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Deliverable 2.1

An Overview of Interfaces for Automated Vehicles (inside/outside)

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Table of Contents

List of Abbreviations

Acronym	Description
ACC	Automated Vehicle Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving System
aHMI	Automation Human Machine Interface
AI	Artificial Intelligence
AR	Augmented Reality
AV	Automated Vehicle
dHMI	Dynamic Human Machine Interface
DL	Deep Learning
DMS	Driver Monitoring System
EEG	Electroencephalography
eHMI	External Human Machine Interface
ERPs	Event-Related Potentials
ESR	Early Stage Researchers
fMRI	Functional Magnetic Resonance
fNIRs	Functional Near Infrared Spectroscopy
FoV	Field of View
HMI	Human Machine Interface
HUD	Head Up Display
iHMI	Infotainment or internal Human Machine Interface
IoT	Internet of things
ISO	International Organization for Standardization
ITN	Innovative Training Networks
ML	Machine Learning
MRM	Minimum Risk Manoeuvre
NDRT	Non-Driving Related Tasks
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OEM	Original Equipment Manufacturer

PEOU	Perceived Ease of Use
PET	Positron Emission Tomography
SAE	Society of Automotive Engineers
tDCS	Transcranial Direct Current Stimulation
TMS	Transcranial Magnetic Stimulation
ToR	Take Over Request
UNECE	United Nations Economic Commission for Europe
vHMI	Vehicle Human Machine Interface
VR	Virtual Reality
VRU	Vulnerable Road User
XR	Extended Reality

Executive Summary

This Deliverable starts with a short overview of the design principles and guidelines developed for current Human Machine Interfaces (HMIs), which are predominantly developed for manually driven vehicles, or those with a number of Advanced Driver Assistance Systems (ADAS), at SAE Levels 0 and 1 (SAE, 2018). It then provides an overview of how the addition of more capable systems, and the move to higher levels of vehicle automation, is changing the role the human inside an Automated Vehicle (AV), and the ways in which future automated vehicles at higher levels of automation (SAE level 4 and 5) must communicate with other road users, in the absence of an “in charge” human driver.

It is argued that such changes in the role of the driver, and more transfer of control to the AV and its different functionalities, means that there will be more emphasis on the roles and responsibilities of HMIs for future AVs. In parallel, the multifaceted nature of these HMI, presented from different locations, both in and outside the vehicles, using a variety of modalities, and engaging drivers in a two-way interaction, means that a new set of design guidelines are required, to ensure that the humans interacting with AVs (inside and outside the vehicle) are not distracted and overloaded, that they remain situation aware and understand the capabilities and limitations of the system, having the right mental model of system capabilities and their responsibilities, as responsible road users, at all times

Following a summary of suggested frameworks and design principles which highlight the significant change needed for new AV HMIs, an overview of results from studies investigating human interaction with internal (or iHMIs), and external (or eHMIs), is provided, with examples of new and innovative methods of communication between humans and their vehicles.

The Deliverable then provides a summary of the innovative approaches that will be tackled by the ESRs of the project, which focus on factors such as use of AI and AR for future design of more intuitive and transparent HMI, studying how HMI can support the long term interaction of humans with AVs, and the use of neuroergonomic methods for developing safer HMIs. The Deliverable concludes by summarising how each ESR’s project contributes to the development of HMIs for future AVs.

1 The definition, use and design guidelines for vehicle HMIs

For disciplines which study human interaction with machines or computers (Human Machine Interaction and Human Computer Interaction, respectively) there is normally some form of **interface** between the human and the machine/computer, which acts as a medium for sharing information and messages, aiding the communication between the two “agents”. In the context of the current Deliverable, HMI will be used to describe the range of Human Machine Interfaces available and proposed for current and future vehicles.

In terms of in-vehicle-based HMIs, and especially those at lower levels of automation (SAE Level 1, SAE, 2018) or manual driving (SAE Level 0), the focus has traditionally been on presentation of visual information/warnings/advice to the driver, using the vehicle dashboard. Normally, this includes information about vehicle-based behaviour, such as its speed, fuel level, engine temperature etc., with additional use of the central console, or Head Up Displays, as the amount of information offered by the vehicle’s systems has increased (see Figure 1; Bach, Jaeger, Skov, & Thomassen, 2008; Maciej & Vollrath, 2009; Sodnik, Dicke, Tomažič, & Billinghurst, 2008).

Figure 1 – A typical vehicle dashboard, showing speedometer and tachometer (left,AnyRGB) use of the central console for information (centre, Tesla, 2017), and a Head Up Display (right) for presentation of navigation information in vehicles (Fogelson, 2017)

In the past 20-plus years, a large amount of work has been conducted by researchers and regulators, contributing to the preparation of suitable guidelines for the safe implementation and activation of these “in-vehicle” systems (see Jordan, 1998; Naujoks, Wiedemann, Schömig, Hergeth, & Keinath, 2019; Nielsen & Molich, 1990; Shneiderman & Plaisant, 2010). The aim has been to ensure these displays impose a minimal degree of driver distraction, and aid drivers by protecting the right level of alertness, workload (Brookhuis & de Waard, 2001), and situation awareness (Endsley, 1995), i.e. ensuring that these systems do not take the human attention away from the main driving task. Good HMI design is clearly important for road safety, and enhances usability, trust, and acceptance by drivers (Kraft, Maag, & Baumann, 2019).

One document frequently used by HMI developers is the European Statement of Principles on HMI (Commission of the European Communities, 2000), with recommendations about interface positioning, the physical appearance of material displayed (colour, luminance, number of letters/numbers/symbols etc.), as well as recommending how visual symbols can help conserve physical space (Gittins, 1986), ease understanding (Rettenmaier, Albers, & Bengler, 2020), and assist individuals with dyslexic problems (Kim & Wiseheart, 2017). Guidelines also exist about the frequency, volume, duration and rate of auditory messages. Here, assessment of HMI, and their suitability, is based on their effect on driving behaviour and safety (Green, 2008), with many techniques also standardised by international organisations such as ISO (Commission of the European Communities, 2000) (e.g. van der Horst, 2004).

One recent set of simple and effective guidelines, providing basic principles for designing displays to support human information processing, and to maintain suitable mental workload, is outlined by Lee, Wickens, Liu and Boyle (2017), in their book on *Designing for People*. Here, four main recommendations are provided regarding the design of individual displays, as follows:

1. Make displays legible (or audible),
2. Make displays discriminable
3. Support top-down processing
4. Exploit redundancy gain

While such guidelines have been helpful for design of vehicle displays, it can be argued that much of the effort in recent years continues to focus on design guidelines for *individual* displays, *inside* vehicles. Yet, the recent surge in technological innovations have pushed the boundaries for new forms of communication to a new realm. For example, communication **to the driver** by the vehicle is now complemented by reciprocal possibilities of the driver communicating back **to the vehicle,** using voice (Embedded Computing Design, 2020; Mehler, et al., 2016) and gesture recognition (Pickering, Burnham, & Richardson, 2007). In addition, communication to the driver, by the vehicle, is no longer limited to presentation of visual information from one location in the dashboard and/or centre console, with other channels such as auditory and tactile feedback commonly used. Thanks to focussed research in this area from a range of disciplines, such as psychology and neuroscience, the value of multimodal and directional messaging is also realised (Ho, Reed, & Spence, 2007), with some studies suggesting that multimodal messaging delivers the highest urgency, with fastest reaction time in terms of drivers' performance (Baldwin & Lewis, 2014; Politis, Brewster, & Pollick, 2014). Finally, haptic feedback, using the vehicle's physical instruments (driver seat, steering wheel and pedals) has also been used as a method to guide driver actions and behaviour (Allison, Fleming, Yan, Lot, & Stanton, 2020; Jamson, Hibberd, & Merat, 2013; Mulder, Abbink, & Boer, 2008). However, there are no clear guidelines about the use of different modalities for different types of messages, although Bengler and colleagues (2020) claim that visual elements should be used more for monitoring and communicating the state of vehicle automation, whereas tactile and auditory cues are more suitable for conveying warnings.

While an exhaustive list of these HMIs, and the results of their success, in terms of adhering to the recommended design guidelines, cannot be discussed at length in this document, it is important to understand how the relatively easy implementation of this large range of technological innovations is changing the means by which machines and humans can communicate with each other, and how such developments are changing our interaction and relationship with our cars, both as drivers and as other road users. One key question for the ESRs of SHAPEIT is whether new guidelines are required in this age of ubiquitous computing, since it can be argued that these technologies are moving our visual attention and monitoring away from the dashboard and forward roadway, to new areas, both inside and outside the vehicle. In addition, reducing, and eventually, removing, the drivers' control of the vehicle will mean that our interactions as vulnerable road users sharing the same road space with these AVs will also change, which begs the development of new design guidelines for an entirely new range of interfaces for future vehicles. This topic is discussed further in the next section.

2 The need for new concepts and frameworks for Automated Vehicle HMIs

As the addition of systems and technologies in our vehicles increases, and vehicles become more automated, our relationship, and the communication and interaction strategies used between us and our vehicles changes, where we will need to rely more and more on HMIs to inform us of our vehicle (and its systems') behaviours, capabilities and limitations (see Figure 2) .

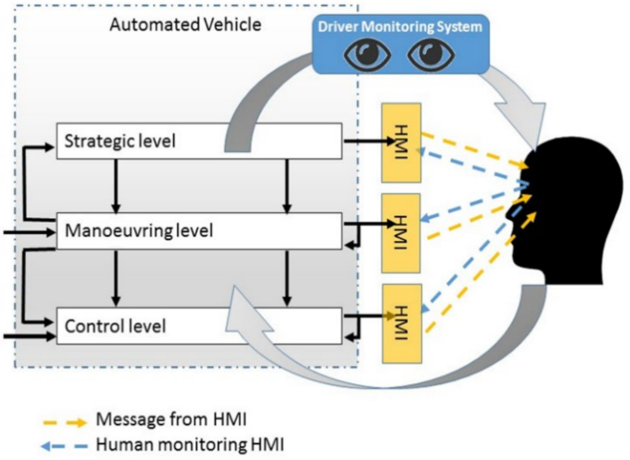

Figure 2 – The changing role of the human with the introduction of automation in vehicles, which moves the control, manoeuvring and strategic control of the vehicle to the automated systems (from Merat & Louw, 2020)

As outlined above, the focus of much of the development during the past 15 or so years has been on technologies which help the human **inside** the vehicle (i.e. the driver). However, as the capabilities of the automated vehicle increase (SAE Levels 4 and 5), the human is no longer in control of the vehicle. Indeed, some forms of such automated vehicles, typically "driverless" shuttles, are already in use in cities airports and carparks around the world, and no longer include conventional controls needed for driving, such as steering wheels and pedals (Figure 3). Here, any communication traditionally managed by the human should ideally be managed by the AV, in order for the AV to safely and efficiently, navigate in a mixed traffic environment with other road users (pedestrians, cyclists, powered two wheelers, and drivers of other vehicles).

The need for some form of **external** communication by the AV (eHMI) was first highlighted by the European project CityMobil2 (see Merat, Louw, Madigan, Wilbrink, & Schieben, 2018), where it was argued that the explicit messages exchanged between drivers and other road users (hand/head gestures, eye contact, flashing lights and honking horns) must, in the future, be portrayed by AVs, if they are to be successfully integrated in a mixed-traffic environment. The interest in this topic has been extensive in recent years, including focused work conducted by the European interACT project (see https://www.interact-roadautomation.eu/about-interact/ and Figure 4)

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Figure 3 – Example of interior of highly automated "driverless" shuttle with no driver controls (left) and the Citymobil2 shuttle (right, Merat et al., 2016)

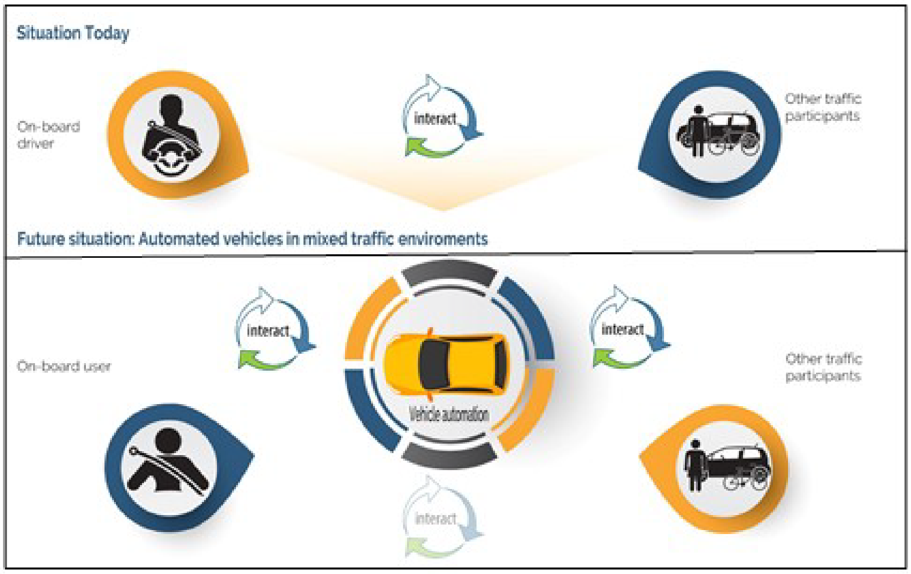

Figure 4 – The evolution of interactions between drivers and other road users today (top) and in the future, bottom (Figure from the interACT project website)

As the number, and variety, of methods by which an AV can communicate with humans increases, there is a real challenge for designers, and OEMs alike, to ensure that the basic design principles of a successful HMI (outlined in Section 1) are achieved, and that humans are not unnecessarily distracted, overloaded, or confused by the range of messages presented. Studies suggest that too many messages and warnings can be distracting and annoying to drivers, leading to system deactivation, which could in turn remove the benefit of systems employed to improve safety (see e.g. Maltz & Shinar, 2004; Navarro et al., 2016). Other issues important for consideration here include the timing, modality, and location of such messages for future AVs, to name a few.

To address this challenge, Bengler and colleagues (Bengler, Rettenmaier, Fritz, & Feierle, 2020) suggest that separating the range of HMIs available to future AVs into more specific task-related strategies might be useful for understanding the underlying cognitive elements imposed by each (Bengler et al., 2020). A framework is proposed, which categorises HMIs into subsections, based on the relationship between the agent (i.e., driver and road user) and the AV (see Figure 5). Here, reference to dynamic HMI (dHMI) is used to recognise the need for a “multi-actor” communication channel between the humans inside the vehicle (whether they are drivers who are occasionally in control of the vehicle at lower levels of automation – SAE Levels 1-3) or passengers in a Level 4/5 vehicle, and other road users. This framework also considers a range of *influencing factors* that will effect HMIs, such as “static”, infrastructure-based, elements of road type and traffic rules, as well as “dynamic” factors, such as weather, lighting conditions and type (e.g. personality/age/experience/gender) of driver/passengers/road users.

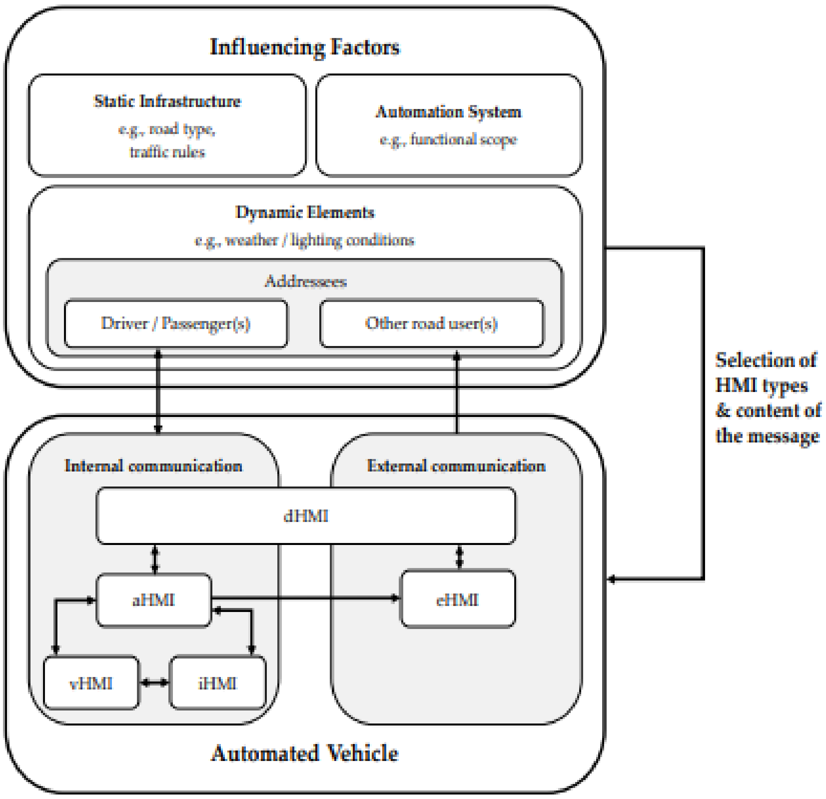

Figure 5 – The HMI framework for future AVs proposed by Bengler et al. 2020

A novel concept here is the introduction of *dHMI*, which is partly related to previous research stating that vehicle movements are a main communication strategy for mediating intentions (Risto, Emmenegger, Vinkhuyzen, Cefkin, & Hollan, 2017). Therefore, when a road user meets the AV, they must be able to infer the intended driving behaviour of the AV, and the dHMI should consider road users' experiences and expectations in order to ensure safety. A challenge with dHMI is the correct, and suitable, integration of all the messages from the different sources, into a holistic communication strategy for internal and external HMIs. Benglar et al. (2020) also divide the various internally presented messages by the AV to the "driver" into three main categories, where vehicle or vHMI provide vehicle-based information, such as tyre pressure, fuel level or engine information, iHMI covers information from the vehicle's *infotainment* system and aHMI is linked to information about the automated system itself, e.g. to ensure mode awareness.

This proposed framework by Bengler and colleagues is quite useful for design of future studies of AV interaction with humans, since, for example, as highlighted by Carsten & Martens (2019) there is currently a distinct lack of well-defined, systematic, design guidelines for the development of suitable HMIs in the context of automated vehicles. This framework may indeed be of benefit to the SHAPE-IT ESRs, especially those considering scenarios which require the three-way interaction between humans as other road users (cyclists and pedestrians), the AV, and humans inside a highly automated AV (SAE L3-5).

However, since not much research has been conducted on the range of HMIs offered by the Bengler et al. (2020) framework, this document will focus on what is beginning to emerge about human response to, and interactions with, two main categories of HMI relevant to AVs, namely, **iHMI**, which include all means of communication between the vehicle and the human inside the vehicle, and **eHMI**, which concern all forms of communication by the AV to other road users. The next two sections provide a brief overview of some recent studies related to these two interface categories.

2.1 Internal or iHMI

In terms of internal HMI for drivers, with the gradual, and continued, inclusion of additional, and progressively more capable, Advanced Driver Assistance Systems (ADAS), drivers' roles in the vehicle is changing, from one of a controller of the moment-to-moment driving task (steering, accelerating, braking), to an observer, who needs to monitor a range of manoeuvres and functionalities (see Merat et al., 2018; Van den Beukel & Van der Voort, 2014).

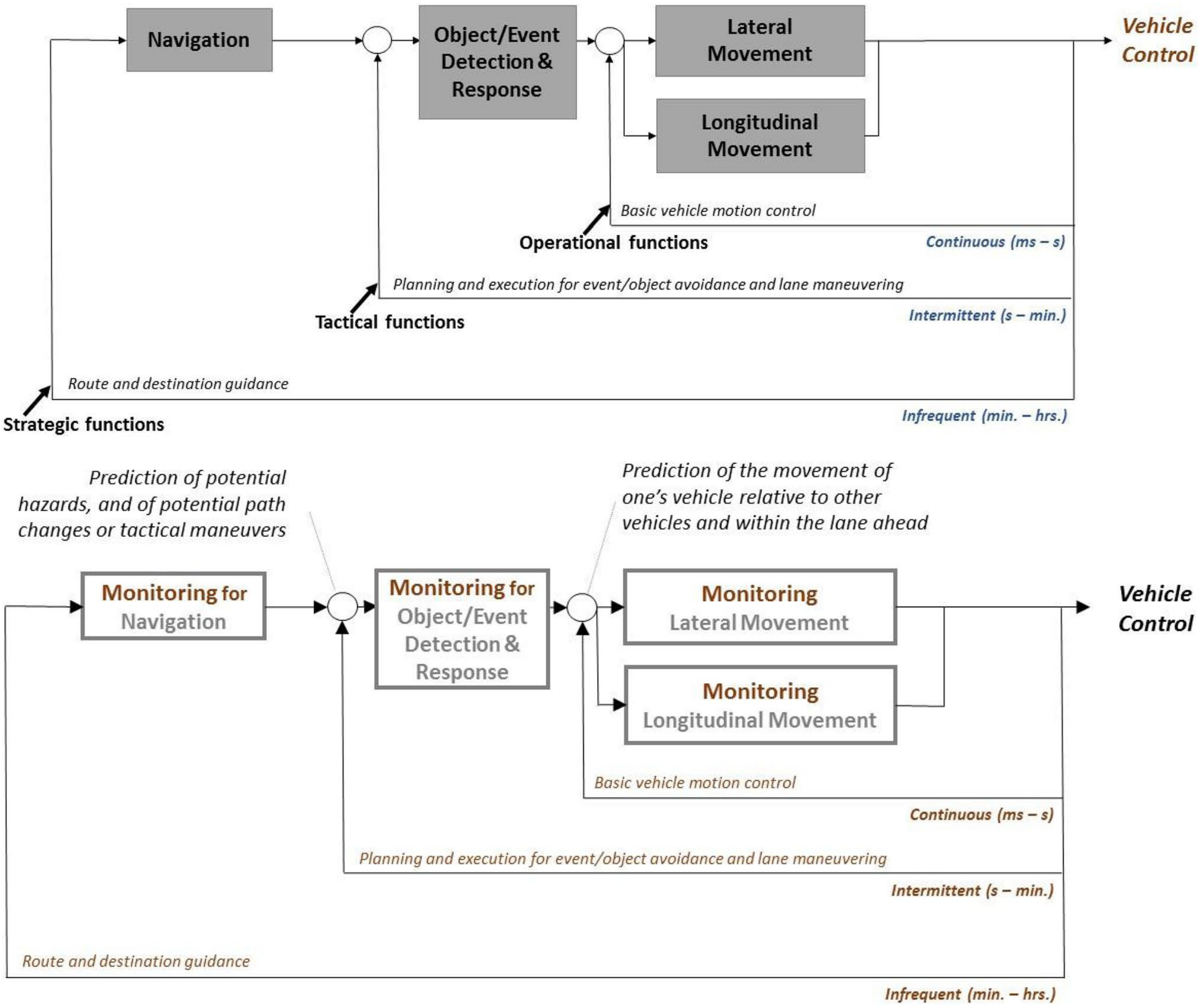

Figure 6 – The change in role of the driver from controller of the vehicle (top), to observer of its functionalities - bottom (Figures from Merat et al., 2018)

As this relationship continues to foster, and more and more control is assumed by the vehicle's automated functions (lane keeping, overtaking, speed control etc.), the reliability, and accuracy, of the vehicle's **iHMI** becomes ever more crucial, especially because, currently, the sensors and radars of the Automated Driving System (ADS) are not capable, or advanced enough, to manage every upcoming scenario and eventuality on the road. In other words, the faultless nature of current ADS means that they cannot handle the whole range of unexpected (or edge case) scenarios.

There are currently many examples of such limitations including (i) sudden changes in the weather, affecting radar capabilities, (ii) obstructed edge and centre road lines (required for navigating the vehicle along its path), (iii) or unexpected objects and obstacles entering the vehicle's lane (including pedestrians and cyclists). Therefore, it is important that humans are aware of, and can anticipate, the likely occurrence of these impending conditions, where an ADS reaches the limits of its Operational Design Domain (ODD) (Koopman & Fratrik, 2019). A number of factors create and support this awareness, such as user experience with the system (Yang, Unhelkar, Li, & Shah, 2017), their level of trust in the technology, as well as their expectations and mental model of system capabilities (Blömacher, Nöcker, & Huff, 2020; Seppelt & Victor, 2020).

In the context of this Deliverable, an important mediator shaping the trust/acceptance/mental model etc. of the humans in such circumstances is the nature of the iHMI, the timing and type of information it provides, and the reliability, accuracy and value of these messages, for the human driver. Here, the iHMI may present simply provide messages about automation status (on/off), or display guidance, information, and warnings about driver responsibility, as part of the take-over request (e.g., you are responsible, take over, etc.) (Eriksson & Stanton, 2017; Gold, Damböck, Lorenz, & Bengler, 2013; Morales-Alvarez, Sipele, Léberon, Tadjine, & Olaverri-Monreal, 2020). In addition, some iHMI may provide more detailed/ informative/ supportive material regarding system capabilities, such as information about the system's Object and Event Detection and Response (OEDR) competence.

One important consideration here is how the information provided by such iHMI should be tuned by the functionalities/capabilities of the ADS, or the level of automation (SAE, 2018), with more sophisticated, and arguably, more accurate, interfaces required as the level of automation increases. The importance of more capable, responsive, and responsible iHMI for higher levels of automation is directly related to the change in driver responsibility, with increasing levels of automation.

For example, studies have shown that, as the level of automation changes from e.g. SAE level 2 to 3, drivers' tendency to engage in other, Non-Driving Related Tasks (NDRTs), increases (Carsten, Lai, Barnard, Jamson, & Merat, 2012; Naujoks, Purucker, & Neukum, 2016), and indeed the SAE (2018) document states that, in Level 3, the human is simply "*required to drive*", *"when the feature requests"*, with engagement in NDRTs allowed and expected. Arguably, this change in the driver's role, where monitoring the environment (Level 2 automation) is no longer required, must be supported by an "intelligent" and informative iHMI, which is a) capable of predicting the vehicle's sensor limitations, in good time, allowing it to signal the end of its ODD to the driver, and b) can, ideally, help guide the driver to achieve the correct response after taking over from the ADS, reducing the risk of collision. Such an interactive iHMI is currently not available on the market, despite recent efforts by the United Nations Economic Commission for Europe (UNECE), to approve deployment of the first SAE L3 functionality in Europe, USA, Japan and China (UNECE, 2020).

Research, using driving simulators, test track studies (Victor et al., 2018), and even real world vehicles, has shown that increased levels of automation leads to a number of performance errors by drivers, especially when compared to manual driving. Examples include, higher levels of engagement in non-driving tasks (Carsten et al., 2012), which results in insufficient situation awareness (Saffarian, de Winter, & Happee, 2012), that can lead to increased response time to a take-over request (ToR) (Gold et al., 2013), reduced quality of response (Gold et al., 2013; Louw et al., 2017; Zeeb, Buchner, & Schrauf, 2015), and slower or failed response to critical incidents (Merat, Jamson, Lai, & Carsten, 2012).

Automation also contributes to a lack of, or incorrect, mental representation of the automated system's capabilities for drivers (Saffarian et al., 2012), leading to driver misuse and overreliance (Parasuraman & Riley, 1997). If designed well, and with the human in mind, also taking account of some of the principles outlined above, the internal HMI of automated vehicles should mitigate some of these negative effects, ensuring mutual comprehension between the automated system and the occupants in terms of their intentions and behaviours.

To assist with the design of more suitable on-board, or internal/iHMIs for AVs, Carsten & Martens (2019) have recently proposed a set of principles, which acknowledges that the adoption of different levels and functions of automated systems, will mean that, for the foreseeable future, humans and vehicles will be *sharing the responsibility* of vehicle operation. Theses authors argue that there is currently a need for the human and the vehicle to accurately comprehend each other, in order for the human to understand their role, and comprehend what appropriate action is required to resume control from a limited AV functionality, and when.

Here, it is important to know what messages should be conveyed by the iHMI, and in what modality. Carsten and Martens (2019) propose six key principles in this context, and have provided some examples, and evaluations, based on existing HMIs. These are outline below:

i. *Provide required understanding of the AV capabilities and status (minimise mode errors).*
ii. *Engender correct calibration of trust.*
iii. *Stimulate appropriate level of attention and intervention.*
iv. *Minimise automation surprises.*
v. *Provide comfort to the human user, i.e. reduce uncertainty and stress.*
vi. *Be usable*

It will be valuable for this framework to be used by the ESRs of SHAPE-IT during the design of their HMIs, to establish its relevance to the huge range of HMIs possible for future AVs, i.e. both internally and externally presented HMI. Establishing if this framework developed by Carsten and Martens (2019) is valuable providing design guidelines for multiple HMIs in AVs is also useful. Following this short discussion on internal HMI, the next section provides a short summary of research results on external, or eHMI.

2.2 External or eHMI

As outlined above, the importance of external HMI for AVs is argued to be related to the absence of an “in charge” human driver in future vehicles, as is currently the case in conventional cars (Deb, Strawderman, & Carruth, 2018). Therefore, any communication in a mixed traffic setting must be achieved (and understood) between the AV and other road users.

There are currently two main methods by which drivers of vehicles and other road users communicate with one another, especially at un-signalised junctions and road sections, where there are no formal infrastructure-based guidelines and regulations, such as traffic lights or pedestrian crossings. For the vehicle/driver, these include **explicit**, vehicle-based, messages (e.g., indicator lights, flashing headlights and honking horns), and driver-based cues (e.g. head and hand gestures or mutual eye contact) (Lundgren et al., 2017; Möller, Risto, & Emmenegger, 2016; Risto et al., 2017; Šucha, 2014). Another form of communication is the subtler, **implicit**, cues, which are primarily based on vehicle kinematics (see also Markkula et al., 2020). Recently, the argument has been that, in the absence of the explicit cues from drivers and vehicles, new forms of external HMI must be designed for future AVs to communicate with other road users (Faas, Mathis, & Baumann, 2020).

However, a recent, real-world, observation study from three different European cities suggests that the use of explicit cues between road users is “rare to non-existent” (Lee et al., 2020) and that implicit cues from vehicles such as movement patterns, approaching speed, and positioning, are used more often by pedestrians to help them decide about crossing the road in front of a vehicle, for example, especially at un-signalized intersections (Clamann, Aubert, & Cummings, 2017; Domeyer, Lee, & Toyoda, 2020; Vinkhuyzen & Cefkin, 2016).

There are however, some conflicting results in this context, with some authors, e.g. Schneemann and Gohl (2016), arguing that the use of explicit and implicit cues is context-based, and may, for example, be based on different driving speeds, with pedestrians relying on eye contact at low speed areas, and on vehicle motions for faster travelling speeds. Using a naturalistic driving dataset, Rasouli, Kotseruba, and Tsotsos (2017) also found that pedestrians gazed at approaching cars prior to crossing in 90% of the cases.

There is, therefore, a clear need for further research in this area, especially to help understand how different road environments influence an AV’s communication strategies with other road users, the value and role of explicit versus implicit communication methods, and how communication between more than two agents is achieved. Studies have suggested that a combination of the following factors play a role in this interaction, and influence pedestrian decision-making, as well as feelings of trust, acceptance and safety, when crossing the road (Ackermann, Beggiato, Schubert, & Krems, 2019; Bengler et al., 2020; Habibovic et al., 2018; Schieben et al., 2019):

i. Modality of messages: visual versus auditory
ii. For visual messages:

   a. Differences between lights, text and symbols
   b. Colour of messages
   c. Location of messages on the vehicle

iii. Rate and timing of message presentation in relation to vehicle behaviour (e.g. before or after the vehicle decelerates)

A questionnaire study, conducted as part of the CityMobil2 project trials, in the city of La Rochelle, indicated that, during their interaction with low speed Level 4 automated vehicles (see Figure 3), pedestrians and cyclists stated that they would like some kind of externally presented communication from such vehicles in the future. This was especially because the shape of these AVs makes it difficult for other road users to distinguish between the front and back of the vehicle, which makes direction of travel hard to establish, in the absence of a driver. The desire for a range of messages were reported in this study, with the most important being whether or not the AV had detected pedestrians (see Merat et al., 2018). The need for an AV signify its detection of pedestrians is also reported by others (Chang, Toda, Sakamoto, & Igarashi, 2017), Othersen et al., 2018; and Schieben et al., 2019). Finally, it has been suggested that external interfaces can simply be used to indicate that the vehicle is in automation mode (Habibovic et al., 2018; Schieben et al., 2019; Figure 7), which helps other road users' trust levels when interacting with AVs, although there are other reports suggesting that this may encouraging unruly behaviour by pedestrians, who may "play the system" and hinder the AV's journey (Habibovic et al., 2018).

Figure 7 - Automated Vehicle Interaction Prototype (AVIP) signals for communication of intent and automation mode to pedestrians (Habibovic et al., 2018).

Bazilinskyy, Dodou and de Winter (2019), suggest that design strategies for eHMIs can be divided into two main categories: Allocentric messages that refer to the AV's current status (e.g., "braking" or "stopping"), and Egocentric messages indicating a behaviour for the pedestrians, such as "walk" or "go". However, there is currently some disagreement and concern by industry regarding any guidance provided by AVs to other road users, because, even though egocentric eHMIs such as "walk" are regarded as clear and effective (De Clercq, Dietrich, Núñez Velasco, De Winter, & Happee, 2019; Fridman et al., 2017; see also Figure 8), they have two main limitations: one is based on their legibility, especially at further distances, and the other is around the liability of advising an action from pedestrians, which can be particularly problematic, dangerous, and confusing, when the AV encounters multiple VRUs (Bazilinskyy et al., 2019). This finding is reported in a number of experiments (Löcken, Golling, & Riener, 2019; Rasouli & Tsotsos, 2020), where VRUs reported ambiguity in scenarios where an AV attempted to communicate with multiple VRUs. In this case, the VRUs were uncertain whether a particular AV yielded to them or to another VRU, or whether the AV had stopped for an entirely different reason.

Figure 8 - The use of different visual external content, in different locations to investigate the effect of display location on crossing intention and eye movements of pedestrians (Eisma et al., 2019).

2.3 New opportunities, new challenges

A short overview of how HMI can be used for communication with humans, for both conventional and future automated vehicles, is provided in the previous sections. However, with extended opportunities to innovate, create, and implement new media for the display of information, advice, and warnings to humans, from a range of locations in and outside the vehicle, comes the need for creating new guidelines, to safeguard basic human factors principles, and ensure road safety.

As two-way interactions between humans and AVs becomes a reality, and interaction by the human is achieved by gesture (Stecher, Michel, & Zimmermann, 2017, Figure 9), and voice (Braun, Broy, Pfleging, & Alt, 2019). Or when there is need for a three-way communication between drivers/occupants inside the vehicle, the AV, and other road users, it is important to ensure that the human is not distracted, confused and overloaded with information, maintains the right level of vigilance and situation awareness and is not overly fatigued, if required to resume control from the vehicle (drivers), or when interacting on the road with AVs (other road users).

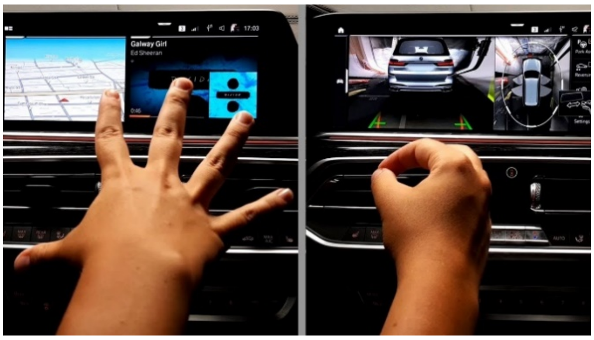

Figure 9 – Use of hand gestures for interaction with HMI, BMW X7 (Cardesign use, 2019)

More knowledge is required to understand the value of new forms of, less overloading and more intuitive, HMI, such as ambient or peripheral lighting for indicating automation state, or requesting a takeover, as is being studies by ESRs 1 and 6 (see also Figure 10). Augmented Reality (as will be studied by ESR 9) is also a promising method for providing information, although little is known about the realism and immersive value of such messages, versus their propensity to distract or confuse the user. The same issue is relevant to use of Head Up Displays (Figure 10, Figure 11, Figure 12), which, while not removing drivers' attention from the forward roadway, could produce too much information, possibly distracting the driver's attention from other, unexpected hazards and events.

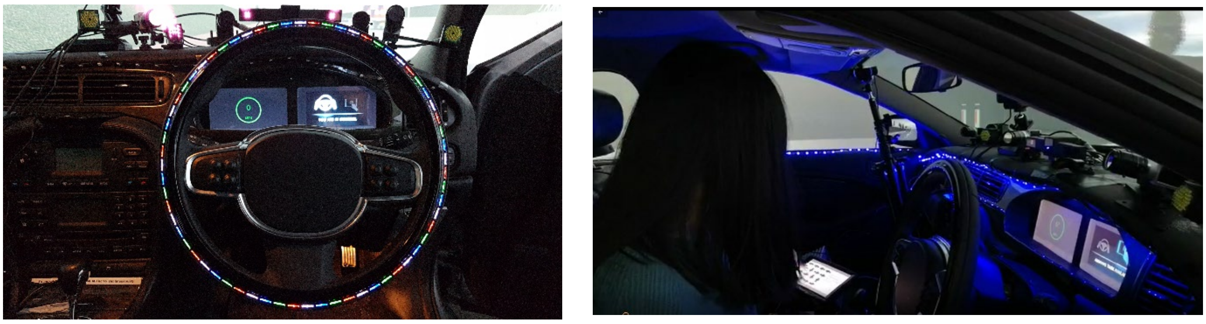

Figure 10 - Take over Request (ToR) communication using the steering wheeel, left, and use of ambient lighting inside the vehicle for communication, right (University of Leeds Driving Simulator)

Figure 11 - . An example of Augmented Reality Head Up Diplay with a wider Field of View (FoV) (Courtesy of Texas Instruments, 2019).

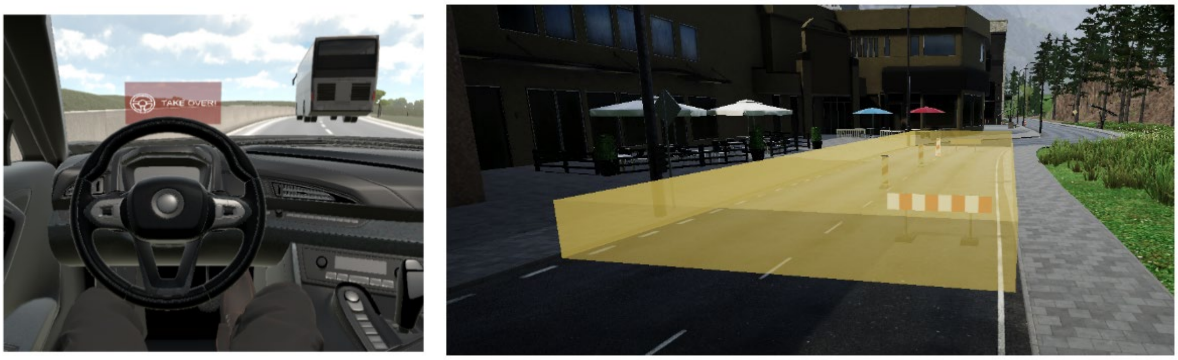

Figure 12 - A HUD warning message is displayed to signal a take-over request to the driver, left and Take over request trigger, displayed in yellow, for triggering a manual take over because of an unexpected road situation, right (Riegler, Riener, & Holzmann, 2019).

Finally, as discussed above, the research on providing the best form of external messaging for future AVs is still in its infancy, with some efforts to study the value of more anthropomorphic messaging, such as eye on the outside of the vehicle, created by a Jaguar Land Rover project (JLR, 2018), or a smiling face, created by Semcon (see Figure 13). One big challenge in this context is the means by which multi-agent communication, e.g. between one AV and many pedestrians can be achieved, with suggestions for use of wearable communication technologies for pedestrians (see Figure 14).

Figure 13 – The Semcon smiling car concept, (Semcon, 2016).

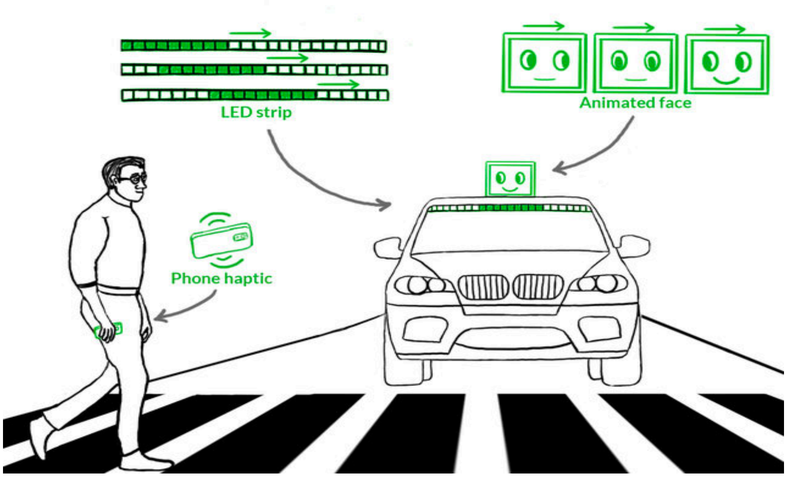

Figure 14 - Potential interface options for communicating awareness and intent to pedestrians in multiple modalities (interface elements in green) (Mahadevan, Somanath, & Sharlin, 2018).

There may be opportunities in the future to create more customisable and adaptive systems, for example by using Machine/Deep Learning and Artificial Intelligence to develop more intelligent systems which aid users and compensate for some of their limitations. As machines become more intelligent and autonomous, disciplines such as affective computing, which develops systems and devices that are able to recognise human emotions (Lee et al., 2017) can be used to identify and aid impaired drivers. This example of Driver Monitoring System (DMS), is an essential part of future AVs, and an additional interface which is required for communication with drivers inside the vehicle, and, ideally, to enhance the three-way communication between the driver, the AV, and other road users (see Figure 2 and Figure 15).

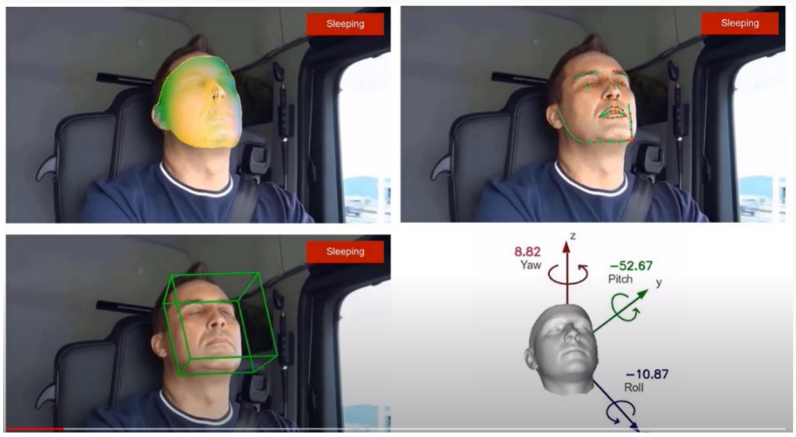

Figure 15 - An example view of cameras used for Driver Monitoring, developed at the University of Leeds (Rezaei, 2021).

Currently, these DMS use "indirect monitoring" techniques, such as steering control and lane keeping measures, to establish if the driver is sleepy/fatigued or distracted, and warn drivers, using a "coffee cup symbol" to advise a break. However, higher end vehicles, such as General

Motors' Super Cruise, an example L2 system, include more advanced, camera-based DMS, which estimate drivers' attention to the road ahead, and can warn fatigued/sleep/distracted drivers if the eyes and head are facing away from the forward roadway for too long. In Europe, organisations such as EuroNCAP (EuroNCAP, 2017) are recommending the implementation of such systems in vehicles, with more advanced versions of the system recommended as levels of automation increase. Such advanced DMS will prevent an "unfit" driver from resuming control from the vehicle, if the DMS deems them unsafe to drive, bringing the vehicle to a safe stop, using a Minimum Risk Manoeuvre (MRM) (Schindler et al., 2020). However, much more research is required to ensure that these systems are indeed capable of correctly identifying driver state, in order to reduce, or illuminate false positives, which lead to unnecessary and irritating warnings, and can lead to user disengagement of the system.

3 Innovative approaches of the project

As outlined above, there are a number of challenges around implementing the right HMI for users inside and outside AVs, and new design frameworks, principles and guidelines are required to ensure these interfaces are effective and safe. It is not yet clear how automated vehicles will progress from the currently available SAE L2 configurations, which are operational in limited ODDs, to more advanced versions, which will ultimately provide Levels 4 and 5 capabilities, able to drive everywhere and manage all road conditions. As this transition occurs hand in hand with developments in AI, ML, and computer power, as a whole, it is essential to investigate the human factors opportunities and challenges that must be studied, in order to ensure that such systems are, trusted/accepted, and adopted en-masse, and that there is minimal opportunity for any unintended consequences, including misuse and disuse by road users. The individual projects of the SHAPE-IT ESRs our outlined in the next section. Next, we provide a brief overview of the innovative approaches which will be used by the ESRs, and the unique contributions of the project in this context.

a. Investigating the interaction of a range of users with AVS

The value of using external HMI for communication with other road users is already outlined above (see also Eisma et al., 2019; Mahadevan et al., 2018; Tabone et al., 2021). To date, most studies in this area have focused on pedestrian interactions with AVs, and these studies have mostly focused on one to one interactions: i.e. between one AV and one pedestrian. In SHAPE-IT, we will investigate whether devices or systems outside the AVs, such as wearables (e.g. AR glasses or smartphones) and on-bike HMIs, can facilitate safe and transparent communication between AVs and VRUs. This holistic approach sets SHAPE-IT aside from other similar projects, as the research embodies road users both inside and outside of the AVs, when developing HMI strategies for future urban scenarios with automated vehicles. The work will also consider studies involving multiple actors, i.e. the communication of AVs with more than one pedestrian/other road user.

b. Use of AI for more personalised HMIs

AVs are using an enormous number of sensors, cameras and software, and, ultimately, AI techniques to make these systems more efficient, reliable and safe. However, the success of these systems relies on efficient HMI, to establish how users are interacting with, and understanding, the system (Carsten & Martens, 2019). Cutting-edge algorithms and software/ programing-based HMI design technologies will be important for producing more efficient and effective outputs/services. Moreover, if designed with the human in mind, AI-based HMI will not just increase the quality of interaction between humans and systems, but also learn from and adapt to the user behaviour, which, it is hoped, will lead to higher trust and acceptance of systems (Kraft, Maag, & Baumann, 2019).

Through AI, the vehicle can learn from previous commands (via data collected over time) and thus produce customised (Atarashi, Morita, & Koga, 2016), and reliable outputs that match users' expectations and preferences. Examples include personalised seating and steering positions, or providing information wherever the user is looking, and so on.

Examples of current AI-based HMI include Google kinematic "touchless control" (Ina & Camp Jr, 2012), and other neural-network-based technologies, such as Google Glasses^{TM} that aim to detect users' changing emotions through voice tone, facial expressions or body movements/physical response. The use of AI for HMIs, and HMI design, is truly in its infancy, and we will likely see many future, and currently unknown, applications of AI in AV HMI designs, in the future.

c. Use of neurergonomics for HMI design

Neuroergonomics is a relatively new field of research, defined as the study of the human brain in relation to performance at work and other everyday settings (Parasuraman, 2003; Parasuraman & Rizo, 2007). It integrates the theories, principles, and methods from neuroscience, ergonomics, human factors, and cognitive psychology (Parasuraman, 2011). The goal of neuroergonomics is to have a better understanding of brain functioning and behaviour, by studying the operators' brain function and mechanisms while at work (Mehta & Parasuraman, 2013).

Many neuroimaging techniques have been adopted by neuroergonomics, including electroencephalography (EEG) and event-related potentials (ERPs), to directly study neuronal activity in response to stimuli. Other techniques, such as functional magnetic resonance (fMRI), positron emission tomography (PET), and functional near infrared spectroscopy (fNIRS), provide an indirect metabolic indicator of neuronal activity. Furthermore, non-invasive stimulation techniques, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) may be used to establish causal links between brain activity and performance (Mehta & Parasuraman, 2013).

When evaluating HMI design, researchers traditionally focus on the subjective perception of participants, and their behavioural performance. The neuroergonomic approach offers a more complete understanding of the complex impact of changes in interface design through better understanding of the neural mechanisms and processes that underlie a driver's behaviour (Hettinger, Branco, Miguel Encarnacao, & Bonato, 2003). Implementing the neuroergonomics techniques, therefore, broadens the possibilities in HMI design assessment. Electroencephalography (EEG) and event-related potentials (ERPs) used to measure mental workload may serve as a good example of neuroergonomics application in HMI design evaluation (Giraudet, Imbert, Bérenger, Tremblay, & Causse, 2015).

Neuroergonomics also plays a key role in the development of neuro-adaptive HMIs. These can be defined as an ensemble of computer-based displays and controls which use information derived from the central nervous system activity, and whose functional characteristics change in response to meaningful variations in the user's cognitive and/or emotional states (Hettinger et al., 2003). There are many challenges associated with development and use of neuro-adaptive HMIs. For example, researchers must identify underlying neural substrates of cognitive and emotional states, implement the appropriate measurement devices in an unobtrusive manner, and determine effective methods of dynamically adapting the HMI, based on the online input information. Therefore, neuro-adaptive interface technologies cannot be developed in the absence of a very advanced knowledgebase about the nervous system functioning. Neuroergonomics, as a broad, multidisciplinary, approach, based on inputs from cognitive neuroscience, functional neuroanatomy, human factors, ergonomics, and psychology provides an ideal framework for development of neuro-adaptive HMIs in this project (Hettinger et al., 2003).

d. Use of Augmented Reality for HMI design

Augmented Reality (AR) technology has been utilised in a number of domains such as medicine (Ha & Hong, 2016), military applications (Livingston et al., 2011), the arts (Tabone, 2020), and inside vehicles, whilst driving (Wiegand, Mai, Holländer, & Hussmann, 2019). Recent research has explored the utilisation of AR in pedestrian navigation (Montuwy, Cahour, & Dommes, 2018), city guides (Lakehal, Lepreux, Efstratiou, Christophe, & Nicolaou, 2020), and for crossing advice in urban traffic areas (Perez, Hasan, Shen, & Yang, 2019). Research is now moving towards the introduction of Extended Reality (XR) technology in traffic, with the likely enhancement of pervasive and context-aware AR technology in the coming years (Grubert, Langlotz, Zollmann, & Regenbrecht, 2016). It is therefore important to understand the value of such technologies in SHAP-IT.

However, there are currently many challenges in the design and use of AR for HMI design. Examples of questions capturing some of these challenges include a) whether AR will be a useful addition to the daily VRU-AV interaction, b) what information to display and how, and b) the various technological challenges in mapping augmented elements on the real layer (e.g., outdoor luminance levels, and latency issues, which may lead to motion sickness). It is also not yet known if AR is a potential solution for handling multi-agent interactions (Tabone et al., 2021). The use of AR technology may provide the opportunity to overcome several challenges which traditional eHMI approaches are encumbered by. Examples include cultural and language barriers, and situations where multiple vehicles are interacting with multiple pedestrians, amongst others (Tabone et al., 2021).

e. The use of agile and transparent HMI for automation

One of the most important human factors issues currently facing automation technology is the risk arising from mode confusion (Banks, Eriksson, O'Donoghue, & Stanton, 2018). At lower levels of automation (i.e., SAE level 0 and 1), users assume the role of a driver, with different levels of automated assistance (SAE, 2018). However, as the levels of automation rise, users will turn into supervisors of the system, or even passengers (Hancock et al., 2020). When the automated system reaches its limit, and the human is required to resume control, it is critical for users to have enough situation and mode awareness to respond correctly, with little opportunity for misuse and disuse. To achieve this goal, users must be provided with sufficient transparency of HMI. Transparency is described as "*the information that agents need to convey about their decision-making process, in order to facilitate the shared understanding required to perform effective human-agent teamwork*" (Chen et al., 2014). This transparency could also assist in avoiding false expectation and over-reliance on the system (Carsten & Martens, 2019), and increase the decision-making accuracy, trust and situation awareness of users (Bhaskara et al., 2020). However, there is yet no systematic method for transparency assessment of systems available in this context. Currently, transparency is often considered only as how detailed an explanation is, or whether information about uncertainty is provided (Körber, Prasch, & Bengler, 2018; Kunze, Summerskill, Marshall, & Filtness, 2019; Yang et al., 2020), rather than how easily users understand the conveyed information. Currently the typical ways of achieving transparency (defined as an increase in information detail) may also increase user workload, and does not guarantee perceived transparency (Miller, 2014). Moreover, the relationship between transparency and different user characteristics, as well as different scenarios where this information is useful, is not yet understood. Hence, a transparency assessment method, to be used by ESR 7, would be of great value in solving the above-mentioned problems, and provide safer human-AV interactions.

f. The importance of short vs long term interactions

Exposure to new information and technology is found to stimulate the learning process (Ditta et al., 2020), which is considered to consist of six main phases (Russell, 1995). These include: 1) awareness, 2) learning the process, 3) understanding and application of the process, 4) familiarity and confidence with the knowledge, 5) adaptation to other contexts, and 6) creative application to new situations.

In addition, Newell & Rosenbloom (1981) proposed the power law of learning (also referred to as the power law of practice), where the learning outcomes are described as a quantitative relationship between the amount of practice and task performance, where reaction times in the experimental tasks decrease with the growth of trials. In the autonomous driving context, with the increasing number of AVs in future urban traffic, there is a challenge for vulnerable road users to learn to interact with AVs, and the cross safely in the presence of AVs, with challenges associated with awareness of the system and its capabilities to adaptation within a dynamic, long-term, automation exposure ecosystem. Beggiato, Pereira, Petzoldt and Krems (2015) conducted longitudinal studies, to investigate drivers' learning process in the context of adaptive cruise control (ACC) systems, across a period of two months, and found that development of trust and acceptance follow a logarithmic pattern, with repeated trials, which can be described by the power law of practice (Newell & Rosenbloom, 1981). A similar pattern regarding drivers' behavioural changes is also found in relation to repeated interactions with automated driving systems (Forster et al., 2019). These studies can form the basis for investigating the learning process for VRUs' interactions with AVs, and how their mental model of the vehicle's behaviour develops when interacting with AVs, over a number of exposures.

Due to their novelty, automated vehicles have different meanings for different people, which can result in different interaction, and use, patterns. In addition, different user characteristics are likely to influence the degree of trust and acceptance of new systems (Becker & Axhausen, 2017; Gold, Körber, Hohenberger, Lechner, & Bengler, 2015), which will also have an effect on their behaviour, over repeated exposures. Other factors likely to have an effect on interactions, which may also change over time, include the effect of familiarity with other automation technologies (Hartwich, Beggiato, & Krems, 2018), personality (Zhang et al., 2020), and age (Abraham et al., 2017) and gender (Hulse, Xie, & Galea, 2018) Some of these factors will be investigated by ESRs 2 and 4, for drivers, and other road users, respectively.

g. Automated vehicles for different sociodemographic groups

Similar to traffic signs, if designed appropriately internal and external HMIs could provide safety critical information and guidelines to drivers, passengers, and other roads users. There has been extensive research on comprehension of traffic signal and signs (Shinar, Dewar, Summala, & Zakowska, 2003). However, the comprehension of iHMIs and eHMIs by human road users have not yet been studied in detail. Therefore, it can be argued that the literature on comprehension of traffic signs and signals may provide useful insights into how different users interact with future AV HMIs, such as the influence of different sociodemographic factors.

Findings from a number of studies suggest that, currently, information provided by different traffic signs are not always understood correctly by different road users. For example, Shinar et al. (2003) compared the comprehension levels of traffic signs used in Canada, Poland, Finland, and Israel, and found that comprehension varies significantly among drivers in different countries. In this study, there was underperformance in comprehension by older driver, novice drivers, and repeat violators. Furthermore, this study showed that signs that were considered to follow good ergonomics design principles were more likely to be understood, compared to signs that violated design requirements. Other factors that influence comprehension of traffic signs include driver demographics (Al-Madani, 2004), age and gender differences (Hawkins, Womack, & Mounce, 1993; Dewar, Kline, & Swanson, 1994), level of education (Al-Madani & Al-Janahi, 2002), and symbolic versus text displays (Shinar & Vogelzang, 2013). These findings can provide some insights into whether a universal HMI design strategy would work for all demographic groups and in different parts of the world.

The next section provides a brief summary of the projects which will consider the next generation of HMI designs for AVs.

4 Overview of the interface concepts being considered in SHAPE-IT

This section provides a short overview of each ESR's project, for those whose work is related to HMI concepts, and outlines how their projects can move knowledge, beyond the state of the art.

ESR1: ESR1 aims to understand AV predictability using neuroergonomics. Her goal is to have a better understanding of the drivers' cognitive processes and states during highly automated driving. The neuroergonomics approach is an innovative way of understanding human brain at work (Parasuraman, 2003). Employing neuroergonomics methods such as electroencephalography (EEG) during the development and assessment of HMIs can lead to the design of more efficient and safer systems. In her first experiment, ESR1 will study the effect of conveying the current level of reliability of the AV to the driver via a peripherally presented visual cue (ambient light). She focuses on the changes in drivers' psychophysiological activation, including EEG, electrocardiography, and electrodermal activity in response to these cues.

The contribution of this ESR is in use of neuroergonomics methods for designing more human-centred, safer internal HMI, by studying how simple cues, such as those portrayed by an ambient light affect driver state, and therefore workload.

ESR2: As most empirical studies in this context normally last around one to two hours they do not necessarily capture or track the users' behaviour towards the automation after the novelty effect has weighed out. The aim of this project, therefore, is to investigate the long-term effects of automation on user behaviour, by exploring the interaction patterns and learning effects between humans and automation over a longer period. This project will further investigate and define human-automation compatibility (where compatibility is measured through learnability, Perceived Ease of Use, etc. over long-term use) and trust (within the continuum of distrust – calibrated trust – over trust) as moderators of acceptance or behaviour intention to use the system.

In simple terms, compatibility is equated (equivalent) as the match between the human and automation during the learning to interact process. E.g., how quickly the users learn to interact with the system in a calibrated manner (including trust and acceptance) and thus avoiding the misuse and disuse of the automated system. When the learning reaches a level of plateau in understanding how the system works, then the human and automation are understood to be compatible or a match (the user's behaviour towards the automation is consistent with the actual designed use of the automation or its capabilities). For instance, this means the users have a clear understanding of the driving task flow, able to locate and understand the automated system's functionality, are aware of the system functionality, and able to transition to efficient behaviour in an accurate manner. With the future seeing a greater favouritism towards highly automated vehicles, we believe proper understanding of how users learn to interact, learn to trust, and learn to accept these automated machines should be highly considered. Thus, an evaluation of AV interaction design strategies will be performed, and patterns of learning strategies of AV users ("drivers/passengers") by user types will be established.

This project will aim to improve understanding of how AV users' experience, trust, and acceptance of AVs change with long-term/repeated use in urban traffic.

ESR 4: The topic of this project is long-term effects of automated exposure on vulnerable road users' (VRU) interactions with automated vehicles. With the introduction of automated vehicles, road users are required interact and communicate with AVs (and vice versa) in a shared and mixed urban environment. Such interactions are developed in a dynamic manner, where users' mental model of the interaction scenario, and their subsequent behavioural responses, are likely to change with time and experience. There is also likely to be an influence of factors such as user-specific factors, such as their trust, acceptance, and experience with new technologies, some of which may which may need time to result in a stabilised behaviour (Lee & See, 2004; Venkatesh, Morris, Davis, & Davis, 2003).

Current studies in this area, whether based on one to one, or one to many interactions, are usually based on one single interaction and experience. In addition, any studies which have considered longer-term effects mostly focus on humans as drivers, rather than pedestrians (Beggiato & Krems, 2013; Brouwer & Hoedemaeker, 2004; Forster et al., 2019). The value of this study rests in understanding how behaviour changes over time, such that it allows the design of robust systems for communication of intent by AVs, which will obtain, and maintain, user trust, understanding and response, with repeated interactions, over time. The project's biggest challenge is defining the appropriate range for "long-term effects" and realising that exposure in controlled experiments. Identifying the minimum time required for the development and formation of road users' mental model of an AV's intentions and behaviour is a key challenge here, while establishing what type of information provided by the AV (e.g. explicit versus implicit messages) is most reliable, and effective in shortening the time required by users to understand the AV's behaviour is also valuable.

This project will assess the value of using externally presented HMI in helping to accelerate pedestrians' understanding of AV behaviour during a series of interactive scenarios.

ESR5: This ESR's project is about "developing more comfortable, transparent and acceptable AV-kinematic cues for drivers". As the task of driving changes with higher levels of automation, the human moves from an active controller of the vehicle to a passive passenger (Kaber & Endsley, 2004). Here, it becomes more important to address how the human drivers want to be driven by the automated vehicle. Comfort, as a positive affect and experience, is known to correlate with trust, acceptance and willingness to adopt AVs by users (Paddeu, Parkhurst, & Shergold, 2020; Siebert, Oehl, Höger, & Pfister, 2013). The basis of a comfortable experience by the passive driver in AVs is considered to be the same as a passenger in a manually driven car, and includes factors such as the driving style (Bellem, Schönenberg, Krems, & Schrauf, 2016), with changes in vehicle kinematics (e.g., speed, acceleration and jerk) known to correlate with subjective evaluation of driving comfort (Bellem et al., 2016). However, it is not currently clear what objective AV kinematics are more correlated to subjective comfort than others, and the threshold for such metrics of comfort. In addition, the concept of comfort itself in this context is ill-defined, and the best methods for its measurement, and evaluation, by a range of AV users' needs further understanding.

This project will assess the comfort associated with using AV kinematic cues to communicate with internal occupants.

ESR 6: The project for this ESR revolves around the use of internal interfaces for transparent and agile automation. During this project, the ESR aims to understand and develop suitable interaction strategies with the AV, focusing particularly on the underlying cognitive resources that influence decision making, and response execution during a critical take-over-request (TOR). Current studies are inspired by the multiple resources theory (Wickens, 2008), implying that peripheral visual cues are processed in a distinct cognitive circuit, which suggest that ambient light has the potential to mediate important information (e.g., a TOR) without compromising drivers' mental workload. This is the first experiment planned together with ESR1. The data is expected to guide us into further research questions. We know, for instance, that the angle of the visual information presented in the periphery affects reaction time. In addition, the intensity of light presented also seem to influence reaction time (Meschtscherjakov et al., 2020). These factors are not considered in this first experiment. Other factors such as brightness and sound of the traffic environment might also influence the efficiency of peripheral perception. We hope that the data-analysis will inspire other-related research questions.

This project will assess the value of ambient peripheral lighting for presenting information to occupants of AVs.

ESR7: Before fully automated vehicles are generally adopted by the public, at mass, the transition of control between human and AVs during critical situations poses a threat to driving safety. To avoid undesirable results, it is of great importance that users are provided with the correct understanding of the AV's behaviour and likely response in different critical situations, i.e., that the AV has sufficient transparency. With sufficient transparency, misuse and disuse of the system can be avoided, promoting safer and more efficient driving. However, there is currently a lack of methodologies for assessing transparency of AVs. In order to bridge the gap, ESR 7 is aiming to develop a systematic transparency assessment tool, which could also be applied to the guideline for creating a transparent in-vehicle AV HMI strategy.

This project will develop a suitable transparency assessment tool, useful for future development of AV HMI strategies

ESR8: In the development of AVs much focus is on technology (e.g., sensors) and software (e.g., image processing, decision making, intent identification and path planning) – engineering fields where the professionals are typically not very knowledgeable in human factors. Nevertheless, many of the components that mechanical, electrical and software engineers design and develop have clear implications for how AV users and other road-users perceive, trust and interact with the AVs, which in turn have implications for safety. Although there is much research being conducted on human factors aspects of AVs, not least in this project, and much knowledge resides in human factors professionals in the automotive industry, there is a lack of processes for communicating and integrating human factors requirements in the engineering-heavy AV design (e.g., requirements related to AV kinematics and control, and AI-based HMI designs). Hence, there is a clear need to develop requirement engineering methods that are suitable to create more reliable and safe systems with higher user satisfaction.

Moreover, much of the automotive industry is transitioning from the traditional “waterfall” way of working (hierarchical with up-front requirements etc.), to an agile way of working (team oriented iterative development). This transition poses additional challenges to the transfer and accretion of human factors knowledge to engineering heavy agile teams, and, not least, the inclusion of appropriate studies with end-users.

This ESR will start with understanding exactly what the problem is with respect to communication of human factors knowledge to engineers in industry, moving toward an agile way of working, mapping the problem of human factors

This project will contribute towards developing a framework for proper communication of human factors (incl. HMI) requirements to AV developers (e.g., software developers).

ESR9: This ESR will investigate the potential of VRUs receiving indirect information using Augmented Reality as eHMI. To date, eHMI strategies have struggled in situations where multiple VRUs are encountered, or multiple vehicles are communicating to one or more VRUs (Löcken, Golling, & Riener, 2019). Such a situation gives rise to ambiguity which may lead to a VRU inferring that a particular AV is signalling them to cross, when in fact it is signalling to another road user it has detected across the road. Another issue is that there is no standard design for these eHMIs, and so VRUs need to learn and infer each design encountered. Furthermore, in cases where text is used as a communication modality, the issue of readability and language barriers arises (Bazilinskyy, Dodou, & De Winter, 2019).

A potential solution to these problems would be the introduction of eHMIs which exist in the virtual domain through the use of Augmented Reality (AR) technology. This approach would allow each VRU to receive communication from the AV individually, providing a potential solution for multi-actor problem in a mixed traffic environment. In this case, only the VRUs involved in the interaction with the AV would be signalled, and so ambiguity would be reduced.

The ESR9 project will therefore infer preferred user AR design elements, using a mixed method survey, and assess their acceptance when compared to no eHMI, and traditional eHMI scenarios. This process follows general recommendations from experts in the field (Tabone et al., 2021). Recent work (Maruhn, Dietrich, Prasch, & Schneider, 2021). Simulation environments will be designed to assess trust and acceptance in the automation when such communication strategies are utilised. At the end of the project, the outcomes of the simulation studies will be validated in a real-world environment study.

The contribution of this ESR is in terms of recommendations for new forms of external HMI for future AVs, including the implementation of Augmented Reality to help road users in multi-actor situations.

ESR10: The aim of this project is to study “HMI on bicycles promoting transparent AV interactions”. In line with creating a sustainable future transport system, road users are encouraged to use active forms of transportation like walking and cycling (Center for Disease Control and Prevention, 2011; POLIS, 2014). Even in a future of full automation, there will still be mixed traffic, where VRUs like pedestrians and cyclists will interact with AVs. To ensure a safer future for all road users, we need more information about how mixed urban traffic will be affected by the interaction between VRUs and AVs in terms of safety, trust and transparency. ESR10 will investigate the possibility of developing a device to enhance communication between cyclists and AVs. This project will explore the aspects constituting cyclists’ interaction in today’s, traffic as well as in future scenarios with AVs. Moreover, the project will identify the needs of cyclists for facilitating safe future interaction with AVs, and explore whether an on-bike HMI can enhance AV-cyclist interaction in terms of safety, trust and transparency.

This ESR will create an HMI for enhancing communication of AVs and cyclists.

ESR11: Although certain rules govern most traffic interactions, some form of nonverbal communication and negotiation is also regularly part of these interactions. However, the introduction of AVs in mixed traffic will make the situation even more challenging. For example, Recent analysis of accidents in California involving AVs shows that, in 57% of cases an AV was rear-ended by a human driver (Schwarting, Pierson, Alonso-Mora, Karaman, & Rus, 2019). Drivers reported that they could not predict the behaviour of the AV, as it stopped suddenly. Therefore, it is necessary to understand if AVs should imitate human-like driving behaviour to stay safe (Gu & Dolan, 2014). The argument is that not only will human-like driving behaviour by an AV increase comfort for its occupants, but it will also enable other roads users to understand and predict the AV’s behaviour more easily (Zhu, Wang, & Wang, 2018).

Therefore, the aim of this ESR’s project on ‘Cooperative Interaction Strategies Between AVs and Mixed Motorized Traffic’, is to investigate how human drivers cooperate in complex traffic situations (e.g., lane changing or passing through a narrow passage), and assess what types of communication means (explicit or implicit) are used for expressing intentions. Furthermore, this project will also investigate driving behaviour during complex situations as stated above. Based on the empirical studies, microscopic simulation models (for interactions during lane changing and narrow passages) will be developed. The overarching goal of this project is to develop guidelines for the safe and efficient mobility of AVs in mixed traffic. The results of this project will contribute to the design of more effective HMIs, which may eventually need to replace any human-based cooperation and communication cues.

This project will consider the interplay between external HMIs and vehicle-based communication for interaction of AVs with other vehicles

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