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User Evaluation Methods

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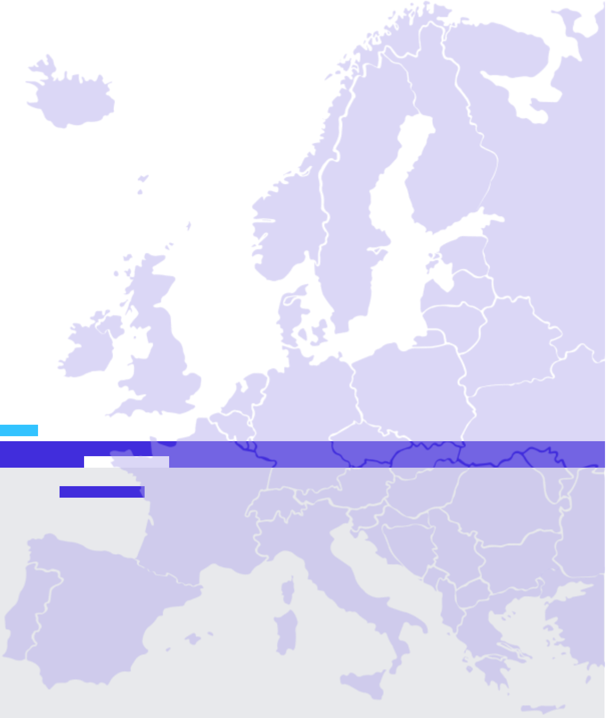

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Executive summary

As higher levels of automated vehicles (AVs) start to enter the market, it is important to understand how these technologies will be used by the general population, what effects they will have on the ordinary driver, and how this human-technology interaction influences traffic flow and road safety. Since AVs are deployed in mixed traffic environments, which include pedestrians, cyclists, and other drivers, understanding how interactions of the AV with these actors influence our traffic system is also important. Consequently, the user sub-project (SP6) of Hi-Drive will conduct empirical studies to develop a firm understanding of user behaviour, expectations, and limitations when interacting with AVs, as drivers/onboard users, external road users, and remote operators.

The current deliverable provides an overview of the methods and measures that will be used for all evaluation areas within SP6, and the research questions that will be addressed using these methods. It provides a summary of the current state-of-the-art in relation to measuring user interactions with AVs, highlighting the importance of the project-level research questions for understanding the experiences of onboard users, external road users, and remote operators. A multi-modal and interdisciplinary approach is taken to investigate road user behaviours and experiences during interactions with AVs, with multiple, complementary methods used for data collection. Specifically, **15 different simulator studies**, **nine test track studies**, and **12 real-world driving studies** are planned or completed. These will incorporate a wide range of use cases relating to the comfort and motion sickness of onboard users, driver state monitoring, and external road user behaviours. Across these experimental studies, data will be collected from over **1,000 ordinary drivers, pedestrians, and cyclists**, along with data from **40 safety drivers** and **35 professional engineers** acting as remote operators. The combination of a range of methods will allow us to establish whether similar patterns of results are obtained in simulator and real-world environments, while the data collected through lab-based experiments can be used to inform knowledge when real-world studies are not possible, due either to safety concerns or the absence of advanced AVs. These studies will help the design of future systems and ensure optimum research effectiveness.

A wide range of objective measures will be used to capture participant behaviours when interacting with AVs. For onboard users, these will include measures of vehicle control after a takeover request, including hands on wheel or brake reaction time. User state during and after takeover can be measured with physiological metrics such as skin conductance, or eye-tracking-based measures such as pupil dilation and direction of gaze. Finally, performance in non-driving related tasks (NDRTs) can inform how drivers divide their attention between secondary tasks and driving, and what effect this has on safe resumption of control. Measures

of external road user behaviour will include the percentage and time of crossings made by pedestrians; cyclists' yielding behaviours at intersections; and the accepted time gap of other drivers when interacting with an AV. Finally, measures of remote operator performance will include eye tracking and cognitive demand metrics, along with measures of performance on primary and secondary task elements, e.g., time to accept the primary task, and performance in NDRTs.

Subjective data from questionnaires, interviews, and focus groups will be used to supplement the data collected through experimental research. This will allow us to draw conclusions on road users' experiences of automation and their attitudes towards the various automated systems under investigation. The development of a set of **Common Questionnaires** will enable comparison across studies, although any responses obtained will be context specific, which must be taken into account when comparing across sites. The **Hi-Drive Global Survey** will focus on exploring both onboard and other road user expectations towards different levels of AVs. In particular, the survey investigates what AV capabilities are required to promote acceptance and use by potential customers. This will allow us to understand what factors influence the uptake of the automated driving (AD) functions (ADFs), and the related technology **Enablers** being developed within the Hi-Drive project (SP2). In addition, large-scale questionnaires investigating propensity towards motion sickness in various European populations will allow us to understand at-risk groups for carsickness during AD, also informing us about the motion factors and driving styles that will lead to increased risk of sickness. Information about users' attitudes towards AVs, the factors affecting their comfort, and the prevalence of motion sickness will be sought across **six different questionnaire studies,** from approximately **20,000 unique questionnaire respondents**, and at least **8 different countries**. Proposed questions include an understanding of users' acceptance of ADFs and human-machine interfaces (HMI), along with ratings of perceived safety, trust, and comprehension of AV communication, as well as an overview of driver and remote operator situation awareness and task loads.

Finally, this deliverable provides a detailed overview of the specific studies which will be used to address each of the **44 medium-level** project-based research questions on users (outlined in Hi-Drive Deliverable 4.1 *Research Questions*). The studies are grouped according to their main research topic and provide an evaluation plan for each of the four work packages of the **User Sub-project** (SP6): user acceptance and awareness (WP6.3), user comfort (WP6.4), driver monitoring (WP6.5), and other road users (WP6.6). As outlined in this deliverable, many of the studies provide a multi-pronged approach to user interactions with AV, allowing an exploration of how different research contexts, scenarios, and methodologies can be used to address a particular research question. The relationships between the findings obtained in these studies will be summarized at the end of the project in Deliverables D6.1 (User acceptance and awareness results); D6.2 (Human-like driving and user comfort), D6.3 (User monitoring and related HMI), and D6.4 (Interactions with other road users).

1 Introduction

1.1 The Hi-Drive project

Connected and automated driving (CAD) has become a megatrend in the digitalization of society and in the economy. CAD has the potential to drastically change transportation and create far reaching impacts. SAE level 3 (L3) automated functions were piloted in Europe by the L3Pilot project in 2017–2021 (L3Pilot consortium, 2021). Hi-Drive builds on the L3Pilot results and advances the European state-of-the-art from SAE L3 'Conditional Automation' further up towards 'High Automation'. This is done by demonstrating in large-scale trials the robustness and reliability of CAD functions under demanding and error-prone conditions with special focus on:

- connected and automated vehicles (CAV) travelling in challenging conditions covering variable weather and traffic scenarios and complex infrastructure
- connected and secure automation providing vehicles / their operators with information beyond the line of sight and onboard sensor capabilities
- complex interaction with other road users in normal traffic
- factors influencing user preferences and reactions including comfort and trust—and eventually through a wide consumer acceptance of automated driving (AD) resulting in purchase and use, enabling viable business models for AD.

The project's ambition is to extend the AD's operational design domain (ODD) from the present situation, which frequently demands taking over control of the vehicle by a human driver. As experienced in the EU flagship pilot project L3Pilot, on the way from A to B, a prototype level-3 automated vehicle (AV) encountered a number of ODD boundaries, leading to fragmented availability of the AD function (ADF). Hi-Drive addresses these key challenges which are currently hindering the progress of driving automation. The concept builds on reaching a widespread and continuous ODD, where automation can operate for longer periods and interoperability is assured across borders and brands. Hi-Drive strives to extend the ODD and reduce the frequency of takeover requests (TORs) by selecting and implementing technology enablers leading to highly capable CAD functions, operating in diverse driving scenarios including, but not limited to, urban traffic and motorways. The removal of fragmentation in the ODD is expected to give rise to a gradual transition from conditional automation towards higher levels of AD.

The work in Hi-Drive started in July 2021 with the collection and description of the different ADFs, their ODDs and limitations (D3.1 *Use cases definition and description* by Bolovinou et al., 2023), and the enabler technologies that help overcome these limitations. When testable functions and use cases of driving automation were defined, research questions were formulated (D4.1 *Research questions* by Metz et al., 2023), leading to specification of data needed for evaluation and recording of vehicle and driver behaviour (D4.2 *Data for evaluation* by Fahrenkrog et al., 2022) and finding solutions for the experimental procedure (D4.3 *Experimental procedure* by Sintonen et al., 2023).

The evaluation will focus on three areas: 1) users; 2) AD performance and availability; and 3) assessment of impacts (on safety, efficiency, environment, mobility, and transport system). Furthermore, these assessments serve as input to determine whether the benefits of higher driving automation for the society outweigh its social costs. The project also engages in a broad dialogue with the stakeholders and general public to promote the Hi-Drive results. Dissemination and communication are boosted by demonstration campaigns to show project achievements.

Overall, Hi-Drive strives to create a deployment ecosystem by providing a platform for strategic collaboration. Accordingly, the work includes an EU-wide user education and driver training campaign and series of Codes of Practice (CoP) for the development of ADFs and road-testing procedures, while also leading the outreach activities on standardization, business innovation, extended networking with interested stakeholders, and coordinating parallel activities in Europe and overseas.

1.2 Objective and scope of the deliverable

This deliverable reports on the work conducted as part of Work Package (WP) 4.6 Methods for user evaluation of the *Methodology* sub-project of Hi-Drive (SP4) and outlines the different methods that will be used by the project partners to study user interactions with AVs.

The work in this deliverable is strongly linked to, and stems from, the work conducted in WP4.3 and Deliverable D4.1 *Research Questions* by Metz et al. (2023), addressing the overall goals outlined in the Description of Work of the Hi-Drive project. In particular, Deliverable D4.4 on User evaluation methods focuses on the agreed upon *User-related* Research Questions (RQs) of D4.1 (Metz et al., 2023).

The work of this deliverable is also directly related to the *User* sub-project (SP6) and includes four dedicated work packages which will implement and execute the user evaluation plan. This work will include different, but related, aspects of user acceptance and awareness, when users interact with and use AVs, as agents on-board the vehicle (drivers/passengers), as other road users (pedestrians, cyclists, and other drivers), and as remote operators controlling the vehicle from afar. As users’ acceptance, awareness and experience can also be investigated “offline”, the methods outlined in this deliverable also include a range of questionnaires and surveys that seek the opinion of participants who are not directly related to the project or may not have had direct experience with AVs, namely respondents to the Hi-Drive Global Survey.

Finally, there is a link between the work reported in this deliverable and D4.2 *Data for Evaluation* by Fahrenkrog et al. (2022), with an emphasis on how the pre- and post-common questionnaire results will be amalgamated into the project’s Consolidated Database.

In the following sections of this deliverable, we will provide a summary of the current state-of-the-art in relation to measuring user interactions with AVs, highlighting the importance of the project-level research questions for understanding the experiences of onboard users, external road users, and remote operators (Chapter 3). Chapter 4 provides descriptions of the various methods that will be used to conduct user-related experiments including simulator (Section 4.2), test-track (Section 4.4), and real-world studies (Section 4.5) and questionnaires (Section 4.6), while Chapter 5 provides detail on the specific measures and metrics that will be used to evaluate user interactions. An overview of the final evaluation plan for each of the project research questions is provided in Chapter 6, with a final wrap-up of the summary and conclusions in Chapter 7.

2 Understanding and improving users' interactions with Automated Vehicles

As higher levels of AVs start to enter the market, it is important to understand how these vehicles will be used, their impact on the ordinary driver, and how this human-technology interaction will influence traffic efficiency and road safety. Since AVs are deployed in mixed traffic environments that include pedestrians, cyclists, and other drivers, it is also important to understand the effects of AV interactions with these actors. For these new forms of mobility to be embraced and accepted by the consumer, and used as intended by system designers, there is a compelling argument for an **interdisciplinary** approach to the design of ADFs and their related human-machine interfaces (HMIs), to reduce the probability of user abuse[1], misuse[2], and disuse[3] (Parasuraman, 1997). This is the ethos of the approach used by the Hi-Drive project, where software engineers, system and user experience (UX) designers, and human factors experts/psychologists from universities, research organisations and Original Equipment Manufacturers (OEMs) are working together to understand how humans use these technologies, and the effect of this interaction on the individual, the AV and the surrounding road environment. If designed well, these systems will adhere to users' expectations, are more likely to be accepted, used appropriately, and as intended by the designers, ultimately leading to improvements in road safety. Other impacts include how this interaction affects the design of our future road infrastructure, traffic flow, energy consumption, and mobility patterns. In Hi-Drive, users' expectations and experiences of these systems will be explored using a series of studies, questionnaires, and surveys focusing on users' **Acceptance, Awareness and Expectations** (WP6.3).

Human-factors and user-related errors, such as inappropriate speed and impairments due to alcohol/fatigue/drugs etc., are regularly quoted as the cause of 90% or more of road-related crashes. The promise of automation and AVs is that these errors and their related crashes will be removed or substantially reduced if technology replaces the human in the driving task. However, until the technology is advanced enough to safely replace all driving functionalities (i.e., at least at SAE Level 4), this "substitution myth" (Sarter & Woods, 1997) may also lead to new and unintended human-related errors (Lee & See, 2004), and indeed the automation itself may not always perform as expected, leading to the potential for new types of accident to arise (Bjorvatn, 2021). For now and the foreseeable future, the human must continue to supervise the operation of various Advanced Driver Assistance Systems (ADAS) in the car

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[1] Abuse occurs when the automation is designed without considering the consequences on human performance, leaving it open to being used incorrectly.

[2] Misuse refers to overreliance on automation which can lead to monitoring failures or decision biases.

[3] Disuse refers to the underutilization of automation, and is commonly caused by false alarms.

(SAE Levels 1-2). When conditional automation is engaged (SAE Level 3), the human is not driving but must resume manual control when requested to do so. Therefore, as the levels of automation in a vehicle increase, the human's role changes from being responsible for Object and Event Detection and Response (OEDR) to supervising the various ADAS and ADFs within a certain ODD. When the AV is responsible for the control, manoeuvring and/or strategic aspects of the driving task (SAE Levels 3-4), there will be times when the human supervisor will need to observe the surrounding driving environment using a range of HMIs that provide information about the correct operation and health of the various ADAS/ADFs. These should provide assistance and guidance for the human to re-enter the driving loop and resume control of the vehicle when required to do so.

Work on the interaction of humans and automated systems from other domains highlights some of the risks associated with poorly designed technologies and interfaces that might not appreciate human factors in the design process. For example:

1. Human resources are limited. This can be problematic for higher levels of automation, where prior to re-entering the driving loop at the end of an ODD, a user must not only monitor the driving environment but also supervise a range of in-vehicle interfaces, directing their attention across many locations in and out of the vehicle.
2. Correct use of a system by humans requires a good understanding of its functionalities and limitations.
3. Prolonged engagement of an ADF leads to a reduction or complete removal of the skills required for that functionality, which can be detrimental if the human is then requested to resume control/responsibility.
4. Extended engagement of an automated system leads to human fatigue and boredom.
5. Trust of the system by the user must be appropriately calibrated, with too little trust leading to lack of use and too much trust leading to complacency about system capabilities.

As highlighted by Merat and Louw (2020), higher level AVs may also need a well-working and reliable **Driver Monitoring System** to ensure that the human supervisor is alert and engaged, honouring their supervision responsibility at SAE Levels 1 and 2 (see Figure 2.1), or is indeed fit and well enough to resume control when requested to do so (e.g., is in the driving seat and not asleep) at SAE Levels 3 and 4.

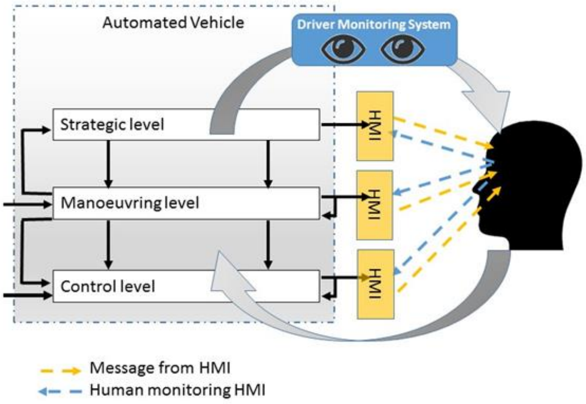


Figure 2.1: A proposed model showing the changing position and role of the human due to the introduction of automated functions in the driving task (from Merat & Louw, 2020)

Studies in vehicle automation and other domains have shown that when automation is engaged, humans are prone to boredom and fatigue (Cummings & Gao, 2016; Desmond & Hancock, 2001). In the driving domain, in order to relieve this boredom, the user may look around the vehicle and driving environment more often, with eye and head-tracking data in both real-world and driving simulator studies showing a reduction of visual attention to areas important for safe driving, such as the road ahead and the side and rear-view mirrors (e.g., Carsten et al., 2012; Louw et al., 2017). Drivers are also more likely to be engaged in more NDRTs, which results in an overall loss of situation awareness, taking them "out of the loop" and increasing their chances of being involved in a crash (Louw et al., 2017), or at least reducing their ability to safely control the vehicle after a Request to Intervene (RtI) / Takeover Request (TOR) by the automated system (Merat et al., 2012). This can either occur at the end of the ODD or due to a limitation of the system. Therefore, for successful deployment of higher-level AVs to be realised, further work is required to improve the functionality and reliability of **Driver Monitoring Systems** of future vehicles, which is the focus of WP6.5 of the Hi-Drive project.

With prolonged engagement of automation, perhaps due to successful extension of the ODD, the user will have the opportunity to disengage further from the driving task, perhaps relaxing more into their seat, taking their eyes off the driving task and the road ahead, or engaging in NDRTs for longer. Studies from manual driving have demonstrated that users' propensity for motion sickness increases in such circumstances (Schmidt, Kuiper, Wolter, Diels, & Bos, 2020). At the same time, the perceived usefulness of the AV depends on the extent to which people are able to engage in NDRTs (Naujoks, Wiedemann, & Schömig, 2017). The motion profile of these vehicles needs to be considered, as research on user comfort has shown that accelerations, decelerations, and cornering can also increase motion sickness, reducing user comfort (Diels & Bos, 2016). Understanding what proportion of the European population is currently prone to motion sickness, how this can be measured, and whether engagement in NDRTs affects this state is studied in a dedicated WP of Hi-Drive on **User Comfort** (WP6.4).

Finally, for AVs to be fully integrated in our traffic system, their intentions and behaviour must be well-understood by **Other Road Users** (WP6.6), including pedestrians, cyclists, and other drivers (Schieben et al., 2019). Without a human driver in control of the AV, communication of intent can either be provided by externally placed Human Machine Interfaces (eHMIs), or via implicit forms of communication such as subtle changes in the AV's lateral and longitudinal position (dynamic (d) HMIs; Bengler et al., 2020). WP6.6 of the User subproject is therefore investigating the value of these forms of explicit and implicit communication by AVs, using both laboratory and real-world studies.

The next section of the document provides a more detailed overview of the Research Questions devised for each of these four main topics on understanding and improving user interaction with AVs.

3 State of the art and research questions for each topic

The Hi-Drive project focuses on investigating human interaction with AVs as three different groups. This includes users inside the vehicles as drivers/passengers, external road users sharing the same space with AVs, such as other drivers/pedestrians/cyclists, and also those who may be required to observe and control the AV from elsewhere and remotely: remote- and tele-operators. This section provides an overview of the state of the art for each research topic relevant to each of these users and identifies the research gaps that will be addressed within Hi-Drive.

Figure 3.1 provides a summary of all evaluation areas, also illustrating some commonalities across the different user groups, especially regarding acceptance and awareness. While distinct empirical studies are conducted for each of the user groups across the Hi-Drive partners, effort has been made to develop a set of consolidated questionnaires which will be administered to as many user groups across the different laboratories and test sites as possible, to increase the power in understanding user acceptance and awareness. This includes one questionnaire developed for all pilot studies conducted by partners in the *Operations* subproject (SP5).

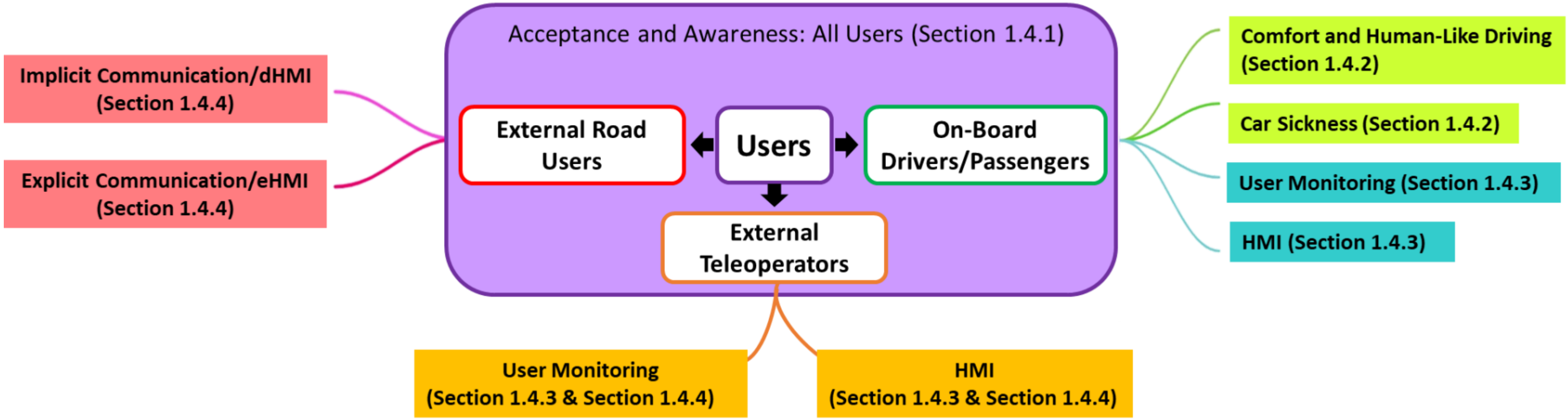


Figure 3.1: An overview of each aspect of user-related research questions to be studied in Hi-Drive.

3.1 User acceptance and awareness (All users)

As previously discussed, the more AD designs adhere to users' expectations, the more likely they are to be accepted, used appropriately, and as intended by the designers, ultimately contributing to the sustainability of future mobility solutions. Thus, it is important to understand the factors which influence the acceptance, awareness, and expectations of AD functionality for all user groups.

This topic is covered by WP6.3: **acceptability and acceptance of AD**. Acceptability is a prospective judgement about a system which will be implemented in the future, whereas acceptance refers to attitudes toward the system after having experienced it (Schade & Schlag, 2003). These constructs have been conceptualised as "receptivity towards AVs" (Deb et al., 2017) when exploring pedestrian and other driver responses to the roll-out of AVs.

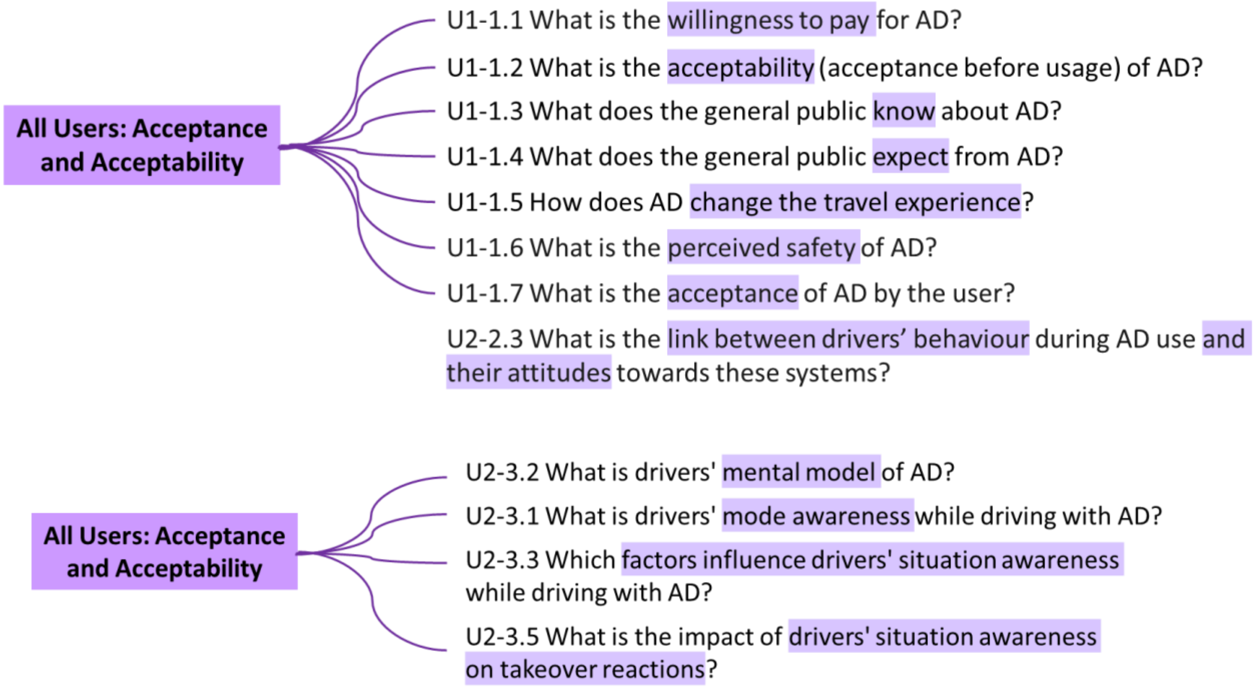
Acceptability and acceptance are usually understood as willingness to use, purchase, or interact with the system either prior to (acceptability) or after (acceptance) gaining experience with it. Trust is considered one of the key factors contributing to acceptance of AVs (Liu et al., 2019; Nordhoff et al., 2023; Zhang et al., 2019). Trust in a system means that the onboard user is willing to allow AD to control the vehicle (Nordhoff et al., 2021), or that external road users are willing to cross in front of the AV or move beside it (Deb et al., 2017; Pammer et al., 2021), even if this means that the system's errors could put the person in danger (Lee & See, 2004). Trust is thus closely linked to perceived safety and the perceived reliability of the system (Nordhoff et al., 2023). In addition to trust, other factors such as perceived usefulness and ease of use have been recognized as highly important in the acceptance of new technologies, AD in particular (Davis et al., 1989; Lehtonen et al., 2022; Madigan et al., 2017; Nordhoff et al., 2020; Venkatesh & Davis, 2000). Factors such as enjoyment, comfort, support in learning the new system, and social influence also play a role in levels of acceptability and acceptance (Venkatesh et al., 2003).

One of the overarching goals of the Hi-Drive project is to defragment and extend the ODD, which would reduce the need for the human driver to re-take control of the car. Repeated experiences of critical takeovers at system boundaries have been found to be detrimental to trust (Metz et al., 2021) and ratings of the usefulness of AV systems (Lee et al., under preparation). This is because such disengagements reduce users' ability engage in other NDRAs. Thus, an extended ODD leading to a reduction in TORs is likely to be highly important for the acceptance of AD.

WP6.3 of the project is also considering all road users' awareness of automation and drivers' awareness during AD. **Awareness of automation** refers to the degree of familiarity with the current ADAS systems and knowledge about the capabilities and limitations of AD concepts currently under development. Increased familiarity with the ADAS and ADFs is assumed to lead to a higher level of acceptance (Louw et al., 2021), even though those with more knowledge of system capabilities have also been shown to be more sceptical than those with less experience (Weber et al., 2021; Lehtonen et al., 2022).

Awareness during automated driving refers to onboard users' situation awareness of their driving environment and mode awareness of the AD. Situation awareness refers to the perception of relevant elements in the driving environment, the comprehension of their relevance to the driving task, and the ability to anticipate what will happen next (Endsley, 1995; Wickens, 2008). Situation awareness is highly important for hazard perception in manual driving. In AD, the takeover situations pose a challenge for drivers' situation awareness (Victor et al., 2018). During conditional automation (SAE Level 3), the driver is not required to pay attention to their surrounding environment. However, when prompted by a TOR they must quickly establish situation awareness of the driving environment and vehicle capabilities before being able to safety take back control of the driving task, perhaps avoiding an impending collision (Louw et al., 2017). Mode awareness is related to situation awareness but focuses more on the driver's and other road users' understanding of how the AV is functioning—i.e., whether it is in AD or manual mode (Feldhütter et al., 2018).

Figure 3.2 provides an overview of the research questions relating to acceptability, acceptance, and awareness that will be addressed in this work package.



All Users: Acceptance and Acceptability

- U1-1.1 What is the willingness to pay for AD?
- U1-1.2 What is the acceptability (acceptance before usage) of AD?
- U1-1.3 What does the general public know about AD?
- U1-1.4 What does the general public expect from AD?
- U1-1.5 How does AD change the travel experience?
- U1-1.6 What is the perceived safety of AD?
- U1-1.7 What is the acceptance of AD by the user?
- U2-2.3 What is the link between drivers' behaviour during AD use and their attitudes towards these systems?

All Users: Acceptance and Acceptability

- U2-3.2 What is drivers' mental model of AD?
- U2-3.1 What is drivers' mode awareness while driving with AD?
- U2-3.3 Which factors influence drivers' situation awareness while driving with AD?
- U2-3.5 What is the impact of drivers' situation awareness on takeover reactions?

Figure 3.2: The two strands of research questions to be used for evaluating users' acceptance and awareness of AD

3.2 Human-like driving and user comfort (onboard drivers/passengers)

One major factor contributing to the acceptance of automated vehicles is the **comfort experienced by its riders** (Arndt, 2011). There are several different definitions of comfort currently in use. For example, Slater (1985) defines it as "a pleasant state of physiological, psychological and physical harmony between a human being and the environment." Bellem, Schönenberg, Krems, and Schrauf (2016) describe comfort as "a state which is achieved by the removal or absence of uneasiness and distress," while according to De Looze, Kuijt-Evers, and Van Dieen (2003), comfort consists of several different components and is a subjective construct that is influenced by physical, physiological, and psychological elements resulting from the interaction of the user with the environment. Comfort is thought to be more than the absence of stress but also a feeling of pleasantness and well-being.

Discomfort, on the other hand, is regarded as "a subjective, unpleasant state of driving-related psychological tension or stress in moments of a restricted harmony between driver and environment" (Hartwich, Beggiato, & Krems, 2018).

Several factors influence the comfort of passengers in an AV. Of special importance are the following:

- Vehicle movement patterns (Diels & Bos, 2016; Elbanhawi, Simic, & Jazar, 2015)
- Naturalness of driving style (Elbanhawi et al., 2015; Peng et al., 2022)
- Propensity to motion sickness (Elbanhawi et al., 2015; Peng et al., 2022)

Studies from manual driving show that the passengers' experience of comfort is largely dependent on the vehicle's driving style (Bellem, Thiel, Schrauf & Krems, 2018). Thus, identifying what driving style is perceived as comfortable will be key for AD and its acceptance. There is a relatively limited understanding of what driving styles contribute to AD user comfort, although studies suggest that vehicle kinematics, i.e., a vehicle's acceleration and braking behaviour, and "proxemics", or the distance the AV keeps to other objects in the road, affect user comfort (Peng et al., preprint). Results from physiological metrics also show higher discomfort (indicated by higher skin conductance response of electrodermal activity and higher heart rate variability) associated with higher jerk and higher acceleration forces of the vehicle (Radhakrishnan et al., 2022).

Avoiding **motion sickness**, called car sickness in this context, is important for ensuring a comfortable driving experience. Motion sickness is a natural response to a mismatch between perceived and real motion and is a conflict between visual and vestibular sensory inputs (Claremont, 1931). Although the exact aetiology of motion sickness has not been fully understood, the most widely accepted theory is the Sensory Conflict Theory proposed by Reason (1978), who described it as follows: "*All situations which provoke motion sickness are characterized by a condition of sensory rearrangement in which the motion signals transmitted by the eyes, the vestibular system and the non-vestibular proprioceptors are at variance one with another, and hence with what is expected on the basis of previous transactions with the spatial environment*" (p.820).

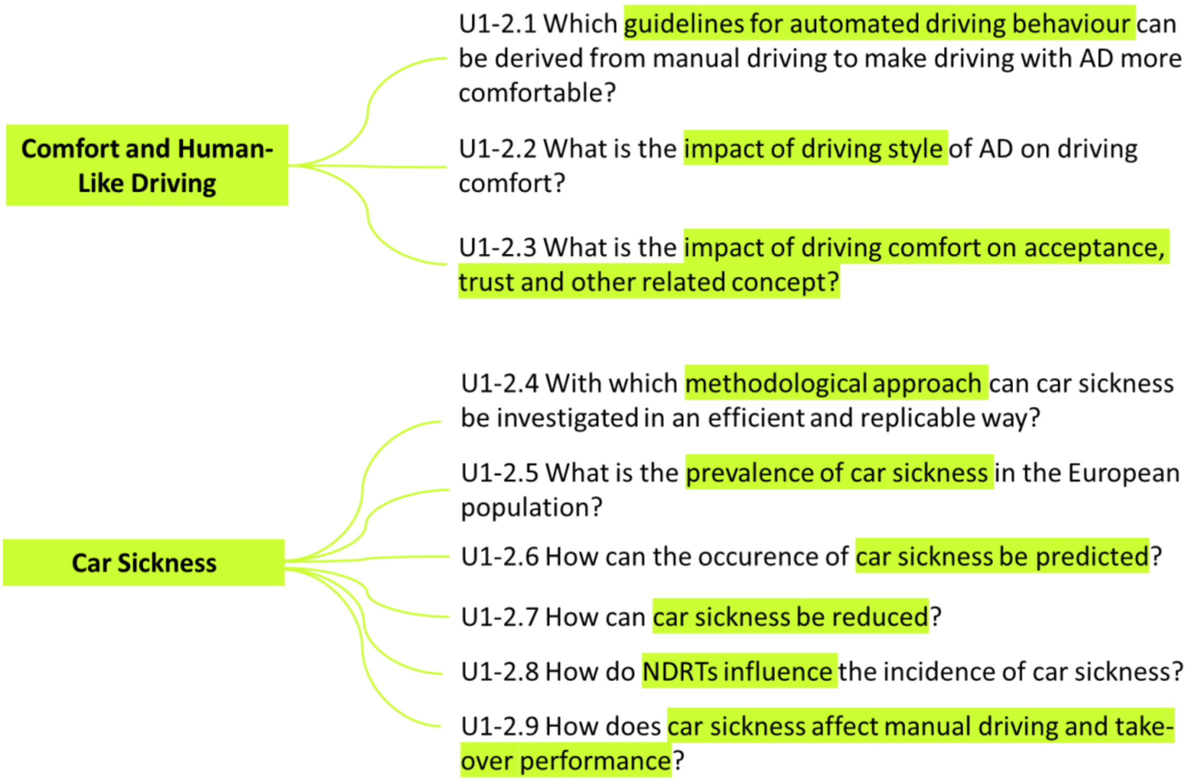
According to this theory, motion sickness occurs when there is a conflict between what we see and feel and what we expect. Relevant sensory systems include the visual system, the vestibular system (a sensory system in the inner ear that provides information about motion, head position, and spatial orientation to the brain, keeping body balance), and the proprioceptive system (a sensory system that provides a sense of self-movement, force, and body position). Motion sickness occurs due to a mismatch between present sensory information and predictions based on prior experience. The main symptom of motion sickness is nausea, which in some cases leads to vomiting (Golding, 2016).

The occurrence of car sickness depends on various factors such as driving conditions or NDRAs (Mühlbacher, Tomzig, Reinmüller & Rittger, 2020; Schmidt, Kuiper, Wolter, Diels &

Bos 2020). The level of motion sickness is highly dependent on the severity and duration of exposure to motion. Car sickness is mainly associated with horizontal accelerations (lateral and longitudinal) caused by accelerating, braking, and cornering (Turner & Griffin, 1999a, b). Both acceleration amplitude and frequency are relevant factors. Accelerations with low frequencies from around 0.1–1 Hz are particularly provocative for motion sickness, whereas higher frequencies provoke general discomfort, also referred to as ride discomfort.

Thus, car sickness is highly dependent on the circumstances. For conditional automation (SAE Level 3), the driver is allowed to engage in a variety of NDRTs during automated driving These include reading, watching videos, etc. Focusing on tasks that require visual attention away from the driving scene may increase the risk of experiencing car sickness (Diels & Bos, 2016; Diels, Bos, Hottelart & Reilhac, 2016). Car sickness is not only a threat to people's comfort but has been shown to impair performance of cognitive and physical tasks (Bos, 2004; Colwell, 2000; Stevens & Parsons, 2002). Thus, there is also a question regarding how car sickness might impact driving performance after a TOR, e.g. during SAE level 3 driving.

Within the Hi-Drive project, research questions in this context will focus on two main topics. One strand of the research will focus on the prevalence of car sickness and how this can be reduced, thereby improving users' comfort during AD. In another strand we will investigate whether designing human-like driving styles will improve user comfort in the AV (see Figure 3.3). We aim to identify methodological approaches to identifying car sickness in an efficient and replicable manner, also investigating the prevalence of car sickness in the European population. It is our aim to reduce car sickness, especially when users engage in NDRTs while automation is active. Being able to predict the occurrence of car sickness would also enable us to prevent it from happening. In cases where drivers would need to take over control at the end of an ODD, it is also important to understand how car sickness affects manual driving and their takeover performance. Avoiding car sickness of users is a minimum requirement for AD, but it is also important to work towards ensuring users' comfort. Thus, a key element of work within the project will be to derive kinematic information from manually driven vehicles and apply it to the automation system to investigate if, and how, these features improve user comfort.



Comfort and Human-Like Driving

- U1-2.1 Which guidelines for automated driving behaviour can be derived from manual driving to make driving with AD more comfortable?
- U1-2.2 What is the impact of driving style of AD on driving comfort?
- U1-2.3 What is the impact of driving comfort on acceptance, trust and other related concept?

Car Sickness

- U1-2.4 With which methodological approach can car sickness be investigated in an efficient and replicable way?
- U1-2.5 What is the prevalence of car sickness in the European population?
- U1-2.6 How can the occurence of car sickness be predicted?
- U1-2.7 How can car sickness be reduced?
- U1-2.8 How do NDRTs influence the incidence of car sickness?
- U1-2.9 How does car sickness affect manual driving and take-over performance?

Figure 3.3: The two strands of research questions to be used for evaluating user comfort in AVs

3.3 User monitoring and related HMI (onboard drivers/passengers and remote operators)

A key challenge for partial and conditional automation is ensuring that drivers are suitably alert when automation is engaged, allowing them to safely resume manual control in a timely manner if and when requested to do so. For automated systems operating at SAE levels 2 (L2), 3 (L3), and 4 (L4), the driver is responsible for the safe resumption of the driving task when a system request is received—e.g., at the end of an ODD. During L2 AD any system limitations should be identified by the "supervisor" of the AD through adequate and continuous monitoring and, when required, suitable action should be taken to resume control, avoiding any impending collision (Louw, Merat, & Jamson, 2015; Merat et al., 2019). However, research has demonstrated that engagement of L2 systems is associated with reduced driver attention to the road centre (Gonçalves et al., 2020), increased horizontal gaze dispersion (Damböck et al., 2013; Louw & Merat, 2017), and a reduction in glances towards safety-critical areas such as the side and rear-view mirrors (Gonçalves et al., 2019). Furthermore, researchers have also found that L2 engagement can result in slower takeover response times (Damböck et al., 2013), which could also lead to collisions.

To ensure that the driver is supervising the automated system appropriately and/or is ready and capable to take over control when prompted, a range of sensors, collectively termed **Driver (or occupant) Monitoring Systems** (DMS/OMS), will need to be implemented in future AVs. Also referred to as Driver Drowsiness and Attention Warning Systems (TRL, 2022), these systems infer driver attention, alertness, and engagement. This can be directly, through the use of camera-based sensors directed at drivers' eyes, face, and head, or indirectly, for example via steering wheel sensors.

Some camera-based systems are already implemented in new and luxury vehicles, allowing hands-free monitoring of L2/3 systems (e.g., Ford, 2023; GMC, 2023). Further incentives are to be provided by the European New Car Assessment Programme's Safety Assist protocols (EuroNCAP, 2021) for their implementation in more vehicles from 2023. A key challenge for Human Factors research is to ensure that these systems are accurate and do not provide too many false negative/positive alarms. Good HMI design principles (Cartsen & Martens, 2019) must be incorporated to address this challenge. The accuracy of data provided by less efficient versions of DMS remains low (mainly due to the lack of a suitable volume of data from a diverse range of users). This leads to driver misuse and abuse; the driver may ignore frequent alarms (Lee et al., 2002), become complacent to the warnings (Ruscio et al., 2015), or even turn the systems off/tamper with their operation (Reagan & McCartt, 2016). Therefore, there is a risk that these systems will not be accepted and adopted by drivers, reducing their potential contribution to driver safety.

The value of these DMS becomes even more fundamental for higher level AD, e.g., at SAE Level 3. This is because drivers are allowed to engage in NDRTs which can typically move their hands, head, and eyes away from the driving task. However, drivers are still responsible and must be *ready to resume control* "when the feature requests" (SAE, 2021). Ultimately, these vehicle-based sensors and wearable devices should be able to accurately assess driver state, including unsafe levels of driver overload/underload, preventing the handover of control back to an unfit driver. If the driver is absent or incapacitated, this may lead to a Minimum Risk Manoeuvre (MRM) for the vehicle.

The concept of "readiness" is particularly relevant to L3 AD and has been defined as "the fastest ability of the driver to get engaged in the driving task from the NDRT" (Georg et al., 2017). Hence a "ready driver" can respond on time, and appropriately, to a given scenario when an intervention is required (ISO/TR 21959-1:2020; Mioch et al., 2017). However, readiness as a metric cannot be directly observed or measured and is usually operationalized as a combination of constructs based, for example, on motoric/physical and cognitive/mental performance data (Mioch et al., 2017). Individual factors such as driver skill, driver intention, trust in the automated system, and the propensity to engage in risk-taking behaviour—

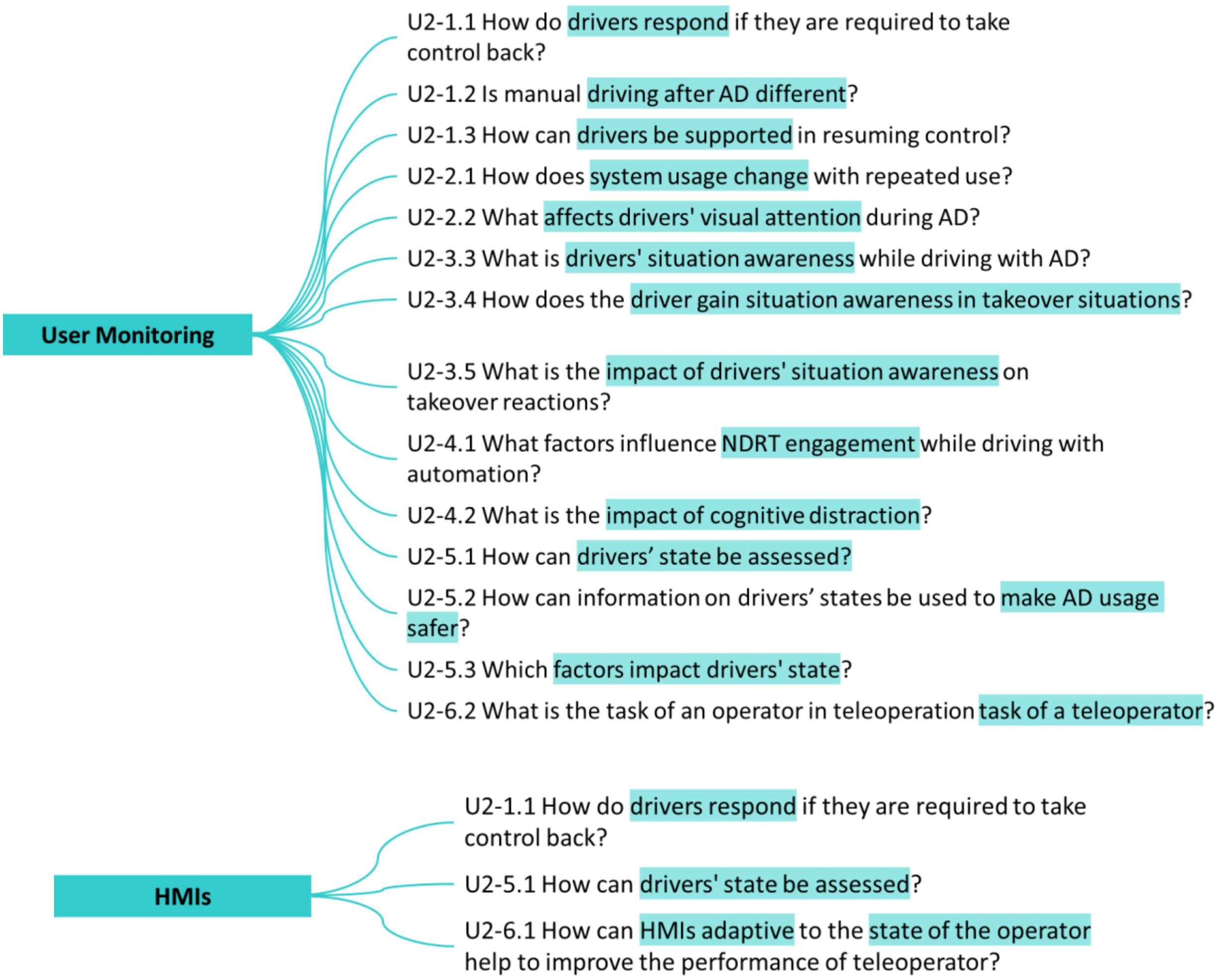
although not directly measurable—are all factors that feed into readiness estimation (Marberger et al., 2017).

As L3 and L4 AD allows driver engagement with NDRTs, current DMS are no longer fit for purpose. Therefore, new methods need to be considered for conditions which cannot guarantee a forward-facing driver. Solutions are currently in place to include more advanced systems, e.g., more accurate occupant monitoring systems integrated in the rear-view mirror. Efforts are also in place to create more accurate sensor fusion techniques that integrate information about the user's posture, and physiological and emotional state, to inform driver readiness estimations.

Potential indicators that have already shown some success in identifying and measuring the internal state of the user include physiological metrics (e.g., heart rate variability, heart rate, and electrodermal activity; Radhakrishnan et al., 2020; Radhakrishnan et al., 2022), behavioural indicators (e.g., eye movements and body posture; Mioch, Kroon, & Neerincx, 2017), vehicle-based measures taken after resumption of control (e.g. steering wheel reversal rate, steering entropy; Kountouriotis et al., 2016), and subjective evaluations (e.g., NASA Task Load Index for workload, Karolinska Sleepiness Scale for establishing fatigue and sleepiness). However, more research is needed to validate the accuracy of these methods for determining user states, ideally integrating the context of the scenario. There is also a distinct lack of knowledge on the best/most successful HMIs to be used. To be effective, these need to capture users' attention rapidly and successfully, perhaps even guiding the user to perform the correct manoeuvre, without being distracting or annoying.

As outlined above, an effective DMS may prevent an unfit or incapacitated driver from resuming control of the vehicle at the end of an ODD. In these circumstances, the AV may enter an MRM and remain inactive until it can be guided or controlled by other means. One proposed solution is using a remote operator to manage this task. Vehicle teleoperation refers to an approach where an attendant who is no longer on board an automated vehicle monitors the situation and is connected to the vehicle from a different location, intervening or assisting as necessary (Kettwich et al., 2021). This approach can be direct (replicating the manual driving process) or indirect (utilising computation to translate human choices into efficient and safe action, Kettwich et al., 2021). Regardless of the approach used, the remote operator's role can be similar to that of an onboard driver, who must be attentive to their role and ready to intervene as required. As with the onboard driver supervising an L2 AV, continuous monitoring of the remote vehicle by the remote operator can be mentally taxing and generate high levels of underload (Sheridan, 1992) if the AV is operating correctly for a long period of time. In contrast, a sudden and unexpected failure of one or more AVs will lead to unmanageable *overload* for the operator, whose attention and supervisory role must be simultaneously directed to multiple functions and locations (Thomson et al., 2015).

This research area is new and rapidly developing. Based on the challenges set out above, the overarching aim of WP6.5: User Monitoring and Related HMIs is to improve the understanding of the range of indicators used to measure driver state, along with investigating how they relate to task performance for both onboard users and remote operators. Figure 3.4 provides more details of the specific research questions, including questions on how HMI can be used to improve DMS adoption and acceptance.



U2-1.1 How do drivers respond if they are required to take control back?
U2-1.2 Is manual driving after AD different?
U2-1.3 How can drivers be supported in resuming control?
U2-2.1 How does system usage change with repeated use?
U2-2.2 What affects drivers' visual attention during AD?
U2-3.3 What is drivers' situation awareness while driving with AD?
U2-3.4 How does the driver gain situation awareness in takeover situations?
U2-3.5 What is the impact of drivers' situation awareness on takeover reactions?
U2-4.1 What factors influence NDRT engagement while driving with automation?
U2-4.2 What is the impact of cognitive distraction?
U2-5.1 How can drivers' state be assessed?
U2-5.2 How can information on drivers' states be used to make AD usage safer?
U2-5.3 Which factors impact drivers' state?
U2-6.2 What is the task of an operator in teleoperation task of a teleoperator?

U2-1.1 How do drivers respond if they are required to take control back?
U2-5.1 How can drivers' state be assessed?
U2-6.1 How can HMIs adaptive to the state of the operator help to improve the performance of teleoperator?

Figure 3.4: The two strands of research questions addressing user monitoring and HMIs

3.4 Interactions with other road users (other drivers, pedestrians, cyclists, remote operators)

In the future traffic system, AVs will coexist with other traffic participants on the road, including drivers of other vehicles, as well as pedestrians, cyclists, and powered two-wheelers. In addition, there are likely to be remote operators monitoring roadway interactions and supervising AV systems from afar. In order for AVs to integrate seamlessly within this social system, they will need to communicate and interact effectively with all other actors sharing the same road space (Markkula et al., 2020; Rasouli & Tsotsos, 2019). Therefore, it is not only important to design AVs for onboard users but also to consider the needs of other road users and remote operators, to help build a better and common understanding between all actors interacting with each other in a future world with AVs (Färber, 2016).

Research has identified three key factors which influence road user interactions in current traffic. These are 1) environment/situational characteristics, e.g., road infrastructure, traffic density, time of day; 2) road user characteristics and behaviours, e.g., age, gender, level of attention; and 3) vehicle characteristics including driver and vehicle behaviours, e.g., hand and eye movements, travelling speed, positioning (Madigan et al., 2019). The manner in which external road users interpret their interactions with AVs will depend on all three factors.

Bengler et al. (2020) have developed a framework to support the understanding of how AVs can use different communication tools to interact with both onboard and external road users. As part of this, they differentiate between external HMI (eHMI) and dynamic HMIs (dHMI; Bengler et al., 2020). eHMIs are interfaces installed on the external surface of the vehicle, or projected onto the roadway ahead, to provide information about the AV’s status or behaviour. dHMI refers to the use of vehicle kinematic information such as speed, lateral and longitudinal accelerations, and road positioning, to provide either intentional or unintentional communication with external road users.

Previous studies have shown that dHMI cues such as the speed of the approaching vehicle, its time gap and headway, and its braking and deceleration behaviour are often used by pedestrians to inform their crossing decisions (Ackermann et al., 2019; Lee et al., 2021, 2022; Madigan et al., preprint; Tian et al., 2022) and by other drivers to coordinate their motion patterns when entering a shared space, turning, or changing lanes (Dietrich et al., 2020; Haar et al., 2018; Papakostopoulos et al., 2021; Rettenmaier et al., 2020).

On the other hand, more explicit communication, either through direct interaction with a driver using hand or head movements or through eHMI displays such as flashing lights, is more likely to be used in low-speed traffic scenarios and where there is a shorter gap between road users (Lee et al., 2021; Rasouli et al., 2017; Sucha et al., 2017; Uttley et al., 2020) or in ambiguous situations where it is not clear who has the right of way, for example at an unsignalised crossing point or a four-way junction (Madigan et al., preprint; Papakostopoulos et al., 2021; Uttley et al., 2020).

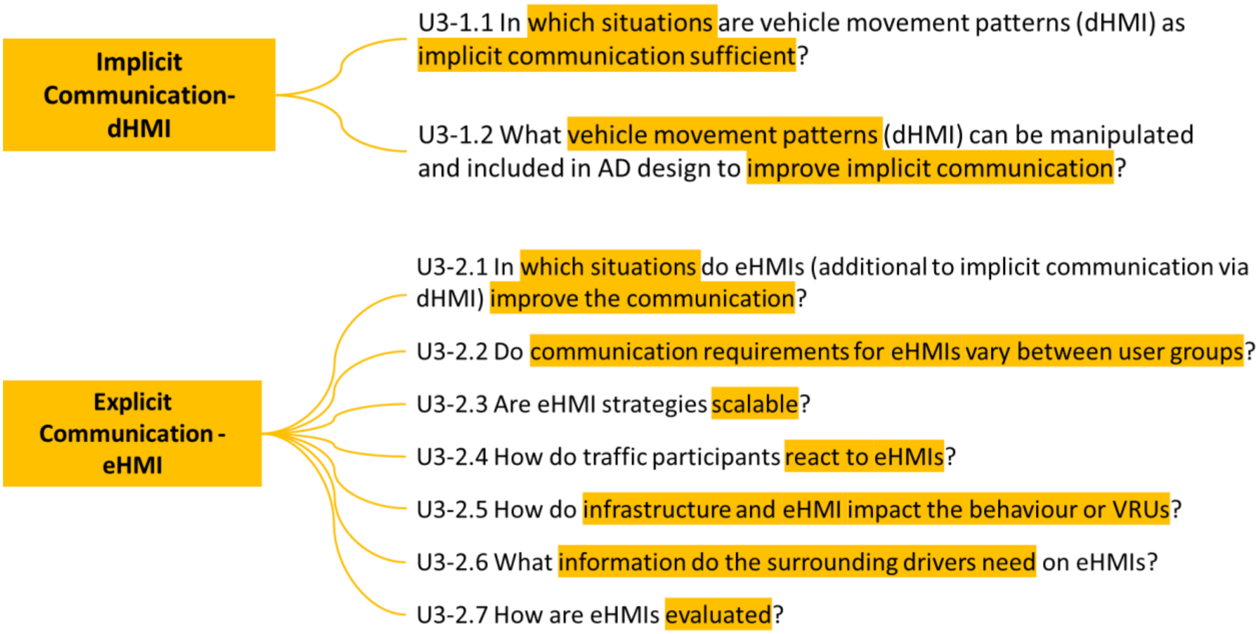
In recent years, a range of tools and methods have been used to study the impact of implicit and explicit communication of AVs with other traffic participants. In particular, visually presented external eHMIs, positioned on the outside of the AV, are offered as a promising communication tool for providing messages from the AV to other traffic participants. Studies have shown positive effects from these eHMIs in terms of pedestrians' perceived levels of safety and acceptance (De Clercq et al., 2019; Horn et al., 2023; Kitazaki & Daimon, 2018), their comfort and trust (Holländer, Wintersberger, & Butz, 2019; Kaleefathullah et al., 2020), and their willingness to cross in front of the AV (Dey et al., 2020; Lee et al., 2022). The use of an eHMI can also have a positive effect on pedestrians' crossing behaviours, i.e., assisting with earlier crossing decisions, linked to a higher level of certainty about this decision (Lee et al., 2022; Wilbrink, Lau, Illgner, Schieben, & Oehl, 2021). Similarly, eHMIs have been shown to be beneficial in helping other drivers to interpret the intended action of an AV more quickly, leading to more efficient decisions and fewer changes in speed (Li et al., 2023; Papakostopoulos et al., 2021; Rettenmaier et al., 2020). However, there are still many unanswered questions in this field, which will be addressed by WP6.6 of the Hi-Drive project on **Other Road Users**.

For example, a large proportion of previous studies have found that vehicle kinematics, or dynamic HMIs, play a big role in shaping road users' interactions and are the dominant cues used for these multi-actor scenarios. Therefore, it is important to understand the situations where implicit dHMI alone will be sufficient compared to those which benefit further from explicit cues. Furthermore, most studies have involved simple scenarios investigating the interaction between two actors: the AV and a pedestrian/other driver. Therefore, the value of eHMIs in more complex traffic scenarios with more than two actors needs to be tested to evaluate if the communication strategies are scalable. This includes a need to gain a better understanding of the impact of different road types and infrastructures on behaviour, and an investigation of whether all road users (including those with physical and psychological impairments) have the same needs from these external communication cues.

Much of the research to date has focused on the communication needs of pedestrians and human drivers with AVs (Dey et al., 2020), often overlooking the unique characteristics of cyclists. It is essential to appreciate that cyclists have different communication needs to pedestrians, owing to variations in their eye-gaze behaviour (Trefzger et al., 2018) and their speed and pattern of movements. Studies have revealed that cyclists engage with AVs from multiple angles and locations around the vehicle, exhibiting complex and speedy crossing, merging, overtaking, and passing interactions (Al-Taie et al., 2023; Berge et al., 2023a; De Ceunynck et al., 2022; Madigan et al., 2019). Moreover, researchers have emphasised the need for effective two-way communication between cyclists and AVs (Al-Taie et al., 2023; Berge et al., 2022). As such, it is imperative to explore the ways in which eHMIs can be modified to be more effective in addressing the specific needs of cyclists.

Finally, there has been increased interest in recent years in the use of a remote operator to monitor AV performance and intervene when required. However, to date there have been no systematic analyses available regarding the communication requirements for remote operation of AVs. Safe, fast, and stable communication links are an essential prerequisite for remotely operating AVs. Kettwich et al. (2022) provide a catalogue of use cases and scenarios for remote operation that can be used to derive communication requirements. One of the central aspects is a communication link between the remote operator and the supervised AV which has high bandwidth to transmit high-resolution video streams and sensor data. In additional, latency in data transmission must be low and stable for the operator to generate situation awareness in a timely and safe manner and keep the workload manageable. A prototypical design for the HMI of a remote operator that considers communication links between the operator and the AV, as well as to additional actors including traffic management, service providers, and first responders, has been described by Kettwich et al. (2021). In the Hi-Drive project, this design will be refined and adaptive elements added where appropriate. The refined design will be evaluated at the end of the project.

Figure 3.5 provides an overview of the specific research questions that will be addressed in this work package, distinguishing between implicit and explicit cues, for a range of road users interacting with AVs.



U3-1.1 In which situations are vehicle movement patterns (dHMI) as implicit communication sufficient?

U3-1.2 What vehicle movement patterns (dHMI) can be manipulated and included in AD design to improve implicit communication?

U3-2.1 In which situations do eHMIs (additional to implicit communication via dHMI) improve the communication?

U3-2.2 Do communication requirements for eHMIs vary between user groups?

U3-2.3 Are eHMI strategies scalable?

U3-2.4 How do traffic participants react to eHMIs?

U3-2.5 How do infrastructure and eHMI impact the behaviour or VRUs?

U3-2.6 What information do the surrounding drivers need on eHMIs?

U3-2.7 How are eHMIs evaluated?

Figure 3.5: Range of research questions to be addressed by the Other Road Users work package

Chapter 3 provided an overview of the state of the art relating to user interactions with AVs, for each of the main areas of research being covered in the Hi-Drive project. Chapter 4 will provide descriptions of the various methodologies and metrics to be used within the project to study these user interactions.

4 Methodologies

One of the key considerations in any user-related research is the level of validity and reliability associated with the research. In psychological terms, **validity** refers to the extent to which any test of performance measures what it sets out to measure, and **reliability** refers to the consistency with which this is done (American Psychological Association, 2017). Another consideration in this space is the ecological validity of the research, or the degree to which the testing environment resembles the situations and task demands that are characteristic of the real world (Ashcraft & Radvansky, 2009). However, as the ecological validity of the research environment increases, it can become increasingly difficult to ensure the reliability of any measures obtained, as the repeatability of the test scenarios becomes more difficult to control.

Thus, in order to really understand driver and other road users' behaviour, it is important to use a mixture of methods that vary in their level of ecological validity. This will ensure that the psychological mechanisms behind road user behaviours can be initially investigated in highly controlled laboratory environments, and the conclusions obtained through these more controlled environments can then be tested in more ecologically valid, real-world environments. Throughout the user investigation process, the knowledge obtained through objective empirical studies will be supplemented with subjective data, obtained via questionnaires, interviews, and focus groups, which provide direct and immediate insights from road users on their experience of the phenomena of interest.

Figure 4.1 provides an overview of the various methodologies that will be used within the Hi-Drive project. Each of these are discussed in more detail in Sections 4.2 to 4.6. The planned research utilises many different environments and approaches, including simulators, test tracks, and real-world environments, regularly supplemented by questionnaires, interviews, and focus groups.

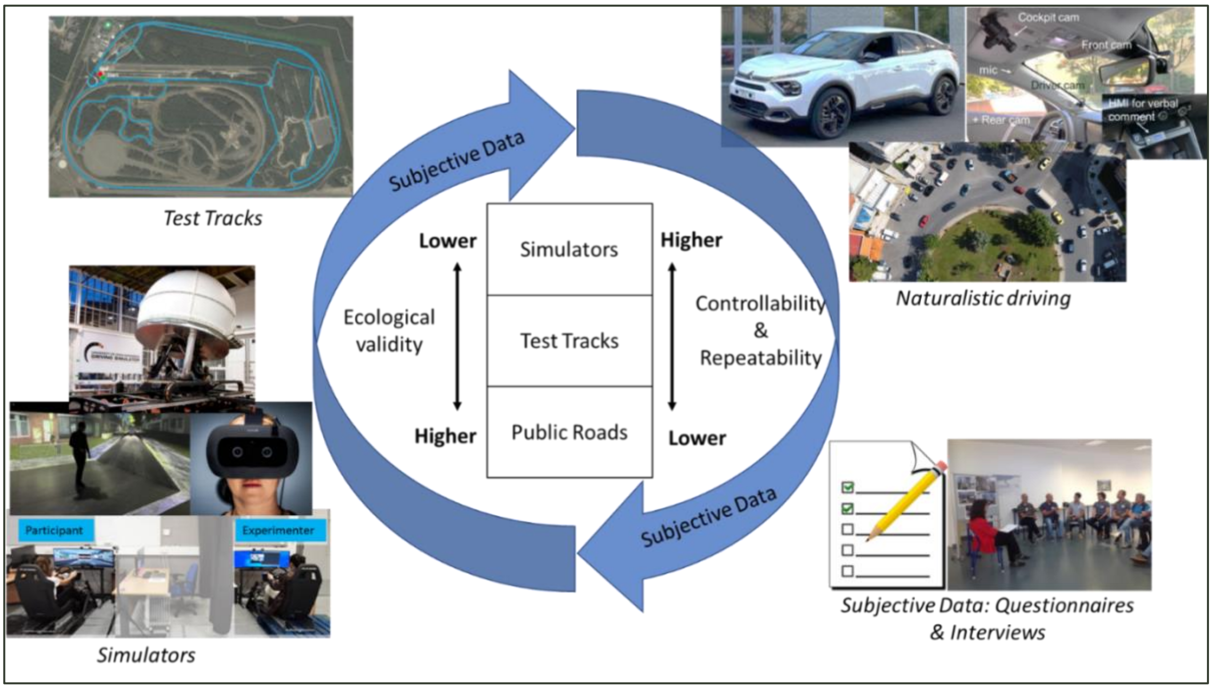


Figure 4.1: Overview of methodologies to be used within Hi-Drive along with their strengths and weaknesses

Human-in-the-loop simulators allow a high level of controllability and repeatability, providing a reliable method for investigating driver, pedestrian, cyclist, and remote operator behaviour in predefined scenarios (see Section 4.2). The virtual environment allows manipulation and implementation of a range of road designs, providing complex scenarios that can be tested in a safe and affordable setting. User interactions with systems and technologies that are not yet available in the real world can also be investigated. However, the experience with AD may not be the same as that in a real vehicle, with participants' perception of risk being one main difference between these two settings. Test tracks provide a more realistic, but safe, means for exploring the impact of real-world vehicle dynamics or specific traffic scenarios in a separated test area, allowing a similar level of controllability and repeatability to simulator studies but with a smaller range of scenarios (see Section 4.4). While simulators and test tracks facilitate the development of highly controlled experiments, this level of controllability makes it difficult to explore unexpected scenarios or edge cases which may emerge during real-world driving. For these scenarios, it is best to use video-based observations of the real world, real-world driving, or evaluations of drivers'/pedestrians'/cyclists' on-road experiences (see Section 4.5). However, these real-world examples lack any controllability, and therefore the experiences of each individual participant may vary greatly. There is also less or no knowledge of user characteristics and demographics, which can help provide a more informed view of how user state and experience etc. affect behaviour and performance.

4.1 Methods for manipulating driver engagement and awareness

For the Hi-Drive project, a number of methods are used to influence driver engagement and awareness during their interactions with AD. These include the use of:

1. a range of NDRTs to manipulate participant state (e.g. workload, attention, and motion sickness) during AD (see section 4.1.1),
2. Different interfaces to communicate with/inform participants (see Section 4.1.2).

These are defined in more detail below.

4.1.1 Non-Driving-Related Tasks

Over the past 25 years or so, a plethora of studies have investigated driver engagement in "secondary tasks" and the effect of this on manual driving performance. Here, distinctions are made between secondary tasks that are presented in the visual, auditory, or tactile modalities (or a combination of these). It can be argued that there is a cognitive component to almost all such tasks which generally remove attention away from the driving task (Victor, 2005). For AD, these secondary tasks are now termed non-driving-related tasks (NDRTs) or activities, since driving is no longer the main/primary task of the onboard user. Allowing users to engage in NDRTs is considered an important benefit of AVs operating at Level 3 automation and above (Lee et al., under preparation). However, there are several consequences associated with engaging in NDRTs during automated driving. Firstly, NDRTs take drivers' eyes/hands/attention away during AD, leading to a potential loss of situation and mode awareness, and to the potential for degraded driving performance, during transitions of control between the automated system and the driver (Louw et al., 2017). This NDRT engagement can also lead to a reduced ability to anticipate vehicle movement and motion, and the incongruence between perceived visual and vestibular signals can also increase the possibility of feeling unwell (motion/car sickness; Rolnick & Lubow, 1991).

Within the Hi-Drive project, NDRTs are used for two main purposes:

1. To assess their effect on user comfort and/or motion sickness, where tasks are generally selected based on visual disruption.
2. To understand how automation supervision is affected by engagement in NDRTs (SAE L2 automation), and to investigate how NDRT engagement affects driver state (attention/boredom/fatigue/vigilance) during automation (SAE L2/L3/L4) and what effect this has on resumption of control and follow-on performance of the driving task.

NDRTs selected to induce car sickness are often visual-dominant tasks, which are designed according to the sensory conflict theory by creating incongruences between visual and vestibular inputs (Diels & Bos, 2016). Some studies have tried to mitigate car sickness while users engage in NDRTs, by changing the positioning of NDRTs (Kato & Kitazaki, 2008; Kuiper et al., 2018). Others combine both vehicle motions and NDRTs to provoke sickness in participants (Talsma et al., 2023). These studies have used both everyday static (e.g., reading text) and dynamic (e.g., watching videos) tasks, along with more standardized artificial tasks, to manipulate participants' engagement and cognitive load.

Studies investigating the effect of NDRTs on driving performance after automation have focused on understanding how attention away from the forward roadway affects resumption of control after a TOR—investigating differences between tasks that take drivers' eyes off the road (visual attention) versus those that allow the eyes to remain on the forward roadway but induce the mind away from the road (cognitive or non-visual attention). The effect of manually distracting tasks on performance has also been studied in this context.

The following section gives a brief overview of some of the standardized tasks most commonly used in both motion sickness and distraction research.

The N-back Task is a highly controlled cognitive distraction task that is used to load the working memory resources of a participant (Gevins et al., 1990; Kirchner, 1958; Mackworth, 1959). The most typical variation of this task is that participants are presented with a list of stimuli at different interstimulus intervals. They are asked to respond whenever a stimulus is the same as the one presented 'n trials back', where n is a predetermined integer (Owen et al., 2005). The most common n values are 0, 1, and 2, with a higher n typically inducing a higher cognitive load and thus increasing the detrimental effects on performance (Jaeggi et al., 2008; Mehler et al., 2011; Zeiltin, 1993, 1995). The presentation of stimuli can vary in many ways; the cues can be verbal (letters, numbers) or non-verbal (shapes, pictures) (Jaeggi et al., 2010) and are usually presented visually or auditorily, and participant response can be either via manual button presses (Lenneman & Backs, 2009) or verbal reactions (Conti et al., 2013).

The Sustained Attention Response Task (SART) is a task that can be used to induce mind wandering in participants, where their attention strays from intended goals (Robertson et al., 1997). The SART involves a participant attending and responding (via a button press) to a string of digits (1–9) and withholding that response when a target digit (i.e., 3) is shown. The target digits are rare, resulting in a pattern of habitual, fast responses (Hawkins et al., 2019). The SART has been widely adopted for the study of mind wandering because it has a simple structure, alongside its ability to habituate the respondent to a repetitive automatic response pattern towards a non-arousing stimulus (Hawkins et al., 2019). This makes it a useful NDRT for combining with other cognitive activities (such as monitoring a Level 2 automated system) and assessing the consequent effects of mind wandering.

The Paced Auditory Serial Addition Task (PASAT) is a task originally designed for measuring information processing rates (Gronwall, 1977; Gronwall & Sampson, 1974) but is now used as a cognitive distraction task. During the PASAT, a random series of numbers are presented and the participant must add each digit to the preceding one. Thus, the second digit is added to the first, the third to the second, and so on (Gronwall & Sampson, 1974). In the original parametrisation of the task, digits can be presented at four standard rates (interstimulus intervals ranging from 1.2 to 2.4 seconds), with longer intervals producing lower error rates.

The Twenty-Questions Task (TQT) (Mosher & Hornsby, 1966) involves a participant asking an experimenter 20 yes-or-no questions to identify a specific item (Heenan et al., 2014). Because the task is lexically based and continuous in nature, it is thought to be more naturalistic than other information processing tasks and thus is used as a proxy for phone conversations (Heenan et al., 2014; Horrey & Wickens, 2006; Merat et al., 2012).

Aside from these non-visual NDRTs that mostly, although not entirely, apply to the cognitive component of distraction, there are a collection of *visual*-based NDRTs that aim to guide visual attention away from the road environment in order to visually distract users during periods of automation.

The Arrows Task is type of visual search task based on feature integration theory (Treisman, 1988). Groups of arrows are displayed on a screen mounted within the vehicle and drivers are required to respond either verbally or manually via a touch screen if the target arrow is present (Engstrom et al., 2005; Jamson & Merat, 2005; Merat et al., 2015) (see Figure 4.2). The speed at which these objects can be identified is influenced by the visual similarity to other displayed objects. Furthermore, reaction times for identifying targets increase as more objects are included in the display, but only when the target is to be recognised by a range of connected features (i.e., shape, orientation) (Engstrom et al., 2005). Therefore, altering non-target characteristics can alter the task difficulty.

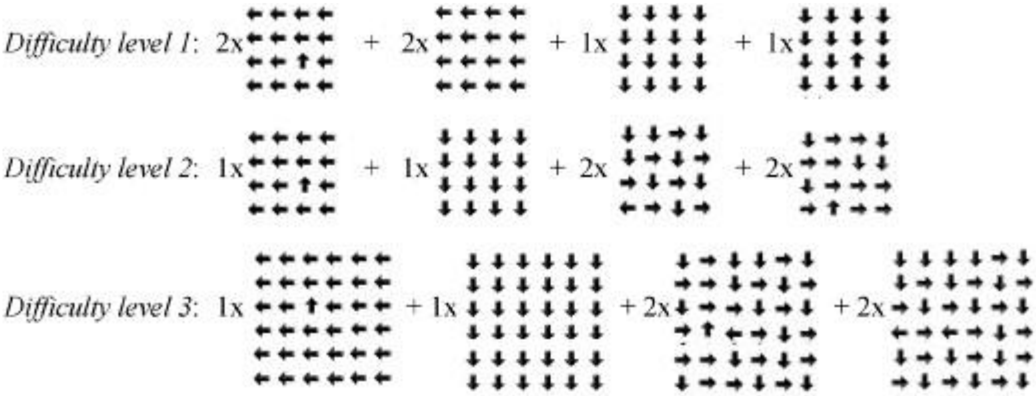


Figure 4.2: Example of the arrows task. Figure taken from Jamson & Merat (2005)

The Surrogate Reference Task (SuRT; Mattes & Hallén, 2009**)** is a similar standardised visual search task where drivers are presented with same-sized circles and one larger target circle. Drivers must point to the larger circle using a touchscreen or keypad (TS14198 ISO, 2012). Varying the size of the non-target circle relative to the target circle can increase or decrease the difficulty of the task (see Figure 4.3).

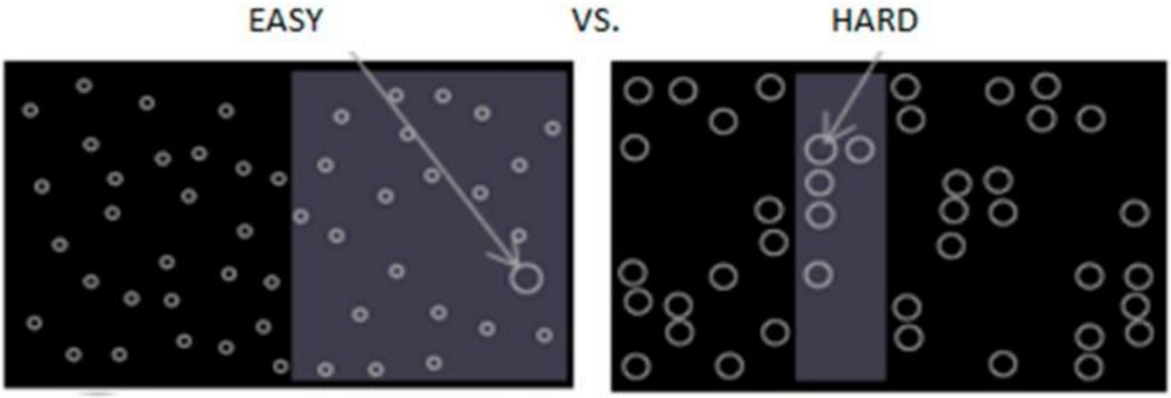


Figure 4.3: Example of an easy and hard SuRT task. Figure taken from Stojmenova & Sodnik, 2018.

For both of these tasks, performance can be measured as a function of correct responses and/or reaction time for a correct response (Jamson & Merat, 2005). Engagement in the task can also be measured as a function of how much time the driver was engaged with the task, or the number of inputs they made onto the display interface (Forster et al., 2020).

Outside of these standardised distraction tasks, there are a variety of NDRTs that are more **naturalistic** in terms of what drivers might be doing during L2 or L3 AD. Examples of these include eating (Carsten et al., 2012; Helldin et al., 2013; Llaneras et al., 2013), watching movies on a phone or tablet (Bloomer et al., 2015; Jamson et al., 2011), reading (Dogan et al., 2014;

Naujoks et al., 2014; Schwalk et al., 2015), or interacting with the in-car information system (Flemisch et al., 2010; Toffetti et al., 2009). Alternatively, drivers could be given a free choice of tasks where it is up to them to decide which NDRTs they partake in during AD (Carsten et al., 2012; Jamson et al., 2013). It should be noted that many of these naturalistic activities combine visual, manual, and cognitive components.

4.1.2 Interfaces

Until full vehicle automation is established (i.e., SAE Level 5), there will be situations where the vehicle requires the driver to take over control from the automated system. In such circumstances, the vehicle may need to provide TOR. A TOR is a signal that indicates to the driver that the automated system can no longer complete vehicle control (Hergeth et al., 2015). For such circumstances, internal human-machine interfaces (iHMIs) are needed to issue TORs and communicate system status information quickly and effectively.

It is also important that AVs are designed in such a way that they can safely and intuitively interact with other traffic participants (Schieben et al., 2019). This communication may consist of a combination of vehicle behaviours, known as dynamic human-machine interfaces (dHMIs), and light or sound-based communication displayed through external human-machine interfaces (eHMIs; Bengler et al., 2020). This type of external communication can also be aimed directly at another road user or projected onto the road (Mahadevan et al., 2018).

4.1.2.1 Human-Machine Interfaces

A variety of facets contribute to the design and implementation of both iHMI and eHMI signals, including their modality, class, and location (Jansen et al., 2022). These are further outlined below.

Modality

Modality refers to the way in which an AV signal is presented. The three most common modalities used are auditory, visual, and tactile interfaces (Drüke et al., 2018; McDonald et al., 2019; Mirnig et al., 2017). These signals can either be presented individually (unimodal), in pairs (bimodal), or all in combination (trimodal) (Jansen et al., 2022). Bimodal and trimodal combinations have been shown to generate quicker responses (McNabb, 2017). Furthermore, using multiple modalities can avoid concurrent signals masking out an important piece of information (Lee & Spence, 2008). For example, loud motorway noise masking the sound of a unimodal auditory TOR signal (Janssen et al., 2019) can be supported by a visual cue. The most common combination of iHMI modalities tested within user-related studies is the combination of auditory and visual signals (McDonald et al., 2019), whereas the most commonly used eHMI modality in the literature is visual (Dey et al., 2020).

Class

Visual

Classes refer to a sub-categorisation of signals that occur within each modality (Miring et al., 2017). Within the visual modality, examples of classes include text, anthropomorphic, or symbolic signals (see Figure 4.4 for examples). Text-based visual signals can include messages given to a driver which explicitly instruct them to take over (Naujoks et al., 2017), or text-based messages displayed on the outside of the vehicle to provide information to other road users such as "stopping" or "please cross" (see Dey et al., 2020; Fridman et al., 2019). Anthropomorphic classes refer to signals that include human-like features such as facial expressions to communicate information about the system (Fridman et al., 2019; Jansen et al., 2022; Kremer et al., 2022). Finally, symbolic classes refer to visual representations that are not human-like; a commonly used symbolic class is an icon of hands on a steering wheel indicating a need for the driver to take over (Naujoks et al., 2019), or the use of a pulsing light band around a vehicle windscreen to communicate with pedestrians (e.g., Lee et al., 2019).

Figure 4.4: Examples of external visual signals used in the literature. Figure taken from Dey et al. (2020)

Auditory

Auditory classes are largely split into two main groups: speech- and non-speech-based (Jansen et al., 2022). Speech-based sounds refer to a human voice providing information regarding a TOR or external signal (Mahadevan et al., 2018; Mirnig et al., 2017). Non-speech sounds are often referred to as acoustic signals (Böckle et al., 2017, Dey et al., 2020; Lee et al., 2019; Mirnig et al., 2017) which can be further divided into sub-categories. Auditory icons are non-speech auditory signals that have previous associations with objects or events (Jansen et al., 2022). Key examples are car horns or skidding tire sounds that are produced in an attempt to warn drivers about imminent collisions in emergency situations (Cabral & Remijn, 2019).

Tactile

Tactile modalities are usually comprised of two classes: vibrational stimuli (Cabrall et al., 2017) and force feedback stimuli (Adell et al., 2008). Vibrational stimuli can be embedded within parts of the vehicle such as the seat (Petermeijer et al., 2017) or seatbelt (Scott & Gray, 2008) to provide drivers with information regarding takeover situations. Furthermore, there are various dimensions of vibrational stimuli that can be manipulated to provide a wider range of information; these dimensions include amplitude, frequency, and the timing of the vibrations (Petermeijer et al., 2015). Although force feedback is an option, these stimuli have mostly been used in the context of manually driven vehicles—for example applying constant force to accelerator pedals to support safer speed and headway distance (Adell et al., 2008), or haptic guidance that continuously produces torques on the steering wheel to support lane keeping (Tsoi, Mulder, & Abbink, 2010). Vibrational cues may also be presented to pedestrians through mobile phones or wearable devices (Dey et al., 2020).

Location

The location of HMIs can vary throughout the vehicle. TOR HMIs can be located on windshields and/or head-up displays (HUD), dashboards, centre consoles, steering wheels, the seat, or even on drivers themselves (Capallera et al., 2022; see Figure 4.5). However, the modality of the TOR signal is likely to constrain its location. For example, tactile stimuli are more likely to be located on the body of the driver/pedestrian, e.g., through a wearable device (Sonoda & Wada, 2017; Yusof et al., 2017) or in the seat (Telpaz et al., 2015) rather than within the windshield. Research has also suggested that delivering TORs of any modality through a device being used for an NDRT generates faster takeovers and reduces lateral deviation after takeovers (Politis et al., 2017). The orientation of the information should also be considered, particularly for visual HMIs. Park & Im (2020) found that symbolic classes that were presented vertically rather than horizontally within an HUD produced quicker responses and reduced levels of subjective workload.

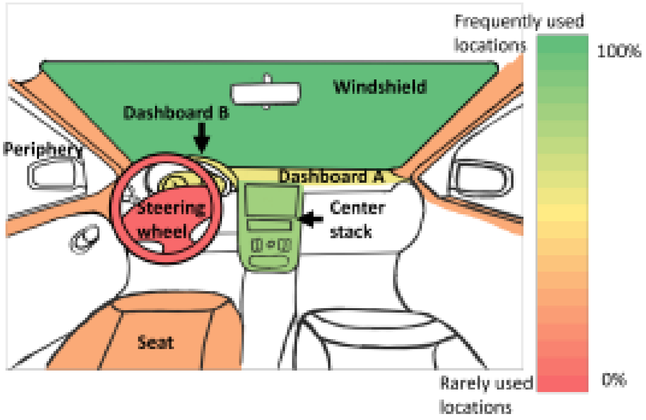


Figure 4.5: Frequency of iHMI locations across 37 studies. Figure taken from Capallera et al. (2022)

The placement of eHMIs can also vary, with the majority of proposed concepts being displayed on the vehicle around the windshield, bumper, and grill areas. However, other proposed designs include the projection of information in front of the vehicle (Dey et al., 2020). Eisma et al. (2019) compared participants' willingness to cross in relation to 36 animations of cars with eHMIs on either the roof, windscreen, grill, above the wheels, or projected onto the road. They found that the roof, windscreen, and grill received the most positive responses, while the wheel-based eHMI received more positive responses when the car appeared from around a corner and the other locations were not visible. The authors concluded that eHMIs should be presented on multiple sides of the car. Many of the eHMI concepts being explored are still at the proof-of-concept stage, and legal and practical considerations need to be taken into account before these solutions are implemented in real-world contexts (ISO TR23735, under preparation).

4.1.2.2 Vehicle behaviour (dynamic HMI)

In addition to the explicit communication signals described in the previous section, road users anticipate other drivers' intent using cues arising from the vehicle behaviour, for example speed variance, stopping distance, lateral position, and/or acceleration (Portouli et al., 2014). These specific vehicle movements, called dynamic HMI (dHMI) or implicit communication tools (Markkula et al., 2020), have been used in the literature to communicate intent to other road users (Bengler et al., 2020; Lau et al., 2021).

In the following sections we provide an overview of the main methodologies to be used within the Hi-Drive project, all of which will make some use of the tools and techniques discussed in this section.

4.2 Simulator Studies

Currently, simulator technology is used in a variety of transport contexts for academic research, government operations, space exploration, recreational computer games, and driver training schools, as well as by the military, medical sector, and automotive industry (Eryilmaz et al., 2014). Flight simulators have played an indispensable role in pilot training and certification for decades. In more recent years, vehicle simulators including car and truck simulators have become more affordable, and thus more widely used as tools for investigating driver behaviours in a variety of road contexts, including the testing of new road designs, traffic calming techniques, impaired driver behaviour due to alcohol or fatigue, and vehicle dynamics and layout. Driving simulation can be a very useful tool when it is not possible to investigate the use of an ADS on real roads, for example because the system is not mature enough or because it is not safe to use, e.g., when investigating the impact of driver distraction, fatigue, or other impairments on performance (Bruck, Haycock, & Emadi, 2020). Driving/truck simulators have several major advantages as research tools. They allow the investigation of user behaviour under controlled conditions, for example using the same (test) scenario for each participant and in each condition, allowing us to obtain generalisable findings about how a given population is likely to interact with a particular system or in a particular scenario. A further advantage is that safety-critical or otherwise rare situations can be repeatedly tested in controlled conditions. However, when compared to the real world, drivers' perception of risk trust and safety will likely be different. These factors should therefore be taken into account when considering the results of driving simulator experiments. Furthermore, the driving situations explored are mostly limited to the situations implemented by the investigator. Completely new and unexpected situations such as edge cases cannot always be assessed in these studies, although these are also generally difficult to test in the real world.

One key consideration around vehicle or pedestrian simulators is their level of fidelity, i.e., the extent to which they emulate driving in the real world (see Blana, 1996; Mullen et al., 2012; Wynne et al., 2019). In general, there are three levels of fidelity (see Figure 4.6):

Low-fidelity driving simulators are usually desk based and consist of a steering wheel and very basic vehicle instruments mounted on a desk, pedals under the desk, and one or more screens where the traffic scene is displayed. For pedestrian research, a low-fidelity simulation may consist of videos or images shown on screens, where pedestrians respond via button pressing or taking one step forward.

Medium-fidelity driving simulators typically consist of a driver seat as part of a mock-up that mimics the interior of a car with all the vehicle instruments of a normal car. Usually, several screens provide a wide view of the driving scene. A medium-fidelity pedestrian simulator may consist of a head-mounted display which allows a participant to move around in the world but does not allow pedestrians to see their own bodies within the virtual environment (Pala et al., 2021).

High-fidelity driving simulators consist of the car body and interior of a production vehicle. Sometimes, only the front part of the car body is used, for example when it sits on a motion platform. In high-fidelity simulators, usually a wide surround view is provided to increase the immersion of the person in the simulator. The view is sometimes displayed on a projection screen, or many screens are used in combination to provide a surround view. Some high-fidelity simulators also simulate vehicle motion or vehicle vibration. High-fidelity pedestrian simulators consist of cave-based spaces which allow participants to walk around within the virtual road environment, with a full body and movement representation available on screen.

Figure 4.6: Examples of driving simulators(low-fidelity, image taken from Park et al., 2005, medium-, and high-fidelity, images taken from Auberlet et al., 2010)

The required level of fidelity depends on the purpose of the study and the level of absolute or relative validity required (Wynne et al., 2019).

Absolute validity occurs when the values obtained in a simulator (e.g., speed or lateral position) match those obtained in a real vehicle in absolute terms. Relative validity occurs when simulator results show the same patterns or effects as real-world driving, e.g., the effects of a phone-dialling task on driving precision (Reed & Green, 1999) or age-related differences in pedestrian crossing behaviours (Pala et al., 2021). While higher fidelity simulators may provide better results in terms of absolute validity, they are often costly to run, and in certain situations the relative validity provided through lower fidelity simulation may be sufficient to draw meaningful conclusions about road users' behaviours.

4.2.1 Simulator studies in Hi-Drive

Within the Hi-Drive project, data will be collected using nine different driving car simulators, one truck simulator, one pedestrian simulator, two Head Mounted Display studies for pedestrians, one bicycle simulator, and one remote operator simulator. These are described in more detail in Sections 4.2.1.1 to 4.2.1.6. Each simulator has been assigned a different identifier (Method ID) in the text, and details of the specific studies being conducted using each of these simulators can be found in Table 4.1 below. Although not all study details are confirmed yet, it is anticipated that approximately 460 ordinary drivers will take part in these experiments, along with approximately 35 professional engineers acting as remote operators.

Table 4.1: Overview of simulator studies being conducted in the User subproject (Study ID incorporates Method IDs outlined in the text below, and information about the study topic described in column 3 (e.g,. DM = driver monitoring).

Study ID	**Users**	**Topic**	**Simulator Characteristics**	**Environment**	**Type of Participant**	**Specific Participant Characteristics***	**Planned No. Participants**	**Additional tools / methods**
DS01_DM	Onboard drivers	Driver monitoring and readiness	Motion base	Motorway	Ordinary	n/a	40	Questionnaire; NDRT; eye tracking; physiological
DS02_ODI	Other drivers	Driver interaction with AV/MV	Fixed base	Bottleneck roads	Ordinary	n/a	40	Questionnaire
DS03_SA	Onboard drivers	Situation awareness	Motion base	Motorway	Ordinary	n/a	TBD	Questionnaire, eye tracking, SART
DS04_DM	Onboard drivers	Driver monitoring and takeover assistance	Fixed base	Motorway	Ordinary	n/a	48	Questionnaire; NDRT; eye tracking; physiological
DS05_DI	Other drivers + Onboard drivers	Behaviour and acceptance of onboard and other drivers	Fixed base	Urban	Ordinary	n/a	20 Onboard drivers 20 Other drivers	Questionnaire; NDRT
DS06_ODI	Other drivers	Driver acceptance of AD HMI	Motion base	Merging Traffic	Ordinary	Previous experience with ADAS	30	Questionnaire
DS07_CI	Onboard drivers	Crossing behaviour when interacting with cyclists (mirror to CS01)	Full immersion, fixed base	Unsignalized Intersection	Ordinary	TBD	TBD	Questionnaire; eye tracking

Study ID	Users	Topic	Simulator Characteristics	Environment	Type of Participant	Specific Participant Characteristics*	Planned No. Participants	Additional tools / methods
DS08_L	Onboard drivers	Lighting	Motion base	Highway	Ordinary	n/a	31	AR approach, real car with videowall
DS09_DM	Onboard drivers	Driver monitoring for the purposes of creating human-like behaviour	Manual (TBD if an ADF application can be included)	Motorway and extra-urban roads High vs Low traffic density. Curves vs straight	Ordinary	Possibly, young drivers (in simulator). Otherwise, anyone	25–40 (depending on the minimum number of manoeuvres to reach for every user)	Questionnaire; physiological
TS01_DI	Onboard drivers	Driver behaviour in merging scenarios + acceptance + behavioural adaptation to implicit communications	Fixed base + HMD	Lane merging	Ordinary	Truck drivers with 3 years' experience	15	Questionnaires / eye tracking data
PS01_PI	Pedestrians	Crossing behaviour when interacting with AVs	CAVE	Daytime vs nighttime, urban	Ordinary	Young (18–35 years) Older (>60 years)	50	Questionnaire
HMD01_PI	Pedestrians	Crossing behaviour when interacting with AVs	HMD	Shared space scenario	Ordinary	n/a	40	Questionnaire

Study ID	Users	Topic	Simulator Characteristics	Environment	Type of Participant	Specific Participant Characteristics*	Planned No. Participants	Additional tools / methods
HMD01_L	Cyclists	Lighting	HMD	Urban	Ordinary	n/a	29	Additionally a stationary test in the light tunnel (see Test Track Studies)
BS01_CI	Cyclists	Crossing behaviour when interacting with AVs	HMD	Unsignalized Intersection (different visibilities)	Ordinary	18–45 y, no disability, no glasses, shorter than 185 cm	27	Questionnaire
ROS01	Remote operators	Remote operation	Prototypical remote work station	Urban	Professional engineers & ordinary	18–35 years with degree in engineering	20	
ROS01	Remote operators	Remote operation	Automated vehicle that needed support from remote operator	Urban: -Puddle of water -Road block -Changing trajectory to avoid parked car	Professional engineers & ordinary	18–35 years with degree in engineering	15 professional 10 Ordinary	Questionnaire; NDRT; physiological; eye and head tracking; behavioural data related to work station (mouse and keyboard data)

*This column provides details on any experiment which targets a specific demographic group. “n/a” means that there are no specific participant requirements, while “TBD” means that the exact participant requirements have not yet been decided.

4.2.1.1 Driving simulators used in Hi-Drive

Method ID: DS01 – The University of Leeds Driving Simulator (UoLDS, see Figure 4.7) is a motion-based driving simulator providing a realistic and immersive driving environment. The vehicle is encased in a large dome with a wrap-around projection of the driver's view of the virtual world. The pedals and steering wheel provide tactile and haptic feedback designed to replicate the forces experienced during real-world driving. This is complemented with longitudinal and lateral movement via a 'hexapod' motion base and X-Y table to provide a realistic motion perception. Vehicle-related data can also be supplemented by physiological sensors (Biopac), eye tracking data, driver monitoring capabilities, and video recordings.

Figure 4.7: University of Leeds Driving Simulator (Method ID: DS01)

Method ID: DS02 – The University of Leeds Static-based distributed driving simulator will also be used to investigate driver interactions with other vehicles (see Figure 4.8). The coupled driving simulators each consist of a 49 inch 32:9 (3840 x 1080 pixels) monitor, a playseat with a seat slider, and a steering wheel with buttons. The accelerator and brake pedals are placed on a stable Next Level Racing® Wheel Stand DD. Unity 3D software or bespoke software developed in-house are used to implement the driving scenario and vehicle behaviours, and the vehicle's engine sound is also replicated. Vehicle data is supplemented with eye-tracking equipment. A black opaque curtain can be pulled across to separate the participant and the experimenter or allow multi-driver studies.

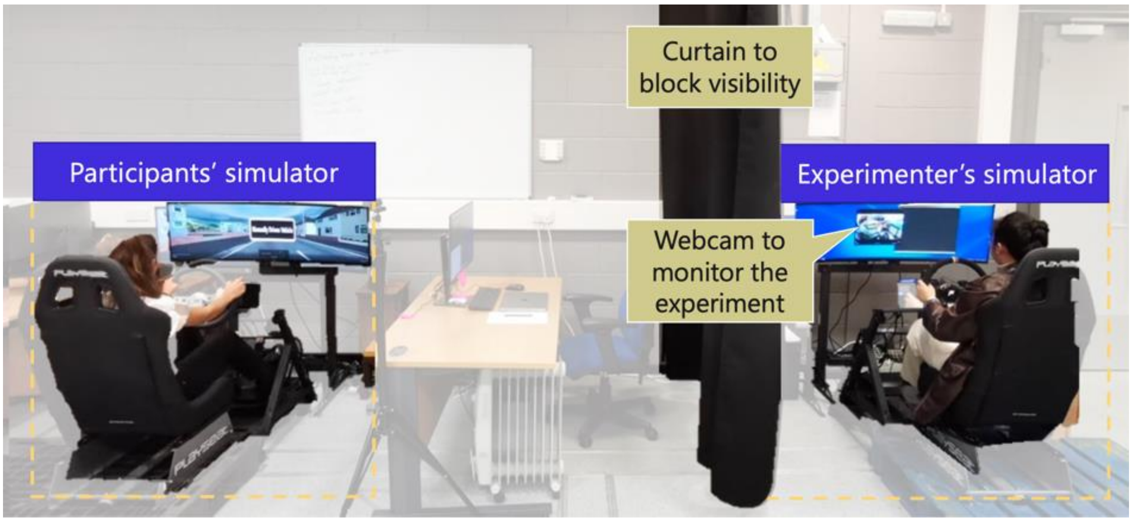


Figure 4.8: University of Leeds distributed driving simulators (Method ID: DS02)

Method ID: DS03 – The dynamic driving simulator at the Würzburg Institute for Traffic Sciences (WIVW) will be used for a study regarding situational awareness in automated driving (see Figure 4.9). The motion system uses six degrees of freedom and can briefly display a linear acceleration up to 5 m/s^2 or 100°/s^2 on a rotary scale. It consists of six electropneumatic actuators (stroke +/- 60 cm; inclination +/- 10°). Three LCD projectors are installed in the dome of the simulator and provide the projection. Three channels provide a 240° screen image. The integrated vehicle's console contains all necessary instrumentation and is identical to a production type BMW 7 with automatic transmission. The simulator is run by the simulation software SILAB®.

Figure 4.9: WIVW Dynamic driving simulator (Method ID: DS03)

Method ID: DS04 – The VEDECOM institute possesses a medium-fidelity static driving simulator that will be used for studies regarding driver monitoring and distraction in AD situations (see Figure 4.10). This simulator consists of a two-seat cabin with seatbelts, a Peugeot 308 steering wheel, pedals, mirrors, a dashboard, and three 140x230cm screens that allow 230 degrees of vision. In addition, the driving simulator allows synchronization of eye-tracking data, physiological data, and video recording data, providing driving monitoring capabilities. The driving simulator currently runs on SCANeR Studio Version 2023.1.

Figure 4.10: VEDECOM static driving simulator (Method ID: DS04)

Method ID: DS05 – The ICCS desktop driving simulator is a fixed-based driving simulator that uses the open-source CARLA software (see Figure 4.11). It is equipped with a 34-inch WQHD (3440 x 1440) curved screen offering a 21:9 field of view, steering wheel, and gas and brake pedals. The driver's field of view can be set via CARLA up to 120 degrees. A button on the steering wheel can be used to engage and disengage the AD system. Besides the button, the AD can be switched off by stepping on the gas or brake pedal or turning the steering wheel.

Figure 4.11: Sample image from ICCS desktop simulator (Method ID: DS05)

Method ID: DS06 – Honda R&D Europe uses the motion platform named DiM250 (Driver-in-Motion) designed by VI-grade and engineered and manufactured by Saginomiya (Figure 4.12). The DiM250 can be used for a wide range of application areas, such as vehicle dynamics, powertrain, ADAS, AD, and HMI. Therefore, it is best suited for aligning HMI elements with AD vehicle manoeuvres. To reproduce vehicle movements and accelerations, the DiM solution is based on nine actuators. The resulting nine degrees of freedom enable this simulator to go beyond the basic six-actuator design of a simple hexapod, providing a larger workspace while maintaining high stiffness and keeping compact dimensions.

Figure 4.12: Honda R&D Europe motion platform (Method ID:DS06)

Method ID: DS07 – The simulator at Toyota Motor Europe (no picture available) provides full immersion while the driver drives a mock-up car. The vehicle controls are from a production vehicle and the mirrors are replaced by screens. The simulator is programmed using CarMaker, which enables the integration of different road users with controlled dynamics. The driving scenario is also customizable so that it can be tailored to the researchers' needs.

Method ID: DS08 – The Audi Lighting simulator (see Figure 4.13) uses a hybrid setup for the evaluation of hazard warnings. The test person sits in a real car in front of a video wall. The position and the point of view is optimized to increase the immersion. In this way, the virtual scenery of a drive on a highway is shown in a correct perspective and without visible edges on the image. Blender by Blender Foundation is used to create the content.

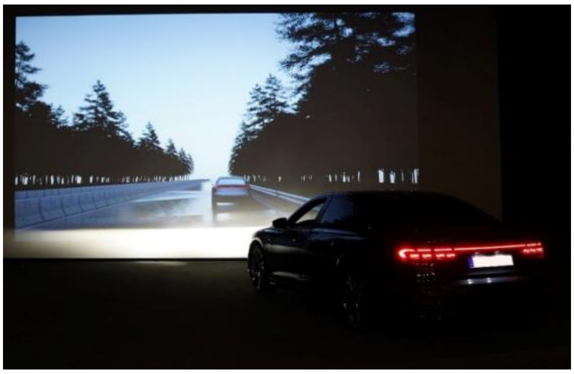


Figure 4.13: Hybrid setup for the evaluation of hazard warnings in the Audi driving simulator (Kraft 2022; Method ID: DS08)

Method ID: DS09 – CRF will use a simulator environment to collect data for the Driver Manoeuvre Intention Recognition (DMIR) enabler, using CARLA, a 3D virtual reality simulator. CARLA provides open-source code and protocols, together with open digital assets (urban layouts, buildings, vehicles). The simulation platform supports flexible specification of sensor suites, environmental conditions, full control of all static and dynamic actors (different types of realistically modelled vehicles, bikes, pedestrian, etc.), and map generation (see Figure 4.14). The simulation environment will be completed using a mock-up of a vehicle cockpit, including driving seat, steering wheel with pedals (accelerator and braking, automatic gears), and a wide screen in front of the user. All the hardware components are connected to the simulator PC using CARLA and MATLAB software frameworks.

The objective of the DMIR enabler is to recognize the manoeuvre (e.g., lane change) intentions of the driver, with a goal of detecting the intended manoeuvre prior to its execution. Thus, in order to collect the dataset required for this enabler, two different types of lab experiments using the CARLA simulator have been designed. Firstly, a classification task will be used to collect data for scenario identification, which will be useful for the assessment of ADFs in various contexts. In this case, scenarios will be generated automatically, with no user participation. Secondly, a prediction task will be used to collect data from driving participants for the recognition of driver intention.

Figure 4.14: Snapshots from the CARLA driving simulator for the CRF study (Method ID: DS09)

4.2.1.2 Truck Simulator

Method ID: TS01 – The Volvo Truck simulator (Figure 4.15) is a fixed base with a truck seat and a gaming steering wheel. The latter has been modified with a Volvo steering wheel (i.e., using the steering column from the gaming steering wheel, but the actual steering wheel and stalks are the same as used in Volvo trucks). The gear shifter is attached to the side of the seat as in a normal truck. Drivers are provided with an immersive experience of the world around them using an HMD. In this way, while the participants are driving, they see the real truck and can interact with the steering wheel and controls as if they were there. Plus, they can look around as in a high-fidelity driving simulator.

Figure 4.15: Volvo Truck Simulator (Method ID: TS01)

4.2.1.3 Pedestrian simulator

Method ID: PS01 – The University of Leeds uses the Highly Immersive Kinematic Experimental Research (HIKER; Figure 4.16) pedestrian lab to conduct its pedestrian-AV interaction research. HIKER is the largest CAVE-based pedestrian simulator in the world, providing a 9m x 4m walking space which allows pedestrians to interact with vehicles in an immersive virtual environment that is projected on plate glass walls, with rear projection from an array of 4k projectors. HIKER also allows tracking of pedestrians' body movements, head position, and eye gaze.

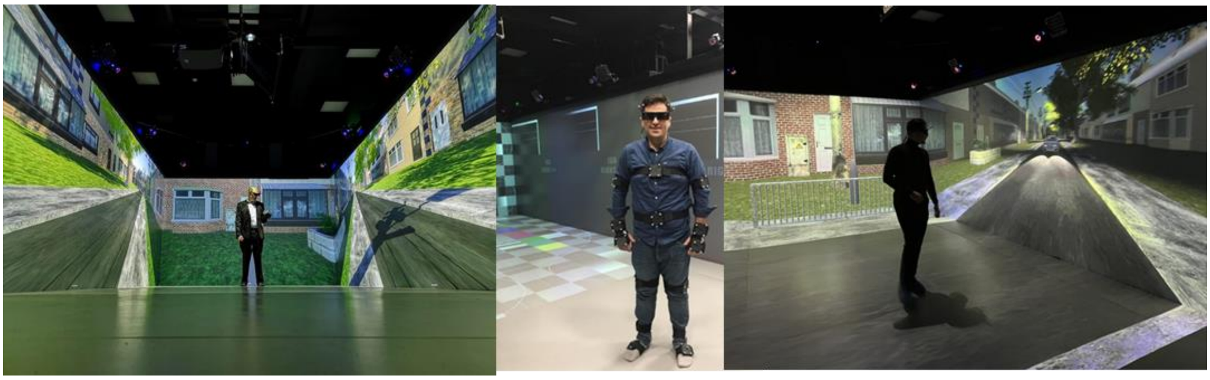


Figure 4.16: University of Leeds HIKER pedestrian simulator (Method ID: PS01)

4.2.1.4 Head-mounted displays

A head-mounted display (HMD) is a wearable device (worn on the head) consisting of two or more displays. The main aim of the HMD is to display information or images directly in front of the user's eyes. HMDs may include built-in sensors (e.g., eye tracking, head tracking) and can be used for a variety of purposes including virtual reality (VR), augmented reality (AR), or mixed reality (MR).

Method ID: HMD01 – In Hi-Drive, two partners (DLR and Audi) make use of an HTC Vive Pro with two AMOLED displays (each 3.5", 1440 x 1600 pixels; 110° field of view in total) and the HTC standard controller as an input device for interaction.

DLR use this equipment to investigate the effect of eHMIs on pedestrians' intention to cross in front of different types of AVs in a shared space. Two different types of AV were used, either a bus or a conventional vehicle. The VR experiment was created by using the Unreal Engine (4.27.2).

To investigate the distraction and the attention caused by the content of an eHMI, Audi used a virtual environment created through the Unity engine by Unity Technologies. In four scenarios the test person wears an HMD and acts as a cyclist who passes a vehicle equipped with an eHMI. The composition follows the rules of the majority of dooring accidents. Therefore, each scenario consists of an urban street without a cycle path surrounded by houses, pavements, masonries, and trees on both sides of the street. To further increase immersion, other objects, like a preceding car, are also added. On the right side there are several vehicles of the same type parked longitudinally. One of the cars acts as the distractor where the brake light will be activated in certain cases. Another one is equipped with a display. In some test runs it shows a hazard warning with different frequencies.

Figure 4.17: Picture of an HMD

4.2.1.5 Bicycle Simulator

Method ID: BS01 – In Hi-Drive, the bicycle simulator at VTI (Figure 4.18) will be used by Chalmers to investigate the interaction between cyclists and AVs. The participant wears an HMD and rides thought different scenarios while interacting with virtual vehicles.

Figure 4.18: A participant riding the bicycle simulator at VTI, Sweden (Method ID: BS01)

4.2.1.6 Remote operator simulator

In order to make the right decisions in difficult and complex traffic situations, the remote operator needs a carefully designed workstation. The focus of the remote operation workstation is on conveying complex information quickly and in a comprehensible manner.

Method ID: ROS01 – In Hi-Drive, DLR’s remote operator workstation (Figure 4.19) is used to evaluate different information displays and interaction strategies. The remote operator workstation is intended to enable remote assistance of a CAV from a central control centre. According to SAE guidelines, remote assistance is defined as the “event-driven provision, by a remotely located human, of information or advice to an automated driving system-equipped vehicle in driverless operation in order to facilitate trip continuation when the ADS encounters a situation it cannot manage” (SAE, 2021). Hence, the workstation is not suitable for (direct) teleoperation or remote driving, which would include the execution of potentially time-critical dynamic driving tasks such as lateral or longitudinal control of the CAV. Rather, it enables the remote operator to provide non time-critical guidance to a CAV in situations it cannot handle by itself. Specifically, the remote operator is requested by the CAV when the AV is threatening to leave its ODD or has already left it. In complex use cases, where the remote operation functions as a fallback, remote operation makes a decisive contribution to increasing user acceptance of AD, along with increasing safety and efficiency.

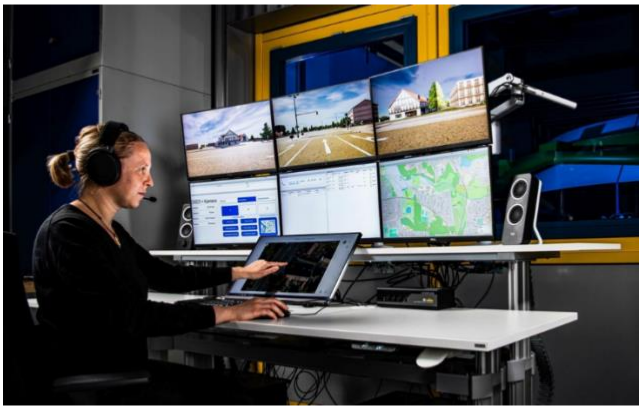


Figure 4.19: Remote operator workstation at DLR (Method ID: ROS01)

4.3 Wizard of Oz approach

For safety reasons, most current AV prototypes tested on real roads operate at low speeds or on constrained routes, and in many cases have a limited ODD. These conditions are not ideal for evaluating the impact of ADFs on user experience, as they do not provide a true representation of how mature versions of the AD will behave. For this reason, many studies have simulated AD in test-track and real-world contexts using a Wizard of Oz (WOZ) approach.

WOZ studies rely on a hidden human controller, the so-called "wizard", who creates the illusion of an interaction with technology, undiscovered by the real user (Kelley, 1983). This method can be used for conducting test-track and real-world experiments, where the WOZ driver controls the vehicle to mimic the actions of an AD system. WOZ studies involving vehicle occupants can be divided into setups where the participant is seated either in the front or the back of the vehicle (Bengler, Omozik & Müller, 2020). In either case, the driving wizard can be hidden through using partitions e.g., a curtain or a hat with covers on the right side, and in many cases control can be passed back and forth between the wizard and the participant driver (Bengler et al., 2020b). To ensure safety and immersion for studies using these vehicles, technical maintenance as well as training of the wizard drivers are essential. This approach will be used to simulate AD in a number of the test-track and real-world studies described in Sections 4.4 and 4.5.

4.4 Test-track studies

A test track is a dedicated facility designed to test and evaluate various vehicle aspects (e.g., performance, handling, safety), or specific traffic scenarios, by using a controlled traffic environment in a separated test area with limited access. Test tracks should simulate real-world driving conditions and simultaneously give all the advantages of a standardized and repeatable study setting in a safe and controlled traffic environment (McLaughlin et al., 2009). Similar to driving simulator studies, test-track experiments allow more controllability than on-road studies with regards to elements such as driving duration, level of traffic, and the specific scenarios encountered. However, they do not provide the same level of flexibility in terms of scenario design that is possible using simulation and, as with simulator studies, the driving situations are limited to those implemented by the investigator. A major advantage of test-track studies is that they allow participants to experience real-vehicle motion properties in a controlled and replicable setting. In addition, from a legal perspective, the implementation of ADFs is much easier on test tracks than on public roads. Test tracks also allow researchers to evaluate the interaction between pedestrians and AVs in a safe environment without managing the huge complexity and risks of public roads.

4.4.1 Test-track studies in Hi-Drive

In Hi-Drive, four test-track studies will be used to evaluate onboard user experiences, while three are planned to investigate pedestrian interactions with AVs, and there will be one study investigating the experiences of other drivers and cyclists interacting with AVs. The specific details of these studies can be seen in Table 4.2 below. Although not all study details are confirmed yet, it is anticipated that approximately 260 ordinary participants (i.e., not automation experts) will take part in these experiments. The methods used by each partner are described in the paragraphs below. Where possible, pictures of the test tracks are included after their descriptions, but this is not possible for all partners.

Table 4.2: Overview of test-track studies being conducted in the User subproject. Study ID incorporates Method IDs outlined in the text below and information about the study topic described in column 3 (e.g., PI = pedestrian interaction).

Method ID	Users	Topic	Vehicle characteristics	Environment	Type of Participant	Specific Participant Characteristics	Planned No. Participants	Additional tools / methods
TT01_PI	Pedestrian	Crossing behaviour when interacting with AVs	Automated	Complex scenario with multiple vehicles	Ordinary	n/a	20	Questionnaires
TT02_C	Passenger	Comfort	Chauffeur	Both	Ordinary	Prone to motion sickness	20	Questionnaire NDRT Physiological measures
TT03_C	Onboard user	Comfort	WOZ	TBD	Ordinary	Prone to motion sickness	TBD	Questionnaires Performance measures
TT04_L	Cyclist	Lighting	Manual – standstill	Urban	Ordinary	n/a	18	Questionnaires Subsidiary Tasks
TT05_PI1	Pedestrian	Crossing behaviour	Automated	Urban	Ordinary	n/a	20	Questionnaire
TT05_ODI	Other drivers	Acceptance	Automated	Urban	Ordinary	n/a	20	Questionnaire
TT05_PI2	Pedestrian	Interaction with AV	Automated	Carpark	Ordinary	n/a	20	Questionnaire
TT06_C & RW06	Passenger	Comfort	Partly automated	Urban	Ordinary	Prone to motion sickness	40	Questionnaires Performance measures

Method ID	**Users**	**Topic**	**Vehicle characteristics**	**Environment**	**Type of Participant**	**Specific Participant Characteristics**	**Planned No. Participants**	**Additional tools / methods**
TT07_C	Passenger	Comfort	Chauffeur	Rural	Ordinary	n/a	100	NDRT Questionnaires Physiological measures

*This column provides details on any experiment which targets a specific demographic group. “n/a” means that there are no specific participant requirements, while “TBD” means that the exact participant requirements have not yet been decided.

Method ID: TT01 – DLR will use the test track on the DLR campus in Braunschweig. The traffic environment has a very urban-like character and geometry. Since an urban environment is simulated, the speed limit of the test track is 30 km/h. For the evaluation of different eHMI interaction designs, DLR will use its test vehicle FASCar (Mercedes Benz EQV). The FASCar is able to perform automated driving functionalities up to SAE L3 and is equipped with a cyan-coloured eHMI LED bar mounted on the front hood. The FASCar can trigger different signals to other road users via the eHMI (see Figure 4.20).

Figure 4.20: DLR test vehicle FASCar equipped with eHMI hardware (l), and test track on the DLR campus in Braunschweig (r) (Method ID: TT01)

Method ID: TT02 – Ford will use a test track at the Ford Lommel Proving Ground in Belgium to induce car sickness. Figure 4.21 shows the route to be driven, with a common start and end point. The track takes about 20–22 minutes per participant slot. The test vehicle is a Ford Tourneo Custom (see Figure 4.21) equipped with an interior camera for participant capture, as well as measurement devices for various physiological functions. The CAN bus data can be accessed and inertial measurement recordings taken via a stand-alone device. The participants will act as passengers driven around by a trained driver. A tablet PC will be used to present NDRTs to the participants.

Figure 4.21: Ford test vehicle (l) and proving ground (r) (Method ID: TTO2)

Method ID: TT03 – The vehicle used in the WIVW/AUDI study is an AUDI Q7 with automatic gearbox, which has been modified to be used as Wizard-of-Oz vehicle (see Figure 4.22). The vehicle has a standard driver's seat on the left with a functional set of pedals and a steering wheel. Participants can sit in the driver's seat and drive the vehicle in manual mode. They can hand over control of the vehicle to the wizard driver by pressing a button on the centre stack,, which inactivates the participant's steering wheel and pedals. The wizard driver is seated at the front on the right-hand side. The wizard driver has pedals in the footwell to accelerate and brake, making the setup comparable to that of a driving school vehicle. There is a joystick mounted in the door panel to steer the vehicle. The wizard also has a separate control panel to change gears (reverse, driving, neutral) and activate the indicators, windshield wipers, and headlights. Finally, there is the possibility to shield the wizard driver from the participant with a curtain. However, within the context of the study this will not be necessary, as the primary focus is not to give participants a perfect illusion of an automated driving experience but rather to simulate takeover performance under the influence of motion/car sickness.

Figure 4.22: Modified WOZ vehicle for WIVW / Audi test-track study (Method ID: TT03)

Method ID: TT04 – Audi's study is conducted in the light channel at Audi Ingolstadt, which is a 120m (about 393.7 ft) long, asphalted, and passable test environment for lighting purposes (see Figure 4.23). The stationary scenery includes a street replica with a cycle path and three cars parked longitudinally. The outer cars are positioned to reduce the visibility of the middle car, which is equipped with an eHMI in the rear lamp. In some test runs the eHMI shows a hazard warning of differing frequency. In addition, the dynamic scenery of an urban street from the perspective of a cyclist is shown on a video wall. The test participant will be passing the parked cars on a bicycle. A combination of subjective and objective measures will be used to evaluate the attention and distraction caused by the content of the eHMI.

Figure 4.23: Audi test setup for the evaluation of hazard warnings (Barthleme, 2023; Method ID: TT04)

Method ID: TT05 – The studies corresponding to this method are conducted by Valeo and Vedecom. The vehicle is a VW Passat equipped with Valeo's in-house automation system, including cameras, LiDARs, and automation software (Figure 4.24). The AD system can control the pedals and the steering wheel. It performs pedestrian and following vehicle detection and activates the eHMIs oriented towards them. The vehicle is also equipped with a data logger. A safety driver will be seated on the driver's seat and may be concealed.

One or several test tracks with the following options will be used:

- A portion of straight road with a pedestrian crossing
- A portion of straight road where the AV will be parked on the side in order to be overtaken by a manual car
- An outdoor parking with perpendicular parking places

Figure 4.24: Valeo equipped vehicle for test-track study (Method ID: TT05)

Method ID: TT06 – This collaboration between TU Delft, Volkswagen, Audi, and WIVW will make use of three test track trials to evaluate the methodological approach by which car sickness can be investigated in an efficient and replicable way (no pictures available). The vehicle used in the experiments can drive pre-programmed trajectories. The test-track trials will be carried out on the former airfield Valkenburg, which is located near Delft. The trials will be performed on the former runway. When completing a circuit, the length of a lap is approximately 1300 meters. The vehicle driving parameters will be based on a set route through open roads in Delft. Prior to the study, the route through Delft will be driven several times in order to get the aggregated motion information for the test track conditions. Across a number of trials, the motion cues captured in the open road study (see Method RW06) will be replicated in the test-track environment.

Method ID: TT07 – The University of Leeds test-track studies[4] related to driving comfort take place on a closed test track. The track consists of one loop with a length of approximately 3.10 km including straight roads, curves, and intersections. The vehicle used for the studies is a VW Golf Variant equipped with an automated system designed to control both longitudinal and lateral operation of the vehicle, achieving Level 4 automation (SAE, 2021; see Figure 4.25). Participants are seated in the driver's seat of the vehicle, with a safety driver always present in the co-driver's seat to intervene in an emergency. In addition, the experimenter is seated in the back seat to be able to ask for the participants' feedback immediately after they experience the scenarios relevant to the studies. The dashboard's HMI interface displays driving-related information such as the vehicle's speed, current set speed, detected traffic signs, curves, and upcoming manoeuvres.

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[4] The studies are conducted within the RUMBA project (www.projekt-rumba.de, accessed on 3rd March 2023), which is funded by the German Federal Ministry of Economic Affairs and Climate Action (funding number: 19A20007K). The RUMBA project sponsors all resources used for the study design, study conduction, and study analysis. The Hi-Drive project (Grant agreement 101006664), funded by the European Union's Horizon 2020 research and innovation

Figure 4.25: Equipped vehicle for test-track study conducted by University of Leeds (Method ID: TT07)

European Union's Horizon 2020 research and innovation program also supported the study, as it sponsors the co-authors and academic supervision of PhD-Student Stefanie Horn: Dr Ruth Madigan and Prof Natasha Merat from the University of Leeds.

4.5 Real-world studies

Real-world driving studies provide a good complement to more controlled ones conducted using simulators or test tracks. They allow an examination of drivers' natural behaviour without intervention, providing an opportunity to define phenomena of interest at the early stages of research, and later ecological validation of more controlled studies in a diverse set of scenarios.

Field operation tests make use of specially equipped vehicles to evaluate the impact of AD on safety, traffic efficiency, driver behaviour and user acceptance in real-life situations (see Benmimoun et al., 2013). This type of study allows the researcher to capture both internal and external road user reactions to various ADFs and enablers in a wide range of scenarios, including the potential to experience unanticipated situations or edge cases. They also allow an exploration of whether the driver reactions observed in highly controlled simulator or test-track experiments also emerge in more natural, and potentially more risky, naturalistic situations. However, a main disadvantage of using public roads is the lack of controllability due to the unpredictability of the behaviour of other road users. This can also reduce comparability between different conditions and participants. Furthermore, there is no guarantee that the targeted phenomena will be observed, and it is not possible to freely add manoeuvres; for instance, situations of car sickness or of perceived risk may not occur.

4.5.1 Real-world studies in Hi-Drive

There are a variety of methods which can be used to collect real-world data. These include video recordings of current traffic interactions (Section 4.5.1.1), pilot testing of vehicles with AD functionality with a safety driver on board, and the use of WOZ techniques to provide an illusion of automated driving (Section 4.5.1.2). In Hi-Drive we plan to conduct nine real-world studies investigating onboard user experiences, and three investigating external road user interactions. Although not all study details are confirmed at this point, it is anticipated that there will be approximately 435 ordinary participants (i.e., non-expert), along with over 26 hours of video recordings of naturalistic road user interactions. More detailed information on the studies and approaches to be used can be found in Table 4.3.

Table 4.3: Overview of real-world studies being conducted in the User sub-project. Study ID incorporates Method IDs outlined in the text below, and information about the study topic described in column 3 (e.g,. ODI = other driver interaction)

Method ID	**Users**	**Topic**	**Vehicle characteristics**	**Environment**	**Type of Participant**	**Specific Participant Characteristics***	**Planned No. Participants**	**Additional tools / methods**
VO01_ODI	Other drivers	Behaviour when more than 2 drivers interact in complex scenarios	Manual	Urban	Ordinary	n/a	26 hours of video recordings	Phenomenological analysis of behaviour and interactions
V02_ORUI	Drivers and cyclists	Interaction among road users	No vehicle, the data is collected from a camera at an intersection	Urban unsignalized intersection	Anyone who happened to pass the intersection	n/a	About 100 interactions	Data from the code book for video reduction.
RW01_PC	Onboard drivers	Psychological comfort	Manual (step1) / automated vehicle (L2 in step2)	Urban/Rural/ Motorway	Ordinary	Including older drivers	40	Comment aloud protocol Questionnaire Interview
RW01_ODI	Other drivers	Implicit communication	Manual vehicle (following AV)	Motorway	Ordinary	n/a	25	Comment aloud protocol Questionnaire Interview
RW02_SA	Onboard drivers	Impact of HMI on driver takeover reaction and situation awareness	WOZ	Motorway	Ordinary	24 to 64 years old, not trained in AD	40	Questionnaire; Interaction with HMI; Eye tracking
RW03_BA	On-board Drivers	Response process / behavioural adaptation	WOZ	Motorway	Ordinary	Volvo employees, not trained in AD	30	Eye tracking;

Method ID	Users	Topic	Vehicle characteristics	Environment	Type of Participant	Specific Participant Characteristics*	Planned No. Participants	Additional tools / methods
RW04_C1	Passengers	Comfort	Chauffeur	Both	Ordinary	Prone to motion sickness	25	Questionnaire NDRT Physiological measures
RW04_C2	Passengers	Comfort	Chauffeur	Both	Ordinary	Prone to motion sickness	25	Questionnaire NDRT Physiological measures
RW05_C	Onboard users	Comfort	Chauffeur	Industrial area	Ordinary	Prone to motion sickness	20	Questionnaires NDRT performance
RW05_BA	Onboard drivers	Behavioural adaptation, Acceptance, perceived safety, and mode awareness of AV users	AV with safety driver	Urban motorway, motorway	Ordinary	Ordinary drivers Company employees	90	Takeover performance, questionnaire, vehicle handling, attention
RW07_C	Passengers	Comfort	Automated vehicle (with safety driver)	Urban	Ordinary	n/a	40	Questionnaires
RW08_C	Onboard users	Comfort Acceptance	WOZ	Urban	Ordinary	Older participants if possible	100	Interviews Questionnaires Physiological data

*This column provides details on any experiment which targets a specific demographic group. “n/a” means that there are no specific participant requirements, while “TBD” means that the exact participant requirements have not yet been decided.

4.5.1.1 Video observations of current traffic

Video recordings at selected locations facilitate the collection of empirical data about driving behaviour and interactions in real traffic, without any danger of researcher bias affecting behaviours. This allows conclusions to be drawn about the patterns of vehicle interaction used in manually driven vehicles, which may help with the development of AV communication solutions. Within the Hi-Drive project, two studies will make use of this type of data.

Method ID: VO01 – At locations where there is the possibility to install cameras at appropriate heights (for example on the top floor of a building), ICCS will use a Go pro HERO session camera, recording at a resolution of 1920 x 1080 and a frame rate of approximatively 30 fps. When there is no such possibility, a wide-angle camera on a lightweight drone will be used. In both cases, the cameras record from an appropriate height to capture the area needed for the observations at the selected location (see Figure 4.26). The video footage will be analysed by two separate analysts to identify recurring patterns of behaviour.

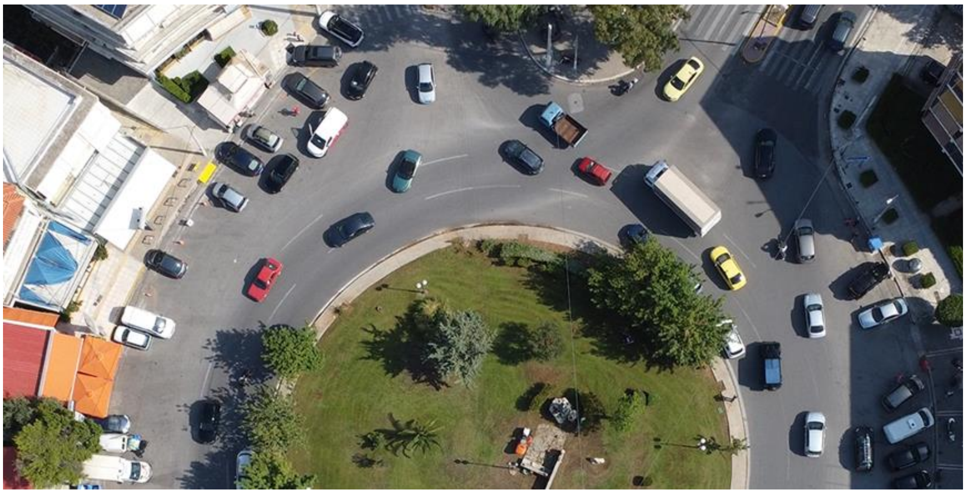


Figure 4.26: Example screenshot from ICCS drone video footage at a study location in Athens, Greece (Method ID: VO01)

METHOD ID: V002 – A Chalmers study will make use of site-based recording with a Viscando camera. This collection obtains its data from an unsignalized urban intersection in Gothenburg, Sweden, with GPS coordinates of 57°42'31.1"N and 11°56'22.9"E. The data will be collected using Stereovision and an AI-based sensor from Viscando, which will be mounted at the intersection's corner. Trajectories of all road users such as pedestrians, cyclists, vehicles, and heavy vehicles will be recorded. The trajectory data include positions, speeds, and headings, which are recorded at a frequency of 20 Hz. All road users will be automatically labelled, with cyclists and drivers of cars and trucks being the most important for Hi-Drive. The trajectory and speed for all road users will also be automatically computed. The raw data will be saved, allowing for *a posteriori* video reduction to enrich the dataset (e.g., as coding whether a cyclist wore a helmet or distinguishing between professional drivers such as taxi drivers and non-professional drivers).

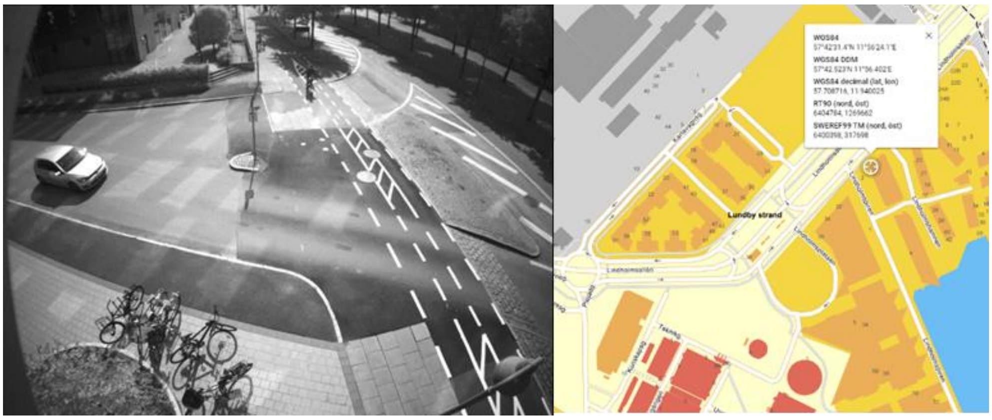


Figure 4.27: Left: view from camera at an intersection in Sweden. Right: position of the camera which was installed on a corner building a few metres from the ground (Method ID: VO02)

4.5.1.2 Other open road data collection

Performing studies in an open-road setting requires data collection tools that are adapted to such driving conditions. These can consist of either specially equipped vehicles with additional data capture capabilities, or WOZ vehicles where an onboard researcher captures the variables of interest.

Method ID: RW01 – The Driving On-Road Study Apparatus (DORSA) vehicle is equipped by CEESAR for the LAB (see Figure 4.28). Four cameras capture the front/back road scene and driver's behaviour (interaction with cockpit + foot position; see Figure 4.28). The recording of the CAN bus is completed with the location thanks to a precise GPS system. An L2 system (adaptative cruise control (ACC) + Lane centring) allows a first level of automated driving and its sensors also offer localizing of the surrounding traffic. Finally, a deported device offers real-time situation tagging by a passenger. A microphone continuously records verbal comments, including those produced as part of the comment-aloud protocol used in driving studies (e.g., Revell et al., 2020) to collect continuous reflexive data on the participant's current main focus of attention. With a bit of training to get people used to verbalizing about the immediate situation, this technique is applied to get data about drivers' perception or discomfort. The DORSA vehicle is used both to collect data from driving participants, including while using the L2 system, and to collect data from participants who are driving behind an AV prototype and are commenting on how it interacts with the traffic from another road user's perspective.

Figure 4.28: Lab's DORSA equipped vehicle (Method ID: RW01)

Method ID: RW02. BASt's Wizard of Oz Vehicle (no picture available) is a technical conversion involving a second driver, the trained wizard, who can drive and control the car from the back seat, hidden from the view of subjects behind a one-way window. To ensure safety, side-mirror information is displayed to the wizard by a camera-monitor system. A computer next to the wizard records all measurement data, e.g., driving parameters or eye-tracking data of participants. Activation and deactivation of the automated driving can be initiated by participants by pressing a green button on the steering wheel. To inform participants about the status of automation while driving, a small display is located in the middle of the instrument cluster. A second and larger display is part of the centre stack and can be used for navigation, NDRTs, and to implement experimental conditions like a countdown to the next TOR. While the wizard is in control of the vehicle, participants are allowed to engage in NDRTs such as reading or smartphone use (as a secondary device).

Method ID: RW03: The WOZ vehicle from Volvo Cars was based on a production vehicle XC90. It includes a set of pedals and a steering wheel in the mid position of the rear seat. Automation is simulated by a person driving the vehicle from the rear seat without the participant being aware of this feature. The wizard's head and shoulders are visible from the front driver's seat, but not the rest of the body or any controls that might arouse suspicion about the setup. The participant is informed that the role of the person in back is merely to oversee the automation for safety reasons, to allay any concerns from the participant. The test vehicle is fitted with extra cameras (compared to the production setup) that record video data at a rate of 10 Hz, capturing the driver's face, upper body, and feet as well as the view of the road ahead.

Figure 4.29: Real-world route for WOZ study by Volvo Cars & Chalmers (Method ID: RW03)

Method ID: RW04: Ford uses the same test vehicles as for the test-track study (see TT02) to measure car sickness in actual traffic. This way, the results gained on the test track can be transferred to a more realistic environment, including the noise of real traffic. The test vehicle is again equipped with an interior camera to capture participants' behaviour. Devices for physiological measurement such as heart rate and skin conductance are available as well. The CAN-BUS data can be accessed, and a device offers the possibility to record inertial measurements. The participant acts as a passenger and is driven by a trained driver. NDRTs are again administered via a tablet PC.

Method ID: RW05: The WIVW study regarding the induction and effects of car sickness on driving performance will take place on open roads in an industrial area with low traffic (no picture available). Participants will experience a standardized highly dynamic driving profile on three different days, each with a different NDRT. The driving profile includes curves, a roundabout, stop-and-go scenarios, slalom, and turning. Participants will be seated in the passenger seat and must engage in the NDRT throughout the whole drive. The test vehicle is a series 5er Touring BMW, which will be driven manually. Cognitive performance tasks will be performed before and after the drive.

Method ID: RW06: This collaboration between TU Delft, Volkswagen, Audi, and WIVW will compare test-track and real-world driving to evaluate the methodological approaches by which car sickness can be investigated in an efficient and replicable way (See Method TT06). In the open road trial, participants will experience a drive in a vehicle on a predefined route through the city of Delft (no pictures available). The participants will be driven in a vehicle by a safety driver. The vehicle will drive pre-programmed trajectories on a set route through Delft. Prior to the study, the route will be driven several times in order to get the aggregated motion information for the test-track conditions.

Method ID: RW07: In the second collaboration between TU Delft, Volkswagen, Audi, and WIVW, a naturalistic open-road driving study will be implemented and will follow an exploratory approach (no pictures available). Participants will drive an autonomous vehicle in Wolfsburg, with a safety driver in the driver's seat, and the participant in the front passenger seat. The route through Wolfsburg will take approx. 20 minutes and will be driven twice per participant. Participants will be instructed to perform an NDRT of their own choice during the drive. The NDRT will not be predefined by the research personnel.

Method ID: RW08: TUD will collaborate with the University of Leeds to investigate the comfort and acceptance of passengers taking a ride in a WOZ vehicle. Passengers will be told that the vehicle is automated, while in reality it will be driven by a human driver continuously during the ride. A mode indicator built inside the car will show the shift of mode from manual to automated. The WOZ drivers will be instructed in a driving session before the experiments to adopt a defensive driving style when driving in automated mode (as this is anticipated to mirror AD). The vehicle is an electric Nissan e-NV200 Evalia (see Figure 4.30). Study participants cannot see the driver and have the illusion of being in an automated vehicle. They sit behind the driver, separated from the driver by a wall. OLED screens are placed on both the separation wall and side windows in the back. Real-time images of the driver's view are produced by several cameras on the vehicle. These images are projected onto OLED screens in such a way that the participant in the back sees what the driver sees and has the impression of sitting in the driver's seat. The participant has no means (steering wheel or brake pedals) of operating the vehicle (SAE level 5).

Figure 4.30: WOZ vehicle and setup for real-world study by TuDelft and the University of Leeds (Method ID: RW08)

4.6 Questionnaires / Interviews / Focus Groups

To supplement the data collected through the experimental methods outlined in Sections 4.2 to 4.5, the project will also gather several different forms of subjective data. Users and prospective users' views will be obtained using questionnaire and interview methods. **Surveys** aimed at the general public are useful for gathering a large number of responses from representative populations, to be used for identifying different kinds of user groups, assessing the prevalence of different factors (e.g., proneness to motion sickness), validating models, and testing hypotheses based on those models. On the other hand, **questionnaires** administered to the experiment participants can provide valuable insights into their experiences and the factors that influenced them within a given study. However, caution is needed when generalizing from these types of questionnaires, as the context of the experiment is key to interpreting the results.

Various **interview** methods will be also used. An interview after a drive can supplement or replace a questionnaire and provide an opportunity to gain more insights into the experiences of a participant (e.g., Madigan et al., preprint). The participants can also be asked to "think aloud" during the experiment, providing real-time insights into the factors influencing their behaviour (e.g., Barbier et al., 2019).

A **focus group**, as a research technique for qualitative data collection, involves in-depth group discussions with a group of participants on a topic determined by the researcher (Morgan, 1996). It is believed that focus groups can generate more ideas and information compared to individual interviews, as interactions within the group can stimulate more discussions (Coenen et al., 2012). Additionally, the interaction within the group can reveal levels of agreement and disagreement on the topic across different participants (Morgan & Krueger, 1993).

In Hi-Drive, we plan to conduct six standalone questionnaire studies investigating driver, pedestrian, and cyclist experiences, along with one focus group and two interview studies. These studies are not linked to any of the experimental studies described in other sections. Although not all study details are confirmed at this point, it is anticipated that there will be approximately 20,000 questionnaire respondents sampled across at least eight countries. This section also includes a description of one common user questionnaire (Method ID: Q02), which will be used by partners, where possible, to gain additional insights from users prior to, and after, engaging in an experiment. Individual partners may also include other subjective measures as part of their data collection (see Section 5.1), but these will depend on the individual context of the experiment, and to avoid confusion they are not described in this section. Detailed information on the studies and approaches to be used can be found in Table 4.4 and the text below.

Table 4.4: Overview of questionnaire, focus group, and interview studies being conducted in the User subproject

Method ID	Topic	Method Type	Data Collection method	Type of Participant	Specific Participant Characteristics*	Planned No. Participants
Q01	Capabilities, expectations, willingness to use, and interactions with AVs	Questionnaire	Online	Ordinary drivers & pedestrians	Cross-cultural (8 countries)	16000
Q02	User awareness and acceptance	Questionnaire	Pre- and post-Experiment	Ordinary drivers	n/a	TBD
Q03	Factors affecting acceptance of AVs	Questionnaire	Online	Ordinary drivers, pedestrians, cyclists & motorcyclists	Cross-cultural	300
Q04	Motion sickness	Questionnaire	On-road (motorway & rural)	Ordinary	Experience of motion sickness	130
Q05	Motion sickness	Questionnaire	Online	Ordinary	Prone to motion sickness Cross-cultural: Germany, Sweden, Spain, Poland	4000
Q06	Mental model & expectations	Questionnaire	Online	Ordinary	n/a	211
Q07	Pedestrian evaluation of eHMIs	Questionnaire	Online	Ordinary	Cross-cultural: UK and Netherlands	100
FG01	Comfort	Focus group	Online	Expert	Multi-disciplinary expert panel	9
I01	Evaluation of eHMIs	Interview	Online	Ordinary	Ordinary drivers Company employees	38

Method ID	Topic	Method Type	Data Collection method	Type of Participant	Specific Participant Characteristics*	Planned No. Participants
I02	AV design considerations for implicit and explicit communication	Interviews	Online	Multiple road users (passengers of AV shuttle service, external road users) & automation experts / designers of communication solutions	Designers of eHMIs Users of eHMIs	50

*This column provides details on any experiment which targets a specific demographic group. “n/a” means that there are no specific participant requirements, while “TBD” means that the exact participant requirements have not yet been decided.

The acceptability and awareness of automated driving will be investigated in multiple surveys within the Hi-Drive project. Although there are some similarities in the topics covered in these questionnaires, they each have a distinct purpose and target different populations. It is anticipated that they will provide a complementary overview of the factors affecting users' experiences of AVs.

Method ID: Q01 - *Hi-Drive Global Survey* (see Annex 1) will collect views from 8,000 respondents from eight countries (China, Greece, Germany, Japan, Poland, Sweden, UK, USA). The survey focuses on the expectations towards different levels of AVs, considering both the user and other road-user viewpoints. In particular, the survey queries what kind of capabilities the AVs will need to have in order to be accepted by potential users. Thus, it is possible to show the relevance of the Hi-Drive project enablers for the acceptance of automated driving.

Method ID: Q02 - *Common user questionnaires* (see Annex 2 and Annex 3), for users experiencing automated driving, were designed to support the harmonization of user data collection across experiments. Where appropriate, pre-questionnaires can be distributed to experiment participants prior to their experience with automated driving, while post-questionnaires can be completed by respondents after experiencing automated driving. The pre-questionnaire covers topics such as the acceptability of automated driving, perceived safety before the experience, sociodemographics, driving experience and mobility, experience with driving automation, technological readiness, personality, and prevalence of motion sickness. The post-questionnaire covers acceptance (including trust and perceived safety) and use of automated driving (including expected activities during automated driving), experienced comfort and motion sickness, willingness to pay for automated driving, and potential changes in the value of travel time.

The common user questionnaires were designed to be generic, with the idea that the studies can adapt them for their purposes when necessary. Vehicle owners working as part of Hi-Drive SP5 *Operations* have been asked also to administer the common questionnaires, where appropriate, to their drivers/passengers when they are conducting vehicle tests of the AD solutions developed within the project. The comparison of ordinary drivers and professional safety drivers can provide insights into how their views differ.

Method ID: Q03 - One of the key aims of the Hi-Drive project is to evaluate the experiences of both onboard and external road users. To this end, a theoretical framework has been used to develop a novel questionnaire to assess AV acceptance from the perspective of multiple road users inside and outside AVs (Nordhoff et al., manuscript under preparation). Respondents can be drivers and passengers but also pedestrians, (motor-)cyclists, and other car drivers interacting with AVs as external road users. A pyramid was developed which provides a hierarchical representation of user needs. Fundamental user needs are organized at the bottom of the pyramid, while higher-level user needs are at the top of the pyramid and are expected to be achieved after the realisation of the needs at the lower end of the pyramid. The pyramid distinguishes between six main needs, which are safety, trust, efficiency, comfort and pleasure, social influence, and well-being (Figure 4.31), and all six will be addressed in the questionnaire. Some user needs exist universally across users, while others are user-specific.

Figure 4.31: Pyramid displaying road user needs and preferences, ordered from basic fundamental needs at the bottom to higher-level user needs and preferences at the top

Method ID: Q04 - A roadside survey will be administered to investigate the experiences of car sickness of people stopping at resting places close to motorways and rural roads in Germany. All participants will be required to have had recent experience with car sickness. Next to standardized items like the misery scale (MISC), several other items on prevalence, passenger activities, and driver behaviour causing car sickness will be included.

Method ID: Q05 - A large online survey will be conducted to investigate the prevalence of car sickness in the European population while performing different activities (e.g., reading, working, entertainment use cases, etc.) and under different driving conditions (curves, straight, speed etc.). Further questions will address topics such as demographics, acceptance of automated driving, strategies people employ to prevent and mitigate car sickness, and the effect of car sickness on driving performance. The MSSQ-short will also be included. The survey will be applied in four countries: Spain, Sweden, Poland, and Germany, with about 1000 participants in each country.

Method ID: Q06 - Based on the experiences in L3Pilot, a questionnaire was designed to assess the mental model of an L3-AD system, as well as drivers' expectations towards such functions (e.g., whether situations are inside or outside the ODD). It consists of statements on the functionality and capabilities of L3-ADFs, which can be correct or incorrect. These statements deal with 1) the behaviour of the AD at ODD boundaries (e.g., AD issues a TOR = correct), 2) the responsibility of the driver (e.g., needs to pay attention all the time = incorrect), 3) the handling of AD (e.g., needs to be activated by the driver = correct), and 4) technically challenging situations (e.g., heavy rain, construction site). The correctness of each statement is indicated. For the items relating to challenging situations there is no clear correct or incorrect answer. These items are used to assess users' expectations of the capabilities of L3-AD. The situations are chosen in a way that they mirror the technical challenges that Hi-Drive aims to address with enabler development.

The questionnaire will be administered as both an online survey and an on-road study. Furthermore, it will also be used in a driving simulator study on situation awareness while driving with L3-AD.

Method ID: Q07 - This questionnaire will be conducted to gain insight into the cross-cultural suitability of selected eHMI communication strategies. A video-based online questionnaire study will be conducted in two European countries (Netherlands & UK). Participants will take a pedestrian perspective in a shared space environment and must interact with an approaching AV (bus or conventional vehicle). Three different eHMI communication signals (no eHMI, VAS, intention-based eHMI) will be presented to support the crossing decisions of the participant. After the videos, participants will rate their willingness to cross in front of the AV and their subjective feeling of safety, trust, and acceptance towards AVs.

Method ID: F01 - To better understand the factors associated with user comfort in automated driving, an online workshop will be conducted with nine internationally recognised experts in this field (Peng et al., 2023). The group workshop will loosely follow a traditional focus group format, where experts discuss a range of proposed topics via the online meeting platform Microsoft Teams. Brainstorming will occur around a range of proposed topics, and participants will be encouraged to write notes, grouping similar items together using the online collaborative whiteboard tool Miro. These notes will be visible on the whiteboard, allowing the facilitators and experts to further discuss the evolving themes. The workshop will last 2 hours and will be recorded via Microsoft Teams. The workshop discussions will be divided into four separate sessions in which different, but connected, topics around user comfort will be covered. These will include a discussion of comfortable and uncomfortable experiences as a passenger in a conventional vehicle, on public transport, and in AVs.

Method ID: I01 - For finding an optimal position for an eHMI, an online survey will be conducted as an interview via Skype. Participants will be presented with three images of a neutral looking car and will be instructed to mark any areas in the front and/or rear and/or side view where they expect an eHMI, in certain scenarios. They should also include the size of the displayed sign/indication in their decision. The overlay of all drawings will generate a heatmap of the desired position for eHMIs (Reschke et al., preprint).

Method ID: I02 - An interview study will be used to investigate the interaction between AVs and vulnerable road users (VRUs). Topics will include the relevance of implicit and explicit communication, the extent to which current eHMIs address the needs of various user groups in more complex situations, the call for standardisation, and recommendations regarding vehicle behaviours, infrastructure, information, and/or HMI. Interviews will be conducted via Zoom with both OEM designers (industry experts) and VRUs who live in the test areas in which AVs are currently being deployed on public roads in California, like San Francisco, Mountain View, and Los Angeles. Respondents include people inside and outside AVs. Inside users can be users of Waymo's and Cruise's automated shuttle services. Outside users include e.g., pedestrians, (motor-)cyclists, car drivers, and drivers of emergency vehicles interacting with AVs on public roads. Participants will be recruited via the personal networks of the researchers involved in this project, social media channels, and through a recruitment agency.

5 Measures implemented in the experimental studies

In the previous sections, we have outlined the various methodologies that will be used to collect data about user interactions with AVs. The current section will provide an overview of the specific measures that will be captured by these methodologies within the Hi-Drive project. One key aim of the Hi-Drive project is to develop an extended and continuous ODD, making it possible to operate AVs for longer periods of time. However, many questions remain about user requirements during extended periods of automation, and there are a wide variety of use cases that need to be understood. The measures described in this section will allow us to evaluate all road users' behaviours and experiences while interacting with AD systems in a variety of contexts. The potential effects of these interactions for drivers' resumption of manual control from automation when required will also be investigated. This will allow us to make recommendations around how user-related factors can facilitate the extension of the ODD.

Traditionally, user-related research has made use of two different types of measures to understand user behaviours—subjective and objective. Subjective measurement refers to measures that examine participants' emotional and/or cognitive experience of an event (Sikes & Dunn, 2020), while objective measurement aims to quantify and assess the conscious and unconscious processing of stimuli (Ferreira & Saraiva, 2019). Thus, subjective measures take account of how people feel while engaged in a task, while objective measures are based on how well people perform the task, irrespective of what they experience whilst doing so. Both types of measures are important to provide a comprehensive understanding of road users' experiences and behaviours while interacting with AVs.

5.1 Subjective measures

Within Hi-Drive we are conducting several large standalone survey studies, outlined in Section 4.6. These surveys include measures of the acceptability of AVs and user acceptance after interacting with AD, along with measures of perceived safety, trust, willingness to use, and susceptibility to motion sickness. We also continue our unique Global Survey (see Annex 1), building on the insights developed through the L3Pilot project to explore new issues relating to the acceptability of AVs across different user groups.

In addition to the standalone surveys outlined in 4.6, several other self-report methods will be used to understand road user experiences before, during, and after their interactions with AVs. Sections 5.1.1 to 5.1.3 provide an overview of some of the measures these self-report methods will capture.

5.1.1 Comfort and motion sickness

One of the key areas to be investigated in Hi-Drive is onboard users' evaluations of their comfort and/or experiences of motion sickness during AD. Several rating scales will be used for this purpose. These include single-item rating scales, such as the **Misery Scale** (MISC; Bos, MacKinnon & Patterson, 2006) or the **Motion Sickness Task Tolerance Scale** (MSTT; Kaß, Tomzig, Marberger, Schulz, Alt, Horn, Teicht, & Engeln, 2022), which combine different symptoms into one scale that can be probed during experiments, at intervals of 30–120 seconds, to obtain a measure of sickness accumulation over time.

In addition, more comprehensive questionnaire instruments comprised of multiple subscales will be used at the end of an experiment to capture more detail on participants' experience of motion sickness and comfort across a number of dimensions. These include:

- **Simulator Sickness Questionnaire (SSQ)** (Kennedy, Lane, Berbaum, & Lilienthal, 1993), which reviews the level of motion sickness on a number of subscales, e.g., nausea, oculomotor and disorientation.
- **Motion Sickness Assessment Questionnaire (MSAQ)** (Gianaros, Muth, Mordkoff, Levine, & Stern, 2001), which allows the calculation of a total index and four subscales: gastrointestinal, central, peripheral, and sopite-related.
- **Motion Sickness Susceptibility Questionnaire (MSSQ-Short)** (Golding, 2006), which is designed to find out how susceptible people are to motion sickness, and what sorts of motions are most effective in causing that sickness. It is not designed to assess the motion sickness associated with a vehicle or system, but is important to quantify people's general susceptibility.
- **Automated Ride Comfort Assessment (ARCA**, Marberger, Otto, Schulz, Alt, & Horn, 2022), which measures comfort ratings during AD. It addresses aspects of ride comfort in automated vehicles that are related to the design of the AV motion, and is subdivided into psychological, physical, and general aspects of comfort.

In addition to these questionnaire-based metrics, an alternative method to capture participants' comfort levels during an experiment is to use **a handset with a trigger** that participants are instructed to press according to their level of discomfort (Rossner & Bullinger, 2020).

5.1.2 Acceptance, attention, and workload

A key element for ensuring that there is a good uptake of AD systems is that they are accepted by both onboard users and the general public alike (see Section 3.1). The **Van der Laan Acceptance Scale** is one of the most commonly used subjective tools for assessing acceptance of advanced transport telematics (Van Der Laan, Heino & De Waard, 1997). It comprises subscales for usefulness and satisfaction. This questionnaire will be used to evaluate both onboard and external road users' evaluations of HMIs.

As outlined in Section 3.1, **trust** and **perceived safety** are key factors which influence the acceptance of automation. Single-item measures of perceived safety (Lau et al., 2022; Lee et al., 2022), perceived risk (Kaleefathullah et al., 2020), and trust (Lau et al., 2022) are commonly used to evaluate pedestrian and other drivers' subjective experiences after each trial during experiments exploring AV interactions, while post-hoc questionnaire-based evaluations of trust (Faas et al., 2020; Hagenzieker et al., 2020; Matthews et al., 2017) and perceived safety (Faas et al., 2020; Hensch et al., 2020; Merat et al., 2018) can also provide useful insights into users' experiences of AV communication tools.

Another important aspect for understanding both onboard and external road users' experiences when interacting with AVs is the level of cognitive load associated with the interaction. More intuitive and simpler designs, requiring less effort on behalf of the user, are more likely to be accepted. There is also a risk of user over/underload while monitoring AV systems (see Section 3.3), which can increase the risk of an accident if and when a driver is asked to resume manual control after automation, or a remote operator is asked to step in to perform a minimum risk manoeuvre. Several measures will be used to capture driver, external road user, and remote operator attention and workload.

Evaluations of the comprehensibility of HMI solutions provide insights into how easily understood these systems are, both from an onboard user and external road user perspective. Single item measures of **comprehension of HMI** will be used to capture road users' understanding of external communication throughout an experiment, using either rating scales (e.g., Horn et al., 2023; Kaleefathullah et al., 2020) or specific questions about the meaning of an icon (e.g., Ackermann et al., 2019; Lee et al., 2019), while overall evaluations of how easily an HMI was perceived and understood will be captured through post-experimental interviews or questionnaires (e.g., Madigan et al., preprint; Palmeiro et al., 2018). The meaning or so-called understandability of an HMI symbol can be evaluated by letting the participants choose from given answers, or through an open question such as: "Write down in a few words what you think the symbol in the image means." (Madigan et al., preprint; Reschke, 2021).

In addition to understanding the meaning of HMI, it is necessary to evaluate the **perception** of these new types of message in terms of their brightness, size, resolution, colour, and position. Perception includes the physical aspect of recognition as well as the correct interpretation of the content. Subjective perception can be captured through open questions or Likert scale evaluations (Kraft, 2022; Renschke, 2021). Another potential method is the use of drawing tools to enable participants to mark the area of a vehicle where an eHMI should be displayed (Rensche et al., preprint). The overlay of all drawings generates a heatmap of the desired position, which can then be used to inform eHMI design.

Measures of workload and system usability include the **System Usability Scale (SUS**; Brooke, 1996) and the **User Experience Questionnaire Short Version (UEQ-S**; Schrepp, Hinderks, & Thomaschewski, 2017) which both provide measures of how easy it is to use an automated system. These will be used to evaluate the design and experience of remote operator workstations. In addition, The **NASA Task Load Index (TLX)** provides subjective ratings of the mental, physical, and temporal demands associated with a task, as well as the frustration, effort, and performance of the task (Hart & Staveland, 1988). It will be used to evaluate drivers' workload during NDRTs and to assess the cognitive demand associated with remote operator tasks. The **Situation Awareness Rating Technique (SART**; Taylor, 1990) and the **After-Scenario Questionnaire (ASQ**; Lewis, 1991), will also be used to measure remote operator performance. Finally, it is likely that long periods of AD, with limited driver input, will lead to high levels of driver fatigue. The **Karolinska Sleepiness Scale (KSS)** is a self-report measure of situational sleepiness. This measure is strongly correlated with time of day, with KSS scores increasing with longer periods of wakefulness (Shahid et al., 2012).

So far, we have mainly outlined questionnaire/verbal response scales. An alternative method used to understand both onboard and external road users' experiences during automation is the **comment-aloud protocol** (e.g., Revell et al. 2020), which allows the researcher to collect continuous reflexive data about participants' current main attention focus during experiments. It requires some training of participants in verbalizing their thoughts about the immediate situation. This protocol can be applied to obtain data about drivers' perception or discomfort factors, for example. Post Drive auto- or self-confrontation interviews (Barbier et al., 2019) complete the comment-aloud protocol to obtain post hoc information about specific situations which the participant has found noteworthy to highlight. Participants are confronted with data likely to remind them about the situation, previously selected by the analyst. These are then used for further analysis after the study, repeating participants' verbalization to prompt them to continue remembering the event and reflecting on their memories.

5.1.3 Personality

Investigating the relationship between driver characteristics (including gender and age) and various personality factors (e.g., sensation seeking) can provide a better understanding of whether different drivers will have different requirements in relation to AD systems. For example, drivers exhibiting certain traits or attitudes such as sensation seeking (willingness to perform risky behaviours) have been found to have a propensity for risky driving and speeding (Adnan et al., 2018). However, it is still unknown how these personality traits might impact on drivers' acceptance and trust in automation, or on their actions while interacting with an automated system. Therefore, several studies will investigate the impact of personality on driver and pedestrian behaviours when interacting with AVs. The **BIG 5 inventory** (Costa & McCrae, 1992) is a standardized questionnaire used to quantitatively assess people's personality rating, using five dimensions. This includes openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism. This metric can be used in conjunction with other scales to develop an understanding of the impact of personality on driving behaviour and/or propensity towards car sickness.

The **Short Sensation Seeking Scale** (Hoyle et al., 2002) provides a measure of how much individuals seek varied, novel, complex, and intense sensations and experiences in their day-to-day lives. Participants report their level of agreement with eight statements including, for example, ''I would like to explore strange places", using a 5-point Likert response scale. This metric will be used to investigate whether a participant's level of sensation seeking has an impact on their evaluations of the driving style and communication techniques implemented during AD.

5.2 Objective measures

The subjective measures described in the previous section will be combined with several objective measures of users' experiences and behaviours to provide a holistic overview of the impact of AD. While the subjective measures tend to be quite similar regardless of topic (e.g., Likert scales, interviews), there are many different types of objective measures, including eye-tracking, physiological measures, video observations, and driver and other road user performance metrics (e.g., driver takeover performance, pedestrian crossing times). Sections 5.2.1 to 5.2.5 provide an overview of some of the measures these objective methods will capture.

5.2.1 Fatigue, workload, and attention

Various different eye-tracking metrics can be used to understand the current workload and/or fatigue of a driver and/or remote operator during periods of automation.

The level of drowsiness a driver/remote operator experiences during automation may indicate how alert and capable they are likely to be if required to supervise the AD system or re-take control. The **percentage of time the eyes are closed (PERCLOS**; see Figure 5.1**)** measures the frequency and duration of eye closure per time unit, with higher values being indicative of increased drowsiness (Dinges et al., 1992). The ratio between the maximum amplitude of a blink and the peak closing velocity of the blink (**amplitude velocity ratio; AVR**) has also been used to measure drowsiness (Johns, 2003).

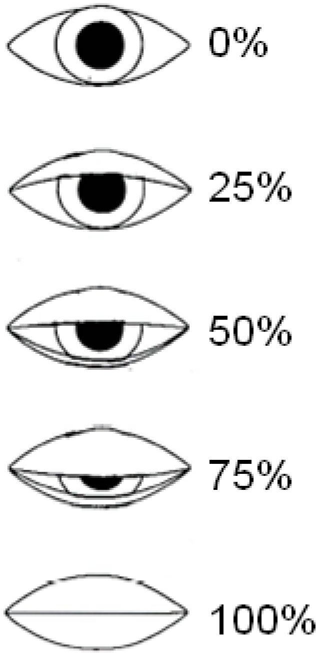


Figure 5.1: Illustration of PERCLOS. Figure taken from Dinges et al. (1999)

Workload and attention can be measured using evaluations of pupillometry, gaze location, and gaze dispersion. In previous studies it has been demonstrated that pupil diameter increases when users are under increased workload (Radhakrishnan et al., 2023; Tsai et al., 2007) and that the **standard deviation of pupil diameter** corresponds to fluctuations in workload (Beatty, 1982; Buettner, 2013; Radhakrishnan et al., 2023). **Percent road centre (PRC)** has been defined as the percentage of fixation data points that occur within the road centre (Ahlström et al., 2009; Victor, 2005), with attentive drivers having higher values of PRC (between 70% and 80%, Victor, 2005; Victor et al., 2005; see Figure 5.2) compared to distracted ones, and this has been associated with increased cognitive load (Engström, Johansson, & Ostlund, 2005; Louw & Merat, 2017). It has been found that drivers in highly automated driving have a more dispersed gaze (**gaze dispersion)** versus manual driving, which could be related to reduced situation awareness (de Winter et al., 2014). These metrics will be used to capture onboard user, other driver, and cyclist workloads when interacting with AVs. Objective indicators of remote operators' situation awareness will be obtained through measuring the **eye fixation times by area of interest (AOI)**, as well as the **fixation deviation** from the ideal AOI.

Another measure which will be used to capture the visual scanning efficiency of drivers is **Gaze transition entropy** (Shiferaw et al., 2019), with increased gaze entropy associated with more disordered sampling patterns (Shiferaw et al., 2017; Shiferaw et al., 2019). The disruption of optimal gaze entropy has been shown to be affected by age (Schieber & Gilland, 2008), sleep deprivation, and task-induced fatigue (Shiferaw et al., 2017). Research has found that reductions in gaze transition entropy are associated with increases in task workload, and that this effect is exacerbated in older drivers (Schieber & Gilland, 2008). The reduction in gaze transition entropy implies that the cognitive resources allocated to a secondary task, or NDRT, reduce the amount of cognitive resources available for the primary driving task (Shiferaw et al., 2019), thus leading to a risk of drivers being out-of-the-loop if required to take over control. Markov chains can also be used to measure the probability of gaze transitions to and from varying regions within the visual field during manual or automated driving (Gonçalves et al., 2019).

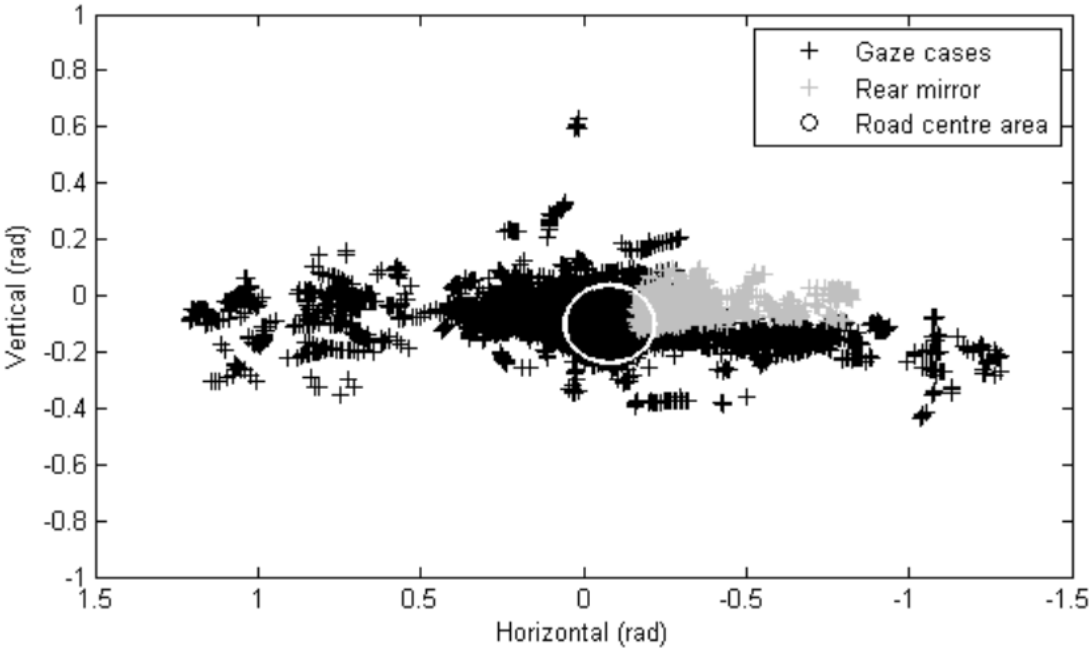


Figure 5.2: Example of gaze fixations during a driving session. Each cross represents a fixation. The white circle represents the road centre. Figure taken from Ahlström et al. (2009).

In addition to eye-tracking measures, workload can also be captured by monitoring increases in **heart rate (HR)** and **ECG-derived respiration rate (EDR)** (Hidalgo-Munoz et al., 2019; Mehler et al., 2009). EDR refers to the number of breaths per minute a person takes and HR to the number of heart beats per minute. Furthermore, increases in workload are associated with a decrease in **heart rate variability (HRV)**, a physiological indicator referring to the variation in time intervals between heart beats (Mehler et al., 2009) (see Figure 5.3). Other relevant metrics which will be used to capture the levels of cognitive demand experienced by remote operators include **regular heart rate** and **inter-beat intervals**.

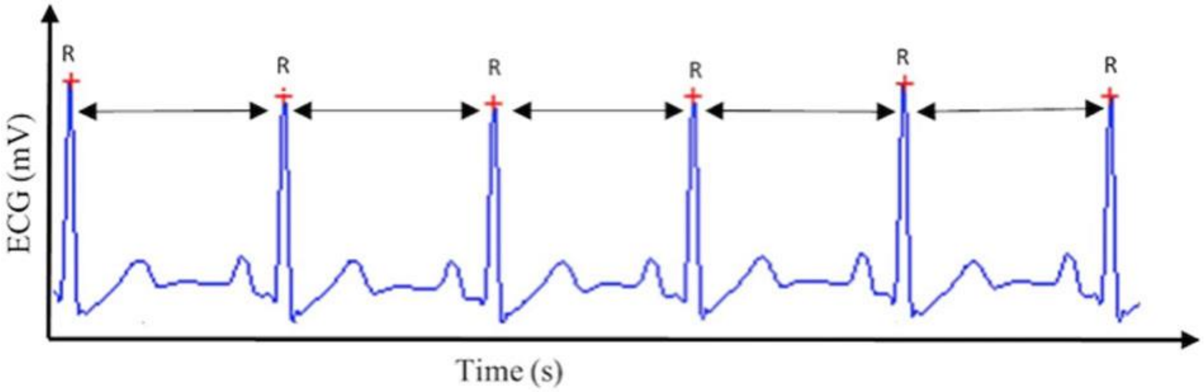


Figure 5.3: Heart rate variability represents the change in the time interval between successive heartbeats. This is calculated based on the R-R intervals from the electrocardiogram (ECG) signals. Figure taken from Laborde et al. (2017).

Electrodermal activity (EDA) can also be used to capture information about driver workload. EDA signals consist of two main components: a tonic mechanism (skin conductance level; SCL) that slowly evolves over time, and a rapid phasic mechanism (skin conductance response; SCR) (Braithwaite et al., 2015; Cacioppo et al., 2007; Radhakrishnan et al., 2022). Increases in SCLs and SCRs have both been associated with increases in stress and workload (Du et al., 2020; Foy & Chapman, 2018; Mehler et al., 2009). However, it has been suggested that SCRs have faster decay times, which makes them more sensitive to fluctuations in user state over short time periods (Braithwaite et al., 2015).

Finally, it is important to consider the impact of an AV's internal and external HMI in capturing driver and other road user attention. **Reaction time to eHMI signals** can be used to evaluate the degree of attention captured by the eHMI. It is also important to consider the propensity of an eHMI to cause a distraction. The Go/Nogo test requires a participant to press a button if recognizing a known stimulus (Go), and avoiding this if a distractor is shown (NoGo) (Pflüger et al., 2003). This method can be used to evaluate how well participants discriminate between an eHMI displayed on the rear lamp of a stationary car and an activated tail-light while travelling at a given speed (e.g., Barthelme, 2023). Response time tasks can also be used to evaluate the distraction caused by an eHMI warning (Barthelme, 2023).

5.2.2 Readiness to drive

In the context of driving and automation, vision and depth sensors (i.e., cameras) can be used to measure the physical state of a user to predict their **physical readiness to drive** (Moich et al., 2017). Physical readiness is comprised of three facets: motoric, which refers to the hands or feet (Rangesh & Trivedi, 2019; Yuen & Trivedi, 2019); pose, which refers to the head and body (Jain et al., 2011); and sensorial availability, which refers to eyes being orientated towards the road. Video recordings can be used to detect if the head, body, and eyes of drivers are in positions synonymous with a ready state—for example, turning to speak with a passenger behind them, not orientating the gaze towards the road for extended periods of time, or not having hands placed on the steering wheel. Detecting feet positioning is particularly difficult if only using pressure sensors, as drivers often hover their feet over the pedals (Moich et al., 2017). Therefore, cameras can also determine whether the feet are in a ready position to take over (Wilschut et al., 2016). Furthermore, camera recordings can be used to derive the users' emotions based on facial expressions. They also provide the possibility to measure pallor as part of car sickness related studies.

5.2.3 Vehicle & bicycle control

Kinematic information plays an important role in the interaction between road users, both in terms of understanding driver performance and control during a takeover from automation, and in terms of understanding how other road users interpret and respond to AV communication. In this section, we discuss measures of driver takeover performance, along with vehicle-based communication metrics.

Automated vehicle takeovers refer to a process of control transition from automation to the human driver (McDonald et al., 2019). This transition can require the human to resume longitudinal and lateral control of the vehicle, as well as the monitoring of in-vehicle displays or of other road users (Bank & Stanton, 2016, 2019; Banks et al., 2014). The literature investigating this area has often used two overriding measures for takeover performance. *Takeover time* refers to the time between the triggering of an event and the first demonstrable input from a driver (Zhang et al., 2018; McDonald et al., 2019). *Takeover quality* refers to the performance of driving following a triggering event (Louw et al., 2017).

There are a variety of temporal measures that can be used to measure **takeover time,** but it is often defined as the duration from a takeover request (or event presentation) until evidence of a braking or steering input from the user (Markkula et al., 2016; McDonald et al., 2019). Evidence of input is usually defined as exceeding some threshold; 2° of steering angle or 10% brake actuation have been commonly used (Gold et al., 2017; Louw, et al., 2017; Zeeb et al., 2015). However, some research has focused on the action time, namely the time between the start of an event and the first significant action intended to mitigate a collision (Louw et al., 2017). Hands-on time is a situation-dependent metric that measures the time it takes for a driver to reposition their hands onto the steering wheel (Petermeijer, Cieler, & de Winter, 2017).

Takeover quality, or post-takeover control, encompasses a range of metrics to measure the performance of takeovers in terms of the longitudinal and lateral forces of the vehicle, and various other vehicle dynamics (McDonald et al., 2019). Ultimately a better-quality takeover will help improve the safety of post-takeover control. **Time to collision (TTC)** and **time to lane crossing (TTLC)** are measures that consider the vehicle dynamics and road geometry during takeovers (Mole et al., 2020). TTC refers to the remaining time a user has before colliding with an obstacle at takeover (Gold et al., 2013; Radlmayr et al., 2014). TTLC is a similar metric which is used for lane keeping paradigms and refers to the remaining time a user has before crossing a lane boundary at takeover (Mammar et al., 2004; Zeeb et al., 2017). In both instances, larger values refer to less critical situations at takeover, and thus potentially safer responses. The **inverse time to collision (invTCC)** is a takeover performance metric that considers the visual looming of a braking lead vehicle (Groeger et al., 2000; Lee, 1976; Summala et al., 1998) and quantifies the criticality of the scenario at the point of takeover. The **takeover controllability rating** (TOC-rating, Naujoks, Wiedemann, Schömig, Jarosch, & Gold, 2018) uses a standardized approach to evaluate a takeover reaction using video recordings. It distinguishes safe takeovers from takeovers with driving errors, and takeovers that lead to a critical or even uncontrollable driving situation.

There are also several measures that evaluate the steering performance and positional location of the vehicle post-takeover. The **standard deviation of lane position (SDLP)** measures lane position variability over a given period (Jamson & Merat, 2005; Kountouriotis et al., 2016). **Steering entropy** is a measure of the predictability of steering patterns (Kersloot, Flint & Parkes, 2003; Nakayama et al., 1999) and has been shown to increase during manual driving post-takeover versus normal manual driving (Kamezaki et al., 2019). Finally, the **steering wheel reversal rate (SWRR)** can be defined as the number per minute of steering wheel reversals larger than a certain angular value (gap size) (Macdonald & Hoffmann, 1980). Kountouriotis et al. (2016) proposed that SWRR measures two different components depending upon how the metric is defined. Larger reversals (or larger gap sizes) are indicative of a change in heading trajectory, whereas smaller reversals imply fine tuning by the driver which indicates increased steering activity but no real change in the vehicle’s trajectory. Research has demonstrated that during the control phase of a takeover, both the traffic density and the original time budget for the takeover are strong influences on SWRR

(Li et al., 2023). This provides good evidence that SWRR can be a context-sensitive measure for post-takeover control quality.

Finally, when interacting with AVs, both cyclists and other drivers may communicate with, or react to, AV behaviours by changing their driving/cycling behaviour. The **interaction zone** is specified as the road area within which the driver/cyclist's behaviour is affected by an AV's motion. Several objective measures within the specified interaction zone have been used to describe the interaction behaviour. These include the **minimum distance, headway, and TTC** between the AV and the external driver's vehicles, and the **mean and minimum speeds** of both vehicles at several relative positions in the interaction zone, along with the **time spent in the interaction zone** (Papakostopoulos et al., 2012; Rettenmaier et al., 2020), the **time to decide about the next action**, and the **accepted time gap** to initiate a turn (Dietrich et al., 2020) or lane change (Rad et al., 2021). **Post-encroachment time** refers to the time gap between the time when the first of two interacting vehicles leaves the interaction/encroachment zone and the time when the second vehicle enters it (Bärgman et al., 2015; see Figure 5.4). **Time to intersection** is the time needed for the car to reach the intersection point of the bicycle and car trajectories at the current speeds (Boda et al., 2018). The **number of crashes** is another indicator that may provide insights related to safety of interaction.

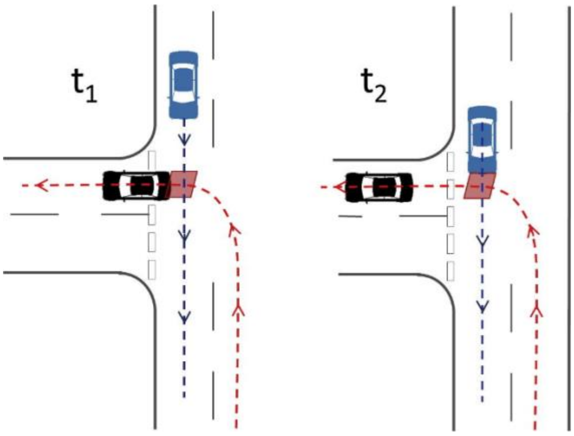


Figure 5.4: Illustration of two moments in time used in the calculation of PET when one vehicle turns left in front of an oncoming vehicle with the right of way. The red rhombus is the encroachment zone. PET = t2–t1 (Figure taken from Bärgman et al., 2015).

5.2.4 Pedestrian crossing performance

Most studies investigating pedestrian responses to AV communication (either through dHMI or eHMIs) have evaluated participants' crossing behaviours using a number of different objective metrics. **Percentage of crossings** has been used to indicate the likelihood of crossing in a given condition. A higher percentage of crossings indicates a higher willingness to cross in front of, or to interact with, an AV. The crossing decision can be captured either through a button-press reaction in HMD or computer-based tests (e.g., de Clercq et al., 2019), taking a step forward in test-track studies (e.g., Horn et al., 2023; Palmeiro et al., 2018) or actual crossing initiation in simulator tests (e.g., Lee et al., 2022).

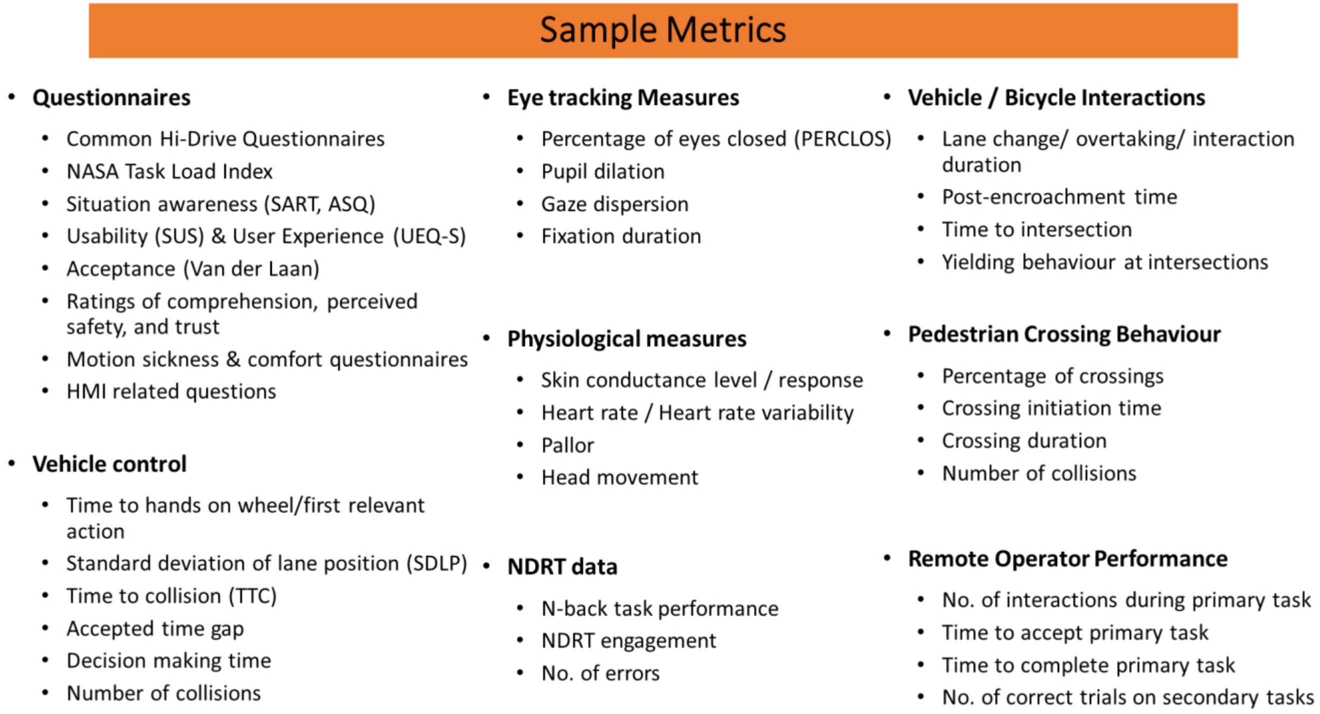
Reaction or decision times are captured using the **Crossing Initiation Time**, measured as either the time taken to make a button-press response indicating willingness to cross (e.g., de Clercq et al., 2019; Eisma et al., 2021; Wang et al., 2021) or the time taken to start a road crossing (i.e., Lee et al., 2022; Madigan et al., preprint; Kaleefathullah et al., 2020; Velasco et al., 2021). Shorter crossing initiation times indicate less hesitation to initiate crossing or make a crossing decision.

Crossing Duration (e.g., Velasco et al., 2021) or **Crossing Speed** (e.g., Jayaraman et al., 2020) can be used to investigate how long it takes a pedestrian to cross the road, providing a proxy measure of the level of urgency experienced in a given scenario. **Gap acceptance**, or the distance/time to the approaching vehicle when a crossing decision is made, can provide insights into the impact of vehicle speed and distance on crossing decisions (e.g., Chen et al., 2020; Jayaraman et al., 2020; Palmeiro et al., 2018). Finally, safety implications of AV communication solutions will be measured by the **number of collisions** which arise in a given condition, with a higher number of collisions indicating a higher level of risk (e.g., Kaleefathullah et al., 2020; Lee et al., preprint).

5.2.5 Remote operator performance

The remote operator’s primary task performance-based metrics include the **number of interactions during the primary task**, the **time to accept the primary task**, and the **time to complete the primary task**. In addition, the n-back task will be used to evaluate **secondary task performance**, with metrics including how many n-back comparisons were correct, how many were incorrect, and how many were missed. The error ratio in the n-back task will also be measured, i.e., the ratio of n-back comparisons completed correctly versus incorrectly.

Not all measures will be used by all partners/in all experiments. Rather, measures are chosen individually by each partner dependent upon the research question being answered. Figure 5.5 provides an overview of some of the more commonly used measures across onboard-user, external road-user, and remote-operator studies. It should be noted that this is not an exhaustive list, and other measures may be used to interpret experimental data in SP6.



Sample Metrics

- **Questionnaires**
  - Common Hi-Drive Questionnaires
  - NASA Task Load Index
  - Situation awareness (SART, ASQ)
  - Usability (SUS) & User Experience (UEQ-S)
  - Acceptance (Van der Laan)
  - Ratings of comprehension, perceived safety, and trust
  - Motion sickness & comfort questionnaires
  - HMI related questions
- **Vehicle control**
  - Time to hands on wheel/first relevant action
  - Standard deviation of lane position (SDLP)
  - Time to collision (TTC)
  - Accepted time gap
  - Decision making time
  - Number of collisions
- **Eye tracking Measures**
  - Percentage of eyes closed (PERCLOS)
  - Pupil dilation
  - Gaze dispersion
  - Fixation duration
- **Physiological measures**
  - Skin conductance level / response
  - Heart rate / Heart rate variability
  - Pallor
  - Head movement
- **NDRT data**
  - N-back task performance
  - NDRT engagement
  - No. of errors
- **Vehicle / Bicycle Interactions**
  - Lane change/ overtaking/ interaction duration
  - Post-encroachment time
  - Time to intersection
  - Yielding behaviour at intersections
- **Pedestrian Crossing Behaviour**
  - Percentage of crossings
  - Crossing initiation time
  - Crossing duration
  - Number of collisions
- **Remote Operator Performance**
  - No. of interactions during primary task
  - Time to accept primary task
  - Time to complete primary task
  - No. of correct trials on secondary tasks

Figure 5.5: An overview of some of the metrics that will be used to evaluate road users' experiences and behaviours. Some of these measures are specific to one user group e.g., pedestrian crossing behaviours, while others can be used to evaluate the experiences of multiple different users, e.g., eye-tracking measures.

In this chapter we have provided an overview of the measures that will be used to measure user experiences and behaviours in the Hi-Drive project. In the next chapter we link the previously described research questions and methodologies to outline the range of user studies that will be used to address each of the individual research questions identified in Deliverable D4.1: *Research Questions* of the project.

6 Evaluation plan

All of the user-related studies to be conducted within Hi-Drive will aim to address one or more critical research questions to increase our understanding of the issues facing human users when interacting with AD systems. Table 6.1 to Table 6.4 present a list of the project's medium-level research questions and the specific study identifiers which will examine these research questions. The studies are grouped according to their main research topic (e.g., acceptance, comfort, or driver monitoring) and they provide an evaluation plan for each of the work packages within SP6 of the Hi-Drive project. More details on the methodologies and scenarios used for these studies can be found in Table 4.1 to Table 4.4 of Sections 4.2 to 4.6.

As Table 6.1 shows, the majority of user acceptance and awareness research questions are being addressed using standalone questionnaire studies. However, there are also two truck simulator studies which are incorporating specific research questions around this topic.

Table 6.1: Table linking the user acceptance and awareness research questions developed in Deliverable D4.1 to the Study identifiers which will address them (see IDs in Table 4.1 to Table 4.4). Explanations of the codes are included below the table.

User acceptance and awareness	Study ID
U1-1.1: What is the willingness to pay for AD?	Q01; Q02
U1-1.2: What is the acceptability (acceptance before usage) of AD?	Q01; Q02; Q03
U1-1.3: What does the general public know about AD?	Q01; Q02; Q03
U1-1.4: What does the general public expect from AD?	Q01; Q02; Q03
U1-1.5: How does AD change the travel experience?	Q02
U1-1.6: What is the perceived safety of AD?	Q02; TS01
U1-1.7: What is the acceptance of AD by the user?	Q02; TS01

*In the Study ID, Q refers to a questionnaire, and TS to a truck simulator study

The research questions relating to human-like driving and comfort (Table 6.2) are being addressed through a combination of test-track, real-world, questionnaire, and focus-group studies. This combination of objective and subjective methods will allow us to explore onboard users' experiences of comfort, discomfort, and car sickness during AD, along with the impact of these feelings on takeovers of control.

Table 6.2: Table linking the human-like driving, user comfort, and car sickness research questions developed in Hi-Drive Deliverable D4.1 to the study identifiers which will address them (See IDs in Table 4.1 to Table 4.4). Explanations of the codes are included below the table.

Human-like Driving and User Comfort	**Study ID**
U1-2.1: Which guidelines for automated driving behaviour can be derived from manual driving to make driving with AD more comfortable?	FG01; DS09_DM
U1-2.2 What is the impact of driving style of AD on driving comfort?	TT07_C
U1-2.3 What is the impact of driving comfort on acceptance, trust, and other related concepts?	FG01; TT07_C
U1-2.4 With which methodological approach can car sickness be investigated in an efficient and replicable way?	TT06_C; RW01_PC; RW04_C1; RW04_C2; RW06_C
Car Sickness	
U1-2.5 What is the prevalence of car sickness in the European population?	Q04; Q05
U1-2.6 How can the occurrence of car sickness be predicted?	TT06_C; RW06_C
U1-2.7 How can car sickness be reduced?	Q04; Q05
U1-2.8 How do NDRTs influence the incidence of car sickness?	Q04; Q05
U1-2.9 How does car sickness affect manual driving and takeover performance?	RW07_C

*In the Study ID, FG = Focus Group; DS = Driving Simulator; TT = Test Track; RW = Real World; Q = Questionnaire

The user-monitoring research questions (Table 6.3) are mainly being addressed using driving simulator and real-world experiments. The driving simulator studies will allow us to conduct highly controlled experiments to get an understanding of the factors impacting drivers' situation awareness, mental models, driver state etc., and the implications of these factors on driving performance. The real-world studies will allow us to evaluate whether similar findings also emerge in on-road conditions. Remote operator performance will also be explored in this work package.

Table 6.3: Table linking the user-monitoring and related HMI research questions developed in Hi-Drive Deliverable D4.1 to the study identifiers which will address them (See IDs in Table 4.1 to Table 4.4). Explanations of the codes are included below the table.

User Monitoring and Related HMI	Study ID
U2-1.1 How do drivers respond if they are required to take back control?	DS01_DM; DS04_DM RW03_BA
U2-1.2 Is manual driving after AD different?	DS01_DM
U2-1.3 How can drivers be supported in resuming control?	DS04_DM
U2-2.1 How does system usage change with repeated use?	DS03_SA; RW03_BA; RW05_BA
U2-2.2 What affects drivers' visual attention during AD?	RW05_BA
U2-2.3 What are the links between drivers' behaviour during AD use and their attitudes towards these systems?	Q02
U2-3.1 What is drivers' mode awareness while driving with AD?	DS03_SA
U2-3.2 What is drivers' mental model of AD?	DS03_SA; Q06
U2-3.3 Which factors influence drivers' situation awareness while driving with AD?	DS03_SA
U2-3.4 How does the driver gain situation awareness in takeover situations?	DS01_DM; DS03_SA
U2-3.5 What is the impact of drivers' situation awareness on takeover reactions?	DS01_DM; DS03_SA
U2-4.1 Which factors influence NDRT engagement while driving with AD?	DS01_DM; DS04_DM
U2-4.2 What is the impact of cognitive distraction?	DS01_DM; RW03_BA
U2-5.1 How can drivers' state be assessed?	DS01_DM; DS04_DM; DS09_DM
U2-5.2 How can information on drivers' states be used to make AD usage safer?	DS04_DM
U2-5.3 Which factors impact drivers' state?	DS01_DM
U2-6.1 How can HMIs adaptive to the state of the operator help to improve the performance of teleoperator?	ROS01

*In the Study ID, DS = Driving Simulator; RW = Real World; Q = Questionnaire; ROS = Remote Operator Simulator

A combination of pedestrian, bicycle, driving, and truck simulators are being used to evaluate other road users' interactions with AVs (Table 6.4). These will be complemented with observations of real-world driving to gain insights into current interaction patterns, along with test-track studies which will allow an exploration of whether eHMIs are interpreted in the same way in laboratory and outside conditions. Remote operator task performance will also be evaluated in this work package.

Table 6.4: Table linking the research questions relating to interaction with other road users developed in Hi-Drive Deliverable D4.1 to the study identifiers which will address them (See IDs in Table 4.1 to Table 4.4). Explanations of the codes are included below the table.

Interaction with Other Road Users – dHMI	**Study ID**
U3-1.1 In which situations are vehicle movement patterns (dHMI) as implicit communication sufficient?	PS01; DS02_ODI; DS05_DI; TS01_DI; VO01_ODI
U3-1.2 What vehicle movement patterns (dHMI) can be manipulated and included in AD design to improve implicit communication?	DS02_ODI; DS07_CI; TS01_DI; PS01_PI; BS01_CI; VO01_ODI; VO02_ORUI; RW03_BA
External Road User – eHMI	
U3-2.1 In which situations do eHMIs (additional to implicit communication via dHMI) improve the communication between traffic participants?	DS02_ODI; DS06_ODI; DS08_L; HMD01_PI; HMD01_L; TT04_L
U3-2.2 Do communication requirements for eHMIs vary between user groups?	PS01_PI; DS06_ODI; Q03
U3-2.3 Are eHMI strategies scalable?	TT01_PI; Q03
U3-2.4 How do traffic participants react to eHMIs?	DS05_DI; DS08_L; HMD01_L; TT04_L; TT05_PI1; TT05_PI2; TT05_ODI; Q03
U3-2.5 How do infrastructure and eHMIs impact the behaviour of VRUs?	TT05_PI1; TT05_PI2
U3-2.6 What information do the surrounding drivers need on eHMIs?	DS02_ODI; TT05_ODI
U3-2.7 How are eHMIs evaluated?	DS05_DI; DS06_ODI; TT05_PI1; TT05_PI2; TT05_ODI; Q03
Remote operator	
U2-6.2 What is the task of an operator in teleoperation?	ROS01

*In the Study ID, PS = Pedestrian Simulator; DS = Driving Simulator; TS = Truck Simulator; VO = Video Observation; TT = Test Track; RW = Real World; ROS = Remote Operator Simulator

All of the user-related project research questions will be addressed in at least one study, with many being examined across multiple studies. This multi-pronged approach will allow an exploration of how different research contexts and scenarios might have an impact on users' experiences and behaviours. The relationships between the findings obtained in these studies will be explored in Deliverables D6.1 (User acceptance and awareness results), D6.2 (Human-like driving and user comfort), D6.3 (User monitoring and related HMI), and D6.4 (Interactions with other road users), due at the end of the project. Each of these deliverables will provide a qualitative overview of the key findings obtained across studies, which should be used to inform the design and implementation of future AVs to take user-related needs into account.

7 Summary and conclusions

Within this deliverable, we have provided a summary of the current state-of-the-art in relation to measuring user interactions with AVs, highlighting the importance of the project-level research questions for understanding the experiences of onboard users, external road users, and remote operators (Chapter 3). As previous research has shown the complexity associated with understanding road users' needs, as well as the advantages and disadvantages of different research environments, it is important to take a multimodal and multidisciplinary approach to answering the project research questions. Therefore, the Hi-Drive partners have chosen a number of different and complementary methods to investigate road user experiences and behaviours (Chapter 4).

Fifteen simulator studies will be conducted to provide highly controlled investigations of driver, pedestrian, and cyclist interactions with AVs. These will be combined with other data sources to address 26 medium-level project research questions (see Chapter 6), particularly in relation to **driver monitoring** and **external road user behaviours**. Across these simulator studies, it is anticipated that data will be collected from approximately 460 non-expert participants, with ten professional engineers acting as remote operators. **Nine test-track studies** are planned, addressing 10 of the medium-level research questions, with a particular focus on **user comfort, car sickness,** and **external road user responses to eHMIs**. It is anticipated that approximately 260 non-expert participants will take part in these experiments. Finally, a total of **12 real-world studies** are planned, combining on-road driving studies and video observations of current traffic. These studies will be used to address eight of the project research questions, particularly in relation to **user comfort, car sickness**, and **driver monitoring**, building on the conclusions obtained through the simulator and test-track studies. Data will be collected from approximately 435 non-expert participants, along with over 26 hours of video recordings of naturalistic road user interactions.

Thus, **across the experimental studies**, data will be collected from over **1,000 ordinary drivers, pedestrians, and cyclists**, along with data from **40 safety drivers** and **35 professional engineers acting as remote operators**. The combination of different methods will allow us to establish whether similar patterns of results are obtained in simulator and real-world environments, and if the data collected through controlled experiments can be used to inform the design of real-world studies to ensure optimum research effectiveness.

Across these experimental studies a wide range of metrics will be used to capture participant behaviours when interacting with AVs (see Chapter 5). For the onboard users, these will include **measures of vehicle control after takeover requests,** such as time to hands on wheel; **physiological measures** such as skin conductance; **eye-tracking measures** such as pupil dilation; and **measures of NDRT engagement**. Measures of external road user behaviour will include the percentage of **crossings made by pedestrians**, **cyclists' yielding behaviours** at intersections, and the **accepted time gap of other drivers** when interacting with an AV. Finally, measures of **remote operator performance** will include **eye tracking and cognitive demand metrics**, along with measures of **performance on primary and secondary task elements**, such as time to accept the primary task, or the error ratio of the N-back task.

Subjective data from questionnaires, interviews, and focus groups will be used to supplement the data collected through experimental research. This will allow us to draw conclusions on road users' experiences of automation and their attitudes towards the various automated systems being proposed. The development of a set of common questionnaires (Method ID: Q02) will enable some comparison across experiments, although any responses obtained will be based on the specific context of a given experiment, and this will need to be taken into account. Within the Hi-Drive project, opinions will be sought from approximately **20,000 unique questionnaire respondents from the general public**, across at least **eight different countries**, addressing topics related to 16 of the mid-level research questions across all research areas. These topics include elements such as **acceptance of ADFs and HMIs**, ratings of **perceived safety**, **trust** and **comprehension of AV communication**, driver and remote operator **situation awareness,** and **task loads**.

It is anticipated that the wide variety of methodologies and measures planned for the Hi-Drive user studies will allow us to provide a comprehensive evaluation of the proposed Hi-Drive enablers, contributing to efforts that will extend the ODDs of AVs and providing recommendations on the needs of both onboard and external road users in terms of future AD developments relating to user acceptance and awareness of AD functionality, user comfort, driver monitoring, and interactions with other road users.

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List of abbreviations and acronyms

Abbreviation	Meaning
ACC	Adaptive Cruise Control
AD	Automated driving
ADAS	Advanced Driver Assistance Systems
ADF	Automated Driving Function
AOI	Area of Interest
AV	Automated vehicle
AVR	Amplitude Velocity Ratio
CAD	Connected and Automated Driving
CAV	Connected and Automated Vehicle
CoP	Code of Practice
dHMI	Dynamic Human Machine Interface
DMIR	Driver Manoeuvre Intention Recognition
DMS	Driver Monitoring System
DORSA	Driving On-Road Study Apparatus
EDA	Electrodermal Activity
EDR	ECG-derived respiration rate
eHMI	External Human Machine Interface
HMI	Human Machine Interface
HR	Heart Rate
HRV	Heart Rate Variability
HUD	Head-up Display
iHMI	Internal Human Machine Interface
invTTC	Inverse Time to Collision
MRM	Minimum Risk Manoeuvre
NDRT	Non-Driving Related Task
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OEM	Original Equipment Manufacturer
OMS	Occupant Monitoring System
PASAT	Paced Auditory Serial Addition Task

Abbreviation	Meaning
PERCLOS	Percentage of time the eyes are closed
PRC	Percent Road Centre
SART	Sustained Attention Response Task
SCL	Skin Conductance Level
SCR	Skin Conductance Response
SDLP	Standard Deviation of Lane Position
SDV	Software Defined Vehicles
SuRT	Surrogate Reference Task
SWRR	Steering Wheel Reversal Rate
TOC	Takeover Controllability Rating
TOR	Takeover Request
TQT	Twenty Questions Task
TTC	Time to Collision
TTLC	Time to Lane Crossing
UX	User experience
VRU	Vulnerable road users
WOZ	Wizard of Oz vehicle
WP	Work Package

Annex 1 Hi-Drive Global Questionnaire

Informed consent form

The purpose of this survey is to collect information on your views on automated driving. By answering the questions, you will contribute valuable information to the development of future transport systems.

This survey forms part of the Hi-Drive research project funded by the European Union. The purpose of Hi-Drive is to develop and evaluate automated driving systems for passenger cars.

All the answers will be stored anonymously. The results will be published in project reports, presentations and scientific publications. It will not be possible to identify individual respondents from the stored data or published results. By completing the survey, you agree that your answers can be stored and used as described above.

Thank you for your time!

Q1 Do you have a full driver’s licence for passenger cars?

Yes/No

If you selected Yes, go directly to question Q3 (General willingness to use). If you responded No, continue to Q2 below.

Q2 Please indicate your level of agreement with the following statements:

I am interested in obtaining a full driver’s licence for passenger cars in the future.

Yes/No

If Yes, display the following:

In the following pages, we ask you to imagine that you have obtained a full driver’s licence for passenger cars. This means that you would be allowed to drive both manually driven and automated vehicles.

End of ‘if Yes’.

If No, display the following:

Future automated driving systems can handle various driving tasks. When activated, you will be allowed to take your hands off the wheel and eyes off the road. Consequently, you will have the option to use the travel time for other purposes than driving. However, you will need to take back control if the system asks you to do so.

Automated driving systems do not need to be monitored by the driver while activated. This is the main difference compared with 'driving assistance systems' currently on the market.

A car with an automated driving system can be called an automated car, even though it may not be able to drive in automated mode everywhere.

Then jump to Interaction: pedestrian role Q40-Q48.

End of 'if No'.

Automated driving systems

Future automated driving systems can handle various driving tasks. When activated, you will be allowed to take your hands off the wheel and eyes off the road. Consequently, you will have the option to use the travel time for other purposes than driving. However, you will need to take back control if the system asks you to do so.

Automated driving systems do not need to be monitored by the driver while activated. This is the main difference compared with 'driving assistance systems' currently on the market.

A car with an automated driving system can be called an automated car, even though it may not be able to drive in automated mode everywhere.

General willingness to use automated driving systems

Please indicate your level of agreement with the following statements concerning automated driving systems:

Code (not shown)	Item	Scale
Q3	I would use an automated driving system if I had it in my car.	1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree
Q4	The next car I buy/lease/rent will have an automated driving system if it is available.	
Q5	I would use the automated driving system during my everyday trips.	

Purchasing a car

Below is a list of different aspects of automated cars.

Please rate the following aspects in terms of **how important they would be for you in making a DECISION TO PURCHASE an automated car (= a passenger car with an automated driving system).**

Q# (not shown)	Item	Scale
Q6	Capability to drive in variable conditions and environments	1 = Not at all important, 2 = Slightly Important, 3 = Important, 4 = Fairly Important, 5 = Very Important
Q7	Having the latest technology in the car	
Q8	Accuracy and reliability of the driving performance	
Q9	Driving as fast as the speed limit and traffic allow	
Q10	Using the travel time for other purposes than driving	
Q11	Safety of driving	
Q12	Energy efficiency (low fuel or electricity consumption)	
Q13	Carbon emissions from driving	
Q14	Cost of owning a car	
Q15	Comfort of driving	
Q16	Complying with local driving customs	
Q17	Following traffic rules	
Q18	Designed for people of all ages and abilities	

Expectations

Please rate **whether you expect using an automated car to be WORSE, SIMILAR, or BETTER than driving yourself for each of the following aspects.**

Q# (not shown)	Item	Scale
Q19	Capability to drive in variable conditions and environments	1 = Much worse, 2 = Somewhat worse, 3 = Similar, 4 = Somewhat better, 5 = Much better
Q20	Accuracy and reliability of the driving performance	
Q21	Driving as fast as the speed limit and traffic allow	
Q22	Using the travel time for other purposes than driving	
Q23	Safety of driving	
Q24	Energy efficiency (low fuel or electricity consumption)	
Q25	Carbon emissions from driving	
Q26	Cost of owning a car	
Q27	Comfort of driving	
Q28	Complying with local driving customs	
Q29	Following traffic rules	

Capabilities of automated driving systems

The first automated driving systems entering the market are likely to have limited capabilities to handle different traffic situations. The capabilities of an automated driving system depend on what kind of sensors the system has, how well it can position itself using GPS, and/or how well it can communicate with other automated cars or traffic lights, for example.

Below is a list of driving situations that most human drivers can handle but where an automated driving system might not be able to function. When an automated driving system cannot drive, it will ask the human driver to take control.

How necessary is it for an automated driving system to have the following capabilities before you would be willing to use it?

Code (not shown)	Capability	Scale
Q30	Observes oncoming traffic and overtakes slower vehicles when possible.	1 = Should not have, 2 = Not necessary, 3 = Nice to have, 4 = Should have, 5 = Must have
Q31	Enters and exits the motorway via on- and off-ramps.	
Q32	Drives in intersections and roundabouts.	
Q33	Adapts its speed before traffic lights so that it does not need to stop.	
Q34	Drives in adverse weather conditions (e.g. heavy rain, fog, snow).	
Q35	Drives in situations where the car cannot locate its position on the map using GPS (e.g. indoor parking lots, tunnels, between high-rise buildings).	
Q36	Continues driving even when road markings are not good.	
Q37	Reroutes to avoid traffic jams or blocked roads.	
Q38	Drives through roadwork zones.	
Q39	Can drive in automated mode on everyday trips.	

Interaction with automated driving systems

Split the main respondent groups in half at random: Pedestrian perspective and Driver perspective.

Pedestrian perspective questions follow:

Automated driving systems interact with human drivers and other road users. The capabilities of automated driving systems will influence the behaviour of the system.

Imagine that you are a pedestrian interacting with automated vehicles.

How necessary it is that automated vehicles would have the following capabilities or behaviours before **you felt comfortable walking** in an environment where such vehicles are around?

Code (not shown)	Capability	Scale
Q40	Communicates its intentions to me as a pedestrian using an external display or voice.	1 = Should not have, 2 = Not necessary, 3 = Nice to have, 4 = Should have, 5 = Must have
Q41	Always politely gives way to pedestrians at zebra crossings.	
Q42	Detects me as a pedestrian even when it is dark or in bad weather.	
Q43	Follows the traffic rules, signs, and lights punctually.	
Q44	Drives slower and more carefully than human drivers.	
Q45	Adapts to the local driving customs.	
Q46	Would not give up its right of way unnecessarily.	
Q47	Lets its driver focus on other activities or rest instead of monitoring the car and traffic.	
Q48	Gives space to other road users even if not strictly required by traffic law (e.g. when they are merging onto a motorway).	
Q49	Stops and contacts human remote assistant if it cannot proceed in automated mode.	

Driver perspective questions follow. Not asked from those who have answered the questions from pedestrian perspective.

Automated driving systems interact with human drivers and other road users. The capabilities of automated driving systems will influence the behaviour of the system.

How necessary it is that the automated vehicles would have the following capabilities or behaviours before **you were willing to use them instead of driving yourself?**

Code (not shown)	Capability	Scale
Q50	Communicates its intentions to pedestrians using an external display or voice.	1 = Should not have, 2 = Not necessary, 3 = Nice to have, 4 = Should have, 5 = Must have

Code (not shown)	Capability	Scale
Q51	Always politely gives way to pedestrians at zebra crossings.	
Q52	Detects pedestrians even when it is dark or in bad weather.	
Q53	Follows the traffic rules, signs, and lights punctually.	
Q54	Drives slower and more carefully than human drivers.	
Q55	Adapts to the local driving customs.	
Q56	Would not give up its right of way unnecessarily.	
Q57	Lets you focus on other activities or rest instead of monitoring the car and traffic	
Q58	Gives space to other road users even if not strictly required by traffic law (e.g. when they are merging onto a motorway).	
Q59	Stops and contacts human remote assistant if it cannot proceed in automated mode.	

Split to Pedestrian and Driver perspectives ends.

Your driving

Only asked if the respondent has a valid driver's licence (Q1 = Yes).

There are many differences between drivers, especially in the different components of driving. We all have strong and weak components. Please indicate your strong and weak components by selecting one of the five alternatives.

Code (not shown)	Driving situation	Scale
Q60	Entering and exiting motorways via on- and off-ramps.	0=Definitely weak 1=Weak 2=Neither weak nor strong 3=Strong 4=Definitely strong
Q61	Driving in congested traffic.	
Q62	Driving in urban centres among pedestrians and cyclists.	
Q63	Driving on single-carriageway roads.	

Code (not shown)	Driving situation	Scale
Q64	Entering and parking in indoor parking lots.	
Q65	Driving through tunnels.	
Q66	Driving in intersections and roundabouts.	
Q67	Overtaking slower vehicles.	
Q68	Driving in adverse weather conditions (rain, snow, fog).	

Traffic situations

Only asked if the respondent has a valid driver's licence (Q1 = Yes).

Please indicate how often you drive a car yourself in the following traffic situations.

Code (not shown)	Item	Scale
Q69	Entering and exiting motorways via on- and off-ramps.	(Nearly) Every day (1) 3-5 days / week (2) 1-2 days / week (3) At least monthly (4) Less often or never (5)
Q70	Driving in congested traffic.	
Q71	Driving in urban centres among pedestrians and cyclists.	
Q72	Parking in indoor parking lots	
Q73	Driving through tunnels.	
Q74	Driving in intersections and roundabouts.	
Q75	Overtaking slower vehicles.	
Q76	Driving in adverse weather conditions (rain, snow, fog).	

Your daily traffic environment

Below, some words are given to describe the traffic system, environment, and atmosphere of your daily traffic environment. State your thoughts about whether these words describe your daily traffic environment by choosing the right response alternative.

Code (not shown)	Item	Scale
Q77	Aggressive	1 = Does not describe it at all, 2 = Does not describe it, 3 = Describes it a little, 4 = Somewhat describes it, 5 = Describes it, 6 = Very much describes it
Q78	Stressful	
Q79	Depends on luck	
Q80	Demands alertness	
Q81	Demands caution	
Q82	Planned	
Q83	Pressurizing	
Q84	Chaotic	
Q85	Irritating	
Q86	Requires vigilance	
Q87	Harmonious	
Q88	Time-consuming	
Q89	Annoying	
Q90	Safe	
Q91	Functional	
Q92	Free-flowing	

Usage of new technologies

Please indicate to what extent you agree with the following statements, which relate to the usage of new technologies.

Code (not shown)	Item	Scale
Q93	Other people come to me for advice on new technologies.	1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree
Q94	In general, I am among the first in my circle of friends to acquire new technology when it appears.	
Q95	I can usually figure out new high-tech products and services without help from others.	
Q96	I keep up with the latest technological developments in my areas of interest.	

Background

Q97 What year were you born?

How old are you in years?

Q98 What is your gender?

Man
Woman
Other
Prefer not to say

Q99 What is the highest level of education that you have completed (including ongoing education or studying at the moment)?

University degree
Trade/technical/vocational training
None of these

Q100 What is your employment status?

Working full time
Working part time
Homemaker or stay at home with kids
Unemployed

Retired
Student

Q101 What kind of environment do you live in?

Urban city/town centre (dense housing)
Suburban area (surrounding a city or town centre)
Small town/village or rural area (sparse housing)

Q102 What category best describes your total household gross income (before taxes) for last year compared to all households in your country?

Less than average
About average
More than average
I prefer not to say

Q103 Which travel modes do you typically use at least weekly?

Car as a driver
Car as a passenger
Public transport
Motorcycle or moped
Bicycle (also electric)
Walking more than 500 m
E-scooter
Other

Q104 Which travel modes did you typically use at least weekly before the COVID-19 pandemic?

Car as a driver
Car as a passenger
Public transport
Motorcycle or moped
Bicycle (also electric)
Walking more than 500 m
E-scooter
Other

Q105 Do you have any advanced driving assistance systems (ADAS) in the car you typically use?

Only asked if the respondent has a valid driver's licence (Q1 = Yes).

I have ADAS and I use them

I have ADAS but I don’t use them
I don’t know if I have ADAS
I don’t have ADAS but I would use them
I don't have ADAS and I would not use them

Q106 Do you consider yourself having a disability?

Yes
No
I prefer not to say

Debriefing form

Thank you for completing the survey!

If you would like to follow the progress of the Hi-Drive project and later learn about the results, please visit the project website https://hi-drive.eu or follow us on Twitter @_HiDrive_ or LinkedIn https://www.linkedin.com/company/hi-drive/

Annex 2 Hi-Drive Common Questionnaires: Pre-drive

- Pre-drive questionnaire should be administered before the respondent experiences the tested automated driving system.
- If the respondent is already familiar with the tested system (e.g. a safety driver), the questionnaire can be filled in before the data collection drives for Hi-Drive begin.
- Printed copies can be used to collect the answers if preferred over an online implementation. The responses are to be inserted into an Excel/CSV template before uploading to Hi-Drive database.
- Text marked in square brackets, e.g. [bg_born], indicates variable names. The coding of the variables is shown in a separate Excel file.

Socio-demographics

What year were you born? ______________________________ [bg_born]
What is your gender? [bg_gndr]

○ **Man**

○ **Woman**

○ **Other**

○ **Prefer not to say**

What is your employment status? [bg_empl1]

○ **Working full-time**

○ **Working part-time**

○ **Homemaker or stay at home with kids**

○ **Unemployed**

○ **Retired**

○ **Student**

Please tick all of those that apply to you in your employment. [bg_empl2_*]

- ☐ **I am an employee of a vehicle manufacturer or supplier**
- ☐ **I work in the development of automated vehicle functions**
- ☐ **I test automated vehicle functions**
- ☐ **I have a professional driving qualification**
- ☐ **I work as a driver transporting goods or people**
- ☐ **I am a qualified safety/test driver**
- ☐ **None of the above**

Could you do part of your job whilst on transportation e.g. travelling on a bus, train or plane? [bg_empl3]

- ○ **Yes**
- ○ **No**

What is the highest level of education that you have completed (including ongoing education or studying at the moment)? [bg_edu]

- ○ **university degree**
- ○ **trade/technical/vocational training**
- ○ **none of those**

How many adults live in your household? [bg_hh1]

- ○ **1**
- ○ **2**
- ○ **3 or more**

How many children under 18 years of age live in your household? [bg_hh2]

- ○ **0**
- ○ **1**
- ○ **2**
- ○ **3 or more**

What kind of environment do you live in? [bg_env]

- ○ **Urban city/town centre (dense housing)**
- ○ **Suburban area (surrounding a city or town centre)**
- ○ **Small town/village or rural area (sparse housing)**

What category best describes your total household gross income (before taxes) for last year? [bg_incm]

- ○ **below 20 000€**
- ○ **20 000-40 000€**
- ○ **40 000-60 000€**
- ○ **60 000-80 000€**
- ○ **80 000-100 000€**
- ○ **more than 100 000€**
- ○ **I prefer not to say**

Driving experience and mobility

How many years of driving experience do you have? [bg_dexp]

- ○ **less than one year**
- ○ **1-2 years**
- ○ **2-10 years**
- ○ **more than 10 years**
- ○ **I don't have a driver's license**

Do you have a car available for your use? [bg_cavai]

- ○ **yes, (nearly) always**
- ○ **yes, sometimes**
- ○ **no or hardly ever**

On average, how often do you drive a car? [bg_usecar]

○ **(Nearly) Every day**

○ **3-5 days / week**

○ **1-2 days / week**

○ **At least monthly**

○ **Less often or never**

Approximately how many kilometres did you drive in a passenger car in the last 12 months? [bg_carkm]

○ **less than 2 000 km**

○ **2 000- 5 000 km**

○ **5 000- 10 000 km**

○ **10 000- 15 000 km**

○ **15 000- 20 000 km**

○ **20 000- 50 000 km**

○ **more than 50 000 km**

Please indicate your agreement with the following statements.

I would travel more in my everyday life… [bg_mor_*]

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
… if travelling was more comfortable.					
… if travelling was easier.					
… if I could use the travel time to do other activities.					
… if I could relax or rest while travelling.					
… if travelling felt safer.					
… if travelling was more fun.					
… if travelling was less expensive.					
… if parking a car was easier.					

Please indicate your agreement with the following statements.
In my everyday life during the last 12 months… [bg_driv_*]

	Never	**Very rarely**	**Rarely**	**Frequently**	**Very frequently**
… I have changed my route in car because of traffic congestion.					
… I have changed the time I choose to drive by car because of traffic congestion.					
… I have decided not to drive a car because of bad weather.					
… I have decided not to drive a car because of darkness.					
… I have decided not to drive a car because of fatigue.					
… I have decided not to drive a car because of traffic congestion.					

On average, how often do you use public transport? [bg_usept]

- ○ **(Nearly) Every day**
- ○ **3-5 days / week**
- ○ **1-2 days / week**
- ○ **At least monthly**
- ○ **Less often or never**

On average, how often do you use active travel modes (walking more than 500 m or cycling)? [bg_useat]

- ○ **(Nearly) Every day**
- ○ **3-5 days / week**
- ○ **1-2 days / week**
- ○ **At least monthly**
- ○ **Less often or never**

Automation experience

Please state if your current vehicle is equipped with the following systems.

Self-parking Assist System (A system that controls the vehicle for parallel parking or reverse parking. Some of these systems control both steering and the throttle; others only control the steering and the driver presses the brake and throttle.) [bg_auto_a]

○ **I have it and I use it**

○ **I have it but I don’t use it**

○ **I don’t know if I have it**

○ **I don’t have it but I would use it**

○ **I don't have it and I would not use it**

Cruise Control (CC) (A system that maintains vehicle speed while driving but does not automatically keep a safe distance from a vehicle ahead.) [bg_auto_b]

○ **I have it and I use it**

○ **I have it but I don’t use it**

○ **I don’t know if I have it**

○ **I don’t have it but I would use it**

○ **I don't have it and I would not use it**

Adaptive Cruise Control (ACC) (A system that maintains vehicle speed while driving and also automatically slows down or speeds up to keep a safe distance from a vehicle ahead.) [bg_auto_c]

○ **I have it and I use it**

○ **I have it but I don’t use it**

○ **I don’t know if I have it**

○ **I don’t have it but I would use it**

○ **I don't have it and I would not use it**

Lane keeping assistance (A system that helps motorists to avoid inadvertently moving out of the intended driving lane.) [bg_auto_d]

- ○ **I have it and I use it**
- ○ **I have it but I don’t use it**
- ○ **I don’t know if I have it**
- ○ **I don’t have it but I would use it**
- ○ **I don't have it and I would not use it**

Willingness to use

An automated driving system lets you take hands off the wheel and eyes off the road when it is activated. You must take back the control when the system requests.
Please indicate if you agree or disagree with the following statements. [pre_wtu_*]

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
I would use an automated driving system if it was in my car.					
The next car I buy/lease/rent will have an automated driving system if it is available.					
I would use the automated driving system during my everyday trips.					

Perceived safety

Please indicate to what extent you agree with the following statements related to your **own driving.** [pre_saf_*]

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
I feel safe most of the time when I am driving.					
I feel anxious most of the time when I am driving.					
I feel comfortable most of the time when I am driving.					

Please indicate to what extent you agree with the following statements related to **automated driving.** [pre_saf_*]

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
I expect to feel safe most of the time while using an automated driving system.					
I expect to feel comfortable most of the time while using an automated driving system.					
I expect to feel anxious most of the time while using an automated driving system.					

Usage of new technologies

Please indicate to what extent you agree with the following statements, which relate to the usage of new technologies. [techre_*]

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Other people come to me for advice on new technologies.					
In general, I am among the first in my circle of friends to acquire new technology when it appears.					
I can usually figure out new high-tech products and services without help from others.					
I keep up with the latest technological developments in my areas of interest.					

Your characteristics

Here are a **number of characteristics that may or may not apply to you**. Please indicate your level of agreement with the following statements. [perso_*]

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I see myself as **someone who is reserved**					
I see myself as **someone who is generally trusting**					
I see myself as **someone who tends to be lazy**					
I see myself as **someone who is relaxed, handles stress well**					
I see myself as **someone who has few artistic interests**					
I see myself as **someone who is outgoing, sociable**					
I see myself as **someone who tends to find fault with others**					
I see myself as **someone who does a thorough job**					
I see myself as **someone who gets nervous easily**					
I see myself as **someone who has an active imagination**					

Here are a **number of characteristics that may or may not apply to you**. Please indicate your level of agreement with the following statements. [sensee_*]

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I would like to explore strange places					
I get restless when I spend too much time at home					
I like to do frightening things					
I like wild parties					
I would like to take off on a trip with no pre-planned routes or timetables					
I prefer friends who are excitingly unpredictable					
I would like to try bungee jumping					
I would love to have new and exciting experiences					

Motion sickness

How frequently do you get car sick? Did you experience any symptoms of motion sickness while reading, working or using a smartphone in a car as a passenger in the last five years? [pre_mosi_a]

- ○ **Never worked/read in a car**
- ○ **No, never**
- ○ **Yes, seldom**
- ○ **Yes, sometimes**
- ○ **Yes, often**
- ○ **Yes, almost always**
- ○ **I prefer not to say**

How severe is your car sickness? How severe were the worst symptoms you experienced reading, working, or using a smartphone in a car as a passenger in the last five years? [pre_mosi_b]

- ○ **Never worked/read in a car**
- ○ **No symptoms**
- ○ **Mild symptoms**
- ○ **Moderate symptoms**
- ○ **Severe symptoms**
- ○ **Very severe symptoms (including vomiting)**
- ○ **I prefer not to say**

Annex 3 Hi-Drive Common Questionnaires: Post-drive

- *Post-drive questionnaire should be administered after the respondent has experienced the tested automated driving system.*
- *If the respondent experiences the automated driving system over multiple drives, the post-drive questionnaire should be filled in after the last drive. Alternatively, the post-drive questionnaire can be filled in multiple times by the same respondent.*
- *Printed copies can be used to collect the answers if preferred. The responses are to be inserted into an Excel/CSV template before uploading to Hi-Drive database.*
- *Text marked in square brackets, e.g. [post_safe_d], indicates variable names. The coding of the variables is shown in a separate Excel file.*

Assessment of the automated driving system

I think that the tested automated driving system was ... [vandel_*]

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

Experiences with the automated driving system

The following questions concerns the automated driving system which you just experienced. Please indicate your level of agreement with the following statements. [post_*]

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Do not know
I would use this system if it was in my car.						
The next car I buy/lease/rent will have this system if it is available.						
I would use the time the system was active to do other activities.						
I would use the system during my everyday trips.						
I would make MORE trips if I had the system in my car.						
I would select destinations further away if I had the system in my car.						
Driving with this system was demanding.						
The system acted appropriately in all situations.						
Driving with the system active was comfortable.						
Using the system was fun.						
Driving with the system on long journeys would make me tired.						

While the automated driving system was on...

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
I was feeling safe most of the time [post_saf_d]					
I was feeling comfortable most of the time [post_saf_e]					
I was feeling anxious most of the time [post_saf_f]					
There were situations when I felt at risk [post_saf_g]					
At the worst moment, I felt being in danger [post_saf_h]					

If you experienced such a situation where you felt being in danger, please describe it in your own words: [post_saf_k]

While the automated driving system was on …

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The system felt safer than I expected. [post_saf_i]					
I would recommend the system because of its safety. [post_saf_j]					

The following questions concern the automated driving system which you just experienced. [trust_*]

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I would trust the system to keep the car centered in the lane.					
I would feel hesitant about using the system.					
I would trust the system to maintain speed and distance to the car ahead.					
I would not feel comfortable using the system.					
I would trust the system.					

Please describe how you experienced the automated driving system by selecting between the following descriptions. [arca_*]

Statement		(1)	(2)	(3)	(4)	(5)	(6)	(7)	
As a user of this system, I felt...	unsafe								safe.
Vehicle control appeared ...	unnatural								natural.
Vehicle behavior appeared ... towards other road users.	unfriendly								friendly
Decisions for lane choice were ... to me.	not transparent								transparent
Automated driving felt like ... control.	losing								gaining
I had the impression to travel ...	inefficiently.								efficiently.

Statement		(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Automated driving made me feel ...	stressed.								relaxed.
Other road users probably think ... about my vehicle's behavior.	negatively								positively
I could ... predict the vehicle's behavior.	hardly								easily
My feeling of trust towards the system is ...	low								high
The driving behavior made it ... to work with the mobile device.	difficult								easy
G-forces due to braking were ...	inappropriate								appropriate
G-forces due to acceleration were ...	inappropriate								appropriate
G-forces in curves/turns were ...	inappropriate								appropriate
G-forces during lane changes were ...	inappropriate								appropriate
My body feels physically ...	fatigued								recovered
Concerning motion sickness, I feel …	sick								well.
All in all, the automated ride was ...	uncomfortable								comfortable.
I am ... with the way the automation controlled the vehicle.	unhappy								happy.

Activities

I would like to engage in the following activities during automated driving: [act_*]

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Spending time with my fellow passengers (e.g., talking, playing games, taking care of children)					
Using digital media (e.g., browsing, watching videos, playing games)					
Eating or drinking					
Working (e.g., meetings, emails)					
Messaging or making video calls					
Reading a book or magazine					
Relaxing and/or resting					
Observing the landscape					
Sleeping					
Listening to music, radio or audiobooks					
Making voice calls					
Observing the road ahead					
Monitoring how the car is functioning					

Willingness to pay

How much extra would you be willing to pay for including this automated driving system in your car? [wtp_a]
NB! Price categories are given for the whole automated driving system (Motorway, Urban and Parking).

- ○ **0 €**
- ○ **less than 2500 €**
- ○ **2500-5000 €**
- ○ **5000-7500 €**
- ○ **equal or more than 7500€**

Travel behaviour

Which travel mode do you use on your commute most often? [vtt_a]

- ○ **Car**
- ○ **Public transport**
- ○ **Walking or cycling**
- ○ **Other**
- ○ **I don't commute** → Please move to the next section: 6 Takeover questions.

If you do commute:
How long is your typical commute in minutes? _____________ [vtt_b]

If your most often used travel mode was car:
How much additional time would you be willing to accept on your commute if the car could drive by itself and you could focus on other activities or relax? [vtt_c]

Additional travel time in minutes: ____________

If your most often used travel mode was something other than car:
I would start using a car on my commute if the car could drive by itself and I could focus on other activities or relax. [vtt_d]

- ○ **Strongly disagree**
- ○ **Disagree**
- ○ **Neutral**
- ○ **Agree**
- ○ **Strongly agree**

Takeover questions

During the automated driving, did you experience any takeover situations where you had to take over the control of the car? [tor_a]

- ○ **No**
- ○ **Yes, once or twice**
- ○ **Yes, several**

If there were a safety driver in addition to you:
During the automated driving, did the safety driver takeover the control from the vehicle? [tor_b]

- ○ **No, I didn't notice any takeovers.**
- ○ **Yes, I noticed a takeover/takeovers.**
- ○ **I don't know.**

Motion sickness

How frequently did you get car sick? Did you experience any symptoms of motion sickness while engaging in eyes-off the road activities (e.g. reading, working or using a smartphone) in the car with an activated automated driving system?" [post_mosi_a]

- ○ **No, never**
- ○ **Yes, seldom**
- ○ **Yes, sometimes**
- ○ **Yes, often**
- ○ **Yes, almost always**
- ○ **I did not engage in eyes-off activities while driving**
- ○ **I prefer not to say**

How severe was your car sickness? How severe were the worst symptoms you experienced while engaging in eyes-off the road activities (e.g. reading, working or using a smartphone) in the car with an activated automated driving system?" [post_mosi_b]

- ○ **No symptoms**
- ○ **Mild symptoms**
- ○ **Moderate symptoms**
- ○ **Severe symptoms**
- ○ **Very severe symptoms (including vomiting)**
- ○ **I did not engage in eyes-off activities while driving**
- ○ **I prefer not to say**

We would like to assess your current state. Please rate your current state on a scale from 0 (no problem) to 10 (vomiting): [post_misc]

State		Response
No Problems		0
Uneasiness		1
Dizziness, Warmth, Headache, Stomach Awareness	Vague	2
	Slight	3
	Fairly	4
	Severe	5
Nausea	Slight	6
	Fairly	7
	Severe	8
Retching		9
Vomiting		10
I prefer not to say		-