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TNO report

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An overview of standards and evaluation criteria to assess the interaction of drivers and other road users with automated vehicles

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Summary

In this report, an overview of available standards and criteria for the interaction of drivers and other road users with automated driving systems (ADS) and advanced driver assistance systems (ADAS) is provided. We also provide information about ongoing research and relevant research groups. In summarizing the results, we distinguish between standards and criteria relevant to the interaction between driver and automated vehicle on the one hand and to the interaction between automated vehicles and other road users on the other. Here, the term ‘automated vehicles’ is taken to refer to both vehicles with ADAS and vehicles with ADS.

Interaction between driver and automated vehicle:

UN regulation No. 157 (2021) provides standards regarding Automated Lane Keeping Systems (ALKS). In particular, it specifies the procedure for dealing with driver unavailability as well as for the case when the driver does not respond to a takeover request. For this, concrete maximum latencies are provided. It also specifies the minimal system information that should be provided to the driver.

This regulation provides the most concrete and specific standards directly concerning the interaction between driver and automated vehicle currently found in the literature. Several authors have provided guidelines for this type of interaction, but so far this has not resulted in evaluation criteria. Moreover, standards exist for classic HMI design, concerning aspects such as the size, colour and location of displays and controls. Although not developed with driving automation in mind, these standards are nevertheless also relevant for the interfaces of ADAS and ADS.

Although few evaluation criteria for the interaction between driver and automated vehicle exist, the literature provides some criteria for driver distraction, which can be the result of using ADAS or ADS. Glances away from the forward roadway longer than 2 s have been found to correlate significantly with the occurrence of accidents. Accordingly, NHTSA (2010) guidelines provide recommendations for maximum time spent looking away from the roadway.

Interaction between automated vehicles and other road users:

Even though external HMIs (eHMIs) for automated vehicles are an active topic of research, few standards or evaluation criteria exist. An exception is the text size used on an eHMI. ISO 9241-303 provides general standards for text size on visual displays to be readable. However, the literature suggests that the text size as specified by this standard for computer displays may be much larger than necessary for eHMIs.

Implicit communication of (automated) vehicles by means of patterns of behaviour in certain traffic situations has been studied far less. Standards or evaluation criteria still need to be developed for this topic.

Abbreviations

AD	Automated Driving
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
ALKS	Automated Lane Keeping System
AV	Automated Vehicle
DDT	Dynamic Driving Task
DRT	Detection-Response Task
eHMI	external Human-Machine Interface
Euro NCAP	European New Car Assessment Programme
HMI	Human-Machine Interface
ISO	International Standards Organization
MRM	Minimum Risk Manoeuvre
NDRA	Non-Driving Related Activities
ODD	Operational Design Domain
PDT	Peripheral Detection Task
SAE	Society of Automotive Engineers
TH	Time Headway
TOR	Take-Over Request
ToC	Transition of Control
TTC	Time-To-Collision
UNECE	United Nations Economic Commission Europe
VRU	Vulnerable Road User

Contents

1 Introduction

Even though true self-driving cars are still beyond the horizon, developments in driving automation happen quickly and are already changing the way we drive. With increasing automation, these developments are expected to have a major impact on mobility and transportation. One important question is how traffic safety in the coming years can be ensured, with vehicles that will be increasingly automated and traffic that will consist more and more of a mixture of traditional, manually driven vehicles and new automated vehicles with potentially different levels of automation. Here, we include both Advanced Driver Assistance Systems (ADAS) on SAE levels 1 and 2 and Automated Driving Systems (ADS) on levels 3-5 (see SAE J3016, 2021).

The Ministry of Infrastructure and Water Management (I&W) aims to develop assessment procedures and test criteria for the evaluation of the safety of these new automated vehicles. Against that background, the Ministry wants to gain more insight in existing knowledge and activities with regards to these topics, in particular concerning the interaction between driver and vehicle and the interaction between automated vehicles and other road users (especially vulnerable road users). Therefore, the Ministry has asked TNO to provide an overview of:

1. Existing standards for the design and evaluation of automated vehicles with respect to the interactions between driver and vehicle and between vehicle and other road users;
2. Criteria to evaluate the safety of automated vehicles with respect to the interactions between driver and vehicle and between vehicle and other road users;
3. Working groups that are working on relevant standards or criteria.

As this is still a developing field of research and technology, also information is included concerning the interaction between drivers/road users and vehicles in general, regardless of automation state. In addition, scientific consensus on test methods that can be used to measure effects of using automation systems that are relevant for their safety (e.g., distraction) will be discussed. The results provide insight into existing standards, criteria and research that can be applied to, or further developed for, the evaluation of the interaction with automated vehicles, without claiming to be comprehensive.

2 Methodology

Vehicles are increasingly equipped with systems that support the driver in executing the driving task and are starting to automate parts of this task. Currently, the main emphasis in the evaluation of the safety of automated driving systems is on the technical aspects of these systems, for instance functional safety. However, for the foreseeable future, the human driver will likely continue to play an important role, even as the level of vehicle automation increases. This means that the role of the human driver will change. Because the drivers increasingly becomes a supervisor, rather than an active driver, this may have an impact on driving safety. Therefore, it is important to develop standards and evaluation criteria for safety assessment of the interaction between drivers and driving automation. Likewise, the interaction between automated vehicles and other road users may change as well, and for this too standards and criteria are needed. The goal of this project is to provide an overview of standards and criteria that are relevant for the evaluation of the interaction of drivers and other road users with automated driving systems (as well as with advanced driver assistance systems, ADAS). In this chapter, first the most important terms related to the driving task and driving automation are defined. Then we briefly describe which information sources were used to create this overview.

2.1 Definitions

The Society of Automotive Engineers (SAE J3016, 2021) defines the Dynamic Driving Task (DDT) as follows:

> “All of the real-time *operational* and tactical functions required to *operate* a *vehicle* in on-road traffic, excluding the strategic functions such as *trip* scheduling and selection of destinations and waypoints, and including, without limitation, the following subtasks:
> 1. Lateral *vehicle* motion control via steering (*operational*).
> 2. Longitudinal *vehicle* motion control via acceleration and deceleration (*operational*).
> 3. Monitoring the driving environment via object and event detection, recognition, classification, and response preparation (*operational* and tactical).
> 4. Object and event response execution (*operational* and tactical).
> 5. Maneuver planning (tactical).
> 6. Enhancing conspicuity via lighting, sounding the horn, signalling, gesturing, etc. (tactical).“

In the same document, the SAE defines an Automated Driving System (ADS) as:

> “The hardware and software that are collectively capable of performing the entire *DDT* on a *sustained* basis, regardless of whether it is limited to a specific *operational design domain* (*ODD*); this term is used specifically to describe a Level 3, 4, or 5 *driving automation system*.”

(where Level 3, 4 and 5 refer to the driving automation levels as defined by the SAE).

Advanced Driver Assistance Systems (ADAS) were defined by the Netherlands Safety Board (2019) as follows:

> "Advanced Driver Assistance Systems (ADAS) are systems that assist the driver in carrying out the primary driving task. ADAS observe the environment using sensors and are able to take-over control of speed or driving direction, subject to the responsibility of the person at the wheel. Systems of this kind are also able to warn the driver in situations that the system considers dangerous."

Note that, although not recommended by the SAE, the term 'driving automation' is often used for both ADAS and ADS and can thus refer to any of the five levels of automation as defined by the SAE (2021). Likewise, the term 'automated vehicles' refers to vehicles that are equipped with ADAS, with ADS, or both.

Driving assistance and automation systems (up to SAE level 4) have to be activated by the driver. The term 'transition of control' (ToC) refers to the process of an automated system taking over control of (part of) the dynamic driving task from the driver (manual to automated) or vice versa (automated to manual). While the manual to automated ToC is always driver initiated, the automated to manual ToC can be initiated by the system or the driver (see ISO 21959-1, 2020 for terminology concerning ToC).

In this report, we provide an overview of both standards and criteria for the interaction with automated vehicles. With 'standard', we refer to a repeatable, harmonised, agreed (by experts) and documented way of doing something, which can apply to the design of a technical system, but also to the measurement of something. With 'criterion', we mean a reference point against which something can be evaluated

2.2 Methods

The research consisted of desktop research. The following methods were used to gather information:

- Literature review: based on the literature database constructed in a previous project for Rijkswaterstaat (Westerhuis et al., 2020), we collected information available in the scientific literature concerning criteria for the assessment of interaction with automated vehicles. Additional literature was identified through references in or to articles that had already been identified, from additional literature searches (using Google Scholar or Scopus) and from personal literature databases.
- ISO[1] standards and reports: the available ISO standards and reports were scanned on relevance for the interaction with automated vehicles.
- Information requests via the authors' (TNO-) internal and external network. This way for instance information concerning Euro NCAP[2] activities and other working groups on driving automation was collected.

[1] The International Standards Organization is an independent international organization with 165 national standardization bodies as members. Founded in 1947, it aims to develop consensus-based market-relevant standards in various domains. It is currently organized in 337 technical committees, each covering a different domain.

[2] Euro NCAP (the European New Car Assessment Programme) organizes crash & safety tests on new vehicles and provides motoring consumers with a realistic and independent assessment of the safety performance of some of the most popular cars sold in Europe. It was established in 1997 and is backed by several European Governments as well as motoring, consumer and insurance organizations.

- Analysis of available standards and evaluation criteria in other domains, such as aviation and robotics. This did not produce directly relevant results and will therefore not be presented in the Results section.

Information on standards, evaluation criteria and working groups was collected and described for the two topics in this project:

- Evaluation of driver-vehicle interaction in the context of driving automation
- Evaluation of road user – (automated) vehicle interaction

As such, the results will also be presented in two different sections (3.1 for driver-vehicle interaction and 3.2 for road user-vehicle interaction).

3 Results

3.1 Driver-vehicle interaction

3.1.1 Design and measurement standards

Table 1 lists current ISO standards aiming to guide either the design of (automated) driving functions or the measurement of the impact of such functions on driver behaviour. As can be seen from this table, these existing standards do not cover driving automation, but concern aspects of driver-vehicle interaction applicable to both manual and automated driving. Some of them specify requirements for the HMI, while others describe testing procedures.

ISO 2575:2021 specifies symbols for use on controls, indicators and tell-tales as well as their colours. ISO 3958:1996 specifies the boundaries of hand-reach of passenger car hand-control locations that can be reached by different proportions of male and female driver populations. ISO 4040:2009 further specifies the location of controls by subdividing the space within reach of drivers into specific zones, to which certain controls essential to the safe operation of vehicles are assigned. ISO 4513:2010 describes a method to establish the location of drivers' eyes in a vehicle by defining elliptical (eyellipse) models in three dimensions for cut-off percentiles of the adult population. ISO 9241-303:2011 is not automotive-specific, but rather concerns requirements for visual displays in general human-system interaction. It specifies the size of symbols to be used at different viewing distances. ISO 12214:2018 gives design recommendations and requirements for the direction-of-motion of hand controls in vehicles. ISO 15005:2017, ISO 15006:2011, ISO 15007:2020 and ISO 15008:2017 specify ergonomic principles for the design of the dialogues that take place between the driver and a vehicle's transport information and control systems (TICS) while the vehicle is in motion, as well as measurement procedures to evaluate the visual aspects of interaction with these systems. In addition, ISO 16673:2017 provides a procedure to measure visual demand due to the use of these systems by means of visual occlusion and ISO 17287:2003 specifies a procedure to assess whether a TICS is suitable for use by drivers while driving. The final two standards in Table 1 concern experimental tasks to measure the effects of a secondary task. ISO 17488:2016 describes a detection-response task (DRT) intended for assessing the attentional effects of cognitive load for secondary tasks (also see section 3.1.4.3). The standard specifies both auditory and visual stimuli. The Peripheral Detection Task (Martens & van Winsum, 2000) is one form of DRT. ISO 26022:2010, finally, describes the Lane Change Task, which can be used to measure performance effects on the primary (driving) task while performing a secondary task.

Table 1. ISO standards relevant to driver-vehicle interaction in automated driving (TC = Technical Committee; SC = Sub-Committee).

ISO standard	Topic	TC/SC
2575:2021	Road vehicles -- Symbols for controls, indicators and tell-tales	22/39
3958:1996	Passenger cars — Driver hand-control reach	22/39
4040:2009	Road vehicles -- Location of hand controls, indicators and tell-tales in motor vehicles	22/39

ISO standard	Topic	TC/SC
4513:2010	Road vehicles -- Visibility -- Method for establishment of eyellipses for driver's eye location	22/35
9241-303:2011	Ergonomics of human-system interaction — Part 303: Requirements for electronic visual displays	159/4
12214:2018	Road vehicles — Direction-of-motion stereotypes for automotive hand controls	22/39
15005:2017	Road vehicles -- Ergonomic aspects of transportation and control systems -- Dialogue management principles and compliance procedures	22/39
15006:2011	Road vehicles -- Ergonomic aspects of transport information and control systems -- Specifications for in-vehicle auditory presentation	22/39
15007:2020	Road vehicles -- Measurement and analysis of driver visual behaviour with respect to transport information and control systems	22/39
15008:2017	Road vehicles -- Ergonomic aspects of transport information and control systems -- Specifications and test procedures for in-vehicle visual presentation	22/39
16673:2017	Road vehicles -- Ergonomic aspects of transport information and control systems -- Occlusion method to assess visual demand due to the use of in-vehicle systems	22/39
17287:2003	Road vehicles -- Ergonomic aspects of transport information and control systems -- Procedure for assessing suitability for use while driving	22/39
17488:2016	Road vehicles -- Transport information and control systems -- Detection-response task (DRT) for assessing attentional effects of cognitive load in driving	22/39
26022:2010	Road vehicles -- Ergonomic aspects of transport information and control systems -- Simulated lane change test to assess in-vehicle secondary task demand	22/39

Some ISO standards specifically addressing the interaction with automated driving systems are currently under development and listed in Table 2. No further information is currently available on these standards. ISO standards for performance requirements and test procedures for ADAS systems like Adaptive Cruise Control (ISO 15622), Forward Collision Mitigation (ISO 22839), Parking Assist (ISO 20900) or Lane Keeping Assistance Systems (ISO 11270) touch upon human-machine interaction briefly. For example, they refer to usage of standardized symbols (in accordance to ISO 2757 from Table 1), usage of visual, acoustic or haptic signals for warnings, or describe requirements such as that the driver should be able to disengage the system, get an indication of system failure and feedback on system state.

Table 2. ISO TC22/SC39 standards under development.

ISO standard	Topic
AWI TS 5283	Road vehicles — Ergonomic aspects of driver monitoring and system interventions in the context of automated driving
AWI 8202	Road vehicles — Box task to measure cognitive and visual-manual workload
AWI PAS 8235	Road vehicles — Taxonomy and definitions for terms related to adaptive in-vehicle information systems
AWI TS 8438	Road vehicles — Modelling approach for driver distraction assessment

The first level 3 system to be admitted to the road is the Automated Lane Keeping System (ALKS), which regulates speed and position on the road for speeds up to 60 km/h. These systems are intended to control both the lateral and longitudinal movement of a vehicle for extended periods of time without further driver command, with the ALKS in primary control of the vehicle (also see Centre for Connected & Autonomous Vehicles, 2020. Its first usage is foreseen on highways (with separated lanes for traffic in different directions and without vulnerable road users) for speeds up to 60 km/h. The United Nations Economic Commission Europe (UNECE) has published a regulation for ALKS that contains specific requirements with respect to the interaction with the driver. UN Regulation No. 157 (2021) stipulates that:

- The ALKS should include a driver availability recognition system that is able to detect driver presence and driver availability/attentiveness. If a driver is not detected in the seat or the seat belt is not fastened for a duration of more than 1 s, a take-over request (TOR) should be issued. Driver availability is checked at least once every 30 s, where at least two criteria such as input to driver-exclusive controls, eye blinking, eye closure or conscious head/body movements have to be fulfilled. If this is not the case, a warning should be issued. If the driver does not respond to this warning within 15 s, a TOR is issued.
- ALKS can only become active when activated by the driver.
- ALKS can be deactivated by the driver by several means.
- ALKS issues a transition demand, also called take-over request, if driver presence or driver availability is not detected or when the system senses that it cannot function properly. If a driver does not respond to a TOR within 4 s, a warning cascade is activated, which consists of repeated warnings and:
- If the driver does not respond to a TOR within 10 s, a Minimum Risk Manoeuvre[3] (MRM) is executed.
- The ALKS displays information to the driver concerning current state, system failures, TOR, MRM and emergency manoeuvres[4].

A driver can 'override' the system by proving steering input above a certain threshold. This threshold should be chosen such that unintentional overrides are prevented. Therefore, the system should be able to detect whether the driver is attentive, by applying one of the following criteria:

- Driver gaze direction is confirmed as primarily looking at the road ahead;
- Driver gaze direction is being confirmed at the rear-view mirrors; or,

[3] A Minimum Risk Procedure is "aimed at minimising risks in traffic, which is automatically performed by the system after a transition demand without driver response or in the case of a severe ALKS or vehicle failure" (UN Regulation No. 157, 2021).

[4] An emergency manoeuvre is performed by the system in case of an event in which the vehicle is at imminent collision risk and has the purpose of avoiding or mitigating a collision (UN Regulation No. 157, 2021).

- Driver head movement is confirmed as primarily directed towards the driving task.

Recently, the European Union (2021) introduced regulation on measuring driver drowsiness and attention. While not directly measuring driver-vehicle interaction, these topics are nevertheless relevant, since they affect driver availability for transitions of control. The most important measurement method in this regulation is the Karolinska Sleepiness Scale (see section 0 below).

3.1.2 Evaluation criteria

For classic HMI design (predating driving automation), guidelines and, to a lesser extent, evaluation criteria have been defined by several authors (e.g., see Campbell et al., 2016; Kroon et al., 2019; Stevens et al., 1999, 2002). Recently, first Human Factors guidelines have been presented for Advanced Driver Assistance Systems and Automated Driving Systems (Campbell et al., 2018; Souman, van Weperen, Hogema, Hoedemaeker, Westerhuis, Stuiver, & de Waard, 2020). However, the development of evaluation criteria for the interaction between driver and vehicle in the context of ADAS or ADS still seems to be in its infancy. In the following subsections, first relevant criteria as well as relevant research with respect to the shared driving task, HMI and transitions of control are discussed. The last subsection provides an overview of criteria for one potential effect of driving automation, namely driver distraction.

3.1.2.1 Shared driving task

Up to and including SAE level 3, driving the vehicle will be a shared responsibility of the human driver and automation. In a study performed by NLR and SWOV for Rijkswaterstaat, called “Verkenning Kwaliteit Gedeelde Rijtaak” (Petermeijer et al., 2021a; Petermeijer et al., 2021b), requirements and methods are described to measure the quality of the shared driving task. This study describes the shared driving task based on various dimensions (such as compatible goals, shared mental models, communication, conflicts), including indicators to determine the quality of the shared driving task. Deliverable D3 in the same project (Tinga et al., 2021) provides methods to measure these quality indicators. The authors conclude that for most quality indicators a measurement method is available. In many cases these methods are subjective measures such as questionnaires, or a combination of subjective and objective measures (see section 3.1.4.2 for an overview of different types of measures). Tinga et al. (2021) mention that measuring the quality of the shared driving task is complex, since the dimensions on which it can be measured are interdependent, and different measurement methods provide insight in (parts of) various quality indicators. Furthermore, the environment of the vehicle / driver and the driving context play an important role in measuring the quality of shared driving. Criteria might therefore have to be determined dynamically based on these variables. Thresholds or ranges for the criteria are not provided in this study. The authors suggest that a combination of measurement methods usually provides the best insight in the quality of the shared driving task.

3.1.2.2 Automated Vehicle HMIs

Although guidelines are in place for the design of HMI in manual vehicles (e.g., see the ISO standards in Table 1; Campbell et al., 2016; Kroon et al., 2019; Stevens et al., 1999, 2002) it is expected that HMIs for higher level automated vehicles will need to fulfil additional requirements. For example, the automated vehicle should be able to efficiently communicate to the driver the current state of the automated system (e.g., is it functioning properly), driving mode (e.g., which level of automation is active) and the driver's responsibility (e.g., is a transition of control expected) (Naujoks, Hergeth, et al., 2019). The HMI is expected to have a crucial role in avoiding side effects of automation as mode confusion, misuse or disuse, and in creating trust and acceptance of the automated driving system (Albers et al., 2020).

Naujoks et al. (2019) provide a first set of guidelines for the design and evaluation of HMIs for automated vehicles. Only the first three guidelines refer specifically to ADAS or ADS:

1. Unintentional activation and deactivation should be prevented.
2. The system mode should be displayed continuously.
3. System state changes should be effectively communicated.

Concerning the last point, the authors note that the best way to effectively communicate the driver's responsibility when automation modes change is still to be determined (Naujoks, Wiedemann, et al., 2019). The other guidelines all refer to more classic HMI topics such as legibility, understandability, colour coding and warning characteristics.

The guidelines by Naujoks et al. (2019) have been evaluated by HMI experts in a workshop setting with two L2 automated driving systems (Tesla Model 3 Autopilot and Cadillac GM Supercruise) (Schömig et al., 2020). From this workshop it was decided to transfer measurable aspects to technical tests. Furthermore, it was recommended to include a new category of perceived complexity in the checklist. The items of this category still have to be defined but according to the experts should consider topics like:

- the visual demands of the HMI in general;
- the cognitive demands resulting from the complexity of the system's logic;
- the motoric demands resulting from the number, positioning, and arrangement of operational devices;
- the ease of learning the interaction with the system.

Furthermore it was proposed to add an item on the appropriate design of other display elements and content of warnings/take-over requests.

Albers et al. (2020) not only propose subjective measures such as standardized questionnaires, but also objective measures to evaluate HMIs regarding visual behaviour (number of gaze switches, percent time on an area of interest) or interaction performance (reaction time, number of unnecessary system deactivations, NDRA performance). The authors do not provide threshold values or criteria for these measures. Souman et al. (2020a) also provided guidelines for the design of ADAS and ADS HMIs. In Souman et al. (2020b) the same authors illustrate how these guidelines might be developed into evaluation criteria by providing four steps:

1. Selection of the most relevant/important guidelines;
2. Definition of the terms involved in a specific guideline;
3. Operationalization of the guideline by proposing a measurement method;
4. Setting a criterion.

However, the authors do not yet provide criteria for the interaction with automated systems.

3.1.2.3 Transition of control criteria

According to the UN Regulation No. 157 (2021) on ALKS, the driver should have 10 s to respond to a request to take-over control (TOR). If the driver does not take-over control within this time, the vehicle should initiate a Minimum Risk Manoeuvre. Some earlier studies suggested that 7-8 s lead time for a TOR should be sufficient (see Eriksson & Stanton, 2017). However, an analysis of different studies by Eriksson and Stanton (2017) showed that there is substantial variation in reported take-over request lead times, from a few seconds up to 30 s. They reported that take-over response times are typically around 2-3 s, with some studies reporting RTs up to 15 s. In their own study, Eriksson and Stanton (2017) found that participants took about 1.5 s longer to respond to a take-over request when engaged in a secondary task. Note that these response times refer to the first measurable behavioural reaction of a participant, for instance in steering or braking. This does not necessarily mean that the driver is also fully aware of the traffic situation at that moment (see Zeeb et al., 2016).

3.1.2.4 Driver distraction criteria

NHTSA (2010) guidelines on visual distraction by in-vehicle electronic devices recommend that devices are designed such that the mean required duration of glances away from the roadway is shorter than 2 s, 85 percent of eye glance durations away from the roadway are 2 seconds or less and the total duration of glances away from the roadway to complete a task on a device is less than 12 s. The 2-second-rule was already part of the 2000 guidelines on driver distraction by in-vehicle information systems from the Alliance of Automotive Manufacturers (AAM; now Alliance for Automotive Innovation). Scientific studies of driver distraction typically conclude that although distraction clearly has detrimental effects on driving performance and safety, the exact effects depend on the type of distraction and the traffic situation, among other factors, and therefore do not give hard thresholds for unsafe looking behaviour (e.g., see Borowsky et al., 2015; ERSO, 2018; Stelling & Hagenzieker, 2012).

3.1.3 Working groups, EU research projects and research centres

We identified international working groups in the area of Human Factors of driving automation from three different bodies: ISO working groups, Euro NCAP working groups and the trilateral working group Automation in Road Transport (ART), which includes subgroups on Human Factors and on “User Awareness, Users and Societal Acceptance and Ethics, Driver Training” and is a collaboration between the EU, the USA and Japan. We were unable to find more information on this last one. Undoubtedly more working groups exist, but these are the ones we are currently aware of.

According to information from one of the TNO representatives in the ISO organization, the safety of driver-vehicle interaction in automated vehicles falls under two ISO committees/working groups:

- ISO/TC 22/SC 39 Ergonomics
- ISO/TC 22/SC 32/WG 13 Safety for Driving Automation Systems

The first (SC 39) is concerned with vehicle ergonomics in general, not primarily related to driving automation. The second working group (SC 32/WG 39) is focused on driving automation, but does not explicitly consider driver-system interaction (the working group falls under sub-committee SC 32, which is titled ‘Electrical and electronic components and general system aspects’). Hence, to the best of our knowledge there currently is no ISO working group which specifically addresses the Human Factors aspects of driver-vehicle interaction in automated vehicles.

Several working groups within Euro NCAP work on the development of test and assessment protocols relevant for driver-vehicle interaction and driving automation. Relevant working groups were identified by consulting the TNO internal network. Table 3 lists these working groups, three of which are working on protocols to be used for star ratings, while two working groups work (or will work) on rating Automated Driving.

Table 3. Euro NCAP working groups related to HMI and/or assisted/automated driving (AD).

WG name	Goal	Topic
AEB/AES	Star rating	Emergency braking/steering systems
Occupant Status Monitoring	Star rating	Driver /Occupant status monitoring
Speed Assist System	Star rating	Speed assist systems
Assisted Driving	AD grading	Assistance Competence (based on Driver Engagement and Vehicle Assistance) and Safety Backup
Automated Driving	AD grading	Automated driving systems (not started yet)

The interaction between driver and driving assistance/automation system is or has been the topic of several EU projects. Table 4 lists some recent projects from the last 5 years. In addition, Table 5 lists examples of research groups working on this topic (please note that this is by no means a complete list; it is meant to be a starting point for further information gathering).

Table 4. European projects on driver-automation interaction.

Project name	URL	Status	Goal
MEDIATOR	mediatorproject.eu	2019 start	Intelligently assess the strengths and weaknesses of both the driver and the automation and mediate between them, while also taking into account the driving context
iDREAMS	idreamsproject.eu	2019 start	Develop a system that provides timely interventions to keep drivers of different modes in a safe driving zone.

BRAVE	brave-project.eu	2021 end	Improve safety and market adoption of automated vehicles, by considering the needs and requirements of the users, other road users and relevant stakeholders, assuring safe integration of key enabling technology advancements
ADAS and me	adasandme.com	2020 end	Facilitate automated driving in conjunction with information on driver state
AutoMate	automate-project.eu	2019 end	Develop, evaluate and demonstrate the “TeamMate Car” concept as a major enabler of highly automated vehicles
AdaptIVe	adaptive-ip.eu	2017 end	Dynamically adapt the level of automation to driving situation and driver status
HoliDes	holides.eu	2016 end	Development and qualification of Adaptive Cooperative Human-Machine Systems in a highly adaptive way to guarantee fluent and cooperative task achievement

Table 5. Research centres on driver-vehicle interaction in automated driving.

Research group	Country	People
AAA	United States	William Horrey
BASt	Germany	Tom Gasser, Andre Wiggerich
BMW	Germany	Frederik Naujoks, Yannick Forster, Andreas Keinath
Chalmers	Sweden	Marco Dozza
CRF	Italy	Antonella Toffetti
Exponent	United States	John Campbell
Ford	United States	Bobbie Seppelt
Insurance Institute for Highway Safety	United States	Alexandra Muller
ITS Leeds	United Kingdom	Natasha Merat, Oliver Carsten
JaguarLandrover	United Kingdom	David Sanchez
MIT	United States	Chuck Green
SWOV	The Netherlands	Nicole van Nes
Technical University Delft	The Netherlands	David Abbink, Marjan Hagenzieker, Riender Happee, Joost de Winter
Technical University Eindhoven	The Netherlands	Marieke Martens
Technical University München	Germany	Klaus Bengler
Texas A&M Transportation Institute	United States	Mike Manser
TNO	The Netherlands	Marieke Martens

Transportation Safety Board Canada	Canada	Missy Rudin Brown
Transport Canada	Canada	Peter Burns, Joanne Harbluck
University of Bologna	Italy	Marco de Angelis
University of Groningen	The Netherlands	Karel Brookhuis, Dick de Waard
University of Wisconsin-Madison	United States	John Lee
Virginia Tech Transportation Institute	United States	Tom Dingus
Waymo	United States	Trent Victor

3.1.4 Scientific consensus

This section describes ISO reports that summarize current consensus on how to measure driver-vehicle interaction, a general classification of measurement methods and some specific measures commonly used in studies on driver-vehicle interaction.

3.1.4.1 ISO reports

The ISO organization has published several technical reports that summarize the knowledge with respect to driver-vehicle interaction underlying their standards (see Table 6). Some of these concern more classic Human Factors topics such as how and when to present information and warning signals to the driver (e.g., ISO TR 12204:2012; ISO TR 16352:2005; ISO TS 16951:2021). Although not describing automated driving systems, these reports are still relevant as automated driving systems also involve information and warning signals for the driver.

Table 6. ISO reports concerning different aspects of driver-vehicle interaction.

ISO report	Topic
TR 12204:2012	Road vehicles -- Ergonomic aspects of transport information and control systems -- Introduction to integrating safety critical and time critical warning signals
TS 14198:2019	Road vehicles -- Ergonomic aspects of transport information and control systems -- Calibration tasks for methods which assess driver demand due to the use of in-vehicle systems
TR 16352:2005	Road vehicles -- Ergonomic aspects of in-vehicle presentation for transport information and control systems -- Warning systems
TS 16951:2021	Road vehicles -- Ergonomic aspects of transport information and control systems (TICS) -- Procedures for determining priority of on-board messages presented to drivers
TR 20545:2017	Intelligent transport systems -- Vehicle/roadway warning and control systems -- Report on standardisation for vehicle automated driving systems (RoVAS)/Beyond driver assistance systems
TR 21959-1:2020	Road vehicles -- Human performance and state in the context of automated driving -- Part 1: Common underlying concepts

TR 21959-2:2020	Road vehicles -- Human performance and state in the context of automated driving -- Part 2: Considerations in designing experiments to investigate transition processes
TR 21974-1:2018	Naturalistic driving studies -- Vocabulary -- Part 1: Safety critical events

Some of the more recent reports directly pertain to driving automation. ISO TR 21959-1:2020 offers definitions and descriptions of various concepts concerning the interaction of the driver with automated driving systems. For instance, it sums up the various aspects of driver state relevant for automation and transition of control: monitoring the driving environment, monitoring driving automation system performance, object and event detection and response, receptivity (ability to focus in response to a stimulus), situation awareness and vigilance. It also lists aspects of the driver state relevant during automated driving: visual distraction/load, visual-manual distraction/load, manual distraction/load, cognitive distraction/load, mind wandering, arousal level, and motivation for a non-driving task. Driver readiness/availability is discussed in relationship to transitions of control, as well as other factors that may affect a person’s use of driving automation, such as prior knowledge, expectations, training, and understanding of a system. The report also mentions measures to assess the quality of a transition of control from an automated system to a human driver (without giving criteria for these measures). It distinguishes four categories of measures:

1. Safety-oriented, objective take-over quality measures (e.g., number of test subjects being able to avoid collision, collision severity, omission of visual checks, operating errors and threshold values for longitudinal/lateral acceleration and time-to-collision or time-to-line-crossing);
2. Sensitivity-oriented, objective take-over quality measures (e.g., Standard Deviation of Lateral Position SDLP, Standard Deviation of steering wheel angle, mean and SD of yaw rate error, metrics for the distance to other vehicles and metrics for longitudinal control quality such as time headway);
3. Expert-based assessment of take-over quality;
4. Subjective take-over quality measures.

In ISO TR 21959-2:2020 these concepts are discussed in more detail. The report describes human factors that influence takeover performance: driver knowledge of a system, experience and trust, demographic attributes such as age, driving experience and driving style and driver readiness/availability (both physically and cognitively). The latter includes sitting position and posture, engagement in non-driving related activities, drowsiness, mind wandering, situation awareness, mode awareness, attentiveness and receptivity to stimuli. The report also describes considerations for test scenarios to be used for the evaluation of human performance in safety-critical transition situations. The demands of a test scenario on the driver depend on its urgency, predictability, criticality and complexity of the required response (defined in terms of skill-based, rule-based or knowledge-based responses). Takeover performance can be measured on the level of the human response (perception, cognition and action), of the vehicle control that results from the human response (lateral and longitudinal) and of the impact of vehicle manoeuvres on traffic safety (driving imprecisions, driving errors, endangerment of self or others, and loss of control, in increasing severity). The report summarizes available measures of human takeover performance in a table of measures, ordered by transition phase, type of transition (driver- or system-initiated), performance aspect and data considerations (temporal performance data, quality of performance data, from the test subject, from an observer or from a measuring device). It ends by listing possible test environments (driving simulator studies and roadway studies, including test-tracks, field operational tests and naturalistic driving studies).

3.1.4.2 Classification of measurement methods

There is a wide variety of methods that are used to quantify different aspects of driver behaviour, performance or state relevant to driver-vehicle interaction. A recent report by Petermeijer et al. (2021a) categorizes these methods as follows:

1. **Subjective measures:**
    a. Questionnaires
    b. Checklists
    c. Interviews
    d. Self-reports
    e. Expert observations
2. **Behavioural measures:**
    a. Eye tracking
    b. Head tracking
    c. Hand tracking
    d. Reaction time
    e. Experimental tasks (e.g., Peripheral Detection Task)
    f. Non-driving related activity (NDRA) engagement
    g. Steering and pedal responses
    h. Driving behaviour measures (e.g., Time-to-Collision or lateral acceleration)
    i. Disengagement of automated functions
    j. HMI inputs
3. **Neurophysiological measures:**
    a. Physiological measures (e.g., heart rate, respiration rate, skin conductance)
    b. Neurophysiological measures (e.g, EEG, fNIRS)
    c. Pupillometry
4. **Evaluation of driver-system communication and automation design**
    a. Error analysis
    b. Design evaluation

Tinga et al. (2021) discuss for different dimensions of the shared driving task how these methods can be used to measure the quality of shared driving. However, they do not provide evaluation criteria.

3.1.4.3 Commonly used measures for driver behaviour and performance

Driver distraction

Many tasks and methods have been developed to measure distraction and its effects on task performance. Driver distraction is a process or condition that draws away driver attention from the driving task, thereby disturbing driving control (Sheridan, 2004). According to Regan et al. (2011) this leads to the driver having insufficient or no attention to activities critical for safe driving. They categorize distraction as a form of driver inattention, which they call ‘driver diverted attention’, and distinguish between driving-related and non-driving related distraction. In driving automation, where drivers are put in the role of system supervisor (for systems up to level 3), several studies have shown that drivers are likely to divert their attention to other tasks to reduce boredom and monotony (Cunningham & Regan, 2018). Measurement of distraction is mainly based on eye or head movement measurements. Commonly used metrics are:

- **Percentage gaze at centre of road (PCR):** the proportion of fixations within 8 (sometimes 10) deg from the most frequent gaze angle (typically the centre of the road). For normal driving, PRCs of 70-80% are considered normal (no distraction); in driving simulator studies PRCs of ~90% are usually found. PRC < 58% for at least 1 min is considered a sign of distraction (Kircher et al., 2009)
- **Horizontal gaze dispersion (HGD):** standard deviation of horizontal gaze positions (either in metres in world coordinates or in degrees) (Reimer, 2009; Wang et al., 2014). This metric resembles PCR, but only takes horizontal gaze dispersion into account.
- **Eyes off forward roadway (EOFR):** cumulative time that glances were away from the road within a 6 s window (from 5 s before a precipitating event until 1 s after) (Klauer et al., 2006). The odds ratio for near crashes and crashes was found to be significantly higher than 1 for EOFR > 2 s (Klauer et al., 2006).
- **Risky visual scanning patterns (RVSP):** based on duration of current off-road glance combined with total off-road glances during last 3 s (Donmez et al., 2007).
- **AttenD:** quantifies the extent to which a single attentional buffer of 2 s has been depleted, based on the duration of glances to the forward roadway, glances necessary for save driving (e.g., mirrors, instruments) and non-driving related glances. AttenD 2.0 extends this to multiple buffers for driving subtasks (Ahlström et al., 2021; Ahlström & Kircher, 2010; Kircher & Ahlström, 2013).
- **Multi distraction detection (MDD):** estimates visual distraction using the percent of glances to the road center (PRC) and long glances away from the road, and estimates cognitive distraction by gaze concentration focused on the center of the road (Victor, 2010, cited by Lee et al., 2013).

Lee et al. (2013) have evaluated some of these metrics for different driving environments (urban, rural, highway) and concluded that some perform better in one type of environment and others in other environments. For urban environments, EOFR and RVSP performed best, while AttenD scored highest in rural environments. In highway environments, differences among the metrics were found to be small.

Commonly used tasks to measure the effects of distraction include:

- **Lane change task** (Mattes, 2003; see ISO 26022): driving simulator task in which the participant has to switch lanes upon detection of lane change signs; used to measure effects of driver distraction on the primary driving task.
- **Detection response task** (DRT; Stojmenova & Sodnik, 2018; see ISO 17488): secondary task in which participants have to respond to stimuli presented every 3-5 s by pressing a button; used to measure effects of cognitive load on secondary tasks. The ISO 17488:2016 standard describes three versions of the DRT (head-mounted, remote and tactile DRT), as well as guidelines for which version best to apply depending on the study purpose. Performance on the DRT only provides insights into the relative attentional effects of a given secondary tasks compared to baseline (without the secondary task).
- **Peripheral detection task** (PDT; Martens & van Winsum, 2000): secondary task in which participants have to respond to a red dot presented at random eccentricities and intervals (3-5 s) by pressing a button; used to measure the

effects of distraction and cognitive load on secondary tasks. The PDT is one form of DRT (which was based on the PDT).

- **Psychomotor Vigilance Task** (PVT; Dinges & Powell, 1985): a simple reaction time task (visual or auditory) to measure vigilance.

Other measures and tasks

Other common methods to measure human performance, state or attitudes include (non-exhaustively):

- **Karolinska Sleepiness Scale** (KSS; Åkerstedt & Gilberg, 1990): 9 point scale used to measure sleepiness.
- **NASA TLX Workload** (NASA, 1986): measures workload on 6 subscales (Mental demand, Physical demand, Temporal demand, Performance, Effort, Frustration).
- **Rating Scale Mental Effort** (RSME; Zijlstra, 1983): single item scale for mental effort.
- **N-back task** (Kirchner, 1958, ISO TS 14198:2016)**:** measures working memory performance, often used as secondary task to increase cognitive load.
- **HASTE task** (Wilschut, 2009): a visual search task with several levels of difficulty, used as secondary task to simulate distraction by visual displays.
- **Paced Auditory Serial Addition Test** (PASAT; Gronwall & Sampson, 1974): mental arithmetic task, often used as a secondary task to increase cognitive load.
- **Situation Awareness Global Assessment Technique** (SAGAT; Endsley, 1988): a task freeze technique which probes situation awareness.
- **Van der Laan acceptance questionnaire** (Van Der Laan et al., 1997)**:** measures acceptance of new in-car technology with two underlying acceptance dimensions: usefulness and satisfaction.

ISO TS14198:2019 describes three tasks that can be used to calibrate participant performance in a dual task setting in order to assess attentional demand due to the use of an in-vehicle system. The N-back task as mentioned above can be used a cognitive task with the DRT as the primary task. It is an auditory-vocal task in which the participant listens to a sequence of numbers and responds with the requested number back in the sequence (e.g. 1 number back for the 1-back task). Performance in this task is measured by the number of correct responses divided by the total responses. The Critical Tracking Task (CTT) and the Surrogate Reference Task (SuRT) can be used with the Lane Change Task as the primary task. ISO TS14198:2019 provides 99% confidence intervals for normative performance. In the CCT, the participant is requested to maintain a target (line) on position (centre line). Participants' CTT performance is measured using the root mean square deviation of the target bar from the centre line and the percentage of time at which the target bar is at the upper or lower limit. The SuRT is a visual-motor task in which the participant has to identify and locate an item (small circle) within a set of distractors (larger circles). Participants' performance in SuRT is measured using the percentage of correctly solved screens and the mean response time per screen.

3.2 Interaction between automated vehicles and other road users

Markkula et al. (2020) defined an interaction in traffic as: "A situation where the behaviour of at least two road users can be interpreted as being influenced by the possibility that they are both intending to occupy the same region of space at the same time in the near future". Road users use communication to coordinate future actions in this shared environment.

There are two forms of communication: explicit and implicit communication. Explicit communication is the most obvious way of communication, for example using hand gestures, headlight flashes or indicator lights. Over the past years, external human-machine interfaces (eHMIs) have been proposed by academia and industry to facilitate explicit communication between automated vehicles (AVs) and Vulnerable Road Users (VRUs). Implicit communication is more subtle. Slowing down in front of a pedestrian crossing is an example of implicit communication. Slowing down communicates to the pedestrian that he/she has been noticed and that the vehicle will stop.

Design and measurement standards, evaluation criteria, research centres, working groups and scientific consensus about both forms of communication are described in this section.

3.2.1 Design standards

Currently, no design standards exist for interactions between driver/vehicles and other road users. Table 7 lists two ISO standards currently under development about communication between AVs and other road users and its evaluation. In addition, ISO 9241-303 sets standards for the use of visual displays in general human-system interaction. It specifies that text characters (in Latin script) should span at least 16 min of arc, with a recommendation to use 20-22 min of arc in order for them to be readable. Note that this standard is focused more on readability of displays at shorter distances than typically used for eHMIs, so it is unclear to what extent this standard applies to eHMIs (also see the research by Rettenmaier et al., 2020, mentioned below in section 3.2.2.1).

Table 7. ISO standards relevant to the interaction between automated vehicles and other road users. (AWI TR: standard under development, currently a technical report)

ISO standard	Topic
ISO 9241-303:2011	Ergonomics of human-system interaction – Part 303: Requirements for electronic visual displays
ISO/AWI TR 23720	Road Vehicles — Methods for evaluating other road user behavior in the presence of automated vehicle external communication
ISO/AWI TR 23735	Road vehicles — Ergonomic design guidance for external visual communication from automated vehicles to other road users

3.2.2 Evaluation criteria

To our knowledge, no evaluation criteria for the interaction between driver/vehicle and other road users exist yet. Therefore, the following subsections focus on guidelines for explicit communication via eHMIs and initial ideas to derive test criteria for implicit communication between AVs and other road users on highways.

3.2.2.1 Explicit communication

Several guidelines for eHMIs have been proposed in the literature (Carmona et al., 2021; Tabone et al., 2021):

- The AV should display the intention of the vehicle, not instructions for the pedestrian;
- Text displays should not be used, because of potential issues with language and reading distance;
- Communication should be based on several modalities, so auditory, visual and perhaps tactile signals;
- The eHMI should have a simple design and display short messages, such that all road users can understand the message;
- The eHMI should be attached to the vehicle itself; no projections in front of the vehicle;
- Standardization of colour usage and design is necessary;
- Training and education of the eHMI meaning is essential.

Rettenmaier et al. (2020) examined the size requirements of displayed text or symbols regarding eHMIs to ensure legibility of a message. The paper concludes that content type significantly influences the required display size; symbols can be displayed in a smaller size than text for them to be legible from a constant distance, and if size is kept constant, symbols can be recognized from a larger distance compared to text (allowing more time for the interacting human to perceive and process the AV's message). If text is used, Rettenmaier et al. (2020) recommend to use a size that provides a visual angle of 6.64 – 7.81 min of arc, corresponding to 170 – 200 mm viewed at a distance of 88 m. As the authors themselves note, this is considerable smaller than the 20 – 22 min of arc recommended by ISO 9241-303.

Additionally, a standardized test procedure has been published where relevant use cases, parameters and criteria and test protocols for eHMIs are described (Kaß et al., 2020). The procedure mentions 864 possible use cases to test the usability of any eHMI, based on interaction partner, the relative orientation of AV and interaction partner, the manoeuvre of the AV, and the speed of both interaction partners at the beginning of the interaction. The use cases to be considered depend on the combination of the eHMI and the automated driving system and will be a subset of all possible use cases. To prove the effectiveness of an eHMI in a simulation environment, an occlusion method is proposed, where participants need to answer the open-ended question: "What will the automated vehicle will do next?" At least 85% of the answers should be correct to pass this test. A pass-fail criterion is proposed for the resulting minimum distance between the AV and the interaction partner, when the participants crosses the path of the AV. The efficiency of the eHMI is proposed to be measured by the mental workload of the participant during the interaction, by the time between the first visual contact with the AV and the actual crossing of the participant and by the proportion of time that visual attention is directed towards the AV during the interaction. Satisfaction with the eHMI should be measured using questionnaires, with questions such as "In the future, would you prefer to interact with AVs with or without eHMI?" A significantly higher proportion of participants has to prefer future interaction with an eHMI to interaction without eHMI. A sufficiently large sample size of at least 20 participants of different age groups should take part in the study, as originally defined in Knapp et al. (2009).

3.2.2.2 Implicit communication

No test criteria or guidelines for implicit communication have been published yet. A first step towards these criteria is investigating the perception of information. Communication between two road users starts with one sending information to the other. This information, for example lateral movement towards a lane marking is received by another road user, who interprets this information and relates this to possible future actions of the sender; in other words: anticipation. In this case, a possible next action could be a lane change. Receiving the correct cues out of all information the driver receives is key to understanding the traffic situation and to acting upon it. Sending the correct cues is part of driving in a predictable way, allowing other road users to anticipate your actions.

Therefore, a first step towards test criteria for interaction with AVs is to define which cues an AV should recognize or send to drive in an understandable and predictable way for other (human) traffic participants. One use case on the highway is the scenario in which an AV performs a lane change into the lane of a human driver. In order to drive predictably, the AV should send specific cues to the human driver. According to literature the indicator signal is the most important cue to predict lane changes (Hensch et al., 2021; Potzy et al., 2019). Other cues include strong deceleration, lateral offset, lateral movement and relative speed. Context cues, such as traffic density, lane markings, and highway on-ramps are also very important to predict lane changes. Combination and timing of these cues are believed to be most important for prediction, acceptance and perceived collaboration of other road users. Therefore defining which series of (implicit) cues make the behavior of an AV predictable could be a first step towards test criteria for AV-other road user interaction.

3.2.3 Working groups and experts

Several working groups are working on the interaction between drivers/vehicles and other road users by means of eHMIs. These groups have been identified from references in papers and from our internal and external network. Additionally, the international Automotive Lighting and Light Signalling Expert group gave an overview of several connected groups in a forum summary (GTB, Informal document No. GRE-79-36, 2018). The following working groups have been identified:

- ISO: ISO/TC 22/SC 39 Ergonomics
- UNECE: GRE Working party on Lighting and Light-Signalling
- UNECE: Task Force Autonomous Vehicle Signalling Requirements (AVSR)
- GTB: The international Automotive Lighting and Light Signalling Expert Group
- SAE J3134 Task force: Automated Driving Systems (ADS) lighting
- USA NHTSA (National Highway Traffic Safety Administration)
- SAE China: China Society of Automotive Engineers
- CLEPA (European Association of Automotive Suppliers): Light Sight Safety

Table 8 lists research centres working on communication with other road users via eHMIs, as well as groups working on communication announcement of lane changes by implicit and explicit communication. This list is not meant to be exhaustive, but more as a first starting point for further information on these topics.

Table 8. Research groups on communication with other road users via eHMIs and communication announcements and recognition of lane changes by human drivers.

Research group	Country	People

Audi AG	Germany	Karl-Heinz Siedersberger
BMW	Germany	Andreas Keinath, Nina Kauffmann, Franz Winkler, Frederik Naujoks, Lenja Sorokin, Hanna Bellem
Chemnitz University of Technology	Germany	Matthias J. Henning, Josef F. Krems, Matthias Beggiato, Konstantin Felbel, André Dettmann, Angelika C. Bullinger
Delft University of Technology	The Netherlands	Joost de Winter, Riender Happee
Jaguar Land Rover	United Kingdom	Zhou Xu, Alex Mouzakitis
RISE: Research Institute of Sweden	Sweden	Azra Habibovic
Technical Hochschule Ingolstadt	Germany	Andreas Löcken
Technical University Braunschweig	Germany	Mark Vollrath
Technical University Eindhoven	The Netherlands	Marieke Martens, Debargha Dey, Jacques Terken
Technical University of Munich	Germany	Michael Rettenmaier, Jonas Schulze, Klaus Bengler
Technical University of Wien	Austria	Philipp Wintersberger
Toyota motor North America	United States	Joshua E. Domeyer, Heishiro Toyoda
Ulm University	Germany	Tanja Stoll, Martin Baumann, Kristin Mühl
University of Berkeley	United States	Ruzena Bajcsy
University of Leeds	United Kingdom	Natasha Merat, Gustav Markkula, Tyron Louw
University of Warwick	United Kingdom	Derrick G. Watson, Jennifer Misyak, Nick Chater
University of Wisconsin-Madison	United States	Joshua E. Domeyer, John Lee
Volkswagen	Germany	Tanja Fuest

Some recent European projects working on communication between AV and other road users are listed in Table 9.

Table 9. European projects on communication between AV and other road users

Project name	URL	Status	Goal
InterACT	https://www.interact-roadautomation.eu/	2021 end	Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

BRAVE	https://www.brave-project.eu/	2021 end	Bridging gaps for the adoption of Automated Vehicles
CityMobil2	http://www.citymobil2.eu/	2016 end	Defining and demonstrating the legal and technical frameworks necessary to enable Automated Road Transport System on the roads

3.2.4 Scientific consensus

The ISO Technical report *23049:2018 Road Vehicles – Ergonomic aspects of external visual communication from automated vehicles to other road users* provides guidance for developers of visual external communication systems for AVs. The report generally describes which information could be of relevance to convey in the communication between AVs and other road users. These elements include the state of the vehicle (such as speed, deceleration), driving mode (whether the AV is operated by automation), explanations of the AVs actions, recognition of other road users, the interpretation of the environment by the AV and its intent. The importance of standardized interfaces is underlined. However, the report provides neither evaluation criteria nor standards for developers.

Tabone et al. (2021) report on interviews with 16 experts on eHMI. According to their report, the majority of the interviewed researchers agreed that eHMIs will form part of the future interaction process between VRUs and AVs. However, implicit communication is regarded as the most dominant way of communication and therefore stays most important. This kind of communication could be perceived by multiple road users at the same time, from different directions and is therefore most efficient. Existing external communication systems such as headlights, indicators and horns should be the prior means for interaction with other road users (Montalvo et al., 2020). eHMIs should be used in situations where implicit communication is ambiguous and should support and confirm implicit cues (Tabone et al., 2021).

Displaying the automation mode of an AV (automated or manual mode) to other road users may have advantages as well as disadvantages. It could be desirable for other road users to know whether the vehicle is controlled by the automated driving system or the driver. This will warn the other road users for potentially unexpected behaviour of the AV. On the other hand, displaying the automation mode may also make the AV prone to bullying, as other road users know the AV is programmed to drive safely. Ultimately, in a workshop with external stakeholders on HMIs, it was decided that the advantages of displaying the AV’s mode outweigh the disadvantages and therefore exterior indication of the AV mode is one of the recommendations to the EU Commission regarding eHMIs (Montalvo et al., 2020).

Measures to evaluate eHMIs include subjective measures and observational measures. Subjective measures are used to measure trust, confidence, perceived safety, user experience and transparency of the information displayed. To measure whether an eHMI might contribute to improved traffic flow, crossing onset and duration can be measured (Faas et al., 2020). Crossing onset represents the time that pedestrians start crossing or are willing to cross before the vehicle comes to a complete standstill (Dey et al., 2020). Crossing duration represents the time the pedestrian takes to cross the street. Fuest et al. (2020) used crossing onset to compare different methodologies. Their results showed that intention recognition times differed between studies using videos, virtual reality and Wizard of Oz vehicles. Participants tended to underestimate the collision risk in virtual reality and video studies, compared to the Wizard of Oz studies. Since many VRU-AV communication studies make use of virtual reality, this is an important finding for the selection of user testing methodologies. Kooijman et al. (2019) presented a method to investigate the effect of eHMIs on participants crossing behaviour, by immersing participants in a VR-environment using a head-mounted display connected to a motion-tracking suit. Velocities were measured at the pelvis to determine the walking velocity of the pedestrian when crossing (or refraining to cross) the street. Furthermore, thorax angle was used as indication where the participant was paying attention to (approaching vehicle or crossing path). Detection range, the moment the eHMI becomes legible, and the crossing onset were highly dependent on the size of the eHMI and on the type of displayed information. When keeping the eHMI size constant, the detection range was significantly smaller for text displays than for symbol displays (Rettenmaier et al., 2020), as also described in section 3.2.2.1. It is important to note that these measures of eHMI efficacy do not have a direct link to safety. Especially increased crossing onset, the moment the pedestrian starts to cross the road, does not necessarily result in a safer situation. Pedestrians crossing at an earlier stage, might be subjected to much higher velocities of the approaching vehicle than pedestrians who wait to cross the street. Misinterpretation could result in dangerous situations.

Consensus about design guidelines for implicit communication, such as deceleration before a pedestrian crossing, have not been found in the literature. However, as discussed in section 3.2.3, many experts are working on the topic of communicating the announcement of lane changes on the highway via implicit and explicit communication.

4 Conclusions

In this report, an overview of available standards and criteria for interaction of drivers and other road users with automated driving systems (ADS) and advanced driver assistance systems (ADAS) is provided. In summarizing the results, we distinguish between standards and criteria relevant to the interaction between driver and automated vehicle on the one hand and to the interaction between automated vehicles and other road users on the other.

4.1 Standards and criteria for the interaction between driver and AV

UN regulation No. 157 (2021) provides standards regarding ALKS. In particular, it specifies the procedure for dealing with driver unavailability as well as for the case when the driver does not respond to a takeover request. For this, concrete maximum latencies are provided. It also specifies the minimal system information that should be provided to the driver.

This regulation provides the most concrete and specific standards directly concerning the interaction between driver and automated vehicle currently found in the literature. Several authors have provided guidelines for this type of interaction, but so far this has not resulted in evaluation criteria. Moreover, standards exist for classic HMI design, concerning aspects such as the size, colour and location of displays and controls. Although not developed with driving automation in mind, these standards are nevertheless also relevant for the interfaces of ADAS and ADS.

Although few evaluation criteria for the interaction between driver and automated vehicle exist, the literature provides some criteria for driver distraction, which can be the result of using ADAS or ADS. Glances away from the forward roadway longer than 2 s have been found to correlate significantly with the occurrence of accidents. Accordingly, NHTSA (2010) guidelines provide recommendations for maximum time spent looking away from the roadway.

4.2 Standards and criteria for interactions between AVs and other road users

Even though external HMIs for automated vehicles are an active topic of research, few standards or evaluation criteria exist. An exception is the text size used on an eHMI. ISO 9241-303 provides general standards for text size on visual displays to be readable. However, the literature suggests that the text size as specified by this standard for computer displays may be much larger than necessary for eHMIs.

Implicit communication of (automated) vehicles by means of patterns of behaviour in certain traffic situations has been studied far less. Standards or evaluation criteria still need to be developed for this topic.

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