BRAVE

BRidging gaps for the adoption of Automated VEhicles

No 723021

D3.1 Development Methodology Report

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Abstract

This Deliverable deals with the test methodology for the HMI development in WP 3. The Deliverable presents the theoretical concepts to be considered throughout the HMI development process, the Use Cases and the Personas to be addressed. This deliverable also describes the iterative user centric HMI development approach and the measures to be collected to evaluate the success of the HMI concepts that have been developed.

Executive summary

This Deliverable outlines the test methodology and the Use Cases for the HMI development and evaluation in WP 3.

A successful HMI concept should be useful, intuitive and easy to learn. It should further maintain the driver's situation and mode awareness and support a safe driving behaviour.

The main purpose of the HMI development process is a concept that supports drivers according to their current level of distraction and achieves high levels of acceptance and trust. This will be technical feasible due to advanced driving monitoring algorithms.

To develop and evaluate the HMI concepts a user centred approach will be applied. During the early phases, a great number of possible solutions will be compiled during expert and focus groups workshops. The most promising concepts will iteratively be tested in user studies regarding usefulness and comprehensibility. The most successful and technical feasible concepts will finally be tested in a driving simulator study at VTI.

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Abbreviations

AD: Automated Driving

ADAS: Advanced Driver Assistance Systems

AEB: Automated Emergency Break

AISS: Arnett Inventory of Sensation Seeking

DBQ: Mini Driver Behavior Questionnaire

DM: Driver Monitoring

DMS: Driver Monitoring System

ECG: Electrocardiogram

EEG: Electroencephalography

ELSI: Ethical, legal, social and social implications

EMG: Electromyography

HMI: Human Machine Interface

MLP: Mean Absolute Lateral Position

SA: Situation Awareness

SDLP: Standard Deviation of Lateral Position

SATI: SHAPE Automation Trust Index

SoA: State of the Art

SUS: System Usability Scale

TET: Time Exposed Time to Collision

TIT: Time Integrated Time to Collision

UDP: User Datagram Protocol

VRU: Vulnerable Road Users

1 Introduction

In recent years, the development of Advanced Driver Assistance Systems (ADAS) has been progressing rapidly. Conditionally and highly automated vehicles (SAE levels 3 and 4) are expected to improve road safety and make driving more efficient and comfortable. BRAVE aims at ensuring a safe and fast adoption of automated vehicles by assuring the acceptance of all relevant users, other road users and organised stakeholders. For that purpose the technical challenges are addressed in compliance with societal values, user acceptance, behavioural intentions, road safety, ethical, legal, social (ELSI) and economic considerations, following a user centric approach.

This document aims to present the user centred Human Machine Interface (HMI) development approach in WP 3. This Deliverable defines and coordinates the different activities in WP 3.

Chapter 2 introduces the theoretical fundaments and a definition of the relevant concepts to be analysed during the development process, like HMI development and driver monitoring.

Chapter 3 provides an overview on the main objectives and requirements of the HMI and driver monitoring concepts to be develop.

In *Chapter 4* a description of possible Use Case to be addressed throughout the HMI development process is given initially. Afterwards a list of the Use Cases to be further addressed during WP 3 is provided as well as a reasoning of the selection process.

Chapter 5 describes the personas to be addressed throughout WP 3 in detail.

Chapter 6 describes the iterative user centred HMI development approach and the methods to be used in detail.

This document is considered as a 'living document' as the planned studies are based on already conducted work within the project.

2 HMI and Driver Monitoring

2.1 Definitions and relevant concepts

In this chapter, relevant constructs and definitions for describing the interaction between humans and automated systems are presented.

A *human machine interface (HMI)* is a device, which is needed by a system for the functional interaction between a human and a technical system [1]. Such interface usually consists of two components, namely an input and an output device. The input device enables the user to transmit information to the technical system and to change machine settings. In context of driving these devices could be throttle, acceleration or braking pedal, steering wheel, indicator switches, knobs, buttons or touch screens. In addition, interaction via speech, gesture or gaze detection is thinkable. The output device in contrast transmits information from the system to the user. The output is presented visually, acoustically or haptically [2].

The driving task can be divided into three levels of skills and control that are related to the driver's decision making: strategical, tactical and operational [3]. The strategical level includes planning tasks by the driver like defining travel modality, evaluating risks and costs, setting trip goals and making a route choice. At the tactical level the driver monitors the traffic and makes decisions on maneuvers (e.g., turning, overtaking, avoiding obstacles or negotiations on prevailing circumstances) in accordance with trip goals and situational circumstances. At the operational level, the driver continuously controls and adapts maneuver execution (i.e. longitudinal and lateral control) based on environmental output.

Advanced Driver Assistance Systems (ADAS) support the driver during the driving task by providing information and/or processing and interpreting information for the driver [4]. ADAS can furthermore aid the driver by automating or performing several driving tasks. From a human factors perspective, automation takes place, when a machine executes a function, which was previously carried out by a human [5]. With automated driving, the division of tasks between human and machine is fundamentally changing. On the one hand the driver is released, since automation completes task that were previously performed by the human. On the other hand, the human driver faces new tasks. Instead of driving, the driver is now responsible for monitoring the automation. However, humans are not good in such tasks [6]. It is expected that driver's tend to shift attention to secondary, non-driving related tasks, such as texting, reading or surfing the internet. Such tasks are highly demanding for the users, and HMI concepts should consider the fact that drivers are not only focusing on monitoring the automation, but are likely to get distracted by secondary tasks or fail to monitor the traffic and automation adequately [7]. Thus, driver distraction remains a problem that has to be considered in the conception of driver HMI concepts by measuring distraction [8], reducing or avoiding distraction or by relocating the driver's attention to relevant stimuli in a given situation. In this context, situation awareness is a suitable construct that subsumes the driver's ability to catch relevant stimuli.

Situation awareness (SA) is defined as ”the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (p. 97) [9]. It is a crucial prerequisite for making the right decisions in a given dynamic situation. The driver has to be aware of what is happening around him in order to behave in an appropriate manner. ADAS and Automated Driving (AD) systems can influence, how involved drivers are in the driving task and the current situation regarding perception, monitoring and mental effort. Thus, they may increase or decrease drivers SA depending on how well they are designed.

In order to understand and predict the behavior of a system they are interacting with, users form an internal representation of that system, a *mental model* [10]. Based on their individual experiences and knowledge of an ADAS, drivers therefore retain their beliefs about the system's handling, behavior, properties, states and boundaries in a mental model. Correct mental models are fundamental for the appropriate operating of the ADAS [11]. However, the states or modes of an ADAS are not always visible or interpretable for the driver. Furthermore, it may not always be clear to the driver, which information of the traffic situation the ADAS receives, how the received information is processed or how it is going to influence the ADAS' reactions [12]. This is commonly described as *system transparency*. To form an appropriate mental model of the ADAS transparency is necessary. A lack of transparency or wrong mental models could result in a wrong using behavior of the ADAS. The ability of the driver “to track and to anticipate the behavior of automated systems” is defined as *mode awareness* (p. 7) [13]. For a successful interaction between the driver and the

ADAS it should always be clear what the current state of the AD system is, who currently is in control of the driving task and how the allocation of the driving task will look like in the near future.

Besides the mental model, system transparency, situation and mode awareness, *trust* in the system plays a major role in interaction between driver and AD systems. Trust is "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (p. 51) [14]. Users reject automation if they do not trust the system. If they trust the automation, they tend to rely on the system [14]. Inappropriate reliance on the system (i.e. overreliance [5]) can result in the misuse of automation. It occurs, when people rely inappropriately to automation by inadvertently violating critical assumptions of the system and thus using the system incorrectly.

Another important concept for assessing the interaction between human and machines is *usability*, which "applies to all aspects of a system with which a human might interact" [15]. In ISO 9241-210:2010 usability is defined as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-210:2010, 2015), whereby effectiveness, efficiency and satisfaction are defined as follows (ISO 9241-210:2010, 2015):

- Effectiveness: "accuracy and completeness with which users achieve specified goals"
- Efficiency: "resources expended in relation to the accuracy and completeness with which users achieve goals"
- Satisfaction: "freedom from discomfort and positive attitudes towards"

Usability can be assessed with both subjective ratings on perceived usability concerns and objective behavioral data concerning task performance. Within the BRAVE Use Cases, behavioral data can be obtained by the observation of performance with prototypes and demonstrators.

With increasing levels of automation in context of the ADAS the need for driver monitoring also increases. The driver state includes relevant information the driver is currently confronted with. This includes outlasting factors (e.g., driving experience, personality traits), intermediate-term factors (e.g., fatigue, drunkenness) and short-term factors (e.g., attention, intention) that can change within a few minutes to seconds.

Driver monitoring (DM) systems have been traditionally based on contextual information gathered from the vehicle systems, such as attending to minor corrections over the steering wheel, speed variations or interaction with on-board systems [16]. Nowadays, the miniaturization of the image capture devices, together with the unprecedented processing capabilities featured by embedded solutions [17], image-based attention monitoring systems are a trend in this area, already identified by car manufacturers [18] as one of the key innovations in future models.

Cameras and computer vision systems have been widely used for driver inattention monitoring in order to evaluate a possible risk during the driving tasks. In these terms, face and eye detection [19], head-pose analysis [20], or eye gaze analysis [21] are key information sources for the monitoring and subsequent classification of the driver's attention levels, which is closely coupled to his/her readiness to takeover during a transition from automated to manual driving modes.

2.2 Requirements and Objectives for HMI and Driver monitoring

In this chapter the requirements and objectives for the HMI and driver monitoring concepts to be developed, are presented on a general level. Chapter 5 outlines the concrete operationalization of the objectives and the methodological approach on how to achieve them.

2.2.1 ELSI Requirements

Within Deliverable D2.1 in WP 2 implications referring to the introduction of automated driving were investigated during a multidisciplinary approach. In this context ethical, legal, and social implication (ELSI), as well as the current state of literature on acceptance, safety and economic implications were summarized. In the scope of A3.1 these implications can be translated to baseline requirements for the developed HMI concepts. The defined basic requirements contain legal, societal and economic issues (ELSI) and also issues on acceptance, road safety, and ethics to be considered during the development of the HMI concepts (see Table 1).

Table 1: Overview on the ELSI requirements

Acceptance requirements	Systems developed in BRAVE should • gain the trust of the user / the public by offering the possibility to intervene via available control elements such as steering wheel, accelerator and brake pedals even at high levels of vehicle automation • enable the user to spend his / her time according to his/ her wishes • reassure the user / the public about cyber security and data privacy • be priced according to the public willingness to pay (under 5,000 €)
Road safety requirements	Within the systems developed in BRAVE • system signals should allow the driver to react in time • system feedback should be transparent and keep the driver in the loop • during driving, the driver should be reminded to engage in safety relevant tasks • interactions should be adapted to the driver state (distraction), driver characteristics (age, experience), engagement in secondary tasks and the resulting reaction times
Ethical requirements	Systems developed in BRAVE should • base their decision-making on the recommendations of experts in ethics • and also include the user perspective by considering ethical values and preferences of the European population
Legal requirements	Systems developed in BRAVE should comply with the respective national / European regulations and standards on • road safety • data gathering and data protection (General Data Protection Regulation (GDPR))
Social and economic requirements	Systems in BRAVE should be developed while being aware of • the amount of people that are included or excluded • their effects on the labour market • congestion • environment

2.2.2 Objectives for the HMI concepts

The following statements reflect additional objectives to be fulfilled by the HMI concept. The theoretical basis for those concepts was derived in chapter 2.1.

- The successful HMI is usable, intuitively understandable, and easy to learn.
- The HMI supports the driver in maintaining mode awareness. This means, that the status of the AD system and the current responsibility for the different components of the driving task (human vs. machine driving) are always clear.
- The HMI supports the driver in maintaining adequate SA while driving automated.
- In case of a possibly critical situation, the HMI supports a heavily distracted driver in relocating his/her attention to relevant situational factors.
- The HMI is usable for and accepted by a large group of users. There are no differences in acceptance concerning gender, age, and technology experience.
- The HMI does not encourage the driver to show risky behavior.
- The driver always knows the intention of the automated car and is able to anticipate its behavior.
- The HMI provides information and support depending on the driver's state.

2.2.3 Relevant Information Flow principles for the HMI

The following generic types of information are identified as relevant for the HMI. The HMI concepts developed in WP 3 shall cover those information flow principals. Information is either provided by the driver via input devices such as buttons or knobs or by the system via output devices such as displays.

General AD status

- During manual drive
    - To Driver:
        - suggestion that the automated function is available
        - general SoA information concerning driving parameters, e.g. current speed
    - From Driver:
        - Adaptation of driving parameters, e.g accelerating via gas pedal
- While AD function is active
    - To Driver
        - Cue that automated function is active (system state)
        - General SoA information concerning driving parameters
        - Target system states regarding trajectory and speed (What is going to be?)
        - Static environment (This information could be provided in advance or offline and does not depend from current situation; map and navigation information)
        - Surrounding traffic and detected objects (This information depends on what the system detects, i.e. actual position and predicted trajectory)
        - *Optional:* Sensor state
    - From driver:
        - adaptation of parametrization (e.g. speed, lane keeping system)
        - driver state / level of distraction (via driver monitoring)

Transitions

- Transition from driver (manual driving) to AD system
- Take-over request from AD system to driver (design depending on driver state and characteristics of the current situation, could be from AD to manual driving or only subtasks)
    - System failure (no warning/information)
    - Transition in critical situation (e.g. system limit is reached, driver has to take over)
    - Transition in predictable situation (e.g. approaching to highway exit)

2.3 Available Equipment

The concepts to be tested and evaluated in detail depend on the on the equipment available at the different testing sites.

2.3.1 Testbeds

FHG simulator

The vehicle interaction driving simulator laboratory at FHG consists of a Porsche Macan vehicle. The simulation of the surrounding environment is realized with the software SILAB by the Würzburg Institute for Traffic Sciences. The vehicle is surrounded by seven planar screens. Three back projections on three planar screens in front of the car enable a frontal view of 180 degrees. Three further projections simulate the two side-view mirrors and the rear-view mirror (see Figure 1).

Figure 1: The driving simulator at Fraunhofer IAO (exterior)

The current set-up of the cockpit consists of a steering wheel, 3 pedals (gas, brake, and clutch – however automatic driving can be simulated), a LCD screen as instrument cluster, a button array at the central instrument console, and a LCD Display array beneath the wind shield (see Figure 2). The display array could be used to simulate ambient lighting. Stationary Smarteye Eye-tracker and a bar-type Tobii Eye-tracker are installed and individually calibrated to the driver's position. Furthermore mobile eye tracking glasses and sensors for physiological data measurement are available that can be utilized to obtain a better understanding of users in- and outside of cars. Optional equipment can be integrated into the vehicle. A Tablet (Android or IOS) can be utilized for simulating a central integrated display to the right-hand side of the steering wheel. Additional Web-cameras can be integrated in order to monitor the driver.

Figure 2: The driving simulator at Fraunhofer IAO (interior)

VTI simulator

Sim IV at VTI has an advanced motion system [22, 23, 24] and is the only one of VTI's simulators to permit significant linear movement along both x and y axes. It is the first choice when simultaneous longitudinal and lateral acceleration is important or if a wide field of vision is a priority [23]. Cabs and passenger compartments can be exchanged quickly in Sim IV as the simulator has both a passenger car cab (Volvo XC60) and a truck cab [22]. It has three LCD displays for rear-view mirrors and a visual system comprising nine projectors.

Figure 3: Sim IV at VTI

Both vehicle cabs have corresponding, validated vehicle dynamics models to enable a realistic experience of driving and can simulate multiple types of ADASs. Additionally, both cabs come equipped with a 5-camera SmartEye eye-tracking system, enabling robust tracking of the drivers' gaze in the entire cab.

The visual system gives the driver a >180-degree forward field of vision [23]. The simulator's imaging system has a camera-based calibration **system**, making it easy to switch between different driver positions. The exact technical specifications of the driving simulator are listed in Table 2. Moreover, Sim IV is equipped with a sound system that has a 6.1 surround set-up allowing for directional sound from objects outside of the cabin [22].

Table 2: Technical specifications of Sim IV at VTI

	Sim IV
Motion system	
Pitch (degrees)	± 16,5
Roll (degrees)	± 16,5
Linear system	
Amplitude (m)	± 2,5 / ± 0,31 (surge) ± 2,3 / ± 0,32 (sway)
Velocity (m/s)	± 2,0 / ± 0,8 (surge) ± 3,0 / ± 0,8 (sway)
Acceleration (m/s^2)	± 5,0 / ± 6,5
Vibration table	*(N/A)*
Vertical motion (cm)	–
Longitudinal motion (cm)	–
Roll (degrees)	–
Pitch (degrees)	–
Visual system	
Forward view (degrees)	> 180
Rear view mirrors (LCD screens)	3
Average resolution on screen* (arc minute per line pair)	5,0** (horizontal) 2,5** (vertical)
Cabin (exchangeable)	Volvo XC60 or Volvo FH

*The human eye has 0.59 arc minute per line pair
** ± 0,5

The simulation software used in Sim IV is to a large extent based on open standards and developed in-house at VTI [22]. The software has three main components, namely: (1) the ViP Core, (2) VISIR, and (3) SIREN. ViP Core runs the simulation, contains the scenario, vehicle dynamics, and other components. VISIR renders the computer graphics but also includes script tools to generate roads. SIREN is used to produce sound; both recorded sounds such as vehicle warnings and from a sound model (engine and tire noise, other vehicles, et cetera).

Through its extensive use Sim IV has proven to be a valuable tool for human factors research [22], but also as a tool for early development of active safety functions [24].

DRIVERTIVE (UAH)

The automated vehicle DRIVERTIVE (Citroën C4) of the University of Alcalá is equipped with stereovision, Velodyne, Laser, Radar, DGPS, accelerometer, inertial system, communication capability, HMI, and access to CAN bus. The vehicle can be operated automatically, being capable of emergency breaking and avoidance manoeuvres.

2.3.2 HMI

Tech@FHG

At FHG a number of tablets (Apple and Android based, different sizes) are available.

The core element of the generic HMI is a windows computer with a java runtime based software. This software receives data from the simulator (SILAB software) via User Datagram Protocol (UDP) socket and vice versa. To display visual HMI elements a tablet, LCD display or the display array can be connected to the computer. Via the tablet, it is also possible to receive input from the user and redirect it to the simulation.

In addition, it is possible to add pictograms or HMI elements to the tachometer via a Qt-based software, which is also connected via UDP socket.

Tech@VTI

The VTI simulators have a digital instrument cluster written in C++ running on a windows PC (which may also run on Linux) consuming data from the simulator over UDP. Additional HMI can be created both in C++, C# and Java. Additionally, VTI has several tablets, and secondary screens on which secondary tasks or additional HMI can be displayed for interaction with the driver, or vehicle. It is also possible to build bespoke HMI’s that receive data over UDP.

Tech@DRIVERTIVE (UAH)

The main element for HMI onboard the DRIVERTIVE vehicle is the so-called GRAIL (GReen Assistive Interfacing Light) system, an array of diodes that is intalled on the frontal part of the vehicle (Citroën C4). GRAIL is intended to turn on, switching to green light mode, whenever a pedestrian is likely to intersect the vehicle’s trajectory, for example, when a pedestrian is standing at the curb looking for eye contact with the driver while waiting to be given way to start crossing the street. By switching GRAIL on, the ego-vehicle interacts with pedestrians and communicates its giving way to them. This HMI is intended to create a better feeling of comfort and safety on pedestrians. The GRAIL system onboard DRIVERTIVE is controlled using an Arduino-based microcontroller board that is connected with DRIVERTIVE main computer via USB. The GRAIL concept has been devised to provide an advanced means for human (i.e. Vulnerable Road Users, VRU) machine (vehicle) interaction.

2.3.3 Driver Monitoring

Tech@TREE

During the first protoype stage, facing the tests to be executed in Fraunhofer's IAO driving simulator,

Figure 4: ZED stereo camera (left). Jetson TX development kit (right)

Treelogic counts now on the following equipment for development and testing purposes.

Perception elements, required for capturing the visual information of the scene in form of images and/or three dimensional data. For the former, a pinhole form factor camera (AXIS P1204) will provide network based HD streaming of the monitored driver. Additionally, a stereoscopic camera from Stereolabs (ZED, see Figure 4 left), featuring a small form factor, is capable of providing not only 2D images, but also 3D reconstruction of the scene.

In terms of visual data processing, Treelogic has a GPU-based environment for intensive image processing and algorithm training tasks. Additionally, for the purpose of on-site computation, different nVIDIA Jetson platform kits (see Figure 4 right) are available, both for development and on-site testing stages.

As a result of the iterative testing stages, it is expected to focus on specific solutions for both perception and processing purposes, so that new equipment should be acquired, assessed and integrated.

Tech@FHG

At FHG different methods for DM are available including eye tracking (stationary SmartEye, portable Tobii bartype and Tobii glasses), camera based DM (facial expression, head tracking), physiological sensors (Electroencephalography (EEG), Electrocardiogram (ECG), Electromyography (EMG)), and rater based DM (Beobachtungsbasierte-Ablenkungs-Bewertungsskala (BABS scale) for measuring distraction [25]).

Tech@VTI

VTI has access to a number of methods to accomplish driver monitoring. The technologies include eye-tracking via a SmartEye 5 camera system, and additional, mobile eye-trackers are available. Additionally, VTI has access to physiological sensors such as EEG, ECG and EMG.

3 Personas, levels of distraction and driver monitoring

Considering the personas, demographic variables (e.g. age and gender) will not be the focus of the studies since they have already been investigated in WP 2 and summarised in the ELSI requirements. Instead, the simulator studies will be focused on different distraction levels, which reflect possible behavioural patterns during automated driving. The patterns are related to driver's needs. The distraction levels are classified based on the Fraunhofer distraction scale BABS ([25]; see Table 3). During highly automated driving mode, drivers are allowed to take up non-driving related tasks. Assuming that many drivers will make use of this possibility [7] it is necessary to develop systems that ensure safety even for drivers who are highly distracted or asleep. Recent studies show that drivers' reaction times increase when they are distracted by a secondary task prior to a takeover [26, 27]. The warning of the system could be adapted to the driver's current state, i.e. be more salient in case of a distracted driver and less salient in case of a driver who is not distracted (Table 3).

Table 3: Distraction level and suitable warning alarm

Distraction level	Driver's state or behaviour	Warning alarm
Low	Driver is looking at the road or at on-board screens, but the hands are not placed at the steering wheel.	Appropriate light in the dashboard
Middle	Driver gets involved in non-driving related tasks: - Talking to passengers or by phone. - Reading, texting or similar. - Using the mirror for making up or similar. - Others	Low level sound alarm or low seat vibration
Middle	Driver is falling asleep or responses incorrect or too slow to transition alert	Activate high level alarm state, initiate minimum risk manoeuvre.
High	Driver is asleep or non-responsive to transition alert	High level sound alarm or intense seat vibration and or initiate safety manoeuvre.

It is assumed, that the driver's current distraction level is going to be monitored and recognized via cameras by the final system. Hence, it is possible to design HMI concepts that are adaptable to the driver's state.

In the following, three different personas are described in a stereotypical way in order to reflect and operationalize different distraction levels:

Andy Sleepyhead (high distraction): Andy is likely to get distracted while driving in highly automated mode, but prefers to take a nap or sleep. He falls asleep very fast, is lethargic after waking up, and needs some time to regain SA.

Justin Time (medium distraction): Justin is always on time and wants to work concentrated while driving in highly automated mode. He wants to use the time while driving in a productive way and thus engages in non-driving related activities such as, reading emails, or doing office work. Other distraction tasks could be watching movies, playing video games, social media or texting. He trusts the automation and is expected to have trouble to perform well and regain SA during time sensitive takeover situations.

Aylin Control (low to no distraction): Aylin always wants to be in control and is sceptical about automated driving. She only performs easy non-driving related tasks while driving in highly automated mode in order to be able to take over control in case of take over request or system failure. Possible tasks are looking out the window, listening to music, radio or podcasts, and smoking.

4 Testing Use Cases and scenarios

4.1 Original BRAVE Use Cases

For the implementation of the user tests, a number of specific Use Cases have been considered and listed in the BRAVE project proposal. The Use Cases to be tested in the BRAVE project are listed in Table 4.

Table 4: Description of the original BRAVE Use Cases

Description	Actors	Driver intervention required?
Automated Emergency Break (AEB) in presence of VRU, pedestrians and cyclists (6 different situations based on EuroNCAP 2016 & 2018)	Ego-Vehicle, VRU (pedestrian or cyclist)	No
Automated parking in case of VRU or pedestrians proximity: The automated car will execute an automated parking manoeuver when ordered by the driver. The parking manoeuver can be automatically interrupted or paused if a pedestrian approaches the vehicle entering the drivable area while parking. If the danger disappears (the pedestrian moves away), the automatic parking manoeuver will resume.	Ego-Vehicle, VRU	No
Automated Driving (AD) in case of aggressive entering vehicles: Upon detection of the entering vehicle the automated vehicle will execute the appropriate merging manoeuver accounting for the position, velocity, and acceleration of the vehicle entering the highway.	Ego-Vehicle, Vehicle	No
AD in case of changing and difficult perception conditions (e.g. tunnels): A number of vehicles will drive in parallel while approaching a tunnel. Before entering the tunnel, some of the vehicles will change lane, due to poor perception conditions, from the left-most to the centre lane. The automated vehicle will react accordingly, implementing the most appropriate manoeuver (velocity profile) in terms of safety and comfort.	Ego-Vehicle, Vehicles	No
AD in case of manoeuvres and transitions at obstacles: The reaction of the automated vehicle in complex traffic situations will be tested in this use case. Thus, the ego-vehicle will face an obstacle on its lane (a stopped car, simulating a technical failure). The ego-vehicle will then assess whether or not there is free space on the adjoining lane to accomplish a safe lane change manoeuver. In the positive case, the automated vehicle will accomplish an automatic lane change. Otherwise, the automated vehicle will diminish speed until coming to a full stop if necessary.	Ego-Vehicle, Vehicles	No

4.2 Final Use Cases to be addressed

Together with the project partners, it was discussed that the VRU Use Cases are especially relevant for the HMI design together with the DMS implementation, because VRU interaction during automated driving have not been analysed sufficiently during prior research.

The AEB Use Cases originally proposed are not the most suitable to propose and evaluate a new HMI design coupled to a driver attention monitoring system. AEB represents basic safety functions and does not require interaction with the driver.

It was therefore decided to build upon Use Cases involving vehicle approaching VRU (AEB in presence of VRU, pedestrians and cyclists), attending to two main factors, namely driver distraction level and risk or criticality of the scenario. It should also be noted that this approach will partially address the other VRU-involved use case (Automated parking in case of VRU or pedestrians proximity). In terms of HMI and DMS design, both use cases share i) the driver monitoring component, ii) the HMI design and iii) the VRU trajectory prediction.

The following Use Cases were compiled and will be further addressed throughout WP 3, driving the design and development of both HMI and DMS components:

- **Use Case VRU 1:** The ego vehicle approaches the VRU. The VRU is detected by the vehicle and is moving parallel to ego vehicles trajectory. This scenario is a low risk scenario because there is no real danger for the driver and passengers of the ego vehicle or the VRU at any time.
- **Use Case VRU 2:** The ego vehicle approaches the VRU. The VRU is detected by the vehicle and it is predicted that the VRU will cross the trajectory of the ego vehicle. This scenario is a high risk scenario because there is potential danger if the driver of the ego vehicle cannot take over control in time.

5 Iterative User Centric HMI Development

5.1 Iterative approach in designing HMI concepts

It is widely recognized that for designing highly usable interfaces or products, an iterative approach is indispensable [15], since even for the best designers it is impossible to design a perfect user interface from the start. The lead idea is that a first version of design concepts is tested and evaluated by users. According to their feedback and/or test results the concepts are redesigned and improved. Then the process starts iteratively from the beginning until a satisfying level is reached.

Users should be integrated during early stages of the product development process because the earlier problems or misconceptions regarding usage or perception of users are detected, the easier these can be taken into account and costly setbacks due to improvements later in the development process can be avoided [11]. The principle of iteration has also settled down in the standard ISO-9241-210 (see Figure 5), and serves as blueprint for an iterative approach in WP 3.

According to ISO the process starts with an overall choice to make use of the process. In a first step the context of use is analyzed and specified. Characteristics about the user (i.e. motives and needs), tasks, and the context, where the system will be used, are collected. This step cannot only be applied to the development of systems but also in order to improve existing systems. In the next step user and organizational requirements a derived. Subsequently a design solution that meets the requirements is developed. At this step it is also possible to develop a prototype or mockup version that is iteratively tested and improved. In the last step the final design is evaluated considering the afore postulated requirements.

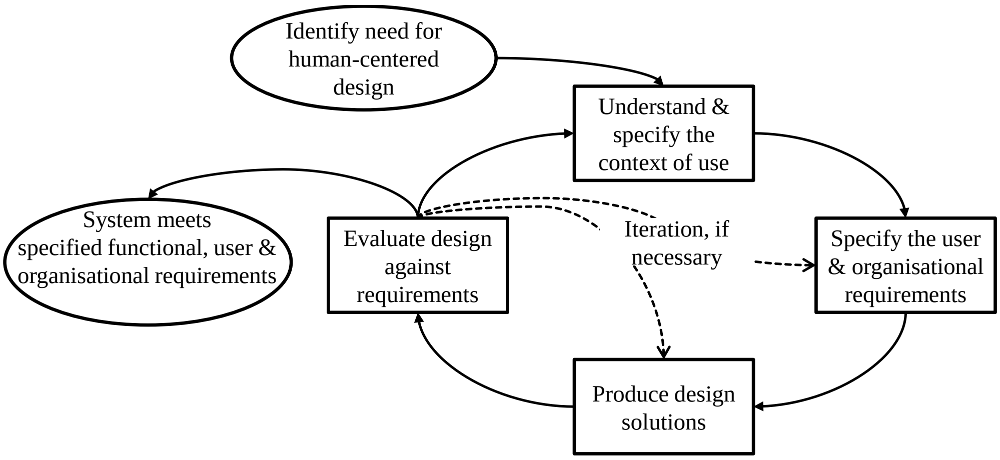

Figure 5: ISO 9241-210 User centered design approach (own representation based on ISO 9241-210:2010, 2015).

When the system does not meet the requirements, it can either be improved (especially when there are only small derivations) or the whole process starts again at the first step and the specifications and requirements are adjusted until the developed system meets all requirements (see ISO 9241-210:2010, 2015). The aim of iteration is to design a HMI concept characterized by high usability and thus helping users to develop an adequate mental model of the HMI and to act according to the maneuver recommendations.

5.2 Success Criteria

Chapter 2.2 provided an outline on the general requirements and objectives of the HMI concept and the driver monitoring. This chapter provides an overview of the objective and subjective measures to define successful design concepts during the different phases of the development process.

5.2.1 Objective measures

During the user tests (step 3 in chapter 5.4) the number of correctly understood concepts is going to be evaluated. Only concepts that are understood by at least 80% of all participants will be accepted for further testing in the driving simulator. Other concepts need to be redesigned and tested afterwards.

During the driving simulator studies (step 4 in chapter 5.4), driving parameters based on the SAE J2944 standard are going to be calculated. Depending on the Use Cases some of the following objective measures will be analysed:

- **Time Exposed Time to Collision (TET)**, defined as the duration of time over which the time to collision is below an undesired threshold [s].
- **Time Integrated Time to Collision (TIT)**, defined as the time interval over which the time to collision is less than some undesired threshold weighted by how far below that threshold the time to collision is at each moment [s].
- **Distance Headway**, defined as the longitudinal distance along the way travelled between two vehicles measured from the same common feature of both vehicles [m].
- **Time Headway**, defined time interval between two vehicles measured from the same common feature of both vehicles [s].
- **Mean absolute lateral position (MLP)**, measure to describe lane keeping accuracy [m].
- **Standard Deviation of Lane position (SDLP)**, measure to describe the variability in lane positioning [m].
- Steering reaction time, defined as the time between a first conscious steering input over a certain threshold [s].
- **Driver's behaviour**, i.e. gaze at relevant objects, interventions like hitting brake pedal
- **Driver's reaction time** [s]

5.2.2 Subjective measures

During the user tests (step 3 in chapter 5.4) users will answer questions considering the acceptance and trust regarding the developed design concepts.

During the driver simulator studies (step 4 in chapter 5.4) the users will fill in some of the listed questionnaires:

- **SHAPE Automation Trust Index (SATI)** – a human factors technique to measure trust in automated systems covering the areas reliability, accuracy, comprehensibility, confidence, liking, and robustness (7-point likert scale; never – always)
- **Van Der Laan Technology Acceptance Scale** – 9 items (pairs of adjectives along 5 point scale) questionnaire to measure usefulness and satisfaction of the tested systems
- **System Usability Scale** – 10 items questionnaire (strongly agree – strongly disagree) to measure usability
- **Nasa Raw-Task Load** – 6 item questionnaire to evaluate perceived workload
- **Arnett Inventory of Sensation Seeking (AISS)** – 20 item questionnaire to assess sensation seeking (along the subscales Novelty and Intensity)
- **The mini Driver Behavior Questionnaire (DBQ)** – 12 item questionnaire to assess number of self-reported aberrant driving behaviour in traffic
- **Driver Skill Inventory** – 13 item questionnaire to assess self-reported driving performance
- **Generic willingness to use technology scale** (trust in tech, confidence etc.)

5.2.3 Usability related measures

During the user tests and the driving simulator studies (step 3 and 4 in chapter 5.4) the following measures are going to be analysed:

- Comprehensibility of HMI elements (e.g. pictograms)
- Preferences concerning different variations of HMI elements
- Ability to discriminate different stimuli (e.g. warning sounds)
- Task performance (appropriate behaviour)

5.3 Participants

Participants will be recruited according to the suggestions in Deliverable 8.1 and 8.2. Prior to participation they will be informed about the risks associated with participating and afterwards a full debriefing will be provided. The study will comply with the American Psychological Association Code of Ethics. There are no restrictions regarding participation concerning age or gender. The only requirement for participating in the studies is a valid driver's licence.

5.4 Iterative approach used in WP 3

To develop suitable HMI concepts for the defined Use Cases a four-step procedure will be conducted following the described iterative user centered design approach in chapter 5.1. During the early phase of the iterative user centred development approach a variety of concepts will be evaluated according to acceptance and trust. Based on those insights a selection of promising concepts, that are technical feasible, will be tested in depth during two driving simulator studies, one located at FHG and one located at VTI. The (prototypical) concepts that are not technically feasible but achieve high levels of acceptance and trust will be documented.

1) Workshop with BRAVE experts
    a. **Purpose:** Define possible display concepts for the selected Use Cases → Does the HMI cover Use Case specific requirements and is it in line with respective guidelines?
    b. **Sample:** 4-5 experts
    c. **Outcome:** Initial design concepts to be further tested and refined with user input
2) Focus group workshops
    a. Focus group workshop 1
        i. **Purpose:** Create initial design ideas with a user group of females
        ii. **Sample:** 4-5 users, female, age range 18-65 years
    b. Focus group workshop 2
        i. **Purpose:** Create initial design ideas with a user group of males
        ii. **Sample:** 4-5 users, male, age range 18-65 years
    c. Focus group workshop 3
        i. **Purpose:** Create initial design ideas and validate results of a. and b. with BRAVE experts
        ii. **Research Questions:** Refining concepts regarding technical feasibility during the project
        iii. **Sample:** 4-5 experts
    d. **Outcome:** Number of concepts to be refined according to usability criteria
3) User tests, redesign and interactive driving simulator experience @ FHG
    a. User Test 1
        i. **Purpose:** Test the initial design ideas elaborated in 2) via paper prototypes
        ii. **Sample:** 4-5 potential users, male or female, age range 18-65 years
    b. User Test 2
        i. **Purpose:** Test an improved version of the design ideas via paper prototypes
        ii. **Sample:** 4-5 potential users, male or female, age range 18-65 years
    c. If necessary: do one more iteration or let users decide between two variants of a. and b.
    d. **Outcome:** Refined concepts to be further tested and evaluated in the simulator study at VTI

4) Interactive driving simulator experience @ VTI
   a. **Purpose:** Evaluation of the complete HMI and DMS implementation
   b. **Research Question:** How much attention is necessary for a safe handling of the situation? At what point is it necessary to warn / inform the driver and when can it be assumed that the driver understands the situation?
   c. **Sample:** 24 drivers (equally distributed between men and women)
   d. **Design:** 3 (distraction: no vs. low vs. high) x 2 (criticality of VRU situation: non-critical vs. critical) within subjects
   e. **Short description:** After a baseline trial in manual mode, containing a non-critical and a critical VRU situation drivers experience six different driving situations that will vary according to distraction and criticality. Based on these experiences an evaluation of the DMS and the developed HMI concept will be undertaken.
   f. **Measures:** see chapter 5.2
5) Further improvements of the concept
   a. **Purpose:** DMS implementation for selected Use Cases at DRIVETIVE.
   b. **Research Question:** How much attention is necessary for a safe handling of the situation? Is it possible to validate gaze behavior of drivers/passengers towards VRUs? Can the driver monitoring information be combined with VRU detection information?
   c. **Short description:** When AD vehicle performs the test track, the gaze behavior towards VRUs of drivers and/or passengers inside the vehicle is measured. The main outcome would be a better understanding of whether the driver monitoring system is also capable to provide real time information on potential drivers gaze behavior and thus recognition of VRUs.
   d. **Measures:** see chapter 5.2

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