOULD give the human confidence in the ADS and when to access which automation level in order to give guidance in the amount of automation levels related to the suiting traffic situations/environments.
  - It could be of importance to have a mode in Mediator where the degree of experience with ADS is selected.

The following functional requirements are applicable while driving in SB or TtS and therefore are also applicable to all use cases which include SB and/or TtS. These functional requirements are detailed below.

- While driving in SB or TtS the HMI *must* communicate the current mode continuously.

  This requirement can be attained through providing an ambience in the car which non-invasively communicates the current mode, for example through ambient light. Especially in the beginning of driving with the HMI system it is desirable to additionally present more specific information on the mode, for example through anthropomorphic icons. Such specific information should reflect the automation status rather than driver task.

- While driving in SB or TtS the HMI *must* communicate the time left in current/time to next mode continuously.

  This requirement can for example be attained through communicating the time in a number, or, through a LED bar depleting over time with decreasing time in the mode.

- While driving in SB or TtS the HMI *should* communicate what the next mode will be

  It is possible that if this next mode is far in the future, e.g., hours, that an HMI element such as the LED bar in experiment 4, will not communicate this mode as it is not immediately relevant. However, in this case the next mode should still be communicated through an HMI element that shows route progress.

- While driving the option to switch on SB or TtS *will* only be offered if it is likely that it will be available for at least 4.5 minutes

  This requirement related to NDRT planning mostly, but it is possible that some drivers also would like to use SB or TtS for shorter periods of time. It is therefore advised to offer the option to the driver to set this minimum time through the HMI. The 4.5 minutes limit is based on questionnaire results from literature. However, it is possible that in certain circumstances, such as when a message arrives to which the driver quickly wants to reply, shorter times are also acceptable.

- When the current mode will change to another mode the HMI *should* communicate the reason for this change in advance.

  This requirement can be attained by for example using icons for an event that will occur in the environment, for example indicating that roadworks are coming up or that the car will leave the city.

- While driving in SB or TtS, the HMI *should* nudge the driver in what to do.

  This requirement can be attained ideally by not directly communicating to the driver what to do but by for example providing the right ambience in which the driver can choose the right task within the boundaries of the current mode.

- While driving in SB or TtS the HMI *should* communicate the foreseen automation status throughout the route.

  This requirement can for example be attained through visualizing the complete route the car is planning on taking on a map and indicating the highest applicable automation status on parts of this route.

- While driving in SB or TtS the HMI *should* communicate maneuvers that the car will perform in the near future.

  This requirement can for example be attained through visualizing through icons whether the car will go left, right, or straight. Or when the car will change lanes, this can also be indicated through an icon for example.

- While driving in SB or TtS the HMI *will* communicate reasons for maneuvers that the car will perform in the near future.

  This requirement can for example be attained through visualizing through icons the reason for actions such as overtaking and changing lanes.

- While driving in SB or TtS the HMI *should* communicate on automation perception.

  This requirement can for example be attained through highlighting traffic aspects that are of importance in the current mode. For example, detected other road users can be highlighted.

- While driving in SB or TtS and if the current mode allows for a setting on presented information to be changed the HMI *should* provide the option to have its settings on presented information changed.

  This requirement can for example be attained through allowing the driver to set a user profile. A user profile for people with a low and a user profile for people with a high information preference can for example be desirable.

- If a driver has never used the HMI before the HMI will guide the driver through all its functionalities and how these functionalities relate to the capabilities of the automation.

  This requirement can for example be attained by highlighting and explaining each element of the HMI before the driver will drive with the HMI for the first time.

Mediator

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Appendix 1. List of possible HMI components and technologies

HMI COMPONENTS

This is an overview of identified HMI components for the Mediator HMI design. This overview is not claimed to be complete in the listed components, nor it is finite in their identified applications. Please share suggested missing components or applications in the lower part of his sheet.
Communication with other traffic i.e. the external HMI is not within the Mediator scope. Components are listed for inspiration, and more importantly because the control of those components (either conventional or new) must be considered in the Mediator HMI design with respect to driver's task and system feedback.

SENSING	ABSTRACT or SPECIFIC	IDENTIFIED	Notes, variables, positions in the vehicle, known affordances	HMI OUTPUT TO			HMI INPUT FROM		
				DRIVER	PASSENGERS	OTHER TRAFFIC	DRIVER	PASSENGERS	OTHER TRAFFIC
AUDIO	Abstract	Music	Ambient: calming, awaking, invigorating or soothing	●	●				
AUDIO	Abstract	Sound signals	Ambient or guiding through repositioning: variations in tone, rhythm and annoyance	●	●				
AUDIO	Abstract	Context sounds	Sounds form outside the car may be amplified over the vehicle audio system	●	●				●
AUDIO	Abstract	Speakers	Sound signals, sirens			●			
AUDIO	Specific	Music tunes	From abstract to specific (known) affordances or by learning	●	●				
AUDIO	Specific	Speakers	Spoken messages	●	●	●			
AUDIO	Specific	Voice control	Spoken messages				●	●	
AUDIO	Specific	Spoken messages	Variables are voices M/F	●	●				
MECH	Abstract	Control disablers	Steering wheel and pedal box	●					
MECH	Abstract	Control positioning	Steering wheel and pedal box	●					
MECH	Abstract	Engine management	Control and limit power and/or torgue, speed limiter	●					
MECH	Specific	Switches - flip	Steps and fixed positions, or hold for duration (e.g. windows)				●		
MECH	Specific	Gear stick	Fixed affordances for manual (H) and Automatic (I)				●		
MECH	Abstract	Joy stick	Age and/or community dependent affordances				●		
MECH	Abstract	Gear levers	On steering wheel. Return to base position. Up/down or push/pull , sometimes different left and right.				●		
MECH	Specific	Pedals	Seamless, return to original position				●		
MECH	Specific	Switches - push	May return to original position, may have multiple positions				●		
MECH	Specific	Switches - slide	Seamless, stay in chosen position				●		
MECH	Specific	Steering wheel	Control turning resistance left and/or right				●		
MECH	Specific	Tensioners	Seat belts	●					
MECH	Specific	Switches - turn	Multiple positions or seamless						
MECH	Specific	Vehicle movements	Longitudinal and transversal vehicle movements indicate vehicle direction			●			
MECH	Specific	Vehicle dynamics	Yaw, pitch and role indicate direction, acceleration and decelleration			●			

HMI COMPONENTS

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SENSING	ABSTRACT or SPECIFIC	IDENTIFIED	Notes, variables, positions in the vehicle, known affordances	HMI OUTPUT TO			HMI INPUT FROM		
				DRIVER	PASSENGERS	OTHER TRAFFIC	DRIVER	PASSENGERS	OTHER TRAFFIC
VIBRATE	Abstract	Vibrators	Seat, backrest, steering wheel	●					
VISUAL	Abstract	Ambient lighting	Below lower daylight, floor area, under instrument panel: with passive or active colours, variable clours and intensity, frequency and eye guidance	●	●				
VISUAL	Specific	Lights, blinkers	Corners of the vehicle and in side view mirrors, orange			●			
VISUAL	Abstract	Lights for driving (dim or passing beam)	Front of the vehicle, left and right. White lights. Directional lighting with steering wheels.			●			
VISUAL	Abstract	Driving lights	Front of the vehicle, left and right. White lights.			●			
VISUAL	Abstract	Driving lights	Rear of the vehicle, red.			●			
VISUAL	Abstract/ specific	Led strips	Any position with passive or active colours, not blue (reserved for emergency services), static and walking lights.			●			
VISUAL	Abstract/ specific	Lighting strips	Same, plus A-pillars and windscreen edges. With passive or active colours, static and walking lights.	●	●				
VISUAL	Abstract/ specific	Lighting strips	Steering wheel. With passive or active colours, static and walking lights.	●					
VISUAL	Specific	Lights for Reverse	Rear of the vehicle, left and / or right: white shining light.			●			
VISUAL	Abstract	Variable window opaque/translucency	Windscreen, sun roof and other windows: levels of transparancy, translucency / opaqueness.	●	●	●			
VISUAL	Specific	Any output on mobile phone, tablet, laptop or watch	In actual view-line of passenger. From device to car already exsists for IOS and Android	●	●				
VISUAL	Specific	Biometric iris identification					●		
VISUAL	Specific	Gesture control					●	●	
VISUAL	Abstract	Head-up display	On the windscreen, sun roof, all windows. Assumptions to be made on future sizes, currently available size is limited.	●	●				
VISUAL	Specific	Projectors	Front of car. Information to other road users, projected on the road in front of the vehicle			●			
VISUAL	Specific	Digital messaging	Trhough console or screen on exterior front of car. Information to other road users, text or icons.			●			
VISUAL	Specific	On screen animations	Centered for driver, or mid-console, in doorpanel or side view camera. Navigation, own vehicle outer view, future trafic situations.	●					
VISUAL	Specific	Head-up display animation	On the windscreen, sun roof, all windows. Assumptions to be made on future sizes, currently the available siez is quite limited	●					
VIBRATE	Specific	Input from mobile phone, tablet, laptop or watch	Technological no problem and already available for some cars (unlocking and climate).				●	●	

HMI COMPONENTS

This is an overview of identified HMI components for the Mediator HMI design. This overview is not claimed to be complete in the listed components, nor it is finite in their identified applications. Please share suggested missing components or applications in the lower part of his sheet.
Communication with other traffic i.e. the external HMI is not within the Mediator scope. Components are listed for inspiration, and more importantly because the control of those components (either conventional or new) must be considered in the Mediator HMI design with respect to driver's task and system feedback.

SENSING	ABSTRACT or SPECIFIC	IDENTIFIED	Notes, variables, positions in the vehicle, known affordances	HMI OUTPUT TO			HMI INPUT FROM		
				DRIVER	PASSENGERS	OTHER TRAFFIC	DRIVER	PASSENGERS	OTHER TRAFFIC
VISUAL	Abstract	On screen camera output	Centered for driver, or mid-console, in doorpanel or side view camera. From the vehicle cameras, or those of connected vehicles.	●	●				
VISUAL	Specific	Head-up display camera output	On the windscreen, sun roof, all windows. Assumptions to be made on future sizes, currently the available siez is quite limited	●					
VISUAL	Specific	Meters	Centered for driver, or mid-console. Not below -30 angle. E.g. tacho or revs,battery charge, compass, distance.	●					
VISUAL	Specific	On screen symbols	Centered for driver, or mid-console. Icons, standardized symbols, new symbols, light bars…	●					
VISUAL	Specific	Head-up display symbols	On the windscreen, sun roof, all windows. Assumptions to be made on future sizes, currently the available siez is quite limited	●					
VISUAL	Specific	On screen text messages	Centered for driver, or mid-console. Not below -30 angle. Variations in fonts, font size, colours and contrast, pulsing or flashing	●	●				
VISUAL	Specific	Head-up display text messages	On the windscreen, sun roof, all windows. Assumptions to be made on future sizes, currently the available siez is quite limited	●					
VISUAL	Abstract	Lights, exterior warning	In side view mirror or similar, prximity warning other vehciles	●					
VISUAL	Specific	Lights, instrument panel	Some functionalities are not allowed to be part of a screen, they must be physical. Use of colours is largely standardised, either within the automotive domain or as general affordances.	●					

SENSING	ABSTRACT or SPECIFIC	SUGGESTED	Notes, variables, positions in the vehicle, known affordances	HMI OUTPUT TO			HMI INPUT FROM		
				DRIVER	PASSENGERS	OTHER TRAFFIC	DRIVER	PASSENGERS	OTHER TRAFFIC

Appendix 2. Exploration of specific HMI elements

Exploration of emoticons to communicate the automation's level of certainty (experiment 3.1)

Research applying emoticon-scales has mostly focused on obtaining an answer *from* participants (e.g., to gain insight into their perceptions, interpretations and opinions) and not to convey a message *to* participants (Alismail & Zhang, 2020). Additionally, such scales are mostly applied to measure constructs like user satisfaction or to obtain insight into basic emotions (Rodrigues, Prada, Gaspar, Garrido & Lopes, 2018; De Angeli, Kelly, & O'Niell, 2020). Limited attention has been given to communicating (un)certainty to participants through emoticons. As discussed in the introduction, a study by Beller, Heesen & Vollrath (2013) demonstrated that it might be valuable to communicate automation (un)certainty to the driver through an emoticon. Yet, in this study only one emoticon was presented to indicate when the automation was uncertain. Yet, there might be different levels of certainty of the automation, ranging from very uncertain to very confident. To the best of our knowledge, no former work has included an emoticon-scale to convey different levels of confidence.

Therefore, five emoticons were designed, with an intended range from 'very uncertain' to 'very confident', see Figure 2.9. The degree of confidence is here used as a proxy for automation reliability.

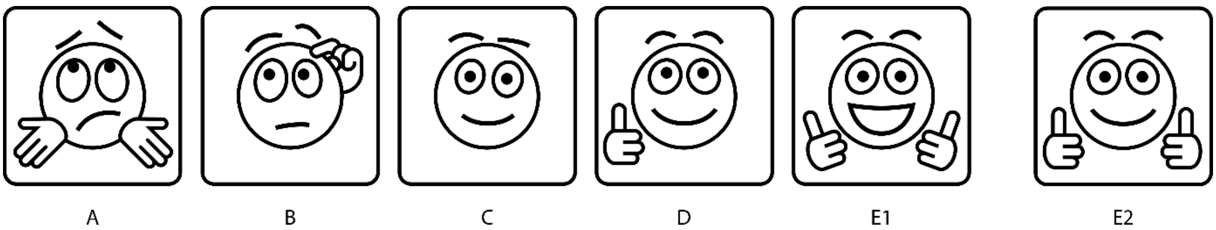


Figure 1: Five emoticons (A-E1) designed to communicate an increasing range of confidence. Emoticon E1 was eventually replaced by E2. Letters were not presented during the test.

A test was performed to check if the intended range of confidence was indeed perceived accordingly. Ten participants volunteered to participate in a Microsoft Teams session. They were told that they would be presented with a number of emoticons intended to communicate the confidence level of an automated vehicle. Two paradigms were used: pair-wise comparison and attribute scaling.

In the pair-wise comparison paradigm participants had to indicate which of two emoticons was considered 'most confident'. Pairs of adjacent levels (e.g., {A-B}, but not {A-C}) were presented in random order with a dedicated Max patch (Cycling '74, 2020), resulting in 8 comparisons in total (i.e., {A-B, B-A, B-C, C-B, C-D, D-C, D-E1, E1-D}). Performance was calculated as the number of comparisons where responses were in agreement with the design, divided by the total number of comparisons. The emoticons were ranked as designed by eight out of ten participants (M = 93.75%, SD = 0.14). Two participants ranked emoticon D as more confident than E1. They considered the wide smile and the slanted thumbs as 'unserious' and 'nonchalant' for an autonomous driving context. A revised emoticon (E2) was created to address these concerns. The results of the pair-wise comparisons suggest that the emoticons communicate transitions between two confidence levels well when they are presented simultaneously (given that emoticon E1 is replaced by E2). However, the pair-wise comparison paradigm does convey how uncertain or how confident each emoticon is perceived, which may be relevant for understanding the circumstances during which participants perform NDRTs.

For this reason, in the attribute scaling paradigm participants were asked to move each emoticon, including the revised emoticon E2 ({A,B,C,D,E2}), to a position on a rating scale ranging from 1 (‘Uncertain’) to 10 (‘Confident’) in Adobe Illustrator. The average rating for each emoticon was in line with the order in which they were previously ranked (A: M = 1.65, SE = 0.30; B: M = 4.26, SE = 0.41; C: M = 6.25, SE = 0.25; D: M = 8.00, SE = 0.22; E: M = 9.45, SE = 0.16).

A one-way ANOVA performed with Jamovi v1.1.9.0 yielded a significant main effect of Emoticon, $F(4,45) = 120$, $p < .001$. Tukey post-hoc tests revealed that all emoticons differed significantly from each other at $p < .01$.

Considering the above results, it was concluded that the emoticons ({A,B,C,D,E2}) were easily distinguishable and were able to communicate (un)certainty of the automation.

Exploration of icons to indicate the desired driver task (experiment 3.2)

Icons or symbols have been part of graphical user interfaces for decades in order to facilitate communication from a system to a user (Marcus, 2003). In general, a lot of the work on icons as a part of user interfaces focusses on communicating access to a function, system status or a change of system behavior (Punchooijt & Hongwarittorrn, 2017). As discussed in the introduction, in previous research examining HMI designs in automated vehicles (Feierle et al., 2020; Feldhütter et al., 2018; Hoeger et al., 2011) icons have been used to communicate the active automation state, however, we did not come across research using icons to communicate the desired driving task. As icons can be recognized quickly and can evoke a readiness to respond (Fitrianie, Datcu, & Rothkrantz, 2007) it might be beneficial to incorporate icons in HMI concepts in the concept group ‘show desired driver task’.

Therefore, five icons to communicate the task that the driver is desired to perform were designed and incorporated in an image of a car’s dashboard, see Figure 2.

Figure 2: Five icons were designed to communicate the desired driver task. The intended meaning of these icons from top to bottom was: It’s allowed to sleep, it’s allowed to use your laptop, it’s allowed to use your phone, you are required to pay attention to the road, you are required to take control of the steering wheel. Only one icon was presented to a participant at a time.

A test was performed to check whether the icons were perceived as intended. Ten participants volunteered to fill in an online questionnaire presented using LimeSurvey Professional Version 3.23.1. Participants were instructed that they would be presented with a center console that contained icons while imagining that they are driving in a self driving vehicle.

Participants were presented with 5 pictures of the interior of the car where one of the icons was highlighted with an arrow. They were asked to describe the icon, to indicate their thoughts on the meaning of the icon and what they would do when the icon would be presented to them in a self-driving vehicle.

The answers to these open questions were rated on whether they were (largely) in line with what they were intended to depict/communicate/elicit. 8 out of 10 participants described the laptop icon (second icon from above in Figure 2) as intended. For the other 4 icons all of the descriptions were as intended. Regarding the meaning of the icons and the action a participant would take, 7 out of 10 participants indicated, as intended, that they had to pay attention to the road when the icon depicting an eye (second last icon from above in Figure 2 was presented and 6 of the participants indicated they would pay attention to the road, and an additional participant already indicated s/he would take over the steering wheel. 8 out of 10 participants interpreted the icon of the hands on the steering wheel as communicating that they would need to take over control of the car and 9 out of 10 participants would take over control of the car. For the other three icons indicating what would be allowed to do in the car (the upper three icons in Figure 2, the meaning and the action the participant would take were less in line with what these icons were intended to communicate/elicit. 3, 1 and 0 out of 10 participants correctly interpreted the meaning of the sleeping icon, the laptop icon and the phone icon respectively. 4 out of 10 participants indicated they would sleep in the car without stopping the car when being presented with the sleeping icon. 3 participants indicated they would work on their laptop when being presented with the laptop icon. 3 participants indicated they would perform a handheld action with their phone when being presented with the telephone icon.

The results demonstrate the descriptions of the icons are in line with what the icons were intended to depict. For the interpretations of meaning by participants and the actions participants indicate they would perform, there is a stark difference between icons indicating what a driver is required to do (pay attention, take over control) and what a driver is allowed to do (sleep, work on laptop, use phone). Participants responded as intended to the icons of required actions, but less so for the icons of allowed actions. Interestingly, from the answers from the participants it became clear that participants did not have an understanding about autonomous cars and/or did not trust the autonomous car. For example, one participant answered: “I don’t have any experience with self driving vehicles and it seems to me that [working on a laptop] at this time would be scary and would also feel dangerous.” Participants are familiar with current cars and actions that need to be performed, that’s also why the phone icon was for example interpreted as communicating that a connection was established between the phone and the car.

Considering the results, the icons were seen as suitable to continue working with, but that some knowledge of autonomous cars and/or more information on context would be necessary for participants to interpret the meaning and intended task of the icons. Adding colors to indicate the suggestive nature or mandatory nature of the icons could potentially make it easier for people to correctly interpret the icons.

Exploration of coupling colors to different automation states/driver tasks (experiment 3.3)

In this exploration it was explored which colors would be suitable to couple to different automation states/driver tasks. Many of the explored HMI concepts as described in the introduction make use of colors. When multiple colors are used to communicate automation status generally colors either range from green to yellow/orange to red (e.g., Large et al., 2017) or blue is used for higher levels of automation with colors like green (e.g., Feldhütter et al., 2018) or different shades of blue (e.g., Hoeger et al., 2011) for lower levels of automation. When only one color is used to indicate activation of the automation, the most frequently used color is blue (e.g., Hecht et al., 2020a; Helldin et al., 2013; Hoeger et al., 2011). It is however not clear, which colors would be best to communicate different automation states/driver tasks.

Research examining the emotional connotations of color (Clarke & Costall, 2008) demonstrates that red orange and yellow provoke active feelings, with red being the most activating and yellow the least. Green and blue are comfortable and soothing, with blue being the most soothing. Purple is also considered as calming and passive, but blue is considered to be calming by more people than purple. From this research together with the colors applied in HMI designs in earlier work, it was hypothesized that for communicating automation reliability from unreliable to very reliable or for communicating driver tasks from what one has to do to what one is allowed to do one of the following ranges of colors could be fitting: 1) red, orange, green, purple, blue; or 2) red, orange, and green (in different shades) for the 3 highest levels of reliability/the tasks that are allowed. The color ranges are depicted in Figure 3. These specific colors were also chosen because of the contrast they had to the interior of the interior of the vehicle.

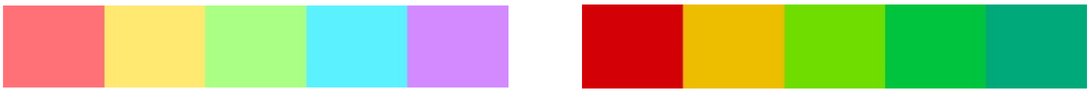


Figure 3: A depiction of the two color-ranges applied to the exploration of the effect of coupling colors to different automation states/driver tasks. From left to right the colors range from less reliable to more reliable automation or from tasks that have to executed to tasks that are allowed. Color range on the left is color range 1. Color range on the right is color range 2

In a study following the same procedure as in experiment 4 of Part 2 focusing on the main evaluation of HMI concepts (see Appendix 3), 3 participants were presented with 4 movies with each showing one HMI concept similar to the one used in experiment 4. In this exploratory experiment, color range 1 was applied to concepts in 2 movies and color range 2 was applied to concepts in the other 2 movies. All 3 participants were confused about the meaning of the colors of color range 1. One participant kept saying when presented with the green color: “It’s green, everything is alright.” The purple and blue colors gave this participant the feeling that something was not completely right anymore, while these colors were meant to indicate higher levels of automation. The other 2 participants explicitly mentioned that the purple and blue colors were confusing and that more straightforward when green indicates that the automation is able to handle the situation. Based on these findings color range 2 (red – orange – (bright) green – green – (darker) green) seemed to be more suitable than color range 1 (red – orange – green – purple – blue).

Exploration of coupling colors to different desired driver tasks (experiment 3.4)

As described above, in the exploration of icons to indicate the desired driver task there was still some confusion in participants about the interpretation of the icons and the actions they should/could perform as described above. Therefore, we tested whether adding colors from color range 2 to these icons with or without a thumbs up for allowed actions and with or without an exclamation mark for required actions would (somewhat) take away this confusion Figure 4.

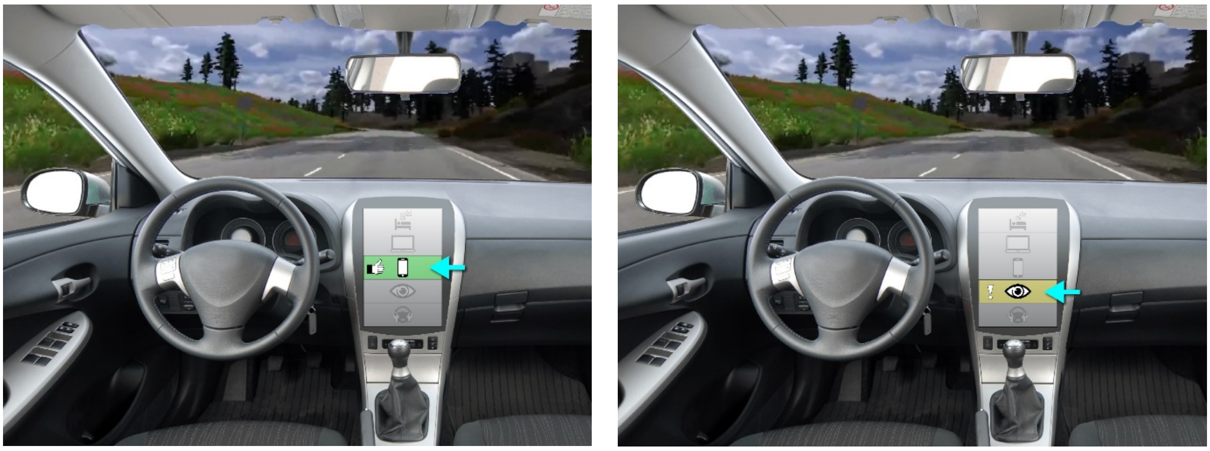


Figure 4: An extension of the five icons communicating the desired driver task. In this extension the presented icon was highlighted in green for actions that were allowed (see example on the left), in orange when the driver is required to pay attention to the road (see example on the right) or in red when the driver is required to take control of the steering wheel. Participants were either presented only with an addition of these colors, or they were presented with an extra addition; namely a thumbs up for allowed actions (see example on the left), or an exclamation mark for required actions (see example on the left).

Six participants volunteered to fill in an online questionnaire using LimeSurvey Professional Version 3.23.1. Participants were instructed that they would be presented with a number of icons in the center console while imagining that they are driving in a self driving vehicle. Participants were told that the car is able to estimate its performance in the present and near future and that it does not evaluate the driver. During driving the system may want to present information, and the way participants receive and understand this information is important.

Participants were presented with 5 pictures of the interior of the car with one icon and it's associated highlighted color with or without a thumbs up/exclamation mark indicated with an arrow. Just as in experiment 3.2, participants were asked to describe the icon, to indicate their thoughts on the meaning of the icon and what they would do when the icon would be presented to them in a self-driving vehicle.

The answers to these open questions were rated on whether they were (largely) in line with what they were intended to depict/communicate/elicit. 5 out of 6 participants described the laptop icon as intended. For the other 4 icons all of the descriptions were as intended. Regarding the meaning of the icons and the action a participant would take, 5 out of 6 participants indicated, as intended, that they had to pay attention to the road when the icon depicting an eye was presented and these participants also indicated that they would do so. 5 out of 6 participants interpreted the icon of the steering wheel as intended; namely that they would need to take over control of the car. All participants would take over control of the car when presented with this icon if they wouldn't be driving the car themselves already. For the other three icons indicating what would be allowed to do in the car, all 6 participants correctly interpreted the meaning of the sleeping icon, with 3 participants indicating they would go to sleep without stopping the car and 2 additional participants showing understanding that they were allowed to go to sleep, but indicating that they did not have enough trust in the automation to do so. 2 out of 6 participants correctly interpreted the meaning of the laptop icon and also indicated that they would use their laptop. 4 out of 6 participants correctly interpreted the meaning of the icon of the phone. 2 participants indicated that they would use their phone. 1 participant showed understanding that s/he was allowed to go use a phone, but indicated that s/he did not trust the automation enough to do so. Answers did not noticeably differ between with or without a thumbs up/exclamation mark.

The results demonstrate, just as in experiment 3.2, that the descriptions of the icons are in line with what the icons were intended to depict. In comparison with the outcomes of experiment 3.2, the meaning of the icons of allowed actions improved. Participants therefore also better understood the allowed action associated with the icons. Yet, it again became clear that not everyone had enough trust in automation to perform an action such as using a phone or sleeping. Again, some participants did not have an understanding about autonomous cars which again led to some icons being interpreted in the context of a 'standard' non-self-driving car.

Considering these results, it seemed suitable to continue working with the icons together with the colors. Additionally, some knowledge of autonomous cars and/or more information on context would be necessary for participants to interpret the meaning and intended task of the icons.

Appendix 3. The effect of communicating anticipatory information

The effect of communicating anticipatory information on available time budgets and a comparison of communicating on automation fitness or on the desired driver task (experiment 4)

This experiment focusses on two HMI aspects in particular. First, we would like to investigate if information on future automation states improves the user experience and helps drivers anticipate to automation changes. It is expected that such information is highly valued by participants and that they will gain a better understanding of the automation than when not providing such information.

Secondly, we are interested in understanding if drivers prefer to receive information on their driver task or on the actual automation status. Both driver task and automation status are depended on the current automation functioning. It is expected, however, that providing information on the driver task will help the driver understand better what is expected of him/her. On the other hand, such information might make it harder to understand the underlying automation functioning. Providing information on the automation status directly would require the driver to interpret this information as to what this entails for their allowed/required driver task. It is expected that automation status information will provide a better understanding of the limits of the automation and possibly reduces overreliance.

Methods

Participants

16 participants (3 female, 13 male, mean age = 41, *SD* = 11, min = 24, max = 57) with a valid driving license and with experience with self driving features (i.e., LKS, ACC) were included in the current study (2 additional participants participated, but these participants were excluded from analysis due to insufficient audio quality in the recorded data). Participants owned a driving license for an average of 21.8 years (*SD* = 10.2, min = 6 max = 39). The median number of km driven per year was 20,000 – 50,000 km (min = less than 5,000 km, max = 50,000 – 100,000 km). All but one participant owned a car with SAE L2 automation options for an average of 2.5 years (*SD* = 1.7, min = 1, max = 5). The participant who did not, did however own such a vehicle in the past.

Apparatus

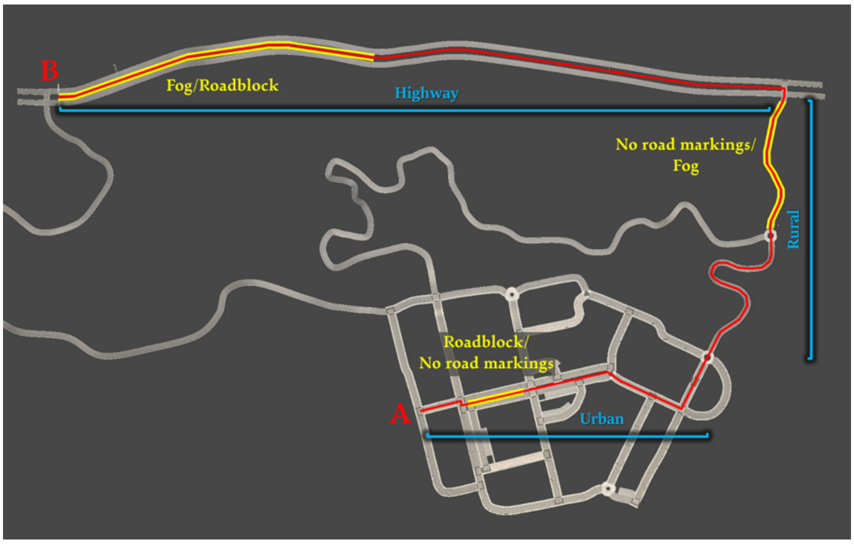
The drives were made in Unity 2019.3.13f1 with the virtual environment being built on the openly available assets Windridge City (Nature Manufacture) and AirSim (Shah, Dey, Lovett, & Kapoor, 2018). The HMI concepts that were superimposed on the drives were developed in Max (Cycling ‘74, 2020).

The experiment took place online using Microsoft Teams version 1.3.00.21759.

Procedure

The 4 different conditions (AF baseline, AF full, DT baseline, DT full; see main text for further details) were presented during 4 different simulated drives of 5 minutes. The viewer’s perspective in the drives was on eye height (vertical position) of someone sitting in the middle of the vehicle in between the driver’s seat and the front passenger’s seat (lateral position), moved slightly towards the back of the car from the driver’s seat (longitudinal position), looking outside through the front windshield (direction) (see **Figure 56** and **Figure 57** in section **6.3.2**). The 4 drives followed the same route between point A to B in the simulated environment of which 2 drives followed the route from point A to B and 2 drives followed the route from point B to A. During each drive 7 changes in reliability level of the automation occurred due to an event along the route. These events included transitions between different road types (urban, rural, highway), roadworks, no road markings, and fog. Except for the transitions between different types of roads, each specific event occurred at 2 different places along the route in such a way that each level of automation was presented an equal number of times during each drive. For the 2 drives from point A to B and the 2 drives from point B to A the events occurred at a different time along the route. The routes and the events occurring along the routes are depicted in Figure 5.

Figure 5: The route between point A and B is depicted in red. 2 drives followed the route from point A to B and 2 drives



followed the route from point B to A. The different road types (urban, rural, highway) along the route are depicted in blue. The 3 places along the route at which events occurred are indicated in yellow. During a drive, at each of the 3 places one of the indicated events (fog, roadblock, no road markings) occurred.

Automation reliability at each point in time during the drive was determined based on the following formula:

*Reliability (R) = (Type of road factor + Road markings present * 0.2 + No roadworks * 0.2 + No fog * 0.2)*

In which the type of road factor was 0 for urban roads, 0.2 for rural roads, and 0.4 for highways. Road markings present, no roadworks and no fog were 1 when true and 0 when false. The possible reliability levels occurring during the drive are presented in Table 1.

Table 1: The possible reliability levels that occurred during the drive.

Area type	Area factor	Road markings present	No obstruction own lane	No fog	Not more than one issue	Reliability R
Freeway	0.4	1	1	1	1	1
	0.4	1	0	1	1	0.8
	0.4	1	1	0	1	0.8
	0.4	0	1	1	1	0.8
	0.4	0	0	0	0	0
Rural	0.2	1	1	1	1	0.8
	0.2	1	0	1	1	0.6
	0.2	1	1	0	1	0.6
	0.2	0	1	1	1	0.6
	0.2	0	0	0	0	0
Urban	0	1	1	1	1	0.6
	0	1	0	1	1	0.4
	0	1	1	0	1	0.4
	0	0	1	1	1	0.4
	0	0	0	0	0	0

The reliability level of the automation at each point in time during the drive and the information on the events was fed into the HMI concept in order to use this information for communication to the participant. Note that there were 4 levels of reliability (1, 0.8, 0.6 and 0.4) varying due to the driving environment. In each of these levels, the automation was still able to execute the driving task and therefore no take over (request) took place.

The 4 different drives were combined with the 4 different HMI conditions, in such a way that each condition was coupled to the drive from A to B and the drive from B to A and that each condition was coupled to the events occurring at a different place. As HMI conditions were tested within participants, it was important to ensure that the experience during the baseline conditions would not be affected by the participants already having received the full HMI version with additional information. Therefore, AF baseline was always shown right before AF full and DT baseline was always shown right before DT full. This resulted in a selection of 8 different combination of the 4 HMI conditions with the 4 different drives. The order of the combinations that were presented to participants was determined using block randomization of 4 different orders of these 8 combinations, as detailed in Table below. In this way it was ensured that an equal number of participants was included for each of the 4 different orders (Goodwin, 2009).

Table 2: The order of the 4 HMI combinations that was presented to the participants.

Order	HMI condition	Drive	Events
1	AF baseline	A to B	Locations 1
	AF full	B to A	Locations 1
	DT baseline	A to B	Locations 2
	DT full	B to A	Locations 2
2	DT baseline	A to B	Locations 2
	DT full	B to A	Locations 2
	AF baseline	A to B	Locations 1
	AF full	B to A	Locations 1
3	AF baseline	B to A	Locations 2
	AF full	A to B	Locations 2
	DT baseline	B to A	Locations 1
	DT full	A to B	Locations 1
4	DT baseline	B to A	Locations 1
	DT full	A to B	Locations 1
	AF baseline	B to A	Locations 2
	AF full	A to B	Locations 2

The evaluation of the HMI concepts was done using two different methods, namely 1) think-aloud and 2) questionnaires.

<u>Think aloud</u>

Prior to the day of the experiment participants received an instruction sheet on the think aloud procedure. The instructions included 1) informing the participant that s/he will watch a video in which s/he will take a ride in a self driving car while receiving information from a system in the self driving car, 2) asking the participants to talk aloud everything that they are seeing and thinking, acting as if they are alone in the room speaking to themselves (following Eccles & Arsal, 2017 and Jaspers, Steen, van den Bos & Geenen, 2004), and 3) informing the participant that the experimenter would almost not interact with them while watching the videos but only would remind them to keep talking when s/he falls silent (following Jaspers et al., 2004).

To prepare participants for thinking aloud during the experiment, the instruction sheet also included an example of how one would think aloud when searching for what one would like on his/her sandwich in the kitchen. A different setting was used to avoid priming them on content of a similar context as provided in the experiment. A similar approach has been used by Key, Morris and Mansfield (2016). An opportunity was provided to read this instruction sheet again and to ask questions on the day of the experiment (following Key et al., 2016).

To provide some context to the video, participants were provided with the following instructions before the first video started:

“You will view a video of about 5 minutes. In this video you will take a ride in a self driving car. During the ride you will receive information from a system in the self driving car. I would like to ask

you to think out load while you watch this movie. Mention everything you see; let your thoughts run freely and mention them out loud."

Before starting the condition's video, the experimenter turned off his/her video image. While a participant was watching the video and thinking aloud, the experimenter prompted the participant to try to keep talking after the participant fell silent for a fixed interval of 15 s (following Jaspers et al., 2004). When the video ended the experimenter asked the participant whether s/he wanted to mention anything else. In order to minimize practice effects, participants were not provided with feedback on their thinking aloud and no further instruction was given (following Rose et al., 2019). The participant's thinking aloud and the participant's screen were recorded using the recording function in Microsoft Teams.

<u>Questionnaires</u>

After each video participants had to answer items from the following 3 questionnaires: 1) shortened NASA-TLX (Hart & Staveland, 1988); 2) the System Usability Scale (Brooke, 1986); 3) automation-induced complacency scale (Merrit et al., 2019). The NASA-TLX was used to gain insight into task load induced by processing information presented in the video. The System Usability Scale was used to gain insight into how participants rate the usability of the HMI. The automation-induced complacency scale was used to gain insight into potential overreliance induced by the HMI.

After being presented with all 4 HMI designs the participants answered items from the following 5 questionnaires: 1) sensation seeking questionnaire (Hoyle et al., 2002); 2) trust in technology scale (Merrit, Heimbaugh, LaChapell, & Lee, 2013); 3) trust in automation scale (Payre, Cestac, & Delhomme, 2016); 4) shortened ITC-SOPI spatial presence scale (Lessiter, Freeman, Keogh, & Davidoff, 2001); 5) and the driving enjoyment questionnaire (Ernst & Reinelt, 2017). All items were translated to Dutch in order to ensure the items were understood by participants. In addition, questions were asked about what the participant thought each HMI system was communicating, whether the participant noticed anything else about the system, and to what degree the HMI system helped the participant to understand where the attention needed to be focused, what s/he was allowed to do at what moment and when an event would happen. Participants were also asked to indicate their preferred HMI system out of the presented systems and to order the systems from most preferred to least preferred.

The NASA-TLX, the ITC-SOPI spatial presence scale and the automation-induced complacency scale were shortened for the purpose of the current experiment. In these shortened versions a few items were discarded that were not applicable to the current experiment. In this way, only applicable items were answered by the participants. This approach is applied more often in research (e.g. Hart, 2006; Tjon, Tinga, Alimardani, & Louwerse, 2019). For the NASA-TLX 3 items on mental demand, temporal demand and frustration level were selected. For the ITC-SOPI 5 items were selected, omitting the items of the spatial presence scale focusing on physical interaction. For the automation-induced complacency scale one item was omitted. In this way, items were excluded which do not apply to a passive task such as watching a video.

Additionally, questions on demographics (i.e., age, sex) and driving experience (i.e., years of having a driver's license, kilometers driven each year and whether someone has a car with self-driving functionalities such as LKS, ACC) were answered by participants. Questionnaires were presented using LimeSurvey Professional Version 3.23.1.

Data processing and analyses

The think-aloud recordings were transcribed verbatim and grouped into a series of statements. Grouping was performed based on temporal adjacency (e.g., a silence of one or more seconds is typically an indicator of a new statement) and contents (i.e., a change of focus initiates a new statement). After transcribing the recordings completely, the recordings were viewed again by two coders and each transcribed statement was categorized using a priori categorization based on a theoretical framework proposed by Rose et al. (2019) who examined situational awareness in think-aloud data collected in a train simulator. Rose and colleagues (2019) based their coding on Endsley's (1988) three levels of situational awareness: 1) perception, 2) comprehension, and 3) projection of future states. For each statement the coders assessed whether its contents expressed situation awareness in relation to the vehicle's HMI and/or the driver's task. If this was the case, the statement was flagged as 'relevant'. The coders categorized relevant statements on the aforementioned three levels of situation awareness, after which it was determined whether the statement was correct or incorrect. In addition, references to HMI components were coded, as well as whether a statement focused on the driver's own actions, on the automation status, and/or on the environment. The underlying coding scheme for this effort is presented in Table 3. Table 4 shows an excerpt of a coded transcription, following the coding scheme presented in Table 3.

Table3: Coding scheme for think-aloud statements. Note: participants 1 and 9 were excluded from analysis due to insufficient audio quality in the recordings.

Coding variable	Coding options	Explanation / Example
Ppn	1-18	Participant number
Order	1,2,3,4	The order in which the conditions appeared.
Condition	AF_baseline AF_full DT_baseline DT_full	Baseline version of concept 'automation fitness' Full version of concept 'automation fitness' Baseline version of concept 'driver task' Full version of concept 'driver task'
Minute	Minutes in video	n.a.
Seconds	Seconds in video	n.a.
Statement	Given by transcription	Statements are separated by temporal adjacency and/or changes in focus.
Relevant	0) not relevant 1) relevant	Coded as '1' when a statement is related to situation awareness focusing on the HMI and/or driver's task. Coded as '0' otherwise. Note: statements focusing on missing HMI elements are also coded as '0'.
SA level	Situation awareness level 1) perception 2) comprehension	Only coded for 'relevant' statements. A statement referring to a signal (e.g. "I see an orange light.") or to a color communicated by the HMI. A statement indicating an understanding of the current implications of the communicated information (e.g. "I think

	3) projection	I have to pay more attention to the road as the emoticon seems to be unsure.”). A statement referring to something or an action coming up in the future (e.g. “A roadblock is coming up soon.”).[2]
Correct vs incorrect	0) Incorrect 1) Correct	Correct or incorrect in relation to the chosen SA level. Coded as ‘0’ when a participant expresses uncertainty (e.g., “I don’t know what the telephone icon means”). Coded as ‘1’ when a participant expresses uncertainty, but when the statement essentially includes a correct speculation (e.g., “I think the telephone icon means I can use my phone, but I am not certain.”). Coded as ‘0’ when a participant includes multiple speculations of which at least one is incorrect (e.g., “The telephone icon means I can use my phone, or it signals that my telephone is connected, but I’m not sure.”).
Reason incorrect	A description of the reason why the statement is incorrect.	Only for incorrect statements.
HMI component	0) Not mentioned 1) Mentioned	Coded as ‘1’ if a relevant statement contains an explicit reference to the corresponding component, or by deduction (e.g., “I see a green button” can only refer to DT icon if there are no other green HMI components).
	Emoticon	Emoticon in the ‘automation fitness’ concept.
	Transition icon	Shows the reason for a transition (e.g., construction work).
	LED bar	Horizontal bar below the windshield in the ‘automation fitness’ concept.
	DT icon	Icons showing the driver task, including references to the level lit behind the icons.
	Arrow	Shows the direction of change between DT icons or between emoticons.
	Ambient light effects	Colored glow in the cabin.
	Color	Any reference to a color and/or to the word ‘color’.

[2] Note that while level 1 is applicable for simple perception of a communicated signal, level 2 and level 3 an interpretation about (changes in) the driver’s action or the status of the automation or the meaning of a specific signal communicated by the HMI needs to be made. When this statement containing such an interpretation is focused on the future, it is coded as level 3 and otherwise it is coded as level 2.

HMI evaluation	0) Not present 1) Present	Coded as '1' if the participant gives a statement related to preferences or an evaluation of the HMI. Otherwise coded as '0'. This field is also coded for 'irrelevant' statements.
Own action	0) Not present 1) Present	Coded as '1' when the statement refers to an own action (e.g. "I can use my phone now"), given that the SA level was either 'comprehension' or 'projection'. Otherwise coded as '0'.
Status automation	0) Not present 1) Present	Coded as '1' when the statement refers to the status of the automation (e.g. "He's telling me that he's not entirely sure"), given that the SA level was either 'comprehension' or 'projection'. Keywords: (un)certainty and readiness of the vehicle, changes in state and/or level. Otherwise coded as '0'.
Environment	0) Not present 1) Present	Coded as '1' when a statement refers to an event or a projected event in the environment (e.g. "The road markings are about to disappear."), given that the SA level was either 'comprehension' or 'projection'. Otherwise coded as '0'.
Coder	Initials of the coder.	

Table 4: Coded excerpts of two participants. 'per' = perception, 'com' = comprehension, 'pro' = projection. Note: the columns 'Minute', 'Seconds', and 'Coder' have been omitted.

Ppn	Order	Condition	Statement	Relevant	SA level	Correct	Reason incorrect	HMI component	HMI evaluation	Own_action	Status_automation	Environment
10	2	DT_ full	There's an oncoming car, but he will be able to pass it.	0	-	-	-	-	-	-	-	-
10	2	DT_ full	We are going slower and now I have to pay more attention, because we're approaching the city boundary.	1	pro	1	-	transition icon	0	1	0	1
10	2	DT_ full	Apprently… and right over there is the entry of the city and there I eh… probably need to take over myself and guard the system.	1	pro	0	One does not need to take over with the telephone icon.	transition icon, DT icon	0	1	1	1
10	2	DT_ full	And there I am indeed arriving in the city and I have ehm… we are taking a roundabout.	1	com	1	-	transition icon	0	0	0	1

15	4	AF_full	Ah, I am getting road markings over there in the left corner.	1	com	1	-	transition icon	0	0	0	1
15	4	AF_full	Hey, why is the car going to the right?	0	-	-	-	-	-	-	-	-
15	4	AF_full	I think this thing here on my screen ehm… in my window… it is very unclear.	1	com	0	Does not understand LED bar.	LED bar	0	0	0	0
15	4	AF_full	Why this arrow…eh… it is not clear to me why we have an arrow to the pleasant head.	1	com	0	Does not understand relation between emoticons.	emoticon	0	0	0	0
15	4	AF_full	Eh… the color is in my screen and yuk… ah, now I am green, oh okay, he's taking over the same color with my eh… this would not be my preference.	1	per	1	-	color, LED bar, ambient light effects	1	-	-	-

The reliability of the coding scheme was assessed in three steps, two of which took place prior to coding all participants, whereas the final step took place by the end of the coding process. In the first step, two coders that are experts in human factors in vehicle automation coded an initial set of the data (i.e., a verbatim transcription of one participant). The inter-rater reliability was calculated with R-package 'irr' for this set of coded data using Cohen's Kappa (Cohen, 1960) and disagreements were discussed and resolved and the coding scheme was made more precise in order to improve the inter-rater reliability. In the second step, the inter-rater reliability was tested again on a new selected set of the data (i.e., a transcription of another participant) and final disagreements were discussed. After this step, the remaining 14 participants were divided for coding between the two coders. In the third step of assessing the reliability of coding, the inter-rater reliability was determined for the last participant coded by one of the coders, coding which was repeated by the other coder using the same transcription after finishing the batch of participants. In each step, inter-rater reliability was first calculated for the selection of relevant quotes. Subsequently, inter-rater reliability on the SA-level at which the statement was to be judged was calculated only for those statements on which agreement on relevance was present. Likewise, inter-rater reliability on correctness of the statement was calculated only for statements on which both relevance and SA-level were in agreement. A further subset was created for variables 'own action', 'status automation' and 'environment', seeing that these were only coded at SA-levels 'comprehension' and 'projection', and not on 'perception'. Finally, the inter-rater reliability of all HMI-components was calculated for statements on which both coders at least agreed on their relevance (i.e., regardless of SA-level and correctness). As a moderate inter-rater reliability of 0.59-0.61 was obtained in the study of Rose and colleagues (2019), the minimum required inter-rater reliability was set at 0.59. This might seem relatively low compared to other types of coded data, but note that inter-rater reliability for this coding procedure is not only about *how* to code the statements but also *what* should be coded (Rose et al., 2019), which makes this coding procedure inherently different from average coding procedures.

The coded think aloud data was analyzed using zero-inflated regression models. Count data, such as the coded data in the current study, exhibit relatively many zero observations and often have a non-normal distribution (Green, Costa & Dellinger, 2011; Zeileis, Kleiber, & Jackman, 2008). For this purpose, GLM with zero-inflation implemented was applied using glmmADMB in *R* (R Core

Team, 2017) to analyze the coded think aloud data. This specific implementation was chosen as it is suitable for mixed models (which is not the case for 'standard' zero-inflated models in *R* such as zeroinfl). These mixed zero-inflated regression models were applied to test the effect of Concept (AF versus DT), the effect of Version (baseline versus full) and the interaction between the two. Participant was added as a random factor to all models. The models were applied with a poisson distribution for the data on correct statements and with a negative binomial distribution for the data on incorrect statements. The resulting models were evaluated with Wald Chi-Squared (*W*) tests and *p*-values to assess the statistical significance of the effects.

Regarding questionnaire data, items on validated questionnaires (i.e., NASA-TLX, System Usability Scale, automation-induced complacency scale, trust in automation, trust in technology, sensation seeking, driver enjoyment, ITC-SOPI) were scored as recommended in the literature. Questions on mode confusion that were developed for the purpose of the current experiment were rated on a scale from 1 – 5, where 5 indicated strong agreement with the statement. For analyses on items with a rating scale, data was analyzed using linear mixed-effects models using LME4 in *R* (R Core Team, 2017) testing the effect of Concept (AF versus DT), Version (baseline versus full) and the interaction between the two with subject as random factor. Post-hoc testing was performed using emmeans in *R* with the Bonferroni correction applied. For analyses on the ranking of the HMI systems presented in the 4 conditions, a Cumulative Link Mixed Model was fitted using the function clmm from the *R* package ordinal, again Version and Concept were added as factors to the model and subject was added as a random factor. It was also explored whether participant characteristics had an influence on the rankings of the HMI designs. To this aim, between subject comparisons were made for participant groups based on their Rank 1 (most preferred HMI condition) and Rank 4 (least preferred HMI condition). Additionally, task load, usability, compliance and mode confusion were grouped per rank of the corresponding HMI design. Such comparisons could indicate which of these measures influences the ranking of HMI designs. For each of the scores a linear mixed model was fitted using LME4 in *R*. The resulting models were evaluated with F tests and *p*-values and $\eta_p{}^2$ to assess the statistical significance and the size of the effects respectively. Post-hoc testing was performed using emmeans in *R* with the Bonferroni correction applied. Answers to open-ended questions were examined in an exploratory fashion.

Results

Think Aloud

The results of the three steps of determining the inter-rater reliability are presented in Table 5 below. Following the interpretation of Cohen's Kappa of Landis & Koch (1977) the inter-rater reliability that was reached in step 2 (i.e., prior to coding the remaining 14 participants) ranged from fair for one variable (HMI LED bar) and moderate for another variable (Correct vs Incorrect) to substantial or higher for the remaining 11 variables. The inter-rater reliability reached in step 3 (i.e., at the end of the coding process) was moderate (for coding of whether the statement was correct versus incorrect) to substantial (for the remaining 12 aspects of coding), with all aspects that were coded having an inter-rater reliability above the set minimum reliability (i.e., Cohen's Kappa ≥ .59, following Rose et al., 2019). In both steps, all variables showed a percentage agreement of 80% or higher. These findings indicated that the inter-rater reliability was consistent throughout the coding process.

Table 5: Details on inter-rater reliability (IRR) in each of the three steps for each coded aspect. N *indicates the number of statements, Cohen's Kappa is the measure used to determine whether the IRR was sufficient, and % of agreement reflects the percentage of statements on which the two raters agreed*

	IRR step 1		IRR step 2		IRR step 3

Measure	*N*	Cohen's Kappa	% Agreement		*N*	Cohen's Kappa	% Agreement		*N*	Cohen's Kappa	% Agreement
Relevant quotes	109	0.68	86		132	0.81	91		125	0.66	82
SA level	68	0.54	75		58	0.75	86		50	0.67	86
Correct vs Incorrect	51	0.71	92		50	0.51	86		43	0.60	84
Own action	33	0.88	94		41	0.90	95		36	0.92	97
Status automation	33	0.08	39		41	0.95	98		36	0.68	83
Environment	33	0.57	79		41	0.90	95		36	0.82	92
HMI emoticon	59	0.91	97		57	0.83	93		49	0.89	96
HMI transition icon	59	0.66	85		57	0.85	93		49	0.91	96
HMI LED bar	59	0.69	92		57	0.31	93		49	1.00	100
HMI DT icon	59	0.67	85		57	0.78	89		49	0.82	92
HMI arrow	59	1.00	100		57	1.00	100		49	0.79	98
HMI ambient light effect	59	1.00	100		57	0.64	95		49	0.73	96
HMI color	59	0.93	97		57	0.88	95		49	1.00	100

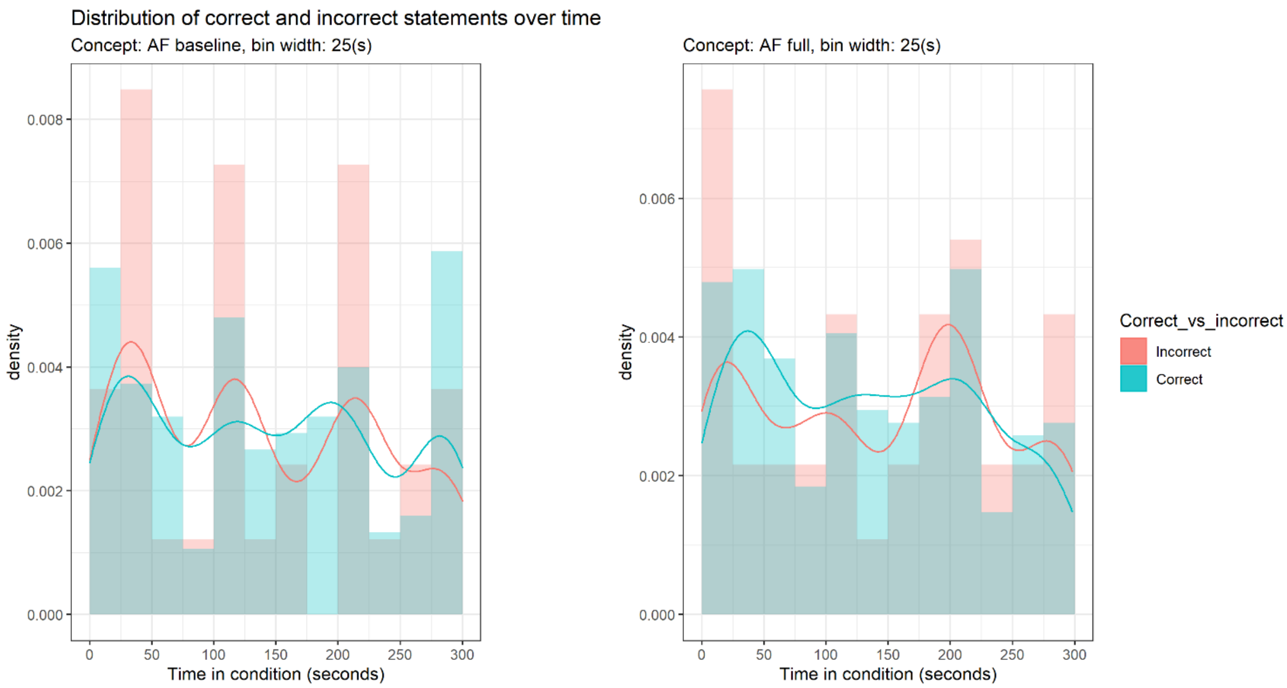
Coding of the think aloud data resulted in 2146 total statements, of which 951 statements were coded as relevant SA statements with 734 correct and 217 incorrect relevant SA statements. Details on overall statements and statements per condition, including total number of statements and mean (and SE) number of statements per participant are presented in Table 6.

Table 6: Details (total number, mean, SE) on overall statements and statements per condition

	Overall statements	***AF baseline***	***AF full***	***DT baseline***	***DT full***

	Total number	Mean (*SE*) per participant	Total number	Mean (*SE*) per participant	Total number	Mean (*SE*) per participant	Total number	Mean (*SE*) per participant	Total number	Mean (*SE*) per participant
Total statements	2146	134.13 (7.51)	592	37.00 (2.30)	496	31 (2.12)	563	35.19 (2.29)	495	30.94 (2.12)
Relevant statements	951	59.44 (4.23)	183	11.44 (1.27)	254	15.88 (1.28)	245	15.31 (1.77)	269	16.81 (1.57)
Correct relevant statements	734	45.88 (4.14)	150	9.38 (0.99)	217	13.56 (1.11)	162	10.13 (1.44)	205	12.81 (1.83)
Incorrect relevant statements	217	13.56 (1.59)	33	2.06 (0.43)	37	2.31 (0.51)	83	5.19 (0.91)	64	4.00 (0.68)

Correct and incorrect SA statements in each of the conditions were distributed relatively evenly over time, with both types of statements occurring over the whole duration of each condition. This might be caused by the fact that changes in the HMI keep occurring and that new information is kept being presented. A visualization of the distributions of statements over time for each condition can be found in Figure 6.



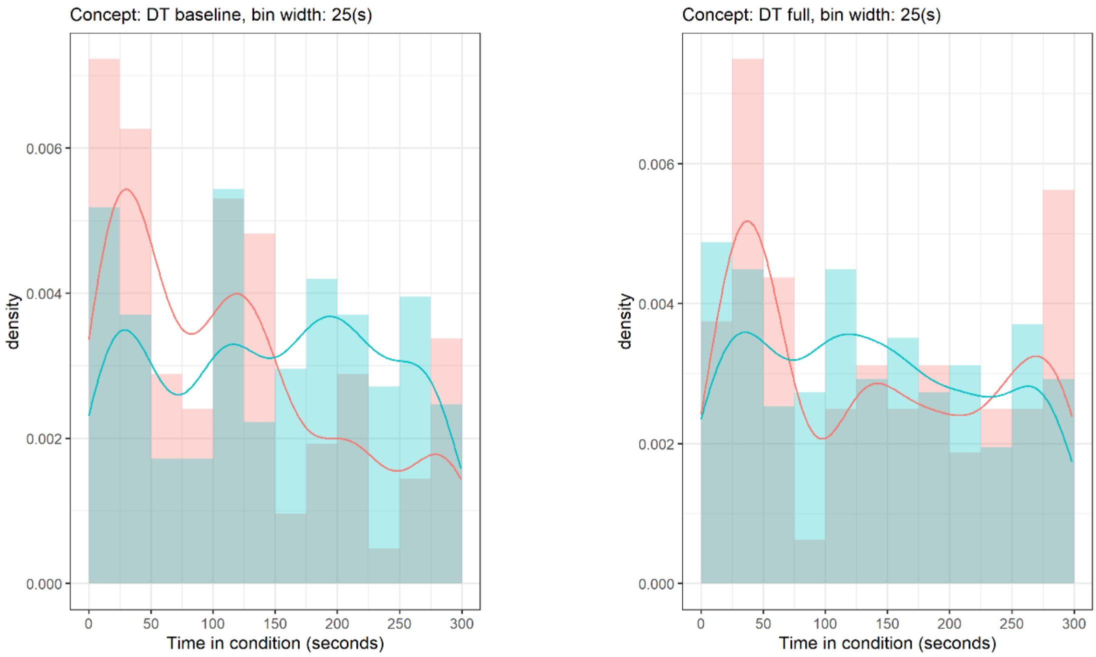


Figure 6: A visualization of the density over time (in bins of 25s) of occurrence of correct (in turquoise) and incorrect (in red) SA statements for each condition. The higher the bar, the higher the density of statements. Note that the height of the bars can be compared directly within a condition, but not directly between conditions

Although statements were distributed quite evenly over time within each condition, an interaction was found between Concept and the order of presentation of concepts (i.e., AF – DT or DT – AF) for correct statements, $W = 17.62$, $p < .001$, demonstrating that less correct statements occurred during DT when it was presented to participants as the second concept compared to as the first concept, see also Figure 7 below.

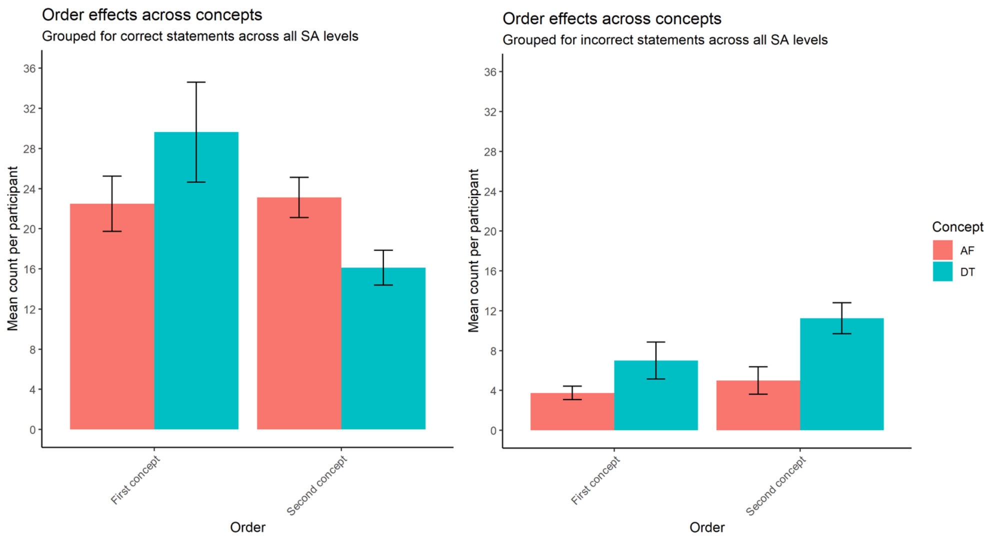


Figure 7: Mean number of correct (on the left) and incorrect statements (on the right) per Concept (AF versus DT) when a concept was presented as the first concept or as the second concept. Error bars represent ±1 standard error of the mean

Regarding the effect of the order of presented concepts, when exploring statements of participants it was apparent that participants made comparisons between the two concepts while being presented with the second concept. For example, during DT as second concept one participant stated: “Now I understand that the two thumbs of the other information system are comparable… The above situation indicates that you can sleep, so one thumb is the one below; the one with the computer. Thus, that one will go together with a somewhat higher level of paying attention.”

As a first step in the statistical analyses the effect of Concept (AF versus DT), the effect of Version (baseline versus full), and the interaction between Concept and Version on the correct and incorrect situational awareness (SA) statements on all SA statements and on statements at SA levels perception, comprehension and projection were tested. The results of these analyses are presented in

Table 7 below.

Table 7: Mixed effects zero-inflated regression models for correct and incorrect situational awareness (SA) statements on all SA statements and on statements at SA levels perception, comprehension and projection

	Concept (AF vs DT)		***Version (baseline vs full)***		***Concept * Version***	
CORRECT SA	***W*(1, *N* = 16)**	***p***	***W*(1, *N* = 16)**	***p***	***W*(1, *N* = 16)**	***p***
Total	0.00	.971	16.72	<.001	0.75	.386
Perception	2.59	.108	0.68	.410	5.25	.022
Comprehension	1.09	.296	8.01	.005	3.27	.070
Projection	15.80	<.001	59.91	<.001	9.31	.002
INCORRECT SA	***W*(1, *N* = 16)**	***p***	***W*(1, *N* = 16)**	***p***	***W*(1, *N* = 16)**	***p***
Total	16.60	<.001	0.52	.470	1.11	.293
Perception	*Models failed to converge due to the low occurrence of incorrect statements on SA level perception (total number of statements was 2)*					
Comprehension	20.05	<.001	2.74	.098	0.28	.597
Projection	0.00	.998	7.21	.007	0.30	.581

Regarding correct SA statements, the average number of statements on each SA level per condition are presented on the left in Figure 8 below. The results presented in Figure 7 above demonstrate that correct statements were affected by Concept, Version and an interaction between Concept and Version. More correct statements on a projection level occurred in the AF conditions compared to the DT conditions. When compared to the baseline conditions, the full conditions led to a smaller number of correct statements on a comprehension level, but to a larger number of correct statements on a projection level and in total on all SA levels combined. The interactions between Concept and Version indicated a larger increase in number of correct perception statements from DT baseline to DT full than from AF baseline to AF full. Yet, the decrease in number of correct comprehension statements and the increase in number of correct projection statements from the baseline to the full version was larger for AF than for DT.

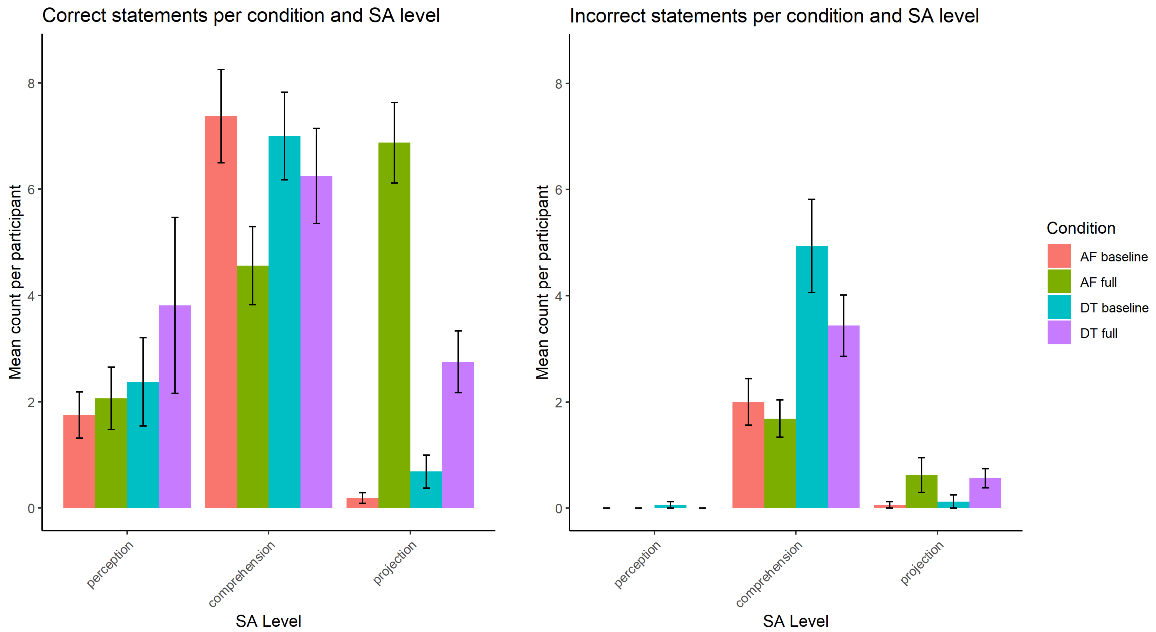


Figure.80 Average number of statements on each SA level per condition for correct statements (left) and incorrect statements (right). Error bars represent ±1 standard error of the mean.

Regarding incorrect SA statements, the average number of statements on each SA level per condition are presented on the right in Figure 8. As can be seen in the figure, the number of statements were averaging around 0 on a perception level, and therefore models failed to converge for this level. The results presented in Table 7 demonstrate that incorrect statements were affected by both Concept and Version, but that interaction effects between Concept and Version were not significant. More incorrect statements on a comprehension level and in total were uttered by participants in the DT conditions compared to the AF conditions. More incorrect projection statements occurred during the full conditions compared to the baseline conditions.

In a next step of statistical analyses the referents in statements were explored. Specifically, it was explored whether a statement was focused on the driver's own actions, the automation status and/or the environment. To this aim, the occurrence of these referents was grouped for correct comprehension and projection per condition, see **Fout! Verwijzingsbron niet gevonden.** on the left. This was repeated for incorrect statements, see Figure X on the right. Regarding correct statements, the referent 'own action' occurred more frequently in statements in the DT than in the AF conditions, while the referent 'status automation' occurred more frequently in statements in the AF conditions than in the DT conditions, both $W \geq 20.26$, and $p < .001$. This finding reflects that the AF concepts communicated mainly on the status of the automation and DT mainly on the driver task. The referent 'environment' occurred more frequently in statements in the AF than in the DT conditions and in the full compared to the baseline conditions, both $W \geq 5.08$, and $p \leq .024$. Note here that HMI information related to the environment (i.e., transition icons indicating [upcoming] changes in the environment that would cause a change in reliability of the automation/desired driver task) was presented for a longer period of time in the full compared to the baseline and in the AF compared to the DT conditions, which might be driving these effects.

Regarding incorrect statements, all three referents occurred more frequently in statements in the DT than in the AF conditions, all $W \geq 9.50$, and $p \leq .002$, indicating that overall incorrect statements that included one or more of the three referents were occurring more often during DT.

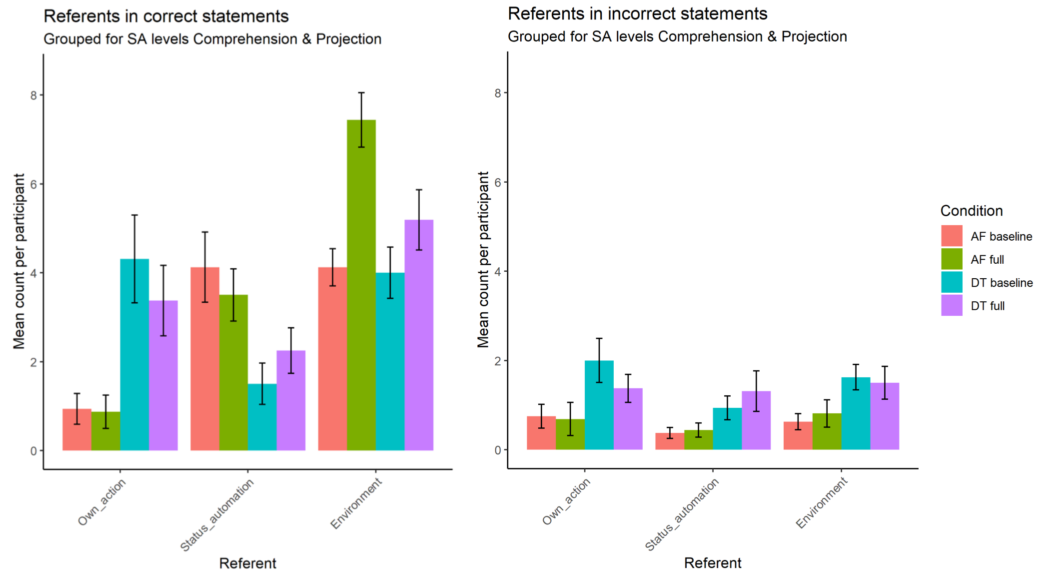


Figure 9: Average number of statements for each referent per condition grouped for correct comprehension and projection statements (on the left) and for incorrect comprehension and projection statements (on the right). Error bars represent ±1 standard error of the mean

It was also explored (through a visualization of the data instead of statistical analyses) which HMI components occurred frequently in correct statements grouped across conditions for each SA level, see Figure 10. This exploration demonstrated that statements on a perception level included the color of the HMI relatively frequently. On a comprehension level, statements relatively included a lot of references to a HMI transition icon, and included frequently a reference to a DT icon and an emoticon (i.e., referring to the driver task and the status of the automation respectively), suggesting that these HMI elements supported comprehension. On a projection level, statements referred relatively often to a transition icon, and somewhat often to the LED strip, suggesting that these HMI elements supported projection.

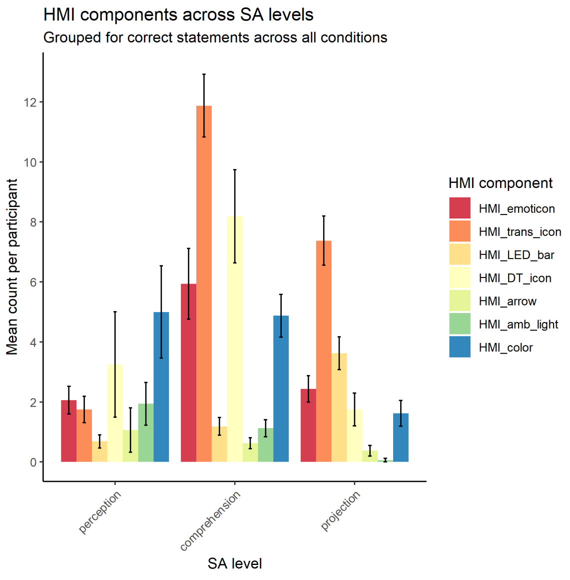


Figure 10: Average number of statements for each SA level per HMI component grouped for correct statements across all conditions. Error bars represent ±1 standard error of the mean

In a next step it was explored which HMI components and referents occurred frequently together in the statements. To this aim, the average occurrence of these combinations in statements were computed for correct and incorrect statements, these results are visualized in Figure 11 below. As can be seen in Figure 11, for correct and incorrect statements a transition icon is often mentioned together with the referent ‘environment’ and a driver task (DT) icon often with the referent ‘own action’. This reflects that a transition icon is communicating information on changes in the environment and that a DT icon communicates information on the desired driver task. The emoticon is often mentioned together with the referent ‘status automation’ for correct statements but not for incorrect statements, reflecting that the emoticon communicates on automation status but that this ‘link’ between the two is only clear for the correct statements. The HMI LED strip occurs relatively infrequently in statements overall, yet it occurs most frequently together with the referent ‘environment’, probably reflecting that this element communicated time to a change in automation level because of a change that will occur in the environment. Yet, referent ‘status automation’ and LED bar occur less frequently together, suggesting that participant might associate the LED bar more with the environment than with the automation. Ambient light is another HMI element that is occurring relatively infrequently in statements, but it occurred most often together with the referent ‘own action’, suggesting that the ambient light is coupled mostly to actions of the driver. Note, however, that the ambient light effect was only presented in DT full and that this concept was focused on communicating on the driver actions, which might explain why ambient light was often coupled to an own action.

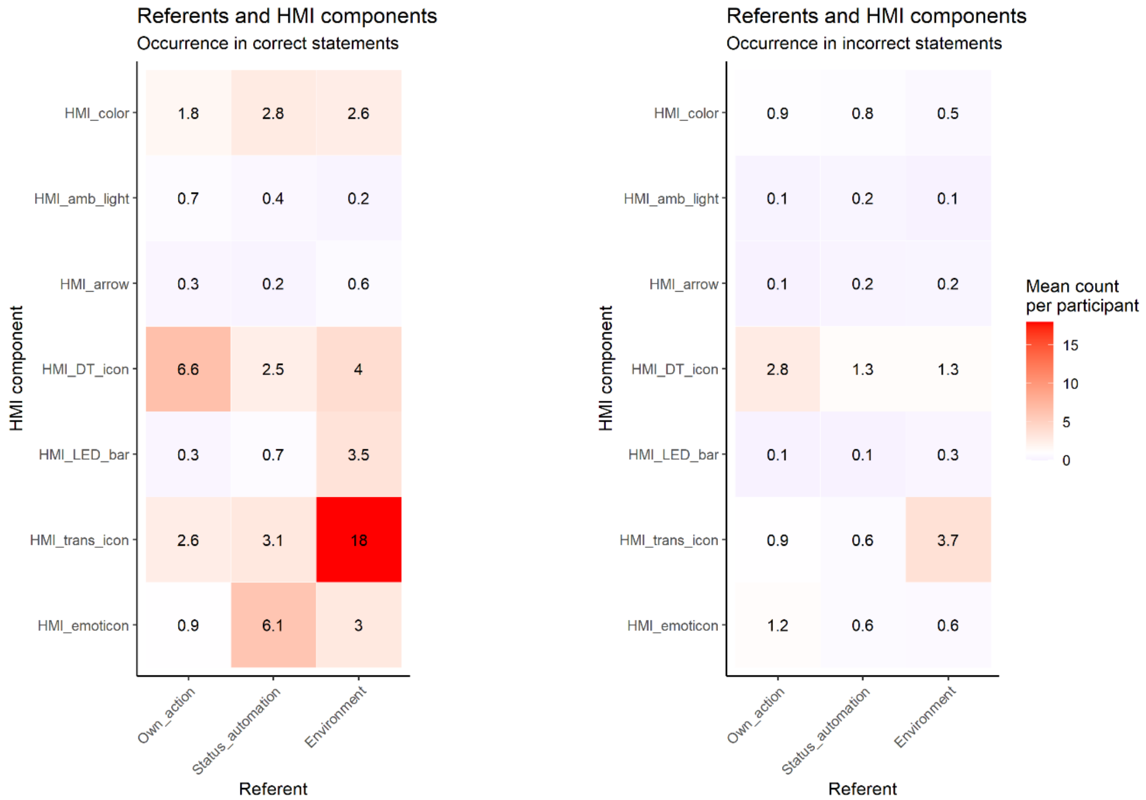


Figure 11: Average occurrence of combinations of HMI components and referents in statements for correct (on the left) and incorrect (on the right) comprehension and projection statements. Blue colors indicate a low occurrence while red colors indicate a higher occurrence

As a final step, incorrect statements were explored at each SA-level separately in order to gain more insight into what HMI information is not perceived or understood correctly. A total of 2 incorrect statements uttered by 2 participants were found at SA-level perception. Both statements were found in the condition DT baseline, demonstrating that the DT icons were not perceived correctly in these cases: once the icons were seen as buttons and once the laptop icon was perceived as depicting a radio. Regarding incorrect statements at the SA level comprehension, a total of 193 statements were uttered involving all 16 participants, with most incorrect comprehension statements being uttered with the DT concept (both baseline and full). In many statements the participants explicitly verbalized confusion. In some of these statements the confusion involved the relation between changes in the HMI and changes in the driving environment, such as “I don’t know why we are alternating between one or two thumbs.”, “I can use my laptop, but why can’t I sleep? I have no idea.”, and “I do not know what is the difference with just a few seconds ago.” Another recurring theme concerned misinterpretation of an emoticon, DT icon, or transition icon, for example: “A telephone…maybe it is connected or something.” (the DT ‘telephone’ icon indicates that the driver is allowed to use a phone), which in some cases was falsely connected to an own action, e.g., “Now that we’re in the city it is entirely green, but I do need to pay attention myself” (the first ‘green’ emoticon indicates that the driver is allowed to be involved in short-duration non-driving activities). Some participants seemingly related transition icons (e.g., lane markings) with the location at which they first appeared in the DT concept (e.g., next to the laptop icon): “Oh, the second button probably denotes the type of road we are on”. Such interpretations appeared to have persisted throughout the experimental trials in which they were uttered. Finally, regarding incorrect projection statements, 22 statements were found, uttered by 12 participants. Most of these statements were made during the ‘full’ versions of each concept (AF: 10, DT: 9). There were two frequently recurring themes as a result of which statements were judged as incorrect. First, participants related an emoticon or a DT icon to an incorrect own action. Typically, the participants thought they had to be more involved with the driving task than intended. For example: “And now I see that construction work is approaching and then probably I need to take over the steering wheel.” (the yellow emoticon is intended to inform the driver that more visual attention to the driving environment is required). Second, participants did not understand the meaning of a transition icon when they were anticipating an upcoming event, for example: “I am seeing a green bar on my windshield, with I guess something like fog that I am approaching” (the participant was already driving through the fog; the transition icon announced the end of the fog).

Statements involving an evaluation of the presented HMI were also explored in order to gain further insight into how the HMI concepts and aspects of these concepts were experienced. A total of 283 statements concerned an HMI evaluation, the majority of which were coded as irrelevant for analyses on situation awareness. The most frequently recurring theme in the HMI evaluation statements concerned participants longing for information that was not presented by the HMI, such as navigation information, detection of traffic signs, and speed (limit) information. Interestingly, the latter was uttered in the context of a future take-over situation: “If I suddenly have to drive myself it would be convenient to know how fast I am allowed to drive.” It also became apparent that the presentation of ambient light effects triggered mixed responses. Some participants liked the idea: “So I don’t necessarily have to monitor the screen, which is very convenient. One immediately feels that it’s safe.” Others, however, expressed negative feelings, e.g., “The whole car has turned green, which is super annoying.”, “At night I would not like all this green light, because I cannot comfortably look outside.”, and “The co-driver will be confronted with what you as a driver are doing, or what the car thinks you as a driver should do.” Additionally, several participants expressed a liking for the full versions of the AF and DT concepts, because these versions allowed them to anticipate on upcoming events. When presented with the LED bar, some participants stated that they would not need the emoticons, in part because (some of) the information was already present in the LED bar (i.e., color as an indication of automation fitness), but also because having a single information display would negate the necessity to continuously look at two physical locations. Five participants expressed doubts on the technology based on which transition icons were presented. These participants claimed that drivers should always remain alert, even if the car is driving fully autonomous, because the sensor systems may not always identify and react to hazards, and because they thought that too much could happen in the time window preceding a next automation fitness state, as a result of which it is not possible to predict so far into the future. With regard to time windows, several participants thought that transition icons occurred too early to be informative: "The construction work alert occurs relatively early, so you do not have any idea where in the city this will occur." Moving from information content to information representation, many participants expected that there would be sounds informing them of changes in the system state, especially when transitioning towards a lower level of automation fitness, and above all when transitioning from the 'sleeping' state during DT full: "Hey, this is interesting. Suppose that we're sleeping. How do we wake up?"

Questionnaires

Regarding task load, as measured by the NASA-TLX items, no significant effects were found for either Version, Concept or the interaction between the two.

Regarding system usability, measured by the System Usability Scale, a significant main effect for Concept was found, F = 6.29, p < .05, $\eta_p{}^2$ = .12. The average system usability scores per condition are presented in Figure 12. The effect of Concept demonstrated that the AF concept was rated higher on usability than the DT concept.

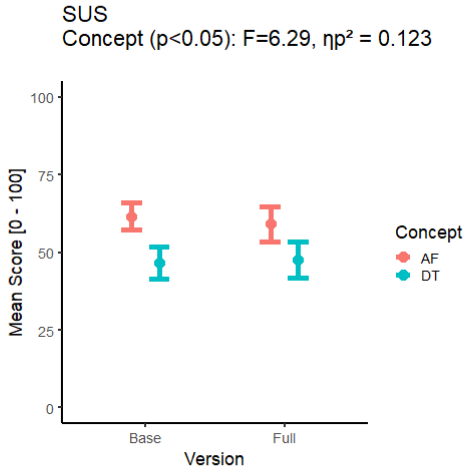


Figure 81: System Usability Score on a scale from 0 (least usability) to 100 (most usability). Error bars represent ±1 standard deviation of the mean

Responses to items of the complacency questionnaire were analyzed separately. For the item "Carefully watching automation takes time away from more important or interesting things." a significant effect of Concept was found, F = 8.28, p < .01, $\eta_p{}^2$ = .16. The average scores on this item per condition are presented in Figure 13. As can be seen in the figure, the DT concept was rated as taking more time away from more important or interesting things than the AF concept.

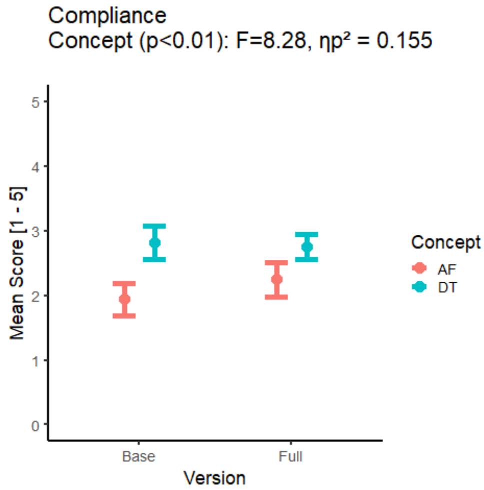


Figure 82: Mean scores for the compliance item "Carefully watching automation takes time away from more important or interesting things.". Scores are on a scale from 1 (strongly disagree) to 5 (strongly agree). Error bars represent ±1 standard deviation of the mean

Regarding items measuring mode confusion, significant effects were found for 4 items. These effects are summarized and depicted in Figure 14. For the first item a significant effect for Version was found for the statement that the HMI helped participants understand when they needed to pay attention to the road, F = 8.28, p < .05, $\eta_p{}^2$ = .16. Post hoc testing revealed a significant difference (p < .05) between AF full and DT baseline. Figure 14 indicates that participants more strongly agreed with the statement after watching the video of the former than the latter concept. For the second item a significant effect of Concept was found for the statement that the HMI made clear to the drivers what they were allowed to do when they were not expected to pay attention at the road, F = 29.40, p < .001, $\eta_p{}^2$ = .40. Post hoc testing demonstrated significant differences when comparing AF baseline to DT baseline (p < .001) and to DT full (p < .01). Additionally, significant differences were also found when comparing AF full to DT full (p < .01) and to DT baseline (p <0.01). *Figure* Figure 14 indicates that after DT participants more strongly agreed with the statement than after AF. For the third item a significant effect for Version was found for the statement that the HMI helped drivers understand if an event (like a road block) would occur, F = 5.61, p < .05, $\eta_p{}^2$ = .11. *Figure* indicates that participants more strongly agreed with this statement after watching the full version of the AF concept. For the fourth and last item a significant effect of Concept was found for the statement that the HMI helped drivers understand when the self driving vehicle would hand back control to the driver, F 4.98, p < .05, $\eta_p{}^2$ = .10. The post hoc test revealed a significant difference (p < .05) between AF baseline and DT full. Figure 14 indicates that drivers more strongly agreed with the statement after watching the video of the latter than the former concept.

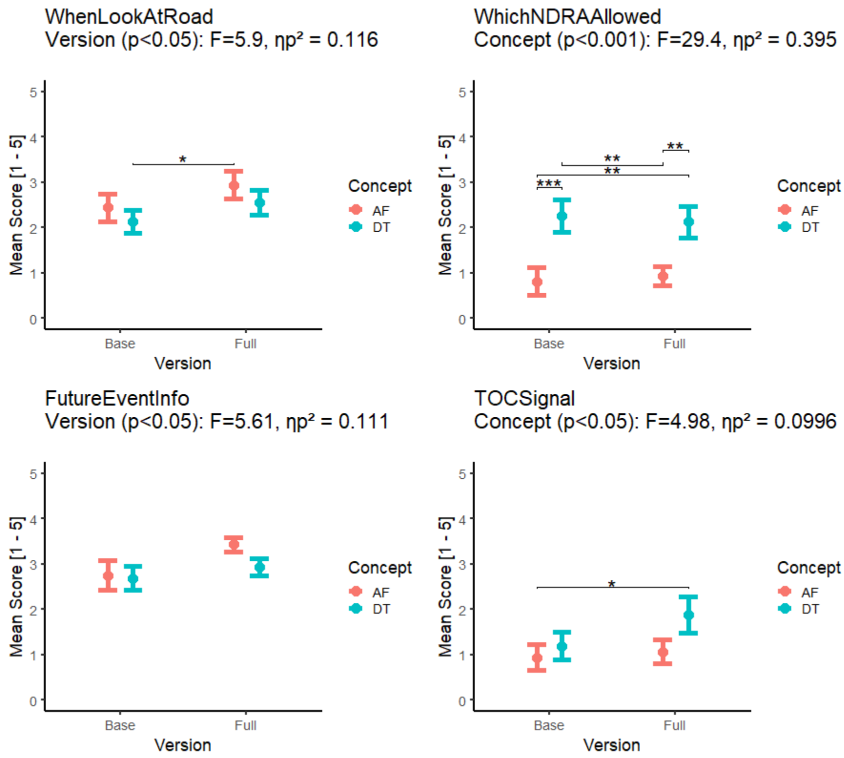


Figure 14: Mean scores for items measuring mode confusion scored on a scale from 1 (strongly disagree) to 5 (strongly agree). Upper right: "The information system in the car helped me to understand when I needed to pay attention to the road." Upper left: "The information system in the car made it clear to me what I was allowed to do during periods at which I didn't need to pay attention to the road." Lower right: "The information system in the car helped me to understand when an event (such as a roadblock) would occur." Lower left: "The information system in the car helped me to understand when the self driving car would hand back control to me as a driver." Error bars represent ±1 standard deviation of the mean

Participants ranked each HMI condition from 1 (most preferred) to 4 (least preferred). The count for each condition and each rank is presented in Figure 15. No significant effect for Version, Concept or the interaction between the two was found on these rankings.

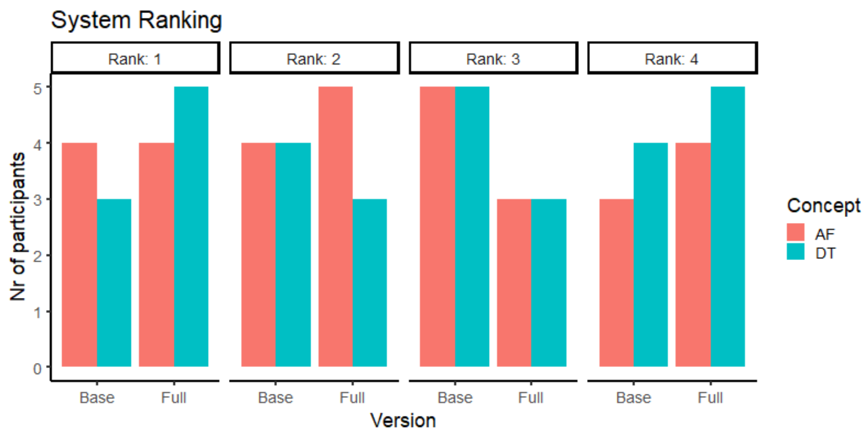


Figure 83: Number of participants that ranked a concept for each position of the ranking. Rank 1 indicating most preferred and rank 4 indicating least preferred design

Next, it was explored whether participant characteristics had an influence on the rankings of the HMI designs. For both Rank 1 (preferred HMI) and Rank 4 (least preferred HMI) no significant effects of age, years owning a driving licence, km driven per year and years owning a SEA 2 vehicle or level of immersion were found for Version, Concept, or the interaction between the two.

Participant's sensation seeking tendency and the level of perceived enjoyment of driving a self driving vehicle did have a significant effect on which HMI participants preferred the most. These effects are depicted in Figure 16. For participant's sensation seeking tendency a significant effect of Concept and a significant interaction between Concept and Version were found, F = 6.73, p < .05, $\eta_p{}^2$ = .36 and F = 5.31, p < .05, $\eta_p{}^2$ = .31 respectively. Figure 16 seems to indicate that participants with a higher score on the sensation seeking scale (BSSS8) prefer the AF concept, and especially AF base. For participant's perceived enjoyment of driving a self driving vehicle a significant effect of Version was found, F = 6.91, p < .05, $\eta_p{}^2$ = .37. Figure 16 appears to indicate that participants with a higher perceived enjoyment have a preference for the full versions of the HMI concepts and in particular for AF full.

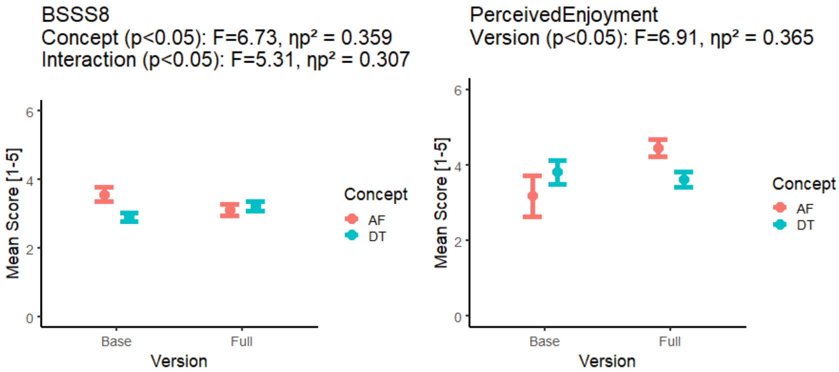


Figure 84: Between subject scores on sensation seeking tendency (BSSS8, left) and perceived enjoyment of driving self driving vehicles (right) for participant groups based on their preffered (Rank 1) HMI design. Scores range from 1 to 5 with 5 indicating high sensation seeking or perceived driving enjoyment, respectively. Error bars represent ±1 standard error of the mean

Regarding the least preferred HMI design, both a participant's trust in technology and the level of perceived enjoyment of driving a self driving vehicle had a significant effect. These effects are depicted in Figure 17. For trust in technology a significant effect of Concept and the interaction between Concept and Version were found, F = 5.53, p < .05, $\eta_p{}^2$ = .32 and F = 4.97, p < .05, $\eta_p{}^2$ = .29 respectively. Post hoc analyses demonstrated a significant difference between the DT baseline and DT full (p < 0.05), suggesting that participants that trust technology more prefer DT baseline the least. For perceived enjoyment of driving a self driving vehicle a significant interaction between Concept and Version was found, F = 4.78, p < .05, $\eta_p{}^2$ = .29. Figure 17 appears to indicate that participants that have a higher perceived enjoyment prefer DT baseline the least.

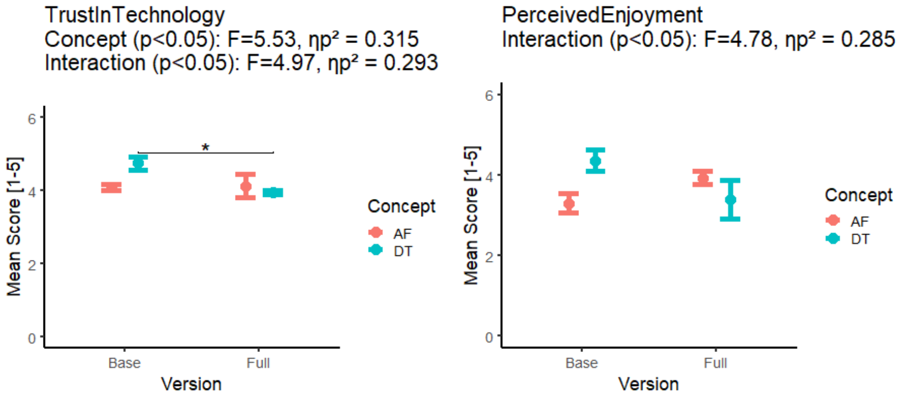


Figure 17: Between subject scores on trust in technology (left) and perceived enjoyment of driving self driving vehicles (right) for participant groups based on their least preferred (Rank 4) HMI design. Scores range from 1 to 5 with 5 indicating high trust or perceived driving enjoyment, respectively. Error bars represent ±1 standard error of the mean

Analyses on task load, usability, compliance and mode confusion significantly affected which HMI condition was preferred. These results are depicted in Figure 18 For mental demand, as measured by the NASA-TLX questionnaire items, a significant effect of Concept was found, $F = 7.15$, $p < .05$, $\eta_p{}^2 = .37$. Figure suggests that subjects who experienced a lower mental demand preferred the AF concept. Regarding compliance, a significant effect of Version and interaction between Concept and Version was found, $F = 7.40$, $p < .05$, $\eta_p{}^2 = .38$ and $F = 5.45$, $p < .05$, $\eta_p{}^2 = .31$ respectively. As can be seen in Figure 18, these effects were probably driven by participants with a higher compliance preferred AF full. A significant effect was also found for Concept when assessing how strongly participant agreed to the statement that the HMI helped them understand when they should pay attention to the road, $F = 6.19$, $p < .05$, $\eta_p{}^2 = .34$. Post hoc testing showed a significant difference ($p < 0.05$) between DT baseline and AF full, demonstrating that participants who preferred the AF concept agreed most with this statement. Additionally, a significant interaction between Concept and Version for the statement that the HMI helped them understand which NDRT they could perform at times they did not have to look at the road. $F = 5.23$, $p < .05$, $\eta_p{}^2 = .30$. Post hoc testing demonstrated a significant difference ($p < .05$) between AF full and DT full, with those that preferred DT full agreeing most with this statement as can also be seen in Figure 18.

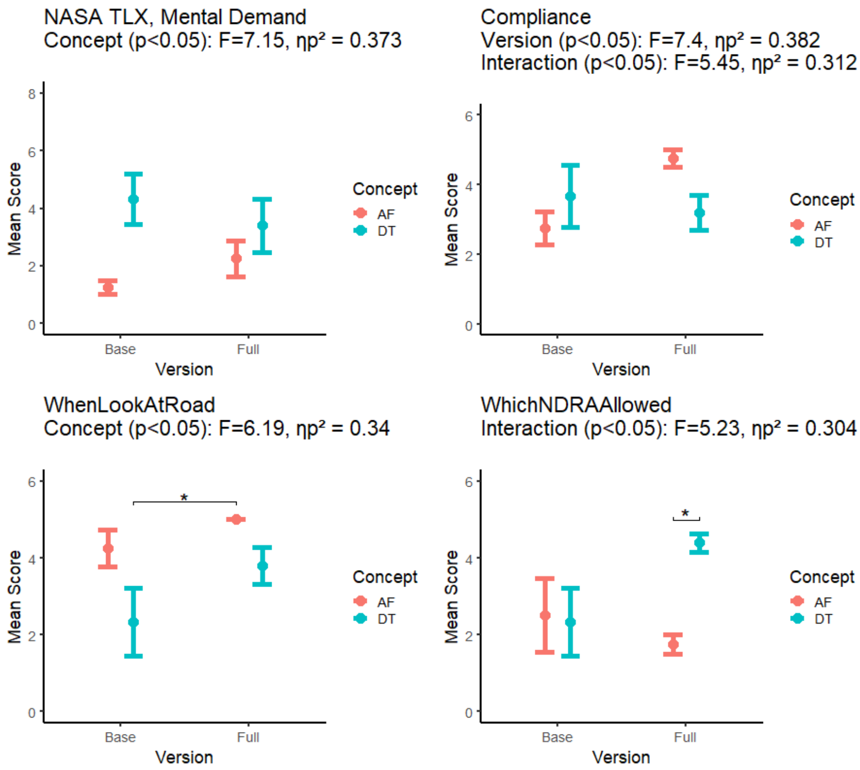


Figure 18: Between subject scores on mental demand (top left) and compliance rated on item 2 (top right) for participant groups based on their preferred (Rank 1) HMI design. Lower left: "The information system in the car helped me to understand when I needed to pay attention to the road." Lower right: "The information system in the car made it clear to me what I was allowed to do during periods at which I didn't need to pay attention to the road." Scores range from 1 to 7 for mental demand and from 1 to 5 for compliance, with 7 and 5 indicating high mental demand and strong agreement with the statements. Error bars represent ±1 standard error of the mean

Additionally, task load, usability, compliance and mode confusion were grouped per rank of the corresponding HMI design. Such comparisons could indicate which of these measures influences the ranking of HMI designs. There was a significant effect of Rank on usability, $F = 4.84$, $p < .01$, $\eta_p^2 = .24$. Post hoc analysis showed a significant difference between usability scores between Rank 4 and Rank 1 ($p < .01$) and Rank 2 ($p < .05$). In both cases, the usability was rated lower for HMI designs that were ranked 4th, as can also be seen in Figure 19.

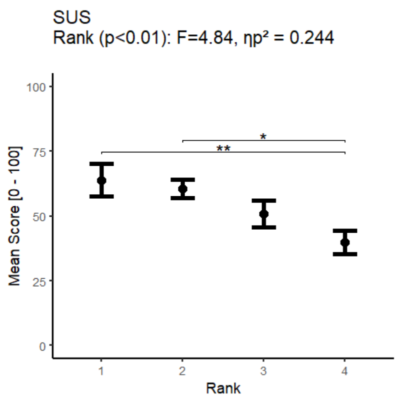


Figure 19: Average usability score for each rank. Error bars represent ±1 standard error of the mean

There was also a significant effect of Rank on the agreement with the statement "Carefully watching automation takes time away from more important or interesting things.", F = 3.50, p < .01, η_p^2 = .19. Post hoc testing demonstrated a significant difference (p < .05) between Rank 4 and Rank 1. HMI designs that were the least preferred were associated with a stronger agreement to the statement than designs that were the most preferred, see also Figure 20.

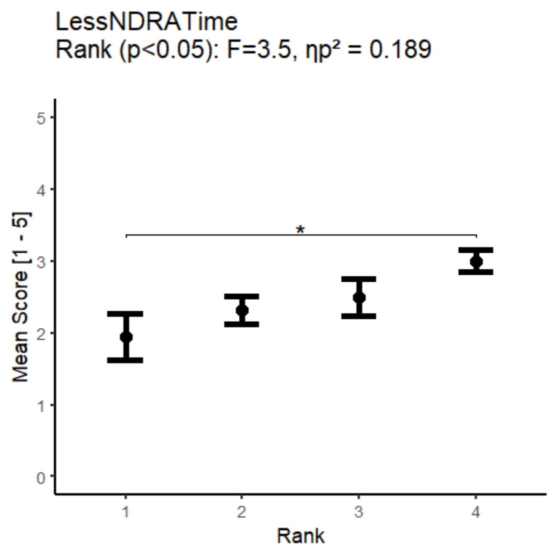


Figure 20: Average agreement to the statement "Carefully watching automation takes time away from more important or interesting things" for each rank. Error bars represent ±1 standard error of the mean

Significant effects of Rank were also found for the questions on mode confusion. The results are summarized and depicted in Figure 21. Rank significantly affected agreement to the statement "The information system in the car made it clear to me what I was allowed to do during periods at which I didn't need to pay attention to the road.", F = 3.03, p < .05, η_p^2 = .17, with a lower agreement with increasing rank number. A significant effect of Rank was also found for agreement to the statement "The information system in the car made it clear to me what I was allowed to do during periods at which I didn't need to pay attention to the road.", F = 3.05, p < .05, η_p^2 = .18, with agreement appearing to be higher for Rank 1 and 2 compared to Rank 3 and 4. A significant effect of Rank was additionally demonstrated for agreement to the statement "The information system in the car helped me to understand when an event (such as a roadblock) would occur.", F = 6.25, p < .01, η_p^2 = .29. Post hoc testing demonstrated a significant difference between Rank 1 and 3 (p < .05), between Rank 2 and 3 (p < .01) and between Rank 2 and 4 (p < .05). Agreement to the statement generally seems higher for Ranks 1 and 2 than Ranks 3 and 4. Finally, a significant effect of Rank was found for agreement to the statement "The information system in the car helped me to understand when the self driving car would hand back control to me as a driver.", F = 7.09=8, p < .001, η_p^2 = .32 . Post hoc testing demonstrated a significant difference between Rank 1 and 3 (p < .01) and 4 (p < .01). Agreement to the statement is stronger for Rank 1 than for Ranks 3 and 4.

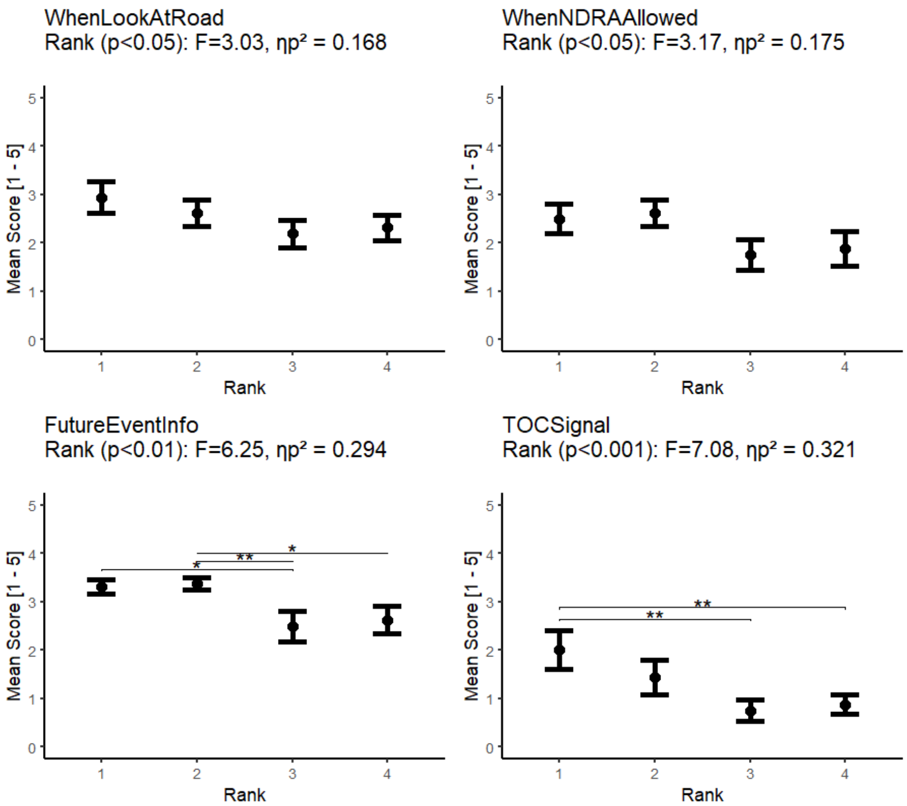


Figure 21: Average agreement to statements on mode confusion for each rank. Upper right: "The information system in the car helped me to understand when I needed to pay attention to the road." Upper left: "The information system in the car made it clear to me what I was allowed to do during periods at which I didn't need to pay attention to the road." Lower right: "The information system in the car helped me to understand when an event (such as a roadblock) would occur." Lower left: "The information system in the car helped me to understand when the self driving car would hand back control to me as a driver." Error bars represent ±1 standard error of the mean

The 5 items that measured spatial presence were rated on average with 3.31 (*SD* = 0.78) on a scale from 1 to 5. The scores for each of the individual items are presented in the table below.

Table 8: Mean, SD, Min and Max on items on spatial presence

Spatial presence item	Mean	*SD*	Min	Max
Item 1	3.69	0.70	2	5
Item 2	3.56	1.03	1	5
Item 3	3.75	0.86	1	5
Item 4	3.19	0.91	2	4
Item 5	3.06	1.12	1	4

Regarding qualitative analyses on open-ended questions, answers of participants were explored on recurring themes. First, results on reasons for a preferred HMI will be presented, after which results about the understanding about the specific HMI designs will be discussed.

Regarding the preferred HMI, the reason for participants to rank AF base as their preferred choice seems to be the ease of interpretation and the reduced amount of information it presented. One participant indicated it was clear, and it was the one that participants were feeling most secure about*: "*Clearly the most simple, and still it gave me more information than the other systems. Maybe specifically because of the simplicity. System A [AF full] gave me a little bit more information that system B [AF base], but system B was more easily understood. I felt more secure with system B*"*. Other participants indicate similar feelings, talking about comfort, ease and cheerfulness : *"*Calm, indicated events on the road in time (however it did so veeery early in advance)" and " Easy and cheerful to interact with. It is brought back to the essence of what the system should do…*".*

Participants who ranked AF full as their preferred system all mentioned the LED bar as a reason for preferring this system: *"*The bar in the front window helps anticipation of changing driving circumstances" and "Especially because I can see what is coming up ahead". One participant remarked the combination of the emoticons with the LED bar: "Simple icons and the green edge at the bottom". One participant indicated that s/he chose this design despite the presence of the ambient light effects function: *"*The choice for A is despite the discoloration of the dashboard", indicating that the overall design would be better without it.

The reasons for participants to prefer DT base seem to be because they did not like the elements from the AF design. Two out of the three participants that preferred DT base indicated that they chose this design because they did not like the emoticon icons and the use of colour: "Emoticons leave to much room for interpretation, colour difference is subtle, just like the expression of the emoticon itself. The lighting is unnecessary additional distraction from the reality", and "I have difficulties taking the emoticons seriously and I find the colours in the car restless". The other participant chose this design because it had one source of information, that was easy to understand.

The participants that preferred DT full most often indicated that they did so because of the ambient light effect. Two participants indicated that they felt that they did not have to monitor the HMI display because they could keep an eye on the ambient light effect: " The green lighting makes sure that you don't have to keep looking at the display to know in which modus the system is", with another participant stating something similar: "I would use the glow whenever I am doing something else, the glow would give me the idea that we are still in a good mode without having to look at the screen…".

Regarding results on understanding of the HMI designs, from the statements that were given for AF baseline it becomes clear that when the transition icon was mentioned it was understood correctly: "That the car is partially in control, because there are not road markings that the car can use". At the same time, the driving context was sometimes misinterpreted: " It was not clear to me. now when I am answering questions, I get that the end of the road markings means that I have to steer" (the end of road markings did not indicate a takeover). Some participants indicated that they did not understand AF baseline, which was mainly due to failure to comprehend the meaning of the emoticon: "I interpreted the emoticon completely wrong, therefore I have ignored the emoticon somewhat…" and " (…) It also shows me a face but it was not clear to me whether it meant that I was doing good or bad. It was also not clear whether it was about now or about what is coming". Regarding the question whether anything stood out to the participants, the main topic seemed to be the simplicity of the system. Some participants remarked that that was a good thing: "Very clear and easy, and you could do other things in the meantime. It is immediately clear what it does. With the help of the emoticons. Enjoyable!"; "Simple to use" and "certainly calmer and clearer than the systems before it". Yet, other participants saw this as a constraint of the system, stating that it provided not enough or very little information: "Very little information, not on what is coming up. Not when it changes, nor if it improves/worsens" and "It is simplified a bit too much, you need to have a lot of trust in it in order to drive around like this". The last thing that participants noted were the colours of the emoticons, and what they could or should mean: "Green is good, yellow is pay attention"; "Green emoticon, so the system is still in control of the car"; " When the emoticon is green, I assume that the system is handling everything and that I don't have to come in between, but what is then the difference between three levels of green?".

Considering AF full, almost all the answers evaluated and interpreted only a specific component of the system. Some interpreted and seemed to understand the concept as a whole: "Soon there will be a different situation, an urban area specifically. The degree of control of the system lowers a bit at that moment" and "Emoticons = confidence/trust that the system has in the current situation (in doing things on its own). Progress bar = announcement of what is coming in the future". Others have trouble with one aspect, misunderstanding the emoticons: "That the system will go outside of its comfort zone (it will probably stop functioning)" and " (…) then I have to start paying attention to the car whether it is driving correctly", while they do correctly understand that the LED bar indicates an upcoming chance in environment: "When to expect this change" and "In a couple of hundred meters I will drive into the city". Finally, just as with AF base, some participants did not understand the emoticons at all: "And the emoticons: no idea" and " No idea, I thought that [name of experimenter] could hear me and gave me a emoticon as a review of the number of information that I spoke aloud". Regarding the question whether anything stood out to participants, the answers were mostly similar to the answers to the previous question. Participants indicated that they were missing some features. Some stated that it was not always clear whether the system could operate on its own: "That it is not always 100% clear on what the certainty of the system is based upon" and "It was not always clear whether the system is working or whether I should take over -> how certain is this system?". Other participants missed certain modalities that they expected from the system: "No warning signals (sound)"; "The green bar in the window: it indicated when the city limits would be reached. I missed the number of meters" and "It is annoying that you only see the next phase, and not the phase that comes after".

The remarks given for DT baseline show that a few participants understood the meaning of the driver task icons: "which activities I am allowed to perform" and "it mainly tried to let me know what I could do, for example telephone, work, sleep and what to pay attention toe, when I have to look and when to hold the steering wheel". Other participants clearly stated that they did not understand the icons: "I still have no idea"; "What the smartphone symbol means is not clear to me" and "Why there is an iPhone there no idea". Finally, some participants seem to connect automation status to the driver task icons: "to what extent the automation can drive autonomous" and "when a certain amount of attention is expected from the driver regarding the trust of the system in the current situation". This could be a consequence of the order in which the videos were presented. Statements on the aspects of the system that stood out seemed to focus again somewhat on aspects that were missing. Some participants missed audio cues: "There is no auditory signal when there is a change"; "This seems dangerous to me when you are using our telephone or laptop while monitoring the system all the time"; " You also hear nothing" and "When you are sleeping, how do you wake up?".

The comments on DT full are mainly about specific components of the system. Participants indicated that the information system informed them that they are about to enter the city: "that we are approaching a city. The car also lets me know how long that will take". Some participants indicated that the ambient light effect was the most prominent and important factor while other stated that it had no added value. Those that liked the ambient light effect stated: "The glow in the car indicated the certainty of the system, actually I don't really need the interface, the glow is enough for me to decide what I want to do, I will know whenever the glow subsides that I have to pay attention because the certainty of the system will lessen" and: " The colour in the car was the most important, the greener, the safer it is to not pay attention”. Those that disliked the ambient light effect stated: “(…) the green light did not add much, only the confirmation of the central display indication”, and: “ (…) the green colour in the car was more of a distraction than an addition”. Statements on anything that stood out were mostly about the ambient light effect. There is no clear opinion on the ambient light effect, however. Some just noticed it: “The green glow on the side of the driver”; “ hue lights, the whole car is green (…)”. Others explicitly did not like it: “Annoying green haze” and “I found it very unclear, especially when the whole cabin became green/blueish, I cannot see which icons where green”, while others mention a feeling of safety: “ The cockpit lights up green, suggesting that everything is safe”.

Due to the nature of the questions, it is difficult to formulate a clear conclusion or reflection. Some participants evaluated the complete system while other evaluated only a specific component. What does stand out is that participants have many different preferences. This is not surprising when we consider the earlier results on which system participants preferred in which no clear preference for a system was apparent.

Appendix 4. Experimentation template TUD-light strips & HUD

T1.5 EXPERIMENT DESIGN & ALIGNMENT TEMPLATE

This template is intended to describe your experiment design, synchronise writing for the final deliverable i.e. describe all experiments in a similar structure. Having comparable data on all experiment designs will also ease the merger into one experiment (one HMI), in later project stages. This template is also intended to share between partners and identify potential cross fertilisation. The whole of templates will also facilitate monitoring the coverage of knowledge gaps and use-cases.

Row heights can be adjusted if you need more space to write or wish to insert images.

To add another experiment design, copy this sheet: Edit -> Sheet -> Copy Sheet -> check 'Create a copy'.

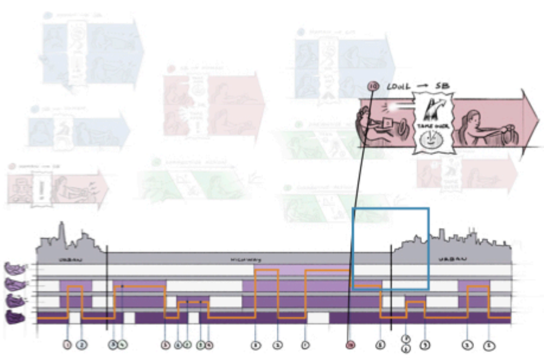
<table>
<tr><th colspan="2">EXPERIMENT</th></tr>
<tr><td>Knowledge gap, ref. D1.1:</td><td>Transfer of controol</td></tr>
<tr><td>Experiment identification:</td><td></td></tr>
<tr><td>Mediator partner(s):</td><td>TUD</td></tr>
<tr><td>Authors:</td><td></td></tr>
<tr><td>Location:</td><td>TUD</td></tr>
<tr><td>Experiment date(s):</td><td></td></tr>
<tr><th colspan="2">KNOWLEDGE GAP</th></tr>
<tr><td>General description of the knowledge gap</td><td>better understanding, effective communication and more support leading to a better takeover per</td></tr>
<tr><th colspan="2">HYPOTHESIS</th></tr>
<tr><td></td><td>Knowledge gap: How to let the driver already by in a reliable state before takeover during takover A -> M. Hypothesis: better understanding, effective communication and more support lead to a better takeover performance.</td></tr>
<tr><th colspan="2">GLOBAL EXPERIMENT CONCEPT</th></tr>
<tr><td>General description of the idea and experiment concept.</td><td>The experiment concept consists of a combination of a HUD and light beams attached to the A-pillars. The light beams radiate different vibes related to the stage of driving, as explained below.

During Automated driving the light beams convey a calm vibe in order to:
-Help maintain driver's SA but do not disturb driver too much
-Provide clear information to enhance understandability
-Indicate TOR in advance and support driver get prepared
-Evoke driver's SA effectively before takeover

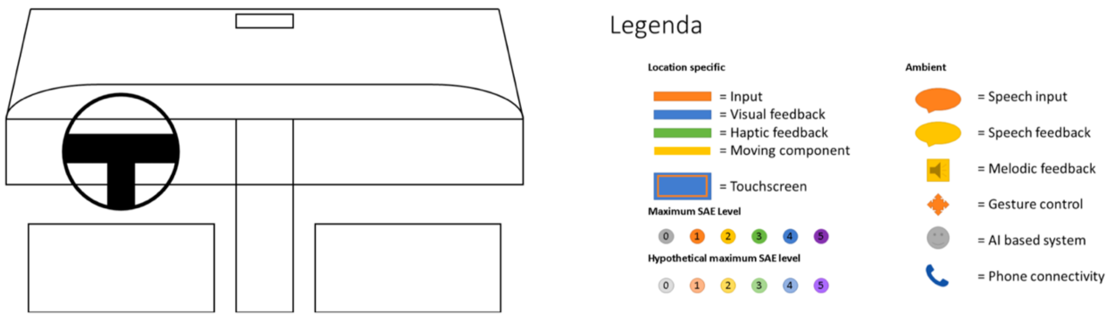
During takeover the light beams will switch from an exciting vibe towards an urgent vibe and the length of the beam itself intuitively shows the time left during takeover. The HUD is also showing messages.
-The takeover request should be clear, effective and takeover actions should be easy and intuitive

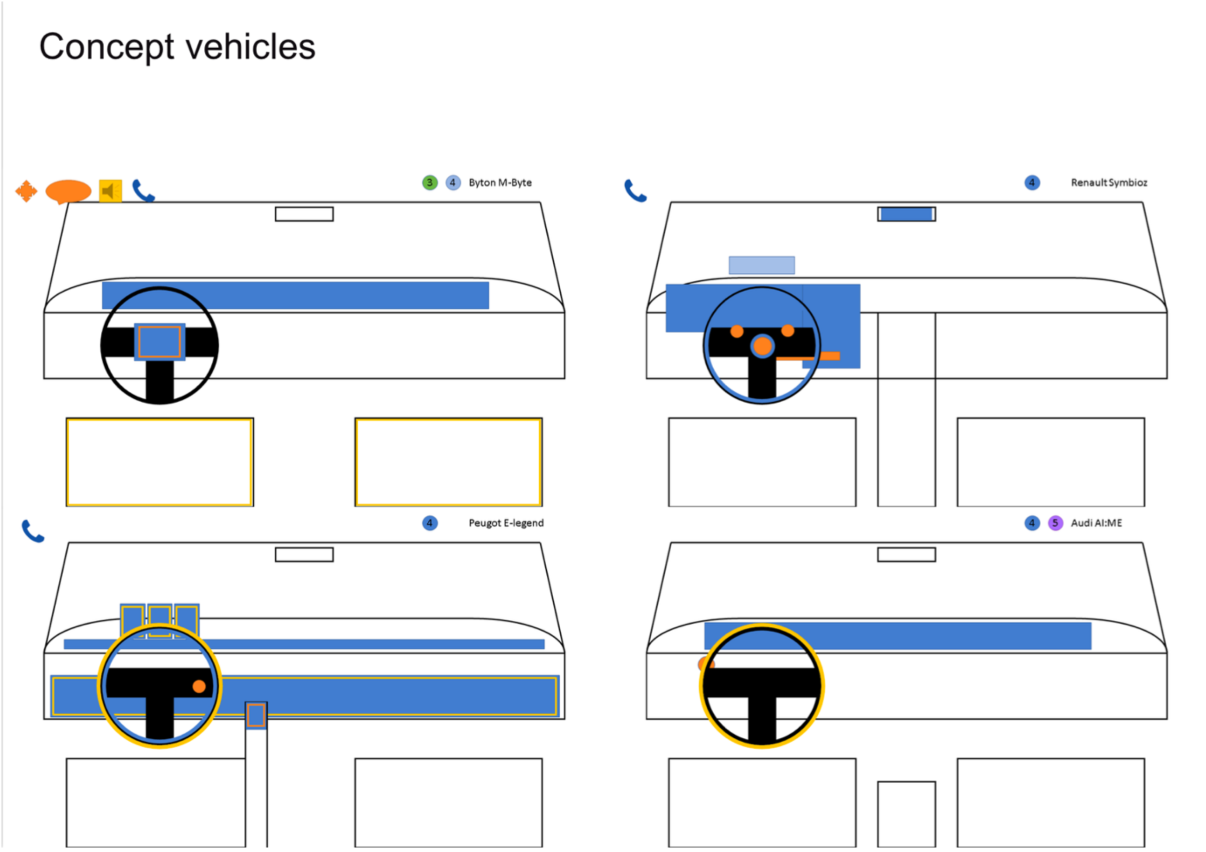
After resuming control, the HUD informs the driver by means of:
-Explicit feedback
-Clear information
-Universal Visual, auditory cues
-The driver's eye should be off the road as less as possible;

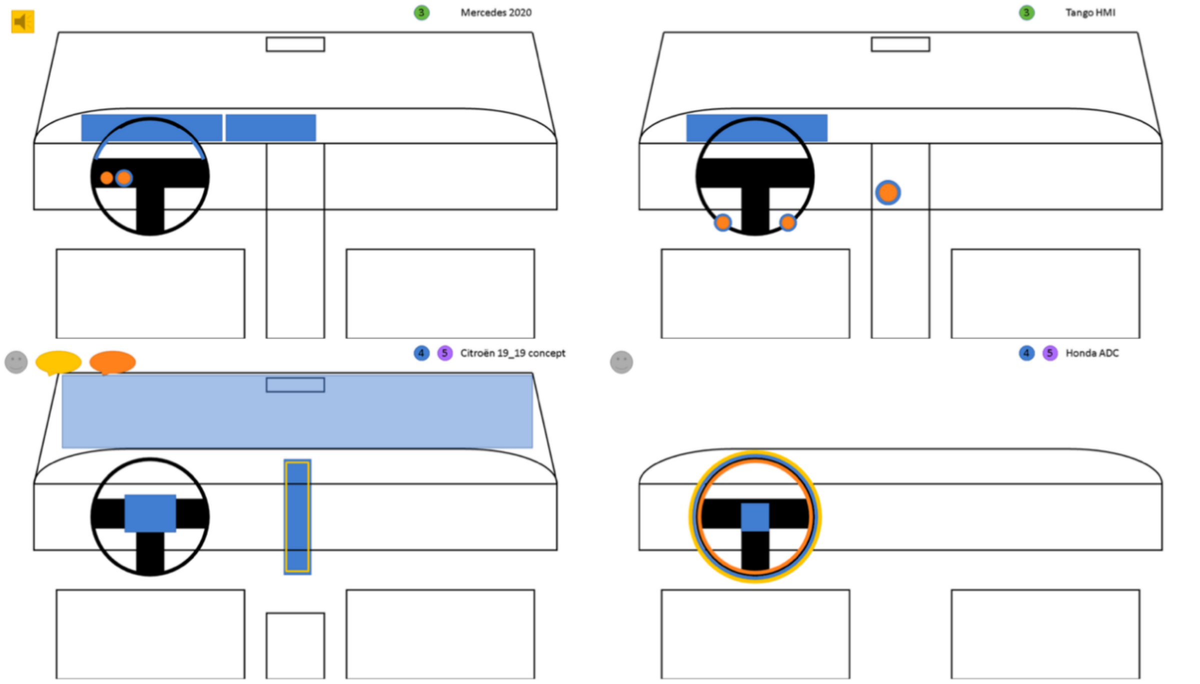
</td></tr>
<tr><th colspan="2">INSTALLATION SET-UP</th></tr>
<tr><td>Describe the physical or on-line set-up of the experiment. What is the seating position, how is e.g. the view on the road displayed? Which HMI components (consult the HMI components list) are being inluded?</td><td>Two light strips were attached to the windshield of a car-model. A display was placed in front of the car (as can be seen in the image below). Because of the car-model, the participants were able to experience the takeover procedure in level 4 in terms of: ability to conduct secondary tasks, be woken up from STs, take over the control and then 'drive' manually.</td></tr>
<tr><td>Picture space</td><td>
</td></tr>
</table>

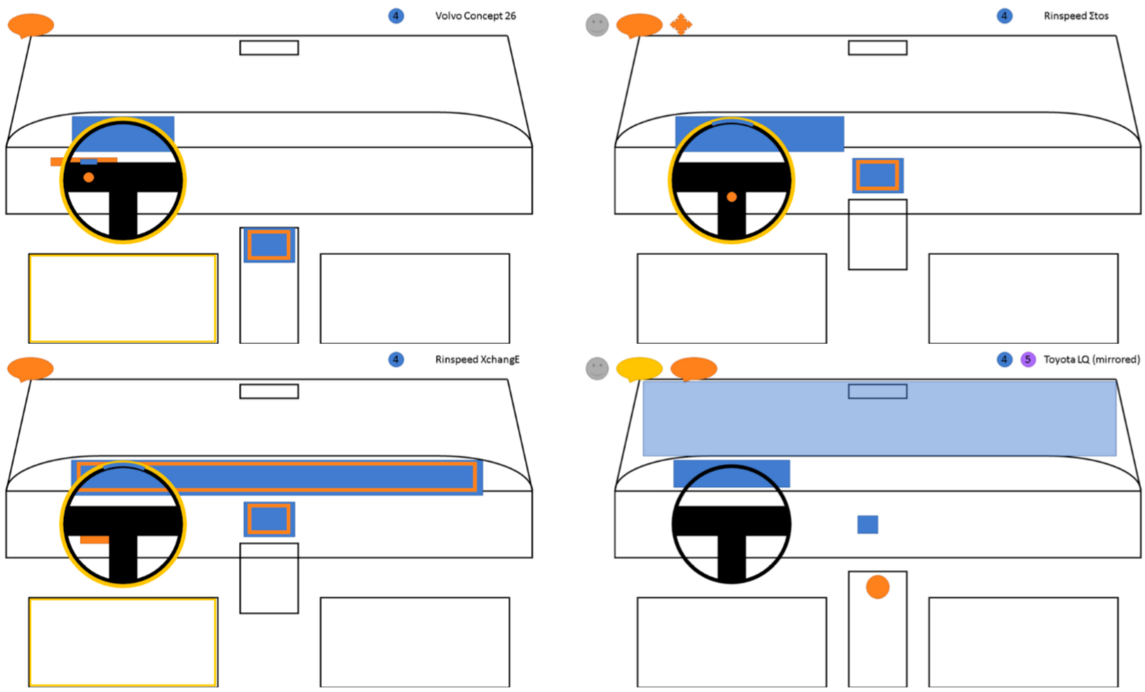
ENVIRONMENT SET-UP	
To merge all experiments into one, in a later stage of the project, experiments must be as comparable as possible in their ambiance. Describe the environment of the installation and any measures you mighthave taken to elicit an 'automotive feel'. Picture space	The experiment was conducted in a car-model and the display had a a simulator effect.
SCENARIO	
	
From the upper part of the image, identify which of the 10 use-cases form your scenario, and the order in which they appear.	 
As in the image timeline, identify which SAE levels are included in your scenario, in each use-case. If participants can choose their SAE level, identify the available levels.	Level 4 and level 1
INDEPENDENT VARIABLES	
Which HMI components (HMI available components in this workbook) will be included and which values (settings) are being tested?	Visual: Lighting strips at A-pillars, Head-up display (animation, meters, symbols, messages). Audio: sound signals
Picture space	Video concept test: https://swov2.sharepoint.com/:v:/r/MEDIATOR/Shared%20Documents/WP1%20-%20Analysis%20%26%20Experimentation/Tasks/Task%201.5/HMI%20design%20concepts/HMI%20concept%20movies/3rdusertest.mp4?csf=1&web=1&e=l4mZ1h
DEPENDENT VARIABLES	
What will be measured and how will data be presented?	The participants fill in a questionnaire in which they rate their experience on a scale from 0 to 5 a regarding the following: -The efficiency of the wakeup light and the ability to take participants' attention off the secondary tasks. -The clarity of information provision by the HUD and the light bars. -The function of the takeover light pattern and the indication of takeover time.
SECONDARY KNOWLEDGE GAPS ON LEARNING	
Considering the variables in this experiment, do you anticipate this experiment might contribute to the seconday knowledge gaps on (un)learning (Intuitive System & Learning and Long Term Skill Degradation)?	

SECONDARY KNOWLEDGE GAP ON HUMAN DRIVER CHARACTERISTICS	
Considering the variables in this experiment, do you anticipate this experiment might contribute to the seconday knowledge gap on Human Characteristics?	
PROCEDURE	
	Before the test a short introduction was given to let the participants emerge with the situation. They were told that the test is focussed on level 4 autonomous driving and specifically about the takeover in the journey. They are informed about the actual meaning of a takeover in this situation. Furthermore they are asked to do a secondary task during AD (playing a game on a seperate hand-held screen). During the test, the participants sat in the car-model and started doing a ST. The participants were aware that the car is driving automatedly on a highway. After 2.30 minutes the participants were introduced to the wake-up mode by messages on the HUD and by the LED bars (off sight a button was being switched, activating the led-bars at the A-pillars). This is followed up by the take-over request. After the test participants were asked to fill in a quantitative evaluation form and they are interviewed regarding their answers.
NOTES	
Notes and remarks, limitations, recommendations	
MEDIATOR EXPERIMENT CROSS FERTILISATION	
Please identify potential opportunities for consortium partners, to add mutual value by sharing or expanding the experiment set-up. Please identify potential opportunities for consortium partners, to add mutual value by sharing or expanding the scenario, components or settings.	
SAMPLE	
Sample size and desciption. Specific selection criteria, like e.g. driving skills, if any. Possible limitations.	6 participants (two with 5+years of driving experience, one with 2 years of experience, two with less than 1 year of experience and one participant with no driving experience)
ADDITIONAL DATA COLLECTION	
Elaborate on any additional inquiries you will perform, like surveys or inteviews.	After the survey that the participants filled in they were asked to elaborate some of their answers during interviews.
MEDIATOR ADDITIONAL DATA CROSS FERTILISATION	
Please identify potential room for consortium partners, to add mutual value by sharing or expanding questionaires, surveys or interviews.	
ADDITIONAL NOTES	
END	

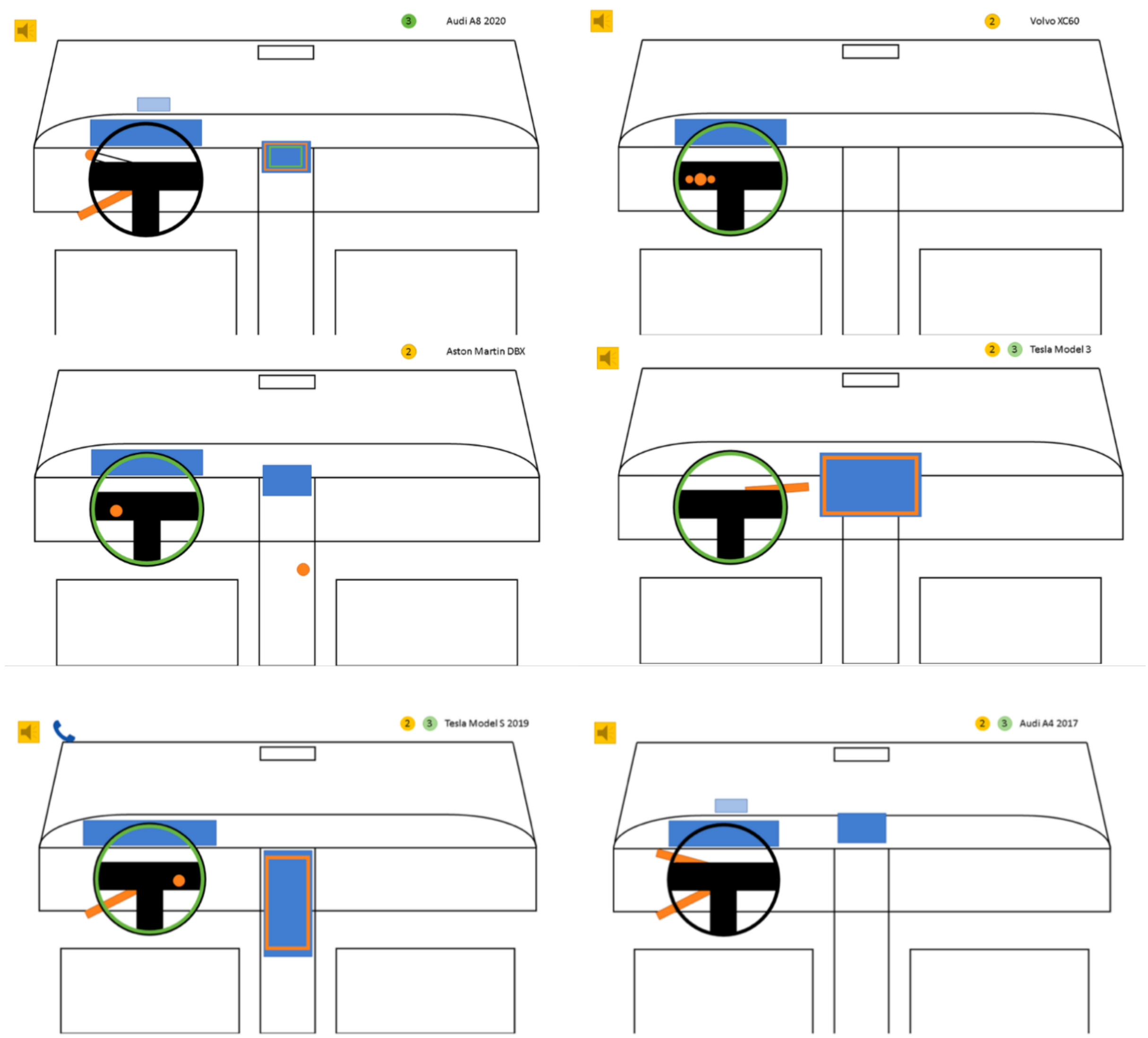

Legenda
Location specific
= Input
= Visual feedback
= Haptic feedback
= Moving component
= Touchscreen
Maximum SAE Level
0 1 2 3 4 5
Hypothetical maximum SAE level
0 1 2 3 4 5
Ambient
= Speech input
= Speech feedback
= Melodic feedback
= Gesture control
= AI based system
= Phone connectivity


Concept vehicles
3 4 Byton M-Byte
4 Renault Symbioz
4 Peugot E-legend
4 5 Audi AI:ME


3 Mercedes 2020
3 Tango HMI
4 5 Citroën 19_19 concept
4 5 Honda ADC

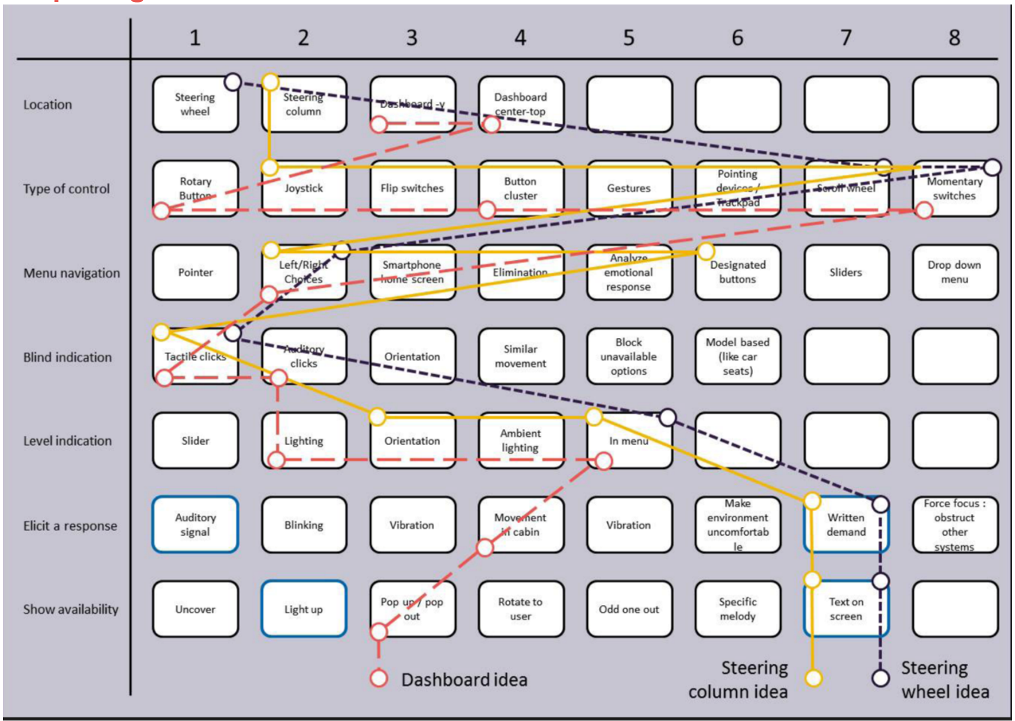

4 Volvo Concept 26
4 Rinspeed Σtos
4 Rinspeed XchangE
4 5 Toyota LQ (mirrored)

Currently existing HMIs



Appendix 5. Ideation Design methods

Morphological chart



Group ideation procedure

Ideation with others 06/10/2020

Objective

To attain a wider perspective on possible solutions to the question of what the input device can look like. This opens up new possible insights into possible bottlenecks, memes, intuitive controls, pros and cons, and placement. This session might affirm current ideas and/or steer towards new ones. The main goal is to fuel my own ideation with ideas from others. This will allow for a wider spectrum of solutions that can be used in a morphological chart.

Agenda

Agenda	*Time:*	*Total time:*
1. Open	1 minutes	0.01 hr
2. Warming up	9 minutes	0.10 hr
3. Introduction	4 minutes	0.15 hr
4. How to's	30 minutes	0.45 hr
5. Ideation	35 minutes	1.20 hr
6. Discussion	10 minutes	1.30 hr
7. Close	1 minute	1.31 hr

Procedure

Because of COVID-19, in-room meetings are avoided to limit the spread of the virus. The solution is a Skype call with a decreased amount of participants (to maintain control). During the skype-call, the participants can send their drawings/text via Whatsapp to the Webwhatsapp on the laptop and the participants can receive drawings/text via Whatsapp. The participants have their drivers licence.

During the call, whilst the timer runs, I will too participate in the session. However, I will not share anything until the discussion as not to influence the participants. If important events happen, such as a critical comment/discussion or the timer runs out, it is noted and solved. This will not pause/stop the session.

Open: 1 min

Warming up:
- Explain the exercise 2 min
- Design your own UFO cockpit 5 min
- Explain what choices have been made and why (choose 2) 2 min

Introduction:
Building a device to select a mode of assistance when driving a personal vehicle. Scales from manual to assisted to automated. A driver is either conscious of the driving and the road (manual and assisted) or not (automated). We'll do a how-to session to explore this domain. 4 min

How-to's:

GOAL: *Get a wide variety of options to use in a morphological chart*
1. How to indicate a level/mode? 5 min
2. How to choose a level/mode? 5 min
3. How to demand action? (machine to human) 5 min
4. How to show a duration? (time left/to go) 5 min
5. How to bargain with a machine? 5 min
(one minute to switch between each) 5 min

Ideation:

GOAL: *Get interesting ideas / twists / products / controls*
- Evaluate (share) how-to's 5 min
- Acquaint the participants with the main functions of the control: 4 min
    - Automation mode selection
    - Confirmation/Declination
    - Engage/Disengage
- Explain the analogy: BARMAN 5 min
- Merge how-to's to ideas:
    - Choose two a solution belonging to two different How-To's, create a concept with that. Preferrably no storyboarding, but an actual control to interact with. 10 min
    - One minute to switch 1min
    - Repeat with different solutions (and how-to's) for a second concept. 10 min

Discussion:
- Share the ideas that one has made; present the best 2. 10 min

Close session 1 min

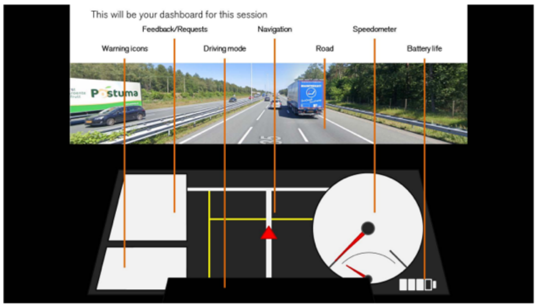
For those that are willing to hang out/stay, the discussion can go more in depth or wider, depending on the flow of the conversation.

Comments:

Appendix 6. Concept evaluation

Concept prototypes and user test setup

Scenario of user test (snippits)



Example of questionnaire prototype testing

CTR Prototype testing

This is the questionair to accompany the three conceptual interaction devices devolleped during the graduation of T.Q. Mallon for the project "Design of Control Transfer Rituals for Automated Vehicles" in 2020.

Initial questions aim to gain insight in the knowledge and experience of the participants. The other questions relate to the prototypes to allow further development and selection.

Do you have a drivers licence?

- (•) Yes, and i drive multiple times per week
- ( ) Yes, i have my licence but do not drive that often
- ( ) No
- ( ) Other: ______

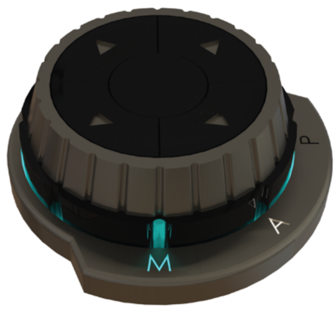
Do you have any experience with automated vehicles (such as Tesla Autopilot)

- ( ) Yes, i fully understand the use of vehicular automation
- ( ) Yes, but very little
- (•) No, but i know what they are capable of
- ( ) No, i have never driven such vehicle in such capacity
- ( ) No, but i do use cruise control
- ( ) No, no experience

How good of a driver are you?

	1	2	3	4	5	6	7	
Horrible	( )	( )	( )	( )	( )	(•)	( )	Excellent

Prototype 1: the button concept



I felt in control

	1	2	3	4	5	6	7	
Not at all	( )	( )	( )	( )	(•)	( )	( )	Very much so

This concept looked very complex

	1	2	3	4	5	6	7	
Very simplistic	( )	(•)	( )	( )	( )	( )	( )	Very complex

The amount of buttons / switches was overwhelming

	1	2	3	4	5	6	7	
Very unclear	( )	( )	( )	( )	( )	(•)	( )	Very clear

The concept is intuitive to use

	1	2	3	4	5	6	7	
Very unintuitive	( )	( )	( )	( )	( )	(•)	( )	Very intuitive

It will be easy to learn the functions of this concept

	1	2	3	4	5	6	7	
Not at all	( )	( )	( )	( )	( )	(•)	( )	Very much so

It was clear when I had to act

	1	2	3	4	5	6	7	
Not at all	( )	(•)	( )	( )	( )	( )	( )	Very much so

The scenario was clear to me

	1	2	3	4	5	6	7	
Very unclear	( )	( )	( )	( )	(•)	( )	( )	Very clear

The feedback informed me why the events in the scenario happened

	1	2	3	4	5	6	7	
Very unclear	( )	( )	( )	( )	(•)	( )	( )	Very clear

The control was easy to reach

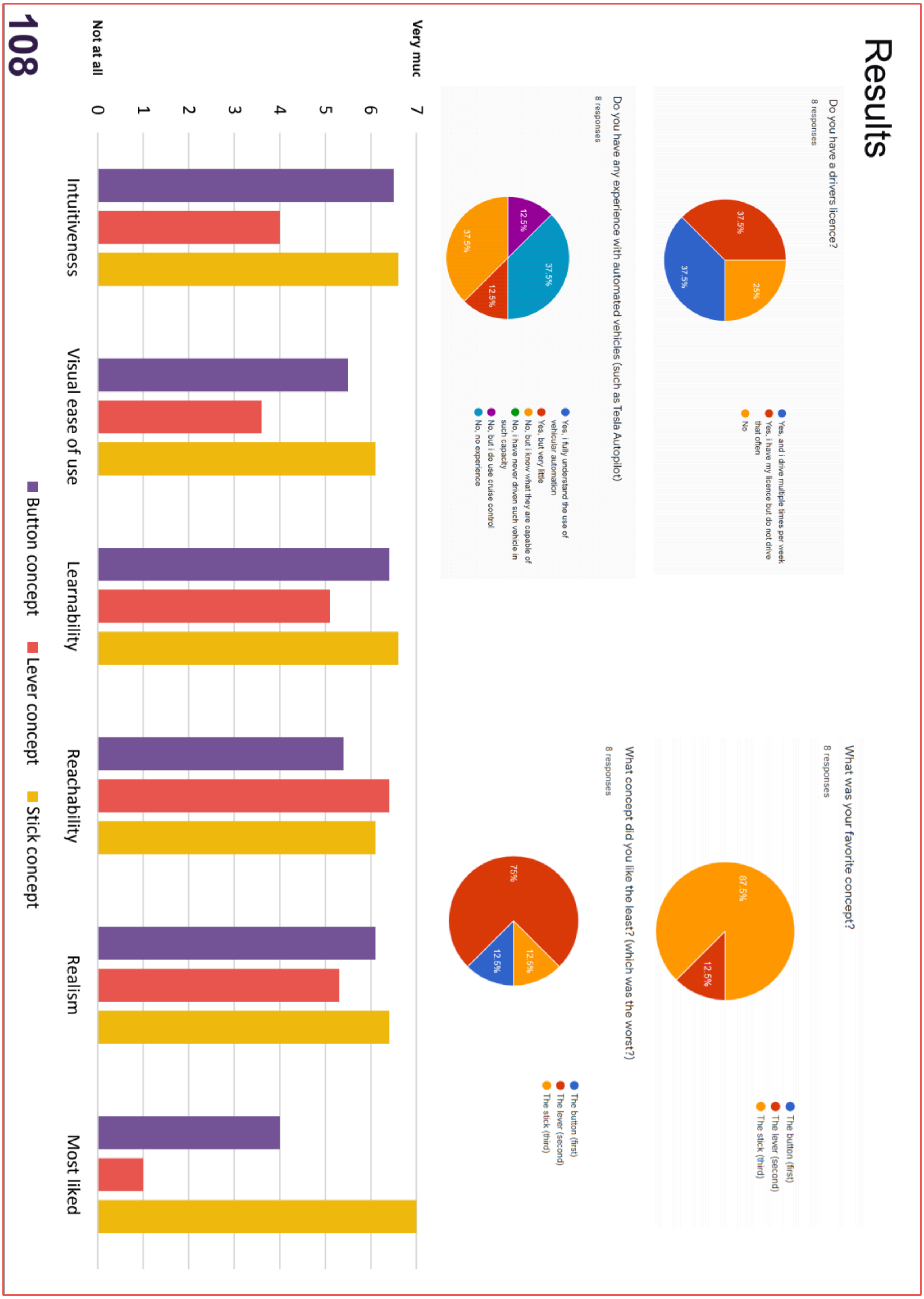
	1	2	3	4	5	6	7	
Not at all	( )	( )	( )	( )	( )	(•)	( )	Very much so

The interactions with the concept were familiar

	1	2	3	4	5	6	7	
Not at all	( )	( )	( )	( )	( )	( )	(•)	Very much so

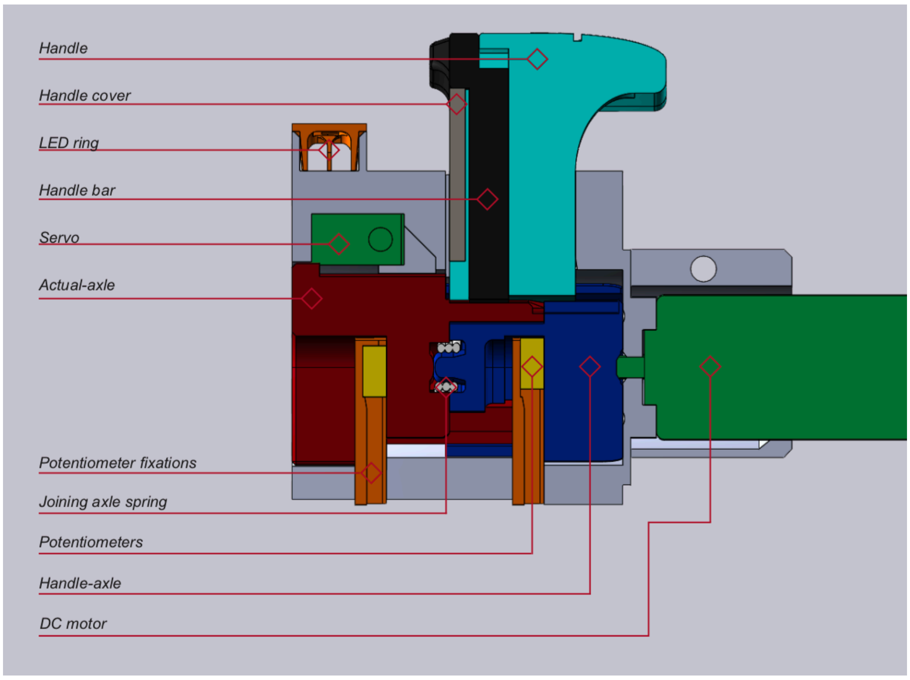
Do you think this form of interaction is realistic?

	1	2	3	4	5	6	7	
Not at all	( )	( )	( )	( )	(•)	( )	( )	Very much so

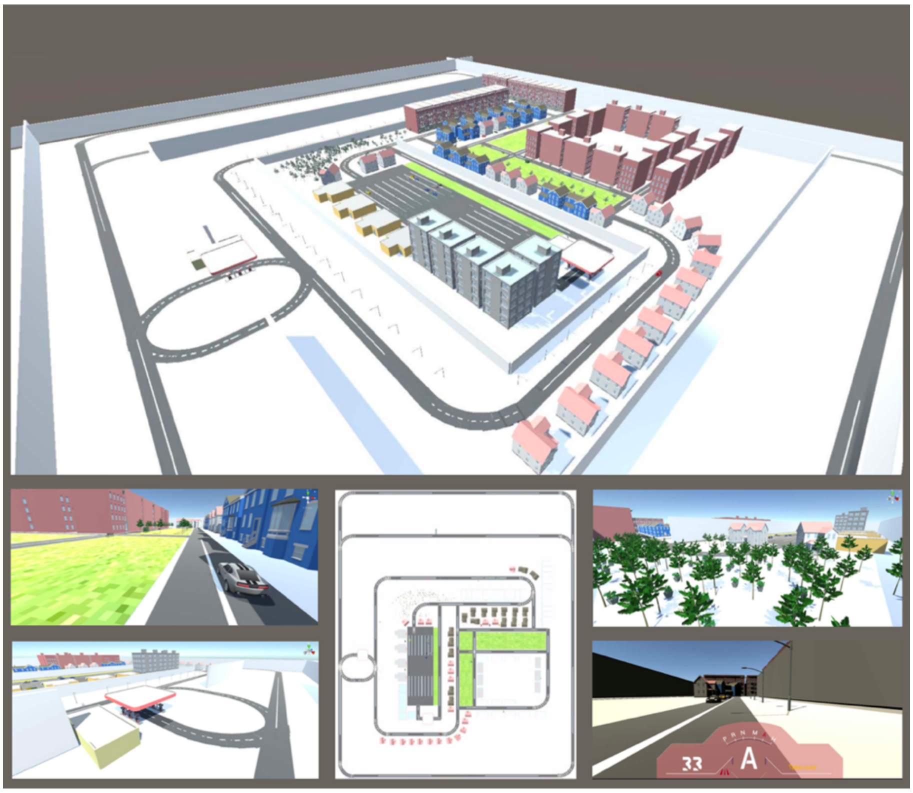

Results
Do you have a drivers licence?
8 responses
37.5%
37.5%
25%
Yes, and i drive multiple times per week
Yes, i have my licence but do not drive that often
No
Do you have any experience with automated vehicles (such as Tesla Autopilot)
8 responses
12.5%
37.5%
12.5%
37.5%
Yes, i fully understand the use of vehicular automation
Yes, but very little
No, but i know what they are capable of
No, i have never driven such vehicle in such capacity
No, but i do use cruise control
No, no experience
What was your favorite concept?
8 responses
87.5%
12.5%
The button (first)
The lever (second)
The stick (third)
What concept did you like the least? (which was the worst?)
8 responses
75%
12.5%
12.5%
The button (first)
The lever (second)
The stick (third)
Very muc
Not at all
7
6
5
4
3
2
1
0
Intuitiveness
Visual ease of use
Learnability
Reachability
Realism
Most liked
Button concept
Lever concept
Stick concept
108

Appendix 7. The prototype

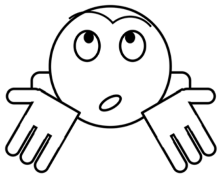
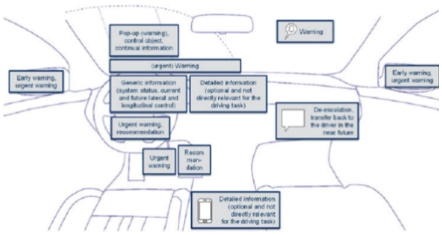
The stick concept – halfway section view



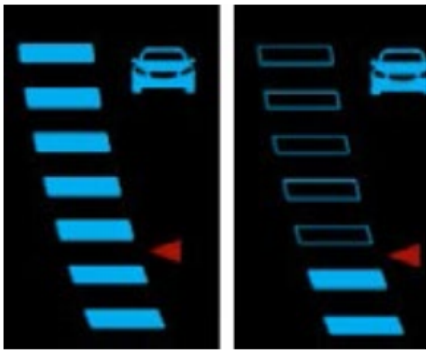
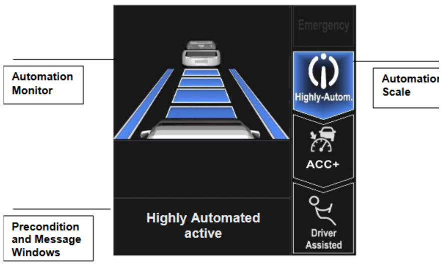
The simulated environment

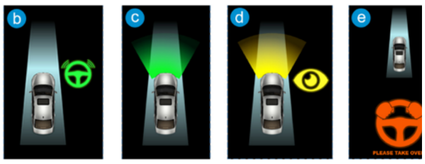
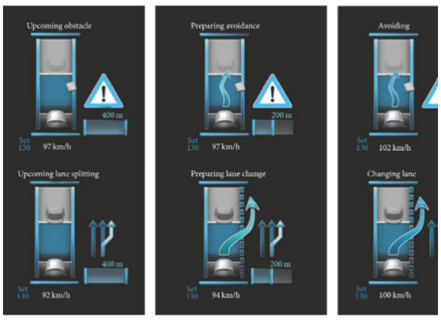


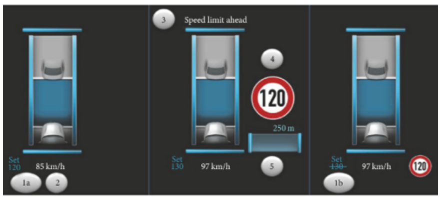
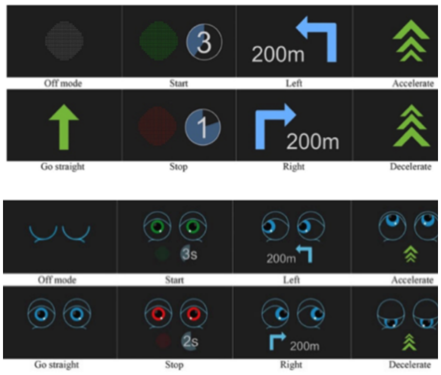
Appendix 8. Overview HMI implementations from literature

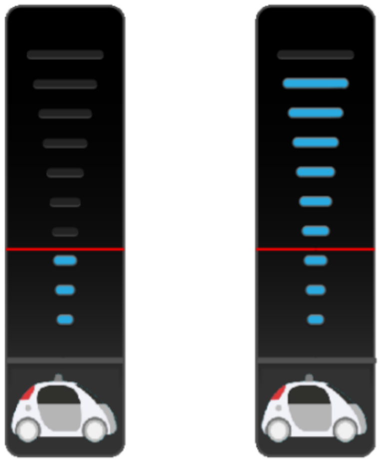
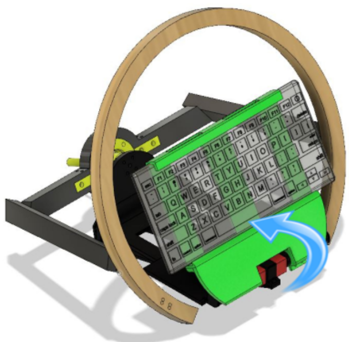
Experiment	SAE level	Description HMI implementation	Image HMI implementation	Findings
Beller et al., 2013	2	Communicating automation uncertainty using a 'confused emoticon' + indicating the reliability of the automation (reliable vs. unreliable) based on how the vehicle behaves.		With unreliable information, an uncertain automation is kept on for longer and trusted less, whereas a certain automation is generally deactivated. Minimum TTC gets larger with uncertain automation. With uncertain automation drivers intervene when TTC was low but did not brake too early or drove slower in general and solve fewer secondary tasks in critical situations but more in noncritical situations.
Cramer & Klohr, 2019	2	Announcing automated lane changes through active vehicle roll motions.		This way of communicating planned lane changes was strongly approved for supporting in supervising and system awareness. A 3.0° roll angle to the left/right was preferred for maneuvers to the left/right.
Drüke et al., 2017	2	Presents HMI 'toolkit' for adequate HMI concepts solutions, defining where and how information should be positioned and designed.		An HUD and the instrument cluster are recommended to inform on system status. Recommended is to present system status close to the wheel. The suggestions are 1) to avoid multiple use of HMI components (e.g. using a component for presenting both warnings and guidance control), 2) to keep visual and auditory messages as limited as possible, 3) to keep HMI simple (e.g. use discrete levels with reduced color selection).

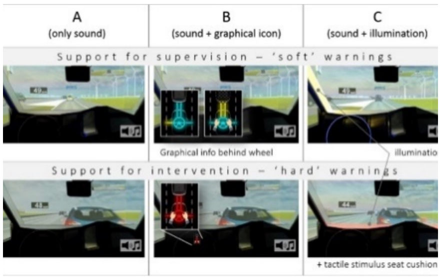
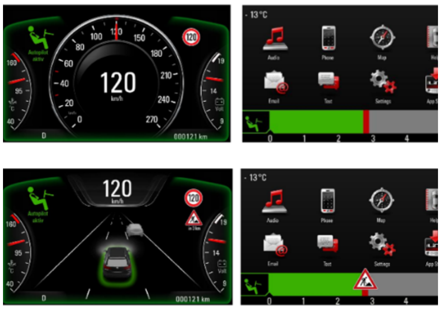
Feierle et al., 2020	4	Communicating the active automation status through a blue LED strip at the bottom of the windshield in combination with a blue icon on the instrument cluster.		Drivers pay less attention to the windshield (but not the instrument cluster) during an NDRT. Yet, it might be the case that the NDRT did not necessarily affect attention on the LED strip, but did affect the degree of looking out the window (to traffic) in general. Communicating system status was subjectively considered the most important factor to communicate by the drivers.
Feldhütter et al., 2018	2 and 3	Communicating the active automation mode through symbols in the instrument panel (blue for conditional automation vs green for partial automation) and a LED strip at the bottom of the windshield in corresponding color. Availability of a higher-level automation mode was indicated by a single acoustic gong and a text in the instrument panel.	 	The HMI was considered as positive by the drivers. Yet, participants indicated to lack auditory feedback for system malfunctions/failures. Mode awareness was not improved by this HMI.
Hecht et al., 2020a	3	Two different HMIs are examined (see images), one announces a TO minutes before (predictive HMI) while the other announces it seconds before. The HMIs are tested while varying the TO frequency between no/few/many take-overs.	  Above: Instrument cluster displaying speed limit, current speed, automation scale, navigation, take-over request and reason for take-over. Below: predictive HMI textbox with 'remaining time in automated mode'.	Frequent TOs had a negative effect on workload and acceptance, which was not mitigated by the predictive HMI. Drivers adjust their NDRT to the frequency of TOs. A questionnaire showed that the average preferred minimum time in automation should be 4.48 minutes and there was a tendency to accept longer manual drives for less TOs. Some participants indicated to miss information on remaining time in automation, map displaying automated driving sections, acoustic information on remaining time, and remaining time prior to activation of automation.

Helldin et al., 2013	2	The ability of the car to drive autonomously was communicated through a continuous representation, with a red marking indicating the threshold for when the performance of the automated driving system cannot be guaranteed anymore.		Drivers who were informed of the car uncertainty were better prepared in take-over situations. They also had a better calibration of their trust in the automatic driving system (drivers without this HMI feature showed a higher trust).
Hoeger et al., 2011	2-4	Primary display is presented in the figure. It indicates the automation monitor that contains information about the current automation status and its functionality (no bars/vehicle visible means no automation available; unfilled, white framed bars or vehicle means automation available but not active yet; blue color means automation is active and working). Additionally, there is an area for messages and warnings. Finally, there is an automation scale which indicates the current level of automation and all available automation levels (the pictogram is highlighted with a corresponding color which is white for driver assisted, light blue for semi-automated, and dark blue for highly automated, when not available the level appears in dark grey).		The focus of experiments was mostly on use cases of distraction and drowsiness. The HMI was rated well. It was concluded that the display seemed to fit well to the information requirements that drivers have when driving a highly automated vehicle. Drivers using this system took the display as the most important indicator of the automation level and said that they understood rather well in which level they were in. Yet, as downsides drivers indicated that they might become more distracted or drowsy or do not want to give control away to an automation. It is indicated that sounds might help supporting mode awareness by indicating downward and upward transitions.

Kerschbaum et al., 2015	3	The current automation mode is communicated through the form of the steering wheel, with the upper part of the steering wheel moving out of sight in highly automated driving mode, which informs that the wheel does not need to be controlled in the current driving mode.	 Image of steering wheel configuration during manual mode	With this transforming steering wheel TOT became longer (while drivers seem to do react earlier, but they act later) and lane change errors somewhat decreased. Moreover, participants rated the transforming steering wheel usable.
Large et al., 2017	4	The reliability of the automation is communicated through a 'health-bar' (see image) with quantity of health markers declining and colors changing from green to yellow to red. The bar was presented on a tablet located in the center console of the vehicle.		Participants spent less than 3% of the time monitoring the health bar. Also, participants indicated that they did not look at the health bar while engaged in a full visual task such as Netflix. Drivers did trust the system. The authors indicate that it is probably more suitable to present more detailed information concerning vehicle status, road conditions, and the status of the automation possibly also stimulating other modalities (auditory, tactile).
Lu et al., 2019	2,3	Information on automation availability and activation was provided in the dashboard. Before a TOR a request to monitor was presented in order to better prepare drivers for TO.	 b: automation available but nog yet activated, c: automation activated, d: monitoring request, e: take-over request	Participants showed better take-over performance, shorter response times to the TOR and a longer minimum time to collision. Participants also reported lower workload higher acceptance and higher trust.
Naujoks et al., 2017	3	The visual part (presented in an HUD) of the HMI is shown in the figure. The set speed, current speed, distance to vehicles ahead, messages on speed adaptation and representations of traffic events are displayed. Additionally, automated maneuvers and the type of traffic event and the remaining distance to the event are communicated		Participants were performing an NDRT. Communicating upcoming automated maneuvers additionally by speech led to a decrease in self-reported visual workload and decreased monitoring of the visual HMI. Interruptions of the NDRT were not affected by the additional speech output.

		in addition to information on the planned maneuver and the execution of the maneuver. In addition to the visual display, auditory output was presented with the announcement of traffic events either through two tones or through speech output.	 + sounds (tones or speech)	
Niu et al., 2018	5	Communication on present and future actions of the vehicle, including acceleration, deceleration, braking, turning left, and turning right was done through symbols or through symbols combined with anthropomorphic representations.	 Above: comunication through symbols, below: communication through anthropomorphic representations “When the vehicle is off mode, eyes are closed; when the vehicle is in normal driving mode, eyes are blinking at a natural rate; when the vehicle is going to start/stop, the color of the eyes changes into green/red; when the vehicle is going to turn left/right, eyes look left/right; when the vehicle is accelerating/decelerating, eyes look up/down.	Participants trusted the system using anthropomorphic representations more than when only using symbols or without any communication. Ratings for perceived anthromorphism were positively correlated with trust and liking. Therefore, the authors conclude that anthropomorphizing information may enhance trust in autonomous systems.
Pokam Meguia et al., 2019	4	Five different HUDs are examined that inform the driver on the automation’s information acquisition, information analysis, decision making and action execution.		Intention of the automation (e.g. planned maneuvers) and why, how and when they are planned do not need to be communicated. Communicating what the autonomous vehicle perceives and what it is doing is important in order to maintain situation awareness, however. Not providing any information on the automation is not beneficial for situation awareness and induces discomfort in the driver.

Ruijten et al., 2018	4	Confidence level of the automation was indicated with an icon in the interface showing either high (90%, see figure b) or low (30%, see figure a) confidence. A threshold was marked by a red bar in the system confidence bar. The other HMI that was examined used communication that provided explanation	 (a) (b) Icons used for indicating low (a) and high (b) system confidence, with the red line indicating the threshold. Other HMI used communication: voice messages were played at situations that demanded explanation (for example: “I’m giving way to the bicyclist”)	The conversational user interface was trusted, liked, and anthropomorphized more and was perceived as more intelligent than the graphical user interface. Additionally, an interface that was portrayed as more confident was scored higher on all four constructs too. The authors recommend communication about reasons for automation actions through conversational interfaces to improve transparency.
Schartmüller et al., 2019	3	Based on whether ‘productive’ (e.g. work-related) NDRTs were allowed a keyboard was usable (automated driving) or unusable (TOR or manual driving), based on the angle of the keyboard. The typed text was visible in the windshield. A baseline (notebook on the lap) was compared to the steering wheel with haptic input or with a touchscreen keyboard	 	The haptic keyboard performed best as reflected in gaze reaction, typing performance, and subjective ratings. TO times decreased by 40 percent when using the haptic keyboard as compared to the conventional notebook. It is recommended to use adaptive input devices to assist the driver and prevent mode confusion.

van den Beukel et al., 2016	2	3 HMI concepts are tested that communicate monitoring (soft warnings) and TO requests (hard warnings) ranging from only auditory warnings, to auditory and visual display icons to auditory and light bars on the sides of the windshield and a light on the steering wheel and seat vibrations.		Findings demonstrate that the light indicators concept works better to direct attention and improve situation awareness and hazard-detection. Yet, no difference in take-over performance exists between the concepts.
Wandtner, 2018	3	Three different HMI were tested: 1 basic HMI (top row in image) and 2 adaptive HMIs (bottom row in image). All versions included the following system states: manual driving, HAD available (white state), HAD active (green state), and take-over request (red state, including a warning chime). The system state was presented in the instrument cluster displays as well as in the center display. The center display also provided a preview of the automation availability and upcoming predictable take-over situations in the next 5 km. The predictive HMIs showed a graphical representation of the driving situation during automated driving + provided icons and speech stimuli to provide a situation-specific take-over notification. HMI 3 additionally took driver availability into account, i.e., implemented an adaptive warning strategy based on de NDRT,	 In the example above, the vehicle is in L3 and there are about 3km left until a take-over situation is reached. + Sound for take-over request ('warning chime') with basic HMI (above), and situation-specific take-over notifications (speech-output + icon displayed) with predictive HMI (below).	Overall, the adaptive HMI concepts including an explicit pre-alert ("notification") were beneficial in terms of NDRT disengagement, monitoring behavior and timing of system deactivation. Subjective ratings indicated a good user experience for all 3 HMI concepts. However, there were slight advantages for the adaptive HMI concepts that also included a graphical representation of the traffic situation.

		providing extra notifications when needed with visual-manual tasks and a larger time to react.		
Yang et al., 2017	3	A LED strip at the bottom of the windshield is used to provide information on the automation reliability through their color and blink frequency. TOR is communicated via the same interface.		The HMI did not lead to significant improvements in take-over quality. Yet, improvements in specific user group, such as extremely bad performing participants and young participants, were found.
Yang et al., 2018	3	A LED strip at the bottom of the windshield is used to communicate 5 different aspects: 1) automation activated through a pulse of 0.15 Hz of white light; 2) intention of automation lane change [3 times flow from middle to the right/left indicating an intended change to the right/left]); 3) blinking in faster frequency to display potential external global hazard; 4) 2 LEDs in the bar are turned blue in direction of a specific hazard (to guide attention of driver to specific hazard); 5) TOR: LED strip turns red and pulses in 1 Hz combined with auditory warning.		Compared to no HMI: LED strip resulted in 1) more trust in automation, 2) more eyes-on-road-time and more glances to windshield area; 3) better reaction to TOR which suggests higher SA.

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