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Study on the effects of automation on road user behaviour and performance

Final Report

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Abstract (EN)

The aim of this study is to provide strategic and practical advice to the European Commission General Directorate DG MOVE on the policy-related actions required to address disruptive digital developments, particularly the transition to automated driving and its effects on driver behaviour and performance. Automated driving brings a number of changes to the traffic system. The topics addressed include the expected evolution of automated driving, changes in human-machine interfaces (in the vehicle and in interactions with road infrastructure), traffic rules, driving licences, and the training of professional drivers. It includes also a reflection on these topics towards the development of a code of conduct for the transition to automated mobility. Based on a broad literature review and the views of experts, different issues are discussed, and a number of policy-oriented recommendations are put forward.

Abstract (FR)

L'objectif de cette étude est de fournir des conseils stratégiques et pratiques à la Direction Générale de la Commission Européenne, DG MOVE, sur les actions politiques nécessaires pour traiter les développements numériques de rupture, en particulier le passage à la conduite automatisée et ses effets sur le comportement et les performances des conducteurs. La conduite automatisée apporte un certain nombre de changements dans le système permettant la mobilité. Les thèmes abordés sont notamment: l'évolution prévue de la conduite automatisée, les changements dans les interfaces homme-machine (dans le véhicule et l'interaction avec l'infrastructure routière), les règles de circulation, le permis de conduire et la formation des conducteurs professionnels. L'étude comprend également une réflexion sur ces sujets en vue de l'élaboration d'un code de conduite pour le passage à la mobilité automatisée. Sur la base d'une large revue de littérature et des avis d'experts, différents aspects et questions sont présentés ainsi qu'un nombre de recommandations politiques.

Contents

TABLES

FIGURES

GLOSSARY AND ABBREVIATIONS

Abbreviation/Term	Definition
ABS	anti-lock braking system
ACC	adaptive cruise control
ADS	automated driving system
ADAS	advanced driver-assistance system
AEB	automatic emergency breaking
AV	automated vehicle (without cooperation abilities)
C-ITS	cooperative intelligent transportation system
CAD	connected and automated driving
CCAM	cooperative connected and automated mobility
Commonality	Having the major features harmonised, while still leaving detailed design open
CPC	certificate of professional competence
DG MOVE	Directorate General for Mobility and Transport
e-HMI	external human-machine interface
ECWVTA	European Community Whole Vehicle Type Approval
ERTRAC	European Road Transport Research Advisory Council
ESoP	European Statement of Principles
ESP	electronic stability programs
FCW	forward collision warning
FRAV	UNECE Functional Requirements Sub-Group
GRE	UNECE Working Party on Lighting and Light-Signalling
GRVA	UNECE Working Party on Automated/Autonomous and Connected Vehicles
HMI	human-machine interface

I2V	infrastructure-to-vehicle communication
ISA	intelligent speed assistance
ITS	intelligent transportation system
ITS-G5	Access technology to be used in frequency bands dedicated to European ITS
LDW	lane departure warning
LKA	lane-keep assist
LOS	level of service (cf. Highway Capacity Manual)
LV	legacy vehicle/conventional (legacy) vehicle
MRM	minimum-risk manoeuvre
NHTSA	The National Highway Traffic Safety Administration, United States Department of Transportation
ODD	operational design/driving domain
OEDR	object and event detection and response
OEM	original equipment manufacturer
SAE	Society of Automotive Engineers
SWIPO	switching from provider and porting non-personal data
ToC	transition of control
TOR	take-over request
UNECE	United Nations Economic Commission for Europe
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
V2X	vehicle-to-anything
VMAD	UNECE Validation Method For Automated Driving Sub-Group
VRU	vulnerable road user
WP	work package

EXECUTIVE SUMMARY

The study aims to provide the European Commission and other public authorities insights into the effects that the deployment of driver assistance, partial and full automation might have on road safety. The study investigates the implications of this deployment for EU policy and legislation. The specific objective is to identify and recommend those actions that need to be implemented in order to address the likely consequences, particularly adaptations of current EU and national legal frameworks for traffic rules, driving licences and the training of professional drivers that would be required as a result. The issues, main stakeholders involved and actions needed for the elaboration of a code of conduct for the transition to automated mobility are also considered. The topics covered concern highly specialised areas of automotive technology and transport regulatory systems. Despite the disparate topics covered these are an integral part of a regulatory infrastructure that ensure the safety of traffic and roads in Europe. The study started with a review of the current available literature on the topics of automation in general, the interaction of road users with automation, traffic rules, licensing and the training of professional drivers. This literature review turned out not to be conclusive, and a number of gaps were identified, which were subsequently the topic of an expert consultation carried out by means of thematic workshops and a survey. The results of the survey and our own findings were validated in two different workshops with invited stakeholders from the relevant fields. These validated results formed the basis for our practical and actionable recommendations.

State of the art

A new era is arising, with partially and fully automated vehicles (AVs) equipped with automated driver systems. Although automated driving has been tested on public roads in a few test areas, the literature review revealed that there are still large gaps where there is a need for more information relevant to policymaking. The transition to automated driving will affect the behaviour and performance of the driver and will influence the way in which road users interact with each other. This transition raises questions about policies related to traffic rules, infrastructure requirements, and curricula for licensing drivers. Research and expert consultations are needed to fill these gaps and to provide insights into the impact of automated driving on traffic safety, along with the harmonisation of the human-machine interface (HMI), legislation and driver training. Original equipment manufacturers (OEMs) are developing automated driver systems (ADS), and pilot experiments are being rolled out in many nations for testing automated vehicles at the Society of Automotive Engineers (SAE) levels 3 to 4. The technology of automated driving goes hand-in-hand with other evolving technologies, such as cooperative intelligent transportation systems (C-ITS) that allow communication between vehicles and between vehicle and infrastructure. The introduction of automated driving guided by policies that facilitate harmonisation can improve road safety.

HMI

In today's vehicles, drivers are used to gathering information about the vehicle's functions and their status from an on-board HMI. For this, the driver usually uses visual information from the display and auditory information from the various auditory alerts. However, the introduction of ADS raises questions about the complexity and importance of the HMI and the need for suitable interaction strategies. With ADS, the role of the driver changes significantly because the ADS can take over partial or even full control of the vehicle. The fact that different functional modes are available in one and the same vehicle makes a comprehensive and efficient interaction strategy very important. Depending on the role of the driver, different information is needed to complete the requested task. The HMI needs to be designed to be adaptable in order to provide the user with optimum support. Additionally, the design of an ADS HMI needs to take earlier research into account. One of the most important tasks is the avoidance of known operator errors, such as mode confusion, automation surprises and overreliance. Since most operator errors are a result of insufficient or inadequate information, it is important for the HMI to deliver information regarding the underlying functional logic of the ADS, the handling of the new control elements and current information provided by the ADS system. Therefore, it is recommended that the "commonality" of an on-board HMI be promoted. This includes the functional logic of ADS, the control elements and the information presented across vehicle types and manufacturers. Further, there needs to be agreement regarding the minimum requirements for the information to be presented to the driver in order to promote user understanding and trust.

External human-machine interface (e-HMI)
Our study on integrating AVs into traffic examined the need for specific communication between AVs and other road users – human drivers, pedestrians, cyclists and motorcyclists. The process started with a literature review, which revealed that most of the experimental studies had focused on the interaction of automated vehicles (AVs) with pedestrians. There were substantial shortcomings in those studies and in many of the communication solutions that were proposed. The next stage of this study was a within-project expert discussion, which identified a set of initial conclusions and recommendations. The conclusions were supported in an interactive stakeholder workshop but received less support in an on-line questionnaire. The overall recommendation is that AVs should use the existing e-HMI that is found on current vehicles (indicators, brake lights, horn, etc.) because new and different solutions could cause confusion when road users have to interact with multiple vehicles, both conventional and automated. A signal light to indicate that a vehicle is being driven by an automated driving system is advocated, as are some specific solutions to address specific needs.

Traffic Rules
In order to ensure the safety of all road users and undisrupted traffic with the deployment of automation, traffic rules and provisions might need to be added or adapted. The consequences of the expected deployment of automation are assessed discussed, using the current general traffic rules in Europe as baseline, and taking into account an increasing penetration rate of automated vehicles. The literature shows that automated driving has not yet resulted in much of a change in current traffic rules. There is one accepted amendment to the Vienna Convention (UNECE, 1968): Article 8 states that "Every moving vehicle shall have a driver" and "Every driver shall at all times be able to control his vehicle or to guide his animals." The amendment now recognises that an automated driving system can be the "driver" and that the driver therefore does not have to be human.

In general it is concluded that the traffic rules for automated vehicles do not necessarily need to be different from existing traffic rules. The main recommendation is that current traffic rules need to be translated into exact and measurable rules that can be programmable for ADS (sometimes also called the "digital traffic act"). Local variations in traffic rules and variations between Member States should be included in the digital traffic act. In this way, an ADS can switch to specific regulations when crossing a border, comparable to switching digital maps for a navigation system. This digital traffic act should indicate how to deviate from the rules in emergency situations. Also, during automated driving, non-driving-related activities that are currently not permitted might be allowed. This depends on the automation level and the type of the activity.

Driver licensing

Whilst there is a harmonised approach to driver licensing in the EU Member States, there is a wide variety of approaches to driver training and testing. Thus, the training of new skills, where identified to be of importance for the safe operation of AVs, would be nationally devolved. However, through consultations with stakeholders, this study has identified a number of suggestions or concerns with regard to the updating of licensing procedures. Drivers have been expected to use Level 1 and 2 automation without specific changes in licensing and training procedures; however, studies have indicated that drivers are not always knowledgeable about the Level 3 or 4 automation functionalities present on their vehicles. In order to reap the benefits of AVs, drivers should be familiar with the purpose of the automation, particularly their role and responsibilities in interacting with it. With regard to drivers yet to obtain their licence, they could theoretically be given the choice of being trained to drive either a standard vehicle or one with autonomous features (or both).

The subsequent testing and licensing of those drivers could also be adapted to lead to newly qualified drivers holding different types of licences that would restrict their driving to certain types of vehicles. However, the timely legislation and enforcement of such an approach could prove to be insurmountable, and given the rapidity of technological advances, such an approach might not be agile enough to cope with changes. The stakeholder consultation indicated that drivers could glean the requisite skills and knowledge via an interactive in-vehicle coaching tool, over and above what is provided by a typical owner’s manual, and implemented on hired or shared vehicles for drivers to access. Further discussion with vehicle manufacturers is required in order to understand the limitations and barriers of implementing this. Not losing “manual” driving skills after an extended period of driving an AV is an additional concern, and the in-vehicle coaching approach could be adapted to help mitigate this. Research in virtual-reality environments is needed as a way of developing knowledge for training new skills. The relaxation of regulations around fitness to drive should be considered as a possibility, except in Level 5 vehicles.

Professional training

Directives 2003/59/EC and 2018/645 provide the framework for the harmonisation of EU professional driver training and the certification of professional competence, which requires periodic training every five years. This legislation improves harmonisation of driver training in the EU to a great extent, but still leaves room for Member States to organise professional driver training differently. In light of automation, the mandatory periodic training, along with the topic of automation prescribed in Directive 2018/645 provide all necessary handles to acquire new knowledge and competence on evolving technologies such as ADS and advanced driver-assistance systems (ADAS).

To provide suggestions on any new knowledge and competence that automation will bring forward, a general overview of the professional environment is outlined, including road safety. This is an important factor in sorting out new knowledge and competence, because the principal aim of driver training is to improve road safety. Automation is a topic that can be covered in the theoretical part of the training in fulfilment of the legislative objective involving the technical characteristics of the safety features to control the vehicle and execute pre-drive checks. Training should allow professional drivers to check their ADS or ADAS, and therefore, they should have a basic understanding of the main components involved in automated driving. While driving, drivers should know the correct operational status of the system and the procedures for interacting with it, including understanding the HMI and the information displayed. Operational competence is better covered by practical training. In the stakeholder consultation it was suggested that, whilst driver simulators can be helpful, especially for basic skills, higher-order skills are best trained on-road, with context and a proficient trainer. These topics are mainly related to driving or monitoring the vehicle, but some topics are not directly linked to the task of driving. One of these is liability. Although it is still an open issue in automated driving, professional drivers should learn about liability as it relates to automation, since their vehicle might carry heavy cargo or many passengers and would result in more damage in case of accident.

Towards a code of conduct to the transition to automated mobility
In this chapter, we discuss insights into the issues that might arise and their likely effects on the behaviour of road users, the changes needed in traffic rules, driver licensing and the training of professional drivers. These insights are reflected in a list of actionable topics aimed at developing a road map to guide the transition to automated driving. Key stakeholders in the implementation of these actions are the European Commission, OEMs, the road authorities in Member States, United Nations Economic Commission for Europe (UNECE), etc. Regarding the time horizon for an implementation roadmap, most actions are related to concerns about automation Level 3 and, in some cases, Level 4. There was agreement among the experts consulted that most of the actions required could be accomplished in the course of three years, with some exceptions for automation Level 4, which is expected to take up to 10 years to be accomplished. The elaboration of the code of conduct would require addressing at least four domains of moral hazard that might arise. The first domain concerns the general principle of safety and autonomy of road users. The second refers to the shift in responsibilities and liability from the driver to other entities. The third concerns the security, safety and privacy of the data flowing between the car and the user. The last points out issues that the drafters of the code of conduct will face while aiming to guide innovation and the behaviour of diverse stakeholders through the transition to automated mobility.

1. INTRODUCTION

1.1. About this study

Nowadays, experiments and pilot projects of automated vehicles (AVs) on public roads are being conducted in many countries. The fact that these pilot projects are managed by well-known car manufacturers all over the world indicates that these manufacturers are competing to bring the AV to the market. Since we are at the dawn of a new era where highly automated to fully automated cars are entering the market, it is important to investigate the impacts of AVs on road safety and the behaviour of road users. In the era ahead, vulnerable road users will share the roads with automated vehicles at different levels of automation, with connected vehicles (able to communicate with the infrastructure and/or other vehicles) and with conventional vehicles. New ways of interacting between different road users and road entities will emerge. This evolution will require an investigation of existing traffic legislation and directives – and their shortcomings – in order to safely manage these new ways of interacting on the road. Another legislative issue is standardisation among competing car manufacturers. New technologies providing the same services are being developed by multiple manufacturers, which is leading to a variety of human-machine interface (HMI) protocols and HMI designs that complicate vehicle operation for the driver. Harmonisation of HMIs should be one of the goals of policymakers.

The main objective of this study is to provide the European Commission and other public authorities with insights on the effects that the deployment of driver assistance, partial and full automation will have on road safety. The implications of this deployment for EU policy and relevant legislation were investigated in this project with respect to road safety, traffic rules and driver training and examination. The specific objective is to identify and recommend those actions that need to be implemented in order to address the consequences referred to above, particularly the adaptations of the current EU and national legal frameworks for traffic rules, driving licences and the training of professional drivers that would be required as a result.

1.2. Structure of this document

Chapter 2 presents the mapping and scope of the available literature on the topics relevant to the study. All the literature has been placed in a separate overview "repository.xls" file and made available to the commission. Based on the literature, we explain the current state of affairs and the expected evolution of automation in the following chapters and identify the concerns explored. Section 2.1 outlines the approach used for the collection of literature and documentation. The focus in chapter 3 concerns the aspects and issues around the interaction of road users with automation, looking into issues related to a vehicle's human-machine interface (HMI) and addressing the challenges arising from the integration of automated vehicles into traffic. Chapter 4 looks into the changes in traffic rules that will potentially be necessary because of the introduction of automated driving on roads. Chapter 5 presents the results of the study on new requirements for driving licences. Chapter 6 presents the results of the analysis of likely new requirements for training professional drivers. Chapter 7 introduces and discusses elements for the development of a code of conduct for the transition to automation in the EU. The report concludes with a brief overview of the main recommendations.

2. STATE OF THE ART OF AUTOMATION

In this chapter we present the state of the art of relevant information from the literature reviewed for this study. It consolidates information concerning the deployment of automation technology and its consequences for road users and traffic, focused on what is needed in the tasks listed below. The information was gathered from the most relevant scientific literature and results of research projects, as well as from the most up-to-date research and national policy initiatives.

2.1. Literature review and scope

2.1.1. The literature review

As part of the study, we created a literature repository to assist in understanding the expected evolution of road automation, as well as the various areas where action will be needed. The repository is a collection of documents, such as journal papers, policy reports and legislative information. In order to keep on top of new developments, such as experiments conducted with automated cars by manufactures, news articles are also included. Each document refers to one or more of the topics treated in this study, as described in Table 1.

Table 1: Number of Documents per Topic in the Literature Repository

Excel Topic ID	Topic name	Number[1]
1	Human-machine interface (HMI): human interaction, safety aspects, harmonisation and standardisation	24
2	Expected evolution of road automation: expected composition of future vehicle fleets, evolution of vehicle autonomy and relevant communication standards, results of mixed traffic effects	30
3	Existing frameworks of national/EU traffic regulations (in light of autonomy)	37
4	Aspects related to vehicle automation (e.g., required skill sets and their relation to foreseen functionalities)	72
5	Existing codes of practices (later serving as a basis for the code of conduct)	14
6	Policy-driven projects, both national and international: objectives, expected outcomes and analysis of available results	1

For each topic, one or more tasks are planned. These include the following:

1. Repository, literature survey
2. Expected evolution of road automation
3. Interaction of road users with automation
4. Issues related to vehicle's human-machine interface (HMI)

[1] Some documents are related to more than one topic. In total, 91 documents were selected for the repository.

5. Addressing the challenges arising from the integration of automated vehicles in traffic
6. Traffic rules
7. Driving licence
8. Training of professional drivers
9. Code of conduct for the transition to automation

Table 2 specifies how the tasks are related to the topics.

Table 2: Correspondence between Topics and Tasks

Topic 1	**Task 2 (a, b)**	**HMIs (human interaction, safety aspects, harmonisation/ standardisation issues,…)**
Topic 2	Task 1	Expected composition of future vehicle fleets, evolution of vehicle autonomy and relevant communication standards, results of mixed traffic effects,…
Topic 3	Task 3	Existing frameworks of national/EU traffic regulations (in light of autonomy)
Topic 4	Tasks 4 and 5	Issues related to vehicle automation (e.g., required skill sets and their relation to foreseen functionalities)
Topic 5	Tasks 4 and 5	Existing codes of practice (later serving as a basis for the code of conduct)
Topic 6	Task 6	Objectives, expected outcomes, and analysis of available results of policy-driven projects, both national and international

The repository, which serves as the foundation of information for the tasks, is collected and annotated in the accompanying Excel sheet, called **Repository.xlsx**. A sample extract is shown in Figure 1. The file is available separately.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Nr	Topic	Title	Organisation-author	Type of literature	Publication forum/ journal	Year	Month	Short description	Link to source	Link to fulltext	Cite
2	1	1	Literature Review on the Impact of Task Activation Takeover from Automated Driving.	O. Carsten	4	Economic Commission for Europe, Inland Transport	2018	9	Carsten 1 Takeover 2018	https://www.unece.org/fileadmin/DAM/trans/doc/2018/wp1/ECE-TRANS-	Articles\ECE-TRANS-WP1-2018-O CARSTEN.pdf	Carsten, O. (2018). Literature Review on the
3	2	3	Autonomous vehicle state bill tracking database	NCSL national conference of state	8	NCSL national conference of state	2019	3	NCSL 3 database 2019	http://www.ncsl.org/research/transportation/autonomou		NCSL–National Conference of State

Figure 1: Sample extract of the literature repository's Excel summary

Each row describes one document. A unique number is assigned to each entry in the first column (A). The documents are classified according to the topics in the second column (B). In the third and fourth columns (C and D), the title and the author/owner of the document are specified, respectively. The fifth column (E) specifies the type of document. The list of document types is diverse and contains the items shown in Table 3.

The number of the document type is indicated in column E. If it was possible to determine the source of the publication, this information is given in the sixth column (F). Columns 7 (G) and 8 (H) provide publication date.

Table 3: Number of Items per Literature Type Available in the Repository

Excel Type ID	Type Name	Number
1	Peer-reviewed publications in scientific journals	50
2	Scientific publications in journals or on web pages	5
3	Peer-reviewed scientific publications from national and international congresses	4
4	Scientific publications from national and international congresses	5
5	Deliverables	0
6	Reports	51
7	Books or book chapters	3
8	Web pages	15
9	Popular magazines related to intelligent transportation systems (ITS) that provide novel insights and evolution of developments	3
10	Existing national and international projects, not only in Europe but also in other continents and pan-European collaborations	0
11	Directives, Regulations	10
12	Slide presentations	2

The last three columns are important. In the 9th column (I), there is a bookmark link to a short description in the word document **ShortDescriptionListing.docx**. This covers the content of the document in a few sentences and indicates its importance in relation to the topics or tasks. An example of this is shown in Figure 2.

Reference: NCSL_3_database_2019

Short description

This database is helpful in inspiring legislation makers for autonomous vehicles legislation. The webpage database interface allows to track and search all bills in the USA related to autonomous vehicles up to date (2019). There are already more than 40 bills pending (many with failed status) for 2019 only.

Figure 2: Sample extract of abstract information from the literature repository

The 10th column (J) provides a link to the source (as of May 2019). Because links to internet sources may change, an additional link is provided in column 11 (K) opening the same document in the subfolder **/Articles**. In order to keep these links working, it is important not to change the placement of the folders. This means that the files **Repository.xlsx** and **ShortDescriptionLising.docx** should be located in the same folder as the subdirectory **/Articles.**

Finally, the repository also contains a BibTeX file, allowing the references to be easily imported into customised libraries.

2.1.2. General overview of the results of the literature study

Although we are at the dawn of a new era in which automated cars are being developed, and where cars equipped with innovative advanced driver-assistance systems (ADAS) are becoming standard, the literature review revealed many gaps. There was little relevant information available on the deployment of automated driving systems (ADS) and the effect that driver assistance, partial automation and full automation will have on the behaviour of all road users. Policymaking questions in these areas concern the harmonisation of HMI among OEMs and legislation among Member States, the need for new traffic regulation, the interaction between road users, and new regulation concerning driver licensing and training.

The topic of "Human Machine Interface (HMI): human interaction, safety aspects, harmonisation and standardisation issues" is well covered for many areas in the broader research on human factors. Some of these studies treat HMI from a more general perspective. For instance, Muslim and Itoh (2018) discussed whether human-machine interactions should be principled on a human-centred or a cooperative approach in automated vehicles. Other studies tend to be focused on one specific aspect. For instance, numerous studies look at the human driver's behaviour and timing when taking over control of the automated system (see Zhang et al., 2018, for an overview). The number of scientific peer-reviewed papers often corresponds to the significance of the technical issues that have been brought up by these technologies; it is difficult to find literature on concrete HMI issues faced by OEMs today and the solutions they propose.

On the topic of "Expected evolution of road automation", reports are more commonplace than peer-reviewed scientific publications. The literature on this topic is often approached from an economic and marketing perspective, looking at market readiness and attitudes of trust and acceptance towards new technologies. Speculation on scenarios (use cases) involving the initial use of these technologies concentrates on features such as automatic parking in which the driver steps out of the car and the automatic system parks it without human intervention. Another example of initial ADS usage is automated driving on motorways because steering control on motorways is considered to be less complex than on urban or rural roads (Wachenfeld et al., 2016).

Autonomy-related topics on national/EU traffic regulations, driving licensing and professional driver training are barely covered in scientific and research publications. Sources of information sources tie directly into legislation such as EU directives and Commission reports evaluating the implementation of the directives and the outcome of the legislation.

Although many promotional films, announcements, newspaper articles and opinions have been distributed about the "self-driving car", the literature review revealed many gaps regarding the topics covered in this report. We dealt with these gaps by exploring the opinions of experts and organising workshops with different stakeholders and experts. The literature on each topic is discussed in the following chapters, with relevant reporting of the workshops and expert discussions.

2.2. State of play and expected evolution of automation

This section focuses on consolidating the available literature and expert opinions into a timeline that will give us deployment scenarios for automated driving, including the state of play today. The fleet composition of the next generation of vehicle will range from conventional vehicles equipped with ADAS; cooperative vehicles communicating with each other (V2Vs), or with the infrastructure (V2Is), or both (V2Xs); automated vehicles (AVs); connected and automated vehicles (CADs); and cooperative automated vehicles (CAVs). Cooperative, automated and intelligent transportation systems will evolve at the same time. The term "cooperative intelligent transportation systems" (C-ITS) is a collective term for such technologies as vehicle-to-anything (V2X) communication and sensor infrastructure, where the vehicles and their on-board devices are capable of sharing information and intentions. The roadmap to automated driving is linked to the development of C-ITS. In contrast to human drivers who are uncertain about the intentions of other road users, automated vehicles can cooperate and share their intentions through C-ITS technology with other ADS or by external HMI to other road users.

The deployment of AVs faces an additional difficulty because these vehicles have to cope with two kinds of drivers – ADS and human drivers – in addition to other road users such as people on foot, cyclists, motorcyclists. They also have to cope with the ongoing deployment of new types of light electric vehicles such as e-scooters, the monowheel, Segway and hoverboard. AVs have to be able to handle ambiguous contexts when the road infrastructure is not built for nor adapted to AVs, which can lead to beginners' mistakes. These safety issues will emerge with the introduction of AVs and will depend on different penetration levels of AVs in the evolving composition of traffic. Therefore, it is important to prepare the market introduction of AVs and to tackle regulation issues concerning traffic rules, driver's licences and training. In this chapter, we review the evolution of automation and discuss the most influential classification system in the literature of driving system automation, which is the definition of the levels of automation from the Society of Automotive Engineers (SAE) (SAE International, 2018).

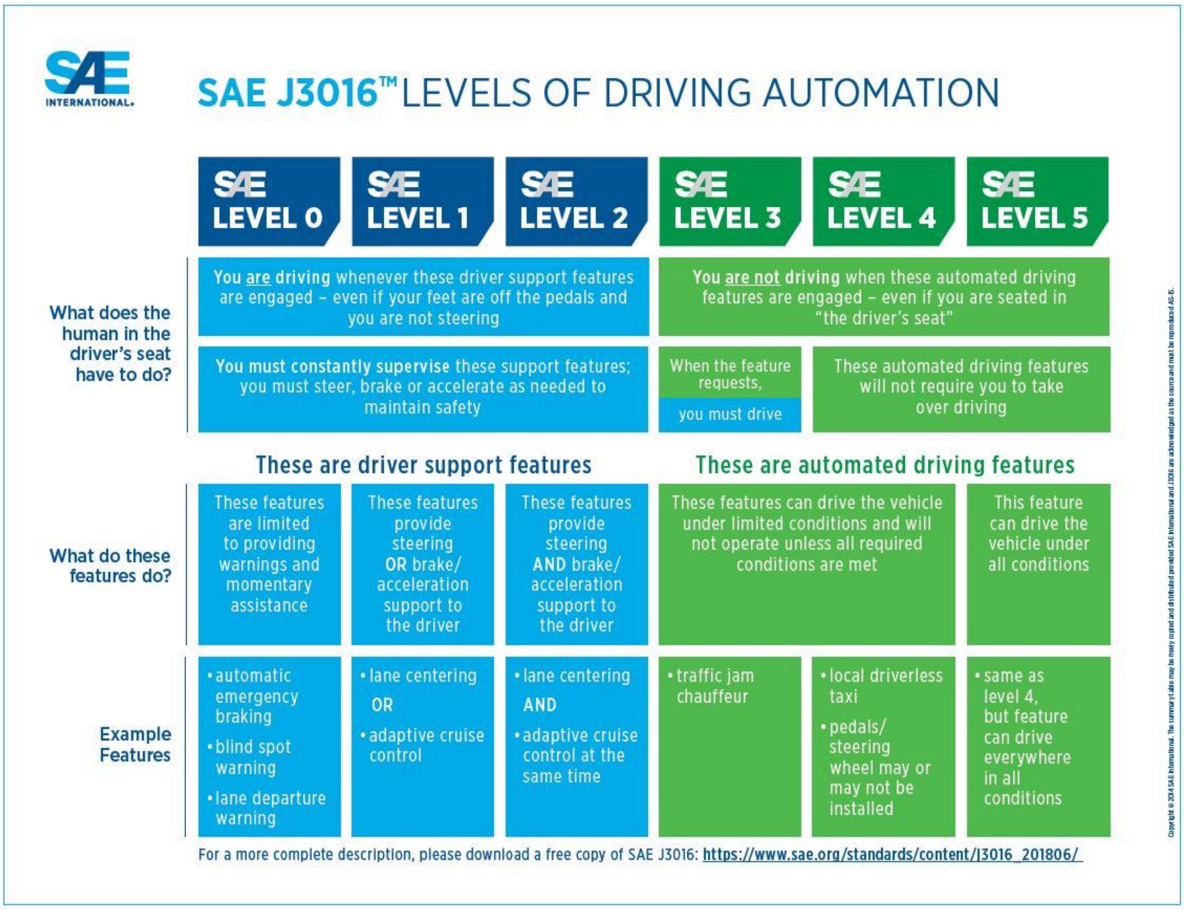
2.2.1. SAE levels of automation

Vehicle automation started with the development of ADAS, such as the anti-lock braking system (ABS). More recently, systems such as forward collision warning (FCW) or lane departure warning (LDW) were introduced on the market. In addition to these safety systems, comfort systems such as cruise control and the more complex systems like adaptive cruise control (ACC) have found their way to the market. By integrating multiple ADAS functionalities, more automation is obtained. For instance, a lane-keeping system can be integrated with a lane-change system and ACC to provide automated longitudinal and lateral control of the vehicle as these controls potentially cover all the steering directions of a human driver.

However, such systems need highly developed decision-making algorithms to provide correct control and full safety to drivers, passengers and other road users. The systems that will be deployed in the near future will operate in a variety of operating environments with different roles and responsibilities for the human driver. Having a clear view of these roles is the main challenge for the future. To this end, SAE International (2018) introduced different levels of automation and specified the roles and liabilities for each level.

At these levels of automation, there are three actors: the human driver, the ADS and the regular vehicle system consisting of all the mechanisms involved in the task of driving. The roles of the first two are depicted in Source: www.SAE.org (accessed 2019).

Figure 3 and depend on who is in charge of the driving. ADAS such as electronic stability control and automated emergency braking, as well as lane-keeping assistance, are excluded from the scope of this ADS because they are meant to provide a temporary intervention in the form of a warning or a driving correction and do not take part on a continuous basis. It is the responsibility of the human driver to use these features properly.



Source: www.SAE.org (accessed 2019).

Figure 3: Levels of automated driving according to SAE J3016

Six levels of automated driving have been proposed by SAE International (SAE, 2016). In Source: www.SAE.org (accessed 2019).

Figure 3, Levels 0, 1 and 2 are coloured in blue, indicating that the human is the main actor in the driving task, even if feet are off the pedals and hands are off the steering wheel. Many features support the driver. Level 3 is a kind of in-between level: automated driving is dependent on the circumstances of the road and the surroundings, probably also on the risk factors measured by the automated system. The main subject of debate on automated driving concerns this level, where the safety of the transition of control (ToC) between a human and the automated system is questioned. ToC is a major theme in studies of the human factor in driving and a difficult technical issue to overcome (Guo et al., 2016; McDonald et al., 2019; Mole et al., 2019; Zhang et al., 2018). In chapter 3, this concern is explored further. Finally, there are two more advanced levels: the two higher automated driving Levels 4 and 5, which give full control to the automated system for at least some of the time.

Liability is a difficult theme to define in these conditions, and a revision of the current legislative EU framework for liability and insurance for connected and automated vehicles is desirable (Evas, 2018). If this future legislation holds the automated system responsible when the driver is not driving (i.e., when the automated system is in charge), then the OEMs might be held responsible for any damage the automated system might cause. Consequently, the OEMs may be more cautious about launching new prototypes on the market, which could slow the deployment of automated vehicles. On the other hand, if future legislation holds the driver responsible at all times, less cautious OEMs will be rewarded with faster and less safe market introductions. The driver might then become reluctant to buy these vehicles because the on-board artificial intelligence could make incorrect decisions for which the driver would be held liable. In chapter 3, this concern is explored further.

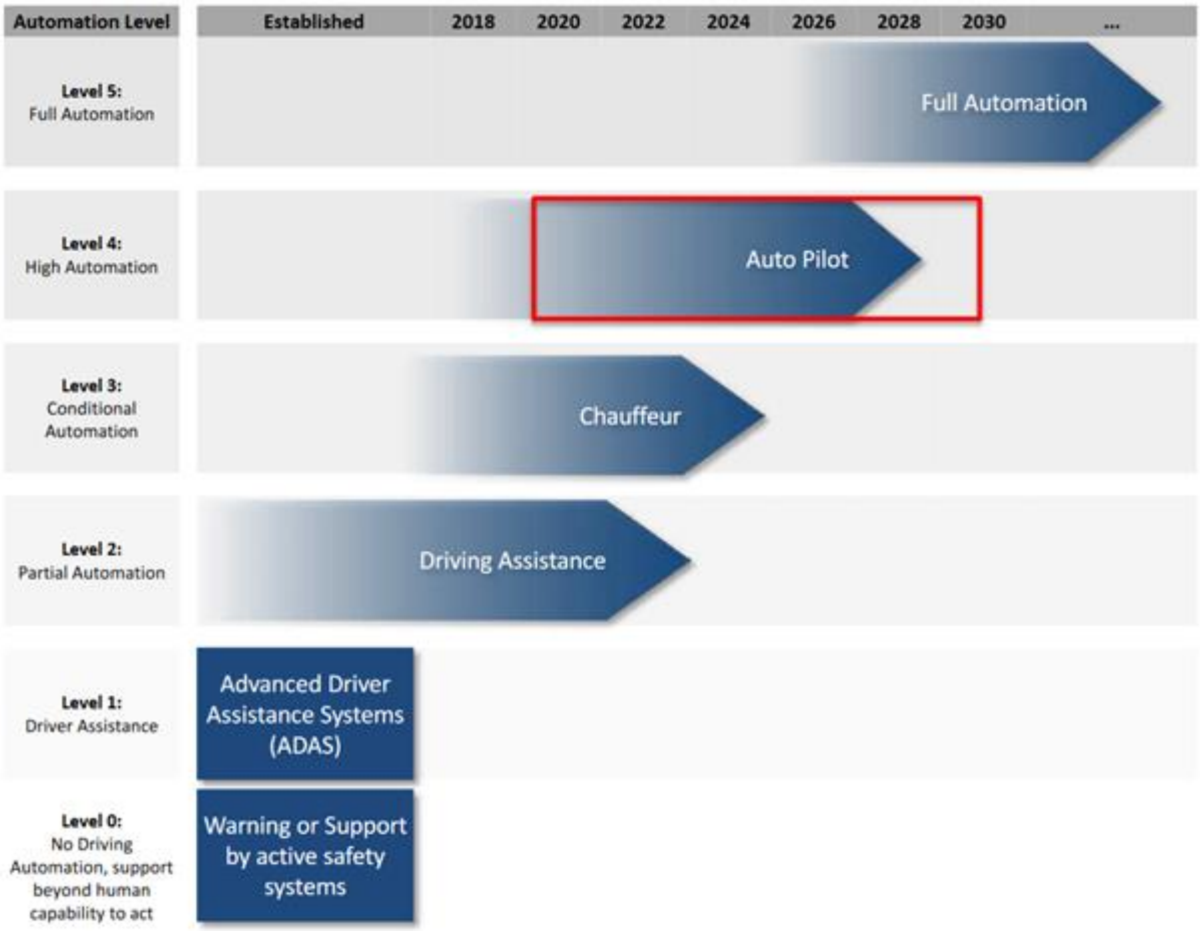
There is a need to define clear roles for the driver and the ADS, along with the related liabilities. The UN has taken some steps forward in regard to these issues. The original Vienna convention (UNECE, 1968, Article 8, paragraph 5) states that "*Every driver shall at all times be able to control his vehicle or to guide his animals.*" An amendment to consider the ADS as the driver is being proposed. Another example concerns addendum 78 (UN Regulation No. 79, paragraph 5.6.2.2.5), which states that the system shall detect whether the driver is holding the steering wheel when the automated system is performing lane changes above a speed of 10 km/hour. In chapters 4 and 5, these kinds of concerns are explored in more depth.

In the US, the necessity of raising the legislative framework to the higher federal level has been recognised, and individual US states are tackling this challenge by filing legislation propositions (see the NCSL database). Uniformity is pursued by filing the Self-Drive Act (Latta, 2017). In 2019, this act passed the House of Representatives but is still pending in the Senate. Legislation on safety, standardisation and liability is necessary for progress and enhancing market introduction. OEMs will be discouraged if legal parameters are unclear.

2.2.2. Market introduction for different automation levels

Currently, ADAS are gradually being introduced, while the first Level 3 and 4 ADS are being tested on the roads in Europe, as well as in the US and a few other non-European countries. State-of-the-art ADAS are integrated into the Tesla Model 3, the 2017 BMW 5 series with "Drive Assistant Plus", the 2017 Mercedes-Benz E-Class with "Drive Pilot" and the 2018 Volvo S90 with "Pilot Assist". An extensive overview of different ADAS and their level of automation is covered in the 2017 report of the European Road Transport Research Advisory Council (ERTRAC, 2017, Sections 2.4, 2.5 and 2.6), providing a concise overview of evolving technology. It lists automated parking and driving-assistance systems for passenger cars in ascending order of their level of automation and provides an overview of different automated freight vehicle systems such platooning and systems that are confined to particular areas or highways. An example is the "Highway Chauffeur", consisting of automated driving on motorways.

Nowadays, SAE Levels 0, 1 and 2 are commonplace. Passenger cars with higher levels of automation (Level 3 systems) are market-ready due to the rapid advancements in the fields of vehicle automation and communication. The United Nations Economic Commission for Europe (UNECE) WP.29 recently approved the first Level 3 system, automated lane keeping, which allows automated in-lane hands-off driving at speeds up to 60km/h (often called the "traffic jam chauffeur"). Projections on the development of vehicle automation indicate that highly automated features (e.g., Highway Pilot) will enter the market during the coming decade (see Figure 4), although a time horizon for full automation is not yet feasible. The following quote from the ERTRAC report on Automated Driving Roadmap (2017) indicates a shared ambition to achieve full automation by 2050: "This roadmap for Automated Driving, therefore, contributes to the long-term vision of ERTRAC for the transport system. In one sentence: in 2050, vehicles should be electrified, automated, and shared." Automated driving and C-ITS also deliver opportunities to address several important societal challenges in the domains of safety, energy efficiency, congestion, urban accessibility and social inclusion.



Source: ERTRAC Working Group Connectivity and Automated Driving (2019).

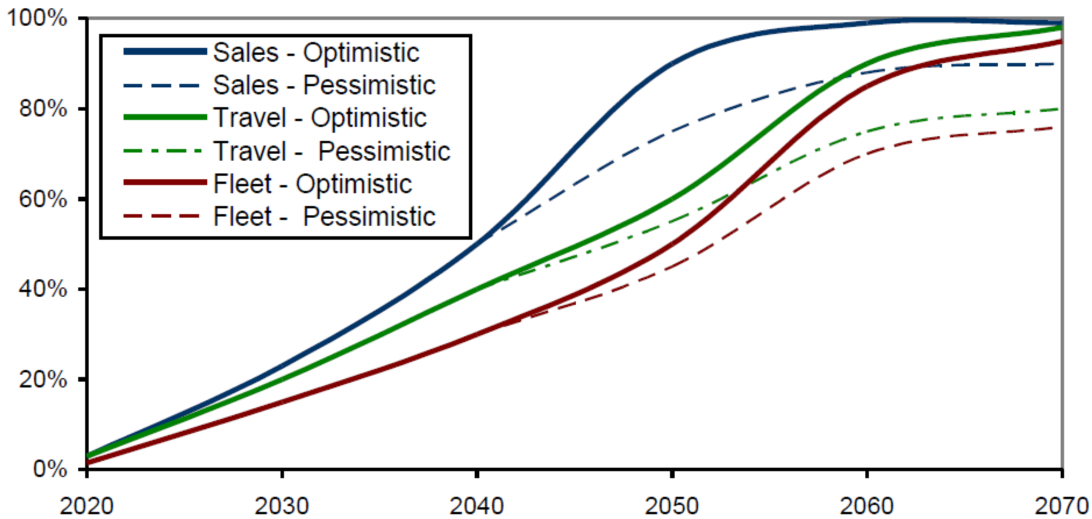
Figure 4: Projection for establishing levels of vehicle automation

Today, Level 4 automation is being tested across the world. For example, Volkswagen is testing five electric versions of the Golf, equipped with Level 4 self-driving technology (Edelstein, 2019). The cars have drivers who can intervene to take over if necessary. For an overview of former pilot experiments on automated driving, see Hottentot, Meines and

Pinckaers (2015). Recently the L3Pilot project[2] was initiated, testing Level 3 and Level 4 functionality and involving 1000 drivers, 100 cars and many OEMs over 10 EU countries.

PTOLEMUS Consulting Services (2017) estimated the future market penetration of automated vehicles according to their automation level. Based on their projections, highly automated vehicles (Level 3 and above) are expected to enter the market around 2025. The share among sales of new Level 3 passenger cars is expected to take off in 2030. Level 2 vehicles will comprise the largest portion of new passenger cars until 2020, but at the end of the next decade, more Level 3 cars will be sold than Level 2 cars.

Litman (2017) predicted that by 2030, automated vehicles would account for 22% of vehicle sales, 19% of vehicle travel and 16% of the vehicle fleet. This is an optimistic estimate, which would lead to these numbers increasing substantially by 2040 when automated vehicles would comprise 50% of vehicle sales, 40% of all vehicle travel and 30% of all vehicles. Although automated vehicle sales would increase during the upcoming decades, manually driven cars would be expected to significantly outnumber AVs until 2040 in Litman's forecast. He also indicated that technological barriers, legal issues, cyber-security concerns, and user preferences might result in a lower adoption rate that would have an impact on sales of automated vehicle. Therefore he developed a set of optimistic and pessimistic scenarios (see Figure 5).



Source: Litman (2017).

Figure 5: Sales, travel and fleet projections for automated vehicles

2.2.3. Estimates of market penetration for automated passenger cars

The TransAID project (Wijbenga, 2018) created fleet penetration rates for different vehicle types in the vehicular fleet according to the projections and estimates of the studies mentioned above, as shown in Table 4 (for convenience, the percentages in the last column have been aggregated for the automated vehicles).

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2 www.l3pilot.eu/.

Table 4: Aggregated Shares per Vehicle Type as Used in TransAID's Deliverable D2.1

Year	Conventional vehicle	Cooperative vehicle	Automated vehicle	Cooperative and automated vehicle	Aggregated automated vehicles
2025	90%	4%	6%	–	10%
2030	85%	6%	8%	1%	15%
2035	80%	7%	10%	3%	20%
2040	70%	8%	15%	7%	30%
2045	60%	7%	20%	13%	40%
2050	50%	7%	25%	18%	50%
2055	40%	7%	32%	24%	60%
2060	15%	7%	38%	32%	70%

Source: Wijbenga (2018).

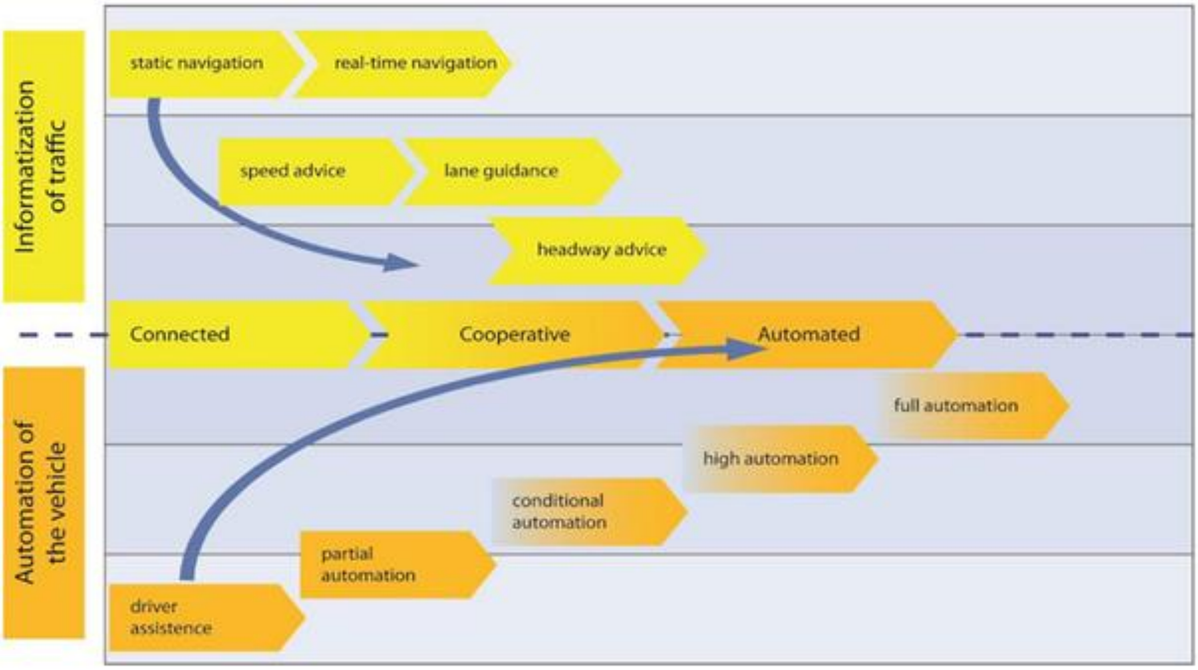
The share of cooperative automated vehicles (CAVs) – those with communication – is expected to increase to significant levels only after a few decades (50% of automated and/or connected vehicles by 2050). Because the level of automation (4 or 5) will depend on available technology, no breakdown into SAE levels was made in Table 4.

2.3. The relation between C-ITS and automated driving

C-ITS and connected and cooperative mobility are intertwined. The ERTRAC working group (2019) reported on the interaction of automated vehicles and infrastructure and the infrastructure support levels for automated driving, which represent a road's capability on such aspects as road signs and other traffic regulations. The Declaration of Amsterdam (European Commission, 2016a) also expresses the indivisibility of connectivity between traffic information and vehicle automation, as shown in Figure 6 below.

In 2014, the European Commission launched the C-ITS Deployment Platform, with the participation of national authorities, C-ITS stakeholders and the EC itself. This platform works in consensus on policy recommendations and on providing solutions to potential future issues (European Commission, 2016b). In support of the deployment of C-ITS on European roads, many C-ITS projects have been funded under the umbrella of the Trans-European Network and Connected European Facilities programmes. The C-Roads Platform (C-Roads, 2014) was created to bring all these initiatives together.

The communication capabilities of automated vehicles will play a pivotal role in the safe and efficient management (centralised or decentralised) of mixed traffic in the upcoming decades. In the C-ITS final report, it is predicted that installation of C-ITS equipment both on the vehicle and in the infrastructure will grow exponentially between 2020 and 2030 (European Commission, 2016b).



Source: Declaration of Amsterdam (European Commission, 2016a).

Figure 6: Traffic information and vehicle automation develop in parallel

The C-ITS Platform (European Commission, 2017b) identified risks related to the driver's lack of knowledge about the functionalities of C-ITS, overreliance on automated systems and a lack of experience. Emergency systems such as emergency breaking execute their action independently of the driver, and therefore, no specific training is required other than ensuring an awareness of the limitations of these systems. However, partially automated driver-assistance technologies will probably require greater knowledge and skill. Drivers will rely on the vehicle for certain tasks or in certain circumstances, and they should learn the proper use of these technologies. Such training can be added to the curriculum of the driving licence, by organising post-licence training or by implementing it in the form of a simulation tool or manual. These issues are explored further in chapters 5 and 6.

2.4. Automation and safety

The final report of GEAR 2030 (European Commission, 2017a, p.43) states:

> *Communication (e.g. through external HMI) with other road users (e.g. vulnerable road users) and Authorities (e.g. the police) will be important in particular for driverless vehicles and should also be considered.*

Annex 3 of the report covers safety and HMI issues and states:

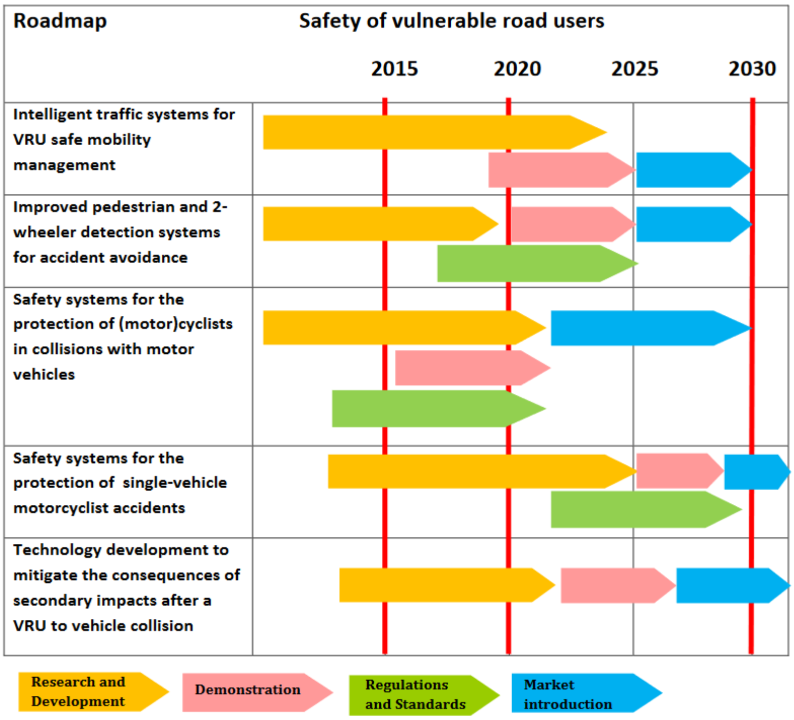
> *The vehicle from SAE level 3 shall be capable of appropriate indication of its intentions in interactions with other road users.... External HMI is even more important for driverless vehicles (Levels 4/5) to help in indicating the vehicle's intention and thereby reducing ambiguity in the interaction of the automated vehicle with pedestrians, motorcyclists, cyclists, other drivers and police.... Such HMI could include other technical solutions, e.g. unique lighting indicating the autonomous driving mode, remote display.*

This and other aspects of external HMI are discussed below in chapter 3 in the section on e-HMI. The UN recognises the need for automated vehicles to “comply with traffic rules, especially those referring to interacting safely with other road users” (UNECE, 2019). The key challenge concerns the assessment of how road users will interact with automated vehicles in relation to the traffic rules that are proposed. In 2011, the ERTRAC Working Group on Road Transport Safety and Security (2011) submitted a report called “European Roadmap: Safe Road Transport”. In this roadmap, actions related to the improvement of the vehicle’s road safety and of the infrastructure, promoting better driver behaviour, and the organisation of the transport system are covered. They propose five domains for increasing awareness of the behaviour of vulnerable road users (VRUs) on the road and on safety and sensor systems to avoid or mitigate accidents, as well as technological developments to mitigate any secondary impact from VRUs.

The roadmap for VRU safety measures, shown below in Figure 7, was drawn by the ERTRAC Working Group on Road Transport Safety and Security in 2011. A more recent report from the ERTRAC Working Group on Road Transport Safety and Security in 2019 supports the need for research on HMIs to include an assessment of the driver’s mental and physical state, the design of adaptive interfaces between human and technology, methods for validating and testing these interfaces, and the design of external interfaces. The expected impact would be less distraction of drivers, passengers and other road users, and safe mobility for road users with mental and physical impairments. With respect to automation, research is needed to address the conditions under which occupants are allowed to remain unbelted during automated driving, to what extent V2X communication enables new safety functions, to what extent the detection of VRUs can be improved by other road users by making use of vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I) communication, and under which conditions specific traffic rules can be relaxed for automated vehicles. These issues are further discussed in the succeeding chapters.

One of the main issues of road safety is transitions of control (ToCs). Some situations require the intervention of the human driver, and control can shift from the driver to the automation system or vice versa for different reasons. Either the driver initiates the transition (by switching on the Highway Pilot, for example) or the system itself triggers the transition in the case where it has misinterpreted a situation or when an obstacle suddenly appears. A ToC can be upwards (giving control to the system) or downwards (returning control to the driver).

ToCs can happen instantaneously and unexpectedly. Depending on the driver’s attentional state, the downward ToC can take more time, especially for higher levels of automation, when the human occupant has disengaged from the driving task. As explained in chapter 3, keeping the driver in the attentional loop is important in the deployment of SAE Level 3 automated vehicles. A related issue is what the vehicle should do to minimise the risks when the ToC is unsuccessful?



Source: ERTRAC Working Group on Road Transport Safety and Security (2011).

Figure 7: Roadmap for safety of vulnerable road users

2.5. Conclusions

Although a new era of ADS is ahead of us, with automated to fully automated driving under development and innovative ADAS becoming standards, the literature review revealed many gaps in the accessibility and availability of relevant information on policy-relevant questions. This is important for the deployment of ADS and the effect that the deployment of driver assistance, along with partial and full automation, will have on the behaviour of all road users. These questions concern the harmonisation of the HMI, the need of new traffic regulations, the interaction of vulnerable road users and conventional vehicles with automated vehicles, and the licensing and training of drivers. In the following chapters, the information from our literature and desk research is complemented by new information obtained through workshops with different stakeholders and the judgment of experts. The relevant literature is reviewed in depth in the introductory parts of the following chapters in relation to the topics, considerations and recommendations provided in these chapters.

Today, pilot experiments have been rolled out in many nations for testing automated vehicles of SAE level Levels 3 and 4 on public roads. These SAE levels of automation are widely accepted standards for describing the functional requirements of different automation levels. SAE Level 3 automated vehicles are expected to enter the market within the coming years. SAE Level 2 vehicles equipped with such ADAS as autopilot are already available on the market. The expected evolution of automated driving goes hand in hand with emerging technologies such as C-ITS, where communication between vehicles and between vehicle and infrastructure can improve road safety. Considering the rapid pace of technical evolution, it is important to investigate how these technologies affect society and how new regulations can pave the way to a new era of human road users interacting with ADS.

3. INTERACTION OF ROAD USERS WITH AUTOMATION

Automated driving fundamentally alters the driver's relationship with the vehicle. With automation (apart from full automation), the human driver now shares the responsibility for driving with the vehicle. That requires new forms of collaboration between the human and the vehicle, with the communication for that interaction being the vehicle's HMI – dashboard displays, controls and feedback. The vehicle also needs to observe the human through a driver-monitoring system. The need for understanding the automated vehicle's behaviour and intention is not limited to the human driver. It extends also to all the human elements in the traffic system outside the vehicle: manual drivers of vehicles, motorcycle riders, cyclists and pedestrians. This chapter explores both core aspects relevant to the understanding of the interaction of road users with the automation of driving operations: internal communication and external communication. The discussion and insights presented are based on the literature review, expert judgment and two workshops with experts and stakeholders. Section 3.1 specifically addresses interactions between the driver/user within the vehicle and the vehicle's HMI, while section 3.2 addresses the interaction of AVs with other traffic participants.

3.1. The human-machine interface

3.1.1. Interaction needs of the driver and the ADS

Drivers of current vehicles are used to gathering information about the functions and status of their vehicle from an on-board HMI. Those most commonly used are visual information on the instrument cluster or on additional displays, along with auditory information such as warning signals. Additional vital elements include control elements such as steering wheel, pedals, buttons and switching devices, which allow driver input into control of the vehicle, the use of external indicators (lights, horn, turn signals) and the control of ancillary equipment such as climate system, entertainment and so on.

The introduction of automated driving systems increases the complexity and importance of the HMI for the driver. Since ADS can take over either parts of or full control of the vehicle, the role of the driver changes significantly. The fact that different functional modes are available in one and the same vehicle, covering different levels of automation, makes it very important for the HMI to have a comprehensive interaction strategy (see Figure 3). This shift of roles and tasks away from the driver to the ADS changes the process of this interaction. In contrast to manual driving, targeted cooperation and exchange between the driver and the ADS is necessary. Depending on the role of the driver, a range of information is needed to fulfil this task. The interaction design of the HMI must take these information needs into account in order to provide the user with optimum support. One of the most important roles of the HMI of ADS is the avoidance of known operator errors (mode confusion, automation surprises, overreliance) as a result of insufficient or inadequate information. In addition to this new information, the driver also needs to deal with new elements for controlling the ADS (aside from the traditional brake and accelerator pedals and steering wheel). Thus, the HMI has an important role in assisting the driver in understanding the following:

- the functional logic of the ADS
- the handling of the new control elements

- the information provided by the ADS system

The **functional logic** underlies the way in which the ADS interacts with the human operator. It provides the experience on which the user forms a mental model or machine model of the automated systems that need to be controlled and monitored. One of the most important aspects of ADS is the functional logic behind the transitions of control. This means that the driver needs to understand which levels of automation are allowed as well as the allocation of authority between the user and the ADS (i.e., whether the user or the system has the ultimate authority to intervene and override the other's input). The driver's mental model must include these procedures and the knowledge necessary to understand the feedback provided by an HMI and enable correct and timely reaction to that feedback.

Within a human-machine interface, the **control elements** refer to the means of steering, braking, accelerating, decelerating the vehicle, and activating and deactivating various vehicle functions. They play an important role in the interaction between the human driver/operator and the ADS. While the traditional control elements, such as the brake pedal, accelerator pedal, and steering wheel, are highly standardised in their form and position, the control elements for activating and deactivating different ADS functionalities and higher levels of automation are not yet standardised. As an example, OEMs do not use consistent control elements for activation or deactivation of automated driving functions (e.g., ACC systems) (Euro NCAP, 2018). With higher levels of complexity due to newly available levels of automation in CAVs, the control elements need to be carefully discussed and designed as well as clearly described in the user manual. Further, there needs to be protection against accidental deactivation of the automation level or functionalities critical to safety. The control elements and their functionality need to be described to the user in an understandable way (in the manual, by videos) so as to ensure a certain degree of driver education in the operation of these new controls.

To enable a successful collaboration between human operator and vehicle, a continuous exchange of relevant **information** is required. The human operator needs to comprehend what automation capabilities are available as well as the state and status of automation in order to understand when intervention is required and to be able to predict automation behaviour correctly for an overall feeling of comfort and safety. The following list includes information that might be of relevance for the driver, depending on the ADS function (as given in ISO 15622; see also Sheridan and Parasuraman, 2005; Carsten and Martens, 2018; Ekman, 2018):

- state and status of functionality (availability, activation)
- indication of activation and deactivation of functionality in operation
- information about the automation capabilities in different automation levels, including information on the operational design domains of different automation levels
- information on transitions of control including transition requests to lower levels of automation and information in the case of automatic emergency intervention (transitions to higher levels of control)
- information on the tasks of the driver/user at specific automation levels, including warnings about deviating behaviour of the driver (e.g., too little engagement in driving or monitoring)

- preview of automated actions
- case-specific user information on vehicle type and use, such as information on truck platooning, automated taxis, etc.
- warnings in the case of automation errors, failures

3.1.2. State of the art: previous research on on-board HMI

From research on human factors in different domains, we know some general requirements that need to be met by the HMI of an ADS to support the driver in the safe handling of the vehicle. According to Carsten and Martens (2018) the HMI should help to

- Provide required understanding of ADS capabilities and status (minimise mode errors)
  - Mode confusion: As complexity increases, the number of automation modes that a user must understand also tends to increase. If the user is unaware of the current system mode, he or she might be led to misinterpret the information being provided or to provide inappropriate inputs. Mode errors occur when the actual automation mode of a system differs from the user's expectations. This can lead to actions that result in unexpected or unwanted consequences. Users in these scenarios are often surprised by the effects of their actions and can be confused as to what is happening and what they should do to return the system to normal operation. Mode confusion has contributed to several significant aviation accidents and incidents (Young and Stanton, 2007).
  - The automated system must communicate to the human user and provide feedback about what it is doing and what it is about to do. The saliency of the indicators of the state of automation is an important design consideration to mitigate mode confusion and encourage monitoring (Sheridan and Parasuraman, 2005; Carsten, 2019).
- Engender correct calibration of trust. Avoid overreliance on automation (also referred to as decision or automation bias and automation complacency)
  - With under-trust, functions may be overruled when the system could actually have coped, negatively affecting acceptance, comfort and possibly even safety. However, when drivers over-trust the functionalities, unsafe situations could certainly result.
- Stimulate the appropriate level of attention and intervention
  - Level of attention is important in order to allow safe interventions when needed with automation systems. However, it is also not appropriate to continuously interfere with the level of attention, thereby increasing the workload and discomfort.
- Minimise automation surprises
  - Out of two types of automation surprises (namely, absence of expected action and presence of unexpected action), the latter is more significant and must be avoided during automated driving. The presence of unexpected action means that the driver is surprised because the system performs an action that does not correspond to what a driver expects and provides the

driver with an increase in arousal and stress. Examples are accelerating when leaving the motorway ahead of a curve in the absence of (the detection of) a lead vehicle or increasing speed on approach to a traffic light in the absence of a lead vehicle. Automation surprises due to the presence of unexpected action should be avoided.

- Provide comfort to the human user by reducing uncertainty and stress (Carsten and Martens, 2018)
  - It is important to address both physical and psychological comfort while working with automation systems.
- Be usable (Carsten and Martens, 2018)
  - Simplicity and commonality of controls between different vehicle makers and models is important. The number of automation modes that are possible for the user to select should be minimised.

3.1.3. Problems with on-board HMI design for ADAS

In vehicles providing ADS with different automation levels, the role of the driver changes according to the automation level activated (see Figure 3). For example, in level 1 ("assisted"), the driver is supported by automated longitudinal or transverse guidance but needs to have his/her hands on the steering wheel and needs to pay attention to the traffic situation ("eyes on"). These tasks change with increasing automation levels: the physical involvement of the driver and the attention required in the task of driving decrease.

To fulfil the requirements listed under 3.1.2, above, the HMI must be designed in a way that the driver receives all relevant information to allow appropriate and safe handling of the vehicle at the different automation levels.

For the on-board HMI design of ADS, we currently see the following challenges:

- In general, the complexity of the HMI for ADS is high. This is caused by
  - different automation levels in one vehicle that can be activated and deactivated either by the driver or the ADS, e.g., in emergency situations
  - different configurations of functions based on the driver's individual preferences of manufacturer type
  - different definitions of the operational design domain (ODD) by different manufacturers or based on different environmental conditions that causes differences in availability of function and switch-on/switch-off conditions
  - different functional logic for the functions in a vehicle
  - different control elements across manufacturers
- The HMI of ADS has not been newly developed from scratch. Already existing HMIs, functional logic and control elements in current vehicles, e.g., adaptive cruise control and lane-keeping support systems affect the driver's mental model and need to be considered in ADS HMI design.
- Despite the complexity of the HMI for ADS, a universal design that accommodates all user groups (e.g., the disabled, elderly) seems to be lacking.

- Additionally, there are currently no official standardised testing procedures and criteria for evaluation of ADS HMIs that would allow researchers, manufacturers or testing organisations to evaluate the safe use of the ADS and to compare and rate different HMI solutions.

3.1.4. A further issue: commonality of HMI

The term "commonality" was used at the end of section 3.1.1. The term appeared, without definition, in the GEAR 2030 final report (European Commission, 2017b), which states on page 43: "Human Machine Interface (HMI) is particularly important for automated vehicles with a driver (levels 2 to 4) and rules should ensure a high level of commonality." But what is meant by this term and what is the justification for it?

The major controls and dashboard in current vehicles have a common design. Examples can be found in the relative positions of the pedals (accelerator, brake, clutch), in the design of the steering wheel, in manual gearbox shift patterns and in major elements of the dashboard such as the speedometer. The obvious justification for such harmonised designs is that the user only has to learn how to drive with one set of controls and one typical dashboard display. Having learned to drive on one vehicle or even several, drivers can readily adapt to driving a different one, without having to learn a new layout, and risking rule-based errors as a consequence. Another way to state this is that drivers can transfer their learned mental model of how to control a vehicle from one vehicle to another (Carsten, 2019). Manufacturers are free to add their own elements of brand and model identity within that common design framework. Most of those features are not specified by *standards* which would detail very precise design elements that need to be followed, but are rather set by convention, i.e., tradition. It took many years of automotive development before manufacturers adopted today's common design. As late as 1929, Skoda introduced their Type 422 vehicle with the brake pedal to the right of the accelerator pedal. Today, however, there is almost universal adherence to the common layout, and departures from it can result in an intervention by regulatory authorities.

An example of such an intervention to address a departure from the harmonised common design of vehicle HMI can be found in the recall imposed by the National Highway Traffic Safety Administration (NHTSA) on Fiat-Chrysler in 2016 for implementing an automatic gearshift with an unusual interface (NHTSA, 2016):

> *Although the Monostable gearshift has the familiar appearance of a conventional console mechanical gearshift assembly, it has an unfamiliar movement that does not provide the tactile or visual feedback that drivers are accustomed to receiving from conventional shifters…. The Monostable design appears to violate several basic design guidelines for vehicle controls, such as: 1) be consistent; 2) controls and displays should function the way people expect them to function; 3) minimize what the user has to remember; and 4) operations that occur most often or have the greatest impact on driving safety should be the easiest to perform*.

In essence, this recall was imposed because a manufacturer had violated the expected commonality of in-vehicle HMI. It can be observed that there was no mention of the violation of a standard.

As stated earlier, automation creates new complexities for vehicle operation, with multiple features of assisted and automated driving available to the user, and therefore much more potential for user confusion about what features are available, how to enable them, whether they can be switched on in the current situation, whether they can be overridden and what the driver's current and upcoming responsibilities are. This potential for user confusion makes the argument for commonality with automation perhaps even more compelling than it is with conventional vehicles. However, the complete standardisation of HMI elements is not recommended. First of all, there may be a need to cater to special user needs, individual user preferences and cultural and language preferences. Further, strict standardisation would lead to serious limitations to design. It would act as an obstacle to innovation, and a brand-specific design, which is a major selling point for the automotive industry, would no longer be possible. Since there is no universal design that fits all users, the full standardisation of HMI is not recommended. However, a commonality of high-level design and control elements between different vehicle manufacturers as well as a specified minimum level of information is urgently needed. Thus, there should be broad harmonisation but sufficient flexibility to allow brand differentiation and catering to user needs.

3.1.5. Aspects of existing policy

ADS of higher automation (Level 3 and above) are still under development; we currently only have standards available for ADAS such as ACC and lane-keeping support systems.

Aspects of HMIs are often included in standardisation. However, there is a lack of agreed research results on how the ideal HMI for ADS should be designed, e.g., with regard to take-over request (TOR) times or the minimum information needed by the driver. Thus, it is often difficult to include exact figures in the standards that would ensure some form of commonality. Therefore, research to establish and regulate minimum take-over times for different situations when the driver is requested to take back control from automated driving, for example, is recommended, and driver monitoring plays an important role in this. The adaptation of transition strategies to consider specific driver states could lead to additional benefits and enhanced traffic safety. Transitions to drivers with an inadequate driver state could be avoided, and in the case of an incapacitated driver, the automation could start to prepare for a possible minimum risk manoeuvre sooner. Consequently, the monitoring of driver position, driver attention and driver engagement is recommended for all vehicle types that can request the driver to take over control.

There are a number of standard-issuing bodies with specific activities related to in-vehicle HMI included under ISO TC22/SC39 "Ergonomics" and SAE. Table 5 shows the topics that are currently under discussion.

At the UNECE level there are also several groups working on automated driving (see Figure 8). However, the expertise related to HMI in these groups is limited. For in-vehicle HMI, the following groups are of relevance:

- WP.29 – GRVA[3] – ACSF "automatically controlled steering function"
- WP.29 – GRVA – VMAD "validation methods for automated driving"
- WP.29 – GRVA – FRAV "functional requirements for automated vehicles"
- WP.1 – IGEAD "informal group of experts on automated driving"

[3] UNECE Working Party on Automated/Autonomous and Connected Vehicles (GRVA).

Table 5: Current Projects of ISO TC22/SC39 "Ergonomics" and SAE Projects Related to HMI

ISO/TS 14198	Road vehicles	Ergonomic aspects of transport information and control systems – Calibration tasks for methods that assess driver demand due to the use of in-vehicle systems
ISO 15007	Road vehicles	Measurement and analysis of driver's visual behaviour with respect to transport information and control systems
ISO/TR 21959-1	Road vehicles	Human state, performance in human state and performance in automated driving systems (ADS) – Part 1: terms and definitions of human state and performance
ISO/TR 21959-2	Road vehicles	Human state, performance in human state and performance in automated driving systems (ADS) – Part 2: experimental guidance to investigate human takeover state and performance
ISO/TR 21974		Naturalistic Driving Studies – Defining and Annotating – Safety Critical Events
ISO/TR 23049	Road vehicles	Ergonomic aspects of external visual communication from automated vehicles to other road users
SAE J3134		ADS Equipped Vehicle Signal and Marking Lights (work in progress)

Source: German Association of the Automotive Industry (2019).

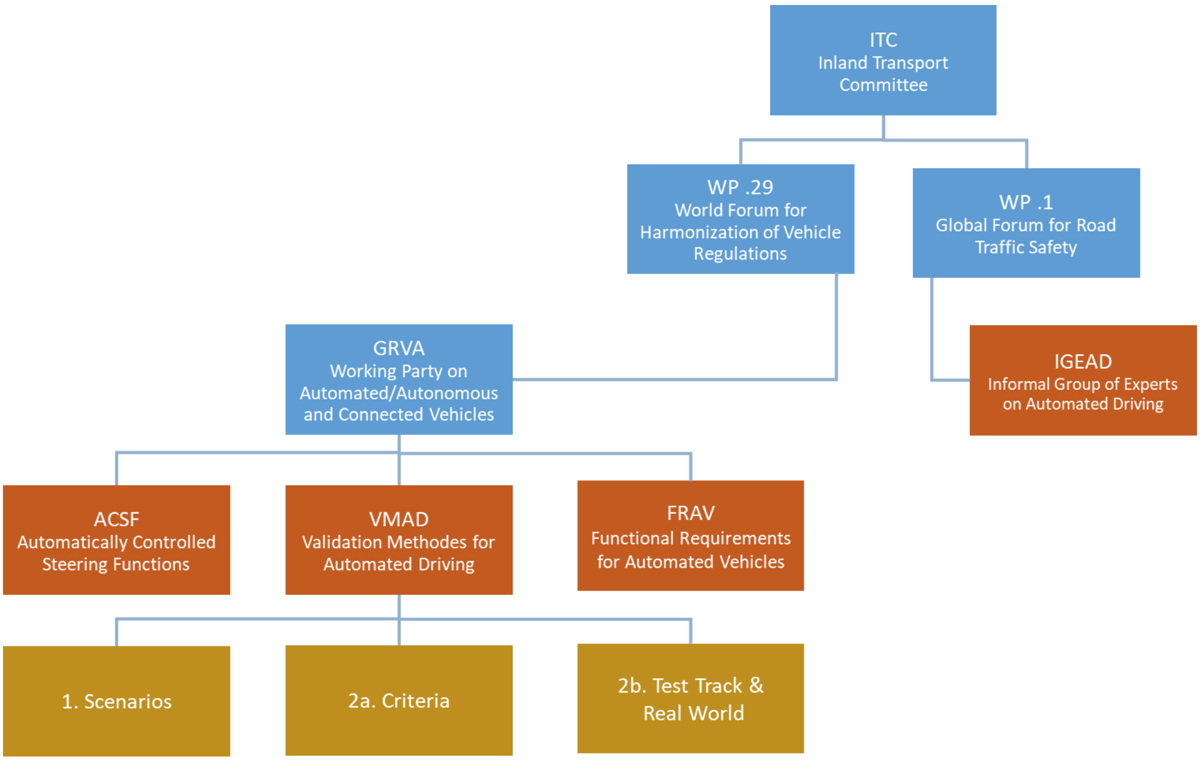


Figure 8: Working groups related to automated driving and HMI at UNECE level

3.1.6. Outcomes of stakeholder consultation

In the stakeholder workshop (16 October 2019, Brussels) several issues were discussed with the stakeholders. Some of the most relevant are summarised below:

- Is there a need for a global HMI for ADS:
  - A global HMI is not per se the right mechanism, and the HMI of the OEMs is brand specific and market sensitive (in order to sell the car, to differentiate it from others by branding it); requirements might hamper this in order to keep in line with a standard.
  - Some commonality between brands might be required, e.g., for icons, control elements, naming of functions (e.g., avoid "Pilot" which might be misleading), take-over request times, minimum information presented to the driver.
  - Basic functionality of the ADS system should be understandable by all, but it should not be necessary to configure the system in order to make it work, e.g., with ACC and lane keeping. The vast majority of people never change any of the settings regarding time-headway, and the ACC system still works. Basic operation here is required, but the actual configuration may not be so strictly urgent. Note, however, that people have individual preferences, which should not be violated.
  - In highly-automated vehicles, we expect the cabins to be more flexible; some makers intend to pull back the driving controls away from the driver (e.g. a collapsible steering wheel that can be retracted), and others tend to do it the other way round (moving the driver's seat away from the steering wheel). There was discussion as to whether there should be some commonality for this as well.
- Discussion of the need for driver monitoring for ADS:
  - There are pros and cons with this, e.g. checks are needed to ensure driver take-over availability at lower automation levels. Does this present a privacy issue?
  - Driver monitoring gives us an opportunity to personalise the ADS to the user's current cognitive state.
- Is there sufficient usability/testing of human factors aspects:
  - There are as yet not many testing standards; however the OEMs do take them into account and come to a configuration, as their own designs give them a competitive advantage.

From the survey results, the following can be concluded about the stakeholders' opinions:

- Respondents agree that commonality in HMI across manufacturers will increase user acceptance and trust, and will increase ease of use, safety and ease of learning.
- The outcome with regard to the question of how commonality could be achieved was mixed – ranging from recommendations and guidelines to regulations.
- There is high agreement between respondents that authorities should:

   - ensure that driver monitoring is included for ADS Level 3 and lower.
   - ensure that the ADS (offering SAE Level 3 and lower) provides appropriate and timely measures to alert and activate the driver, such as a hands-off warning.
- We see mixed results for the question "SAE Level 3 automation that requests the need for the user to take back control is considered by some as unsafe. Should authorities forbid this level?"
- There is high agreement between respondents that there should be common control elements for similar ADS functions across manufacturers.
- We see high agreement on whether the minimum amount of information should be standardised across manufacturers. The most essential information that should be provided can be found in Figure 12.
- There is high agreement between respondents that ADS functions should have identical standardised icons across manufacturers.
- We see high agreement on whether common testing standards and identification of important test scenarios for HMI are important.

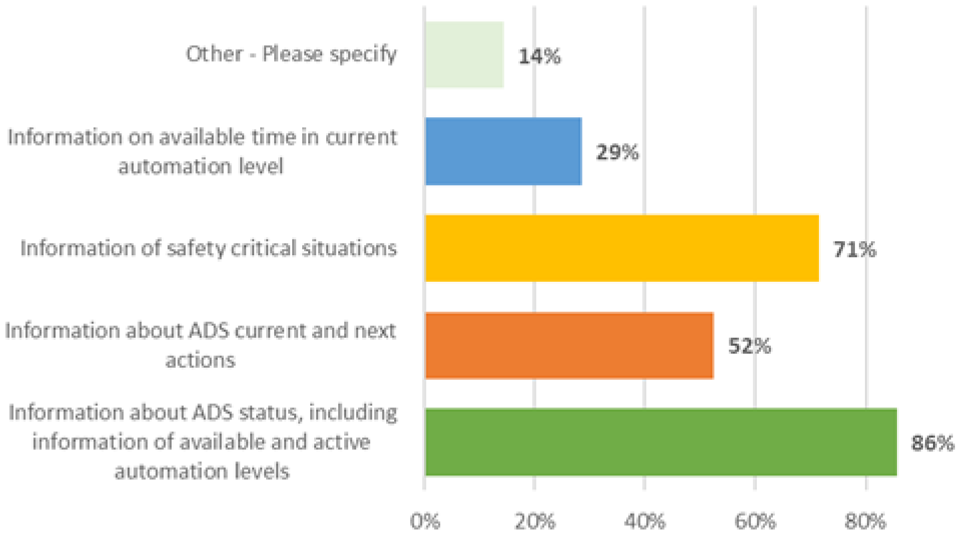


Figure 9: Results for the question "According to you, authorities should ensure that the ADS continually provides (multiple options)…"

3.2. Challenges of the integration of automated vehicles in traffic

3.2.1. The potential need for external HMI (e-HMI)

Automated vehicles under the control of an automated driving system (i.e., operating under Level 3 or Level 4 automation) will, in the future, have to interact with other traffic participants: pedestrians, cyclists and motor vehicles driven and ridden by humans. Safe interactions in many cases imply the ability to indicate intention, e.g., for current vehicles the intention to change lane or direction is indicated to other road users (pedestrians, cyclists, motorcyclists, vehicle drivers, etc.) through the use of a vehicle's indicators. Some automated vehicles in the form of driverless low-speed shuttles are already operating in mixed environments, where they have to interact with various types of road users. The recent collision of a Navya shuttle with a pedestrian in Vienna[4] shows that interactions can break down. According to the Vienna public transport agency, the pedestrian failed to pay attention: "Thursday morning around 09:30 at 42 rue Ilse-Arlt-Straße in Seestadt, a pedestrian, who according to witnesses, wore headphones and was looking at her mobile phone, crossed the street and walked against [into] the bus on the side."[5] Thus it appears that a failure by the vehicle to indicate its intentions was not a factor.

The focus of the project work here has been on whether there are specific needs for AVs to indicate manoeuvring intentions beyond the devices already present and required in existing vehicles: brake lights, indicators, horn and flashing of headlights. As a justification for such specific needs, it has been claimed that direct communication with human drivers is an important element in safe interactions between drivers and vulnerable road users, with the means for such interactions being eye contact and gestures.[6] In particular, these needs have been argued for pedestrians in interactions with AVs, but the same argument can be extended to other road users.

If there is a need to substitute communication such as eye contact and gestures, then AVs will have to be fitted with alternatives in the form of e-HMI, which would display visual and/or auditory messages to other road users as needed. There might be a greater need for such e-HMI for interactions with pedestrians and perhaps cyclists, but it could also be useful to human drivers and to motorcyclists — leading to the following series of research questions:

1. What types of e-HMI have been proposed and trialled?
2. What types of e-HMI are preferred by road users?
3. What types of e-HMI have been shown to be effective in trials?
4. Do any types of e-HMI have inherent problems?
5. Is it correct that direct explicit communication is an important element in the safe interaction with particular groups of road users such as pedestrians (and maybe cyclists) with motor vehicles?
6. Is such communication only important in specific circumstances?
7. Is there a need for a generic exterior indication that a vehicle is being operated by an ADS?
8. Are there implications regarding external interactions for internal HMIs?

3.2.2. State of the art: Previous research on e-HMI

Almost all the research has focused on interactions between AVs and pedestrians, with a dearth of studies on interactions with human-driven vehicles and with motorcyclists. A

[4] www.bloomberg.com/news/articles/2019-07-19/driverless-bus-hits-pedestrian-in-vienna-interrupting-trials.

[5] Quoted at www.theregister.co.uk/2019/07/19/selfdriving_bus_injuries/.

[6] See, e.g., https://spectrum.ieee.org/cars-that-think/transportation/self-driving/driveai-solves-autonomous-cars-communication-problem.

large variety of external displays have been proposed. To this end, Fridman et al. (2017) investigated the comprehension of 30 alternative designs of visual e-HMIs. These can be classified into categories:

- Text messages, usually on the vehicle windscreen, with or without colour, e.g., “Walk” or “I’m waiting for you to cross” in green or “Stop” in red (Note here the contrast between showing vehicle action and encouraging pedestrian action.)
- Similar messages projected onto the roadway ahead of the vehicle
- Use of symbols similar to those used in pedestrian crossings, e.g., green man or red man
- Projection of a path across the front of the vehicle (typically in green)
- Use of LED lighting to indicate emotion, such as a smile, or by use of colour to indicate “go” vs. “stop” for the pedestrian
- A strip across the front of the vehicle indicating a walking pedestrian

Study participants generally preferred information over no information, and unambiguous information such as “Walk” or a green man symbol over more ambiguous information such as a smiley face (see, e.g., Deb et al., 2018). They also preferred advice (Ackermann et al., 2019a). Audible information (symbolic or verbal) was not highly rated (Deb et al., 2018).

The provision of a clear message reduced pedestrian crossing time, and the addition of an audible message to a visual one further reduced crossing time (Deb et al., 2018). Text messages have been found to be the least ambiguous, leading to faster decision making (de Clerq et al., 2019).

It should be noted that the studies on these e-HMIs have typically been done

- with one pedestrian interacting with one vehicle
- in a safe environment, i.e.:
    - virtual reality
    - campus
    - private road

Thus, they might not realistically represent the variety of real-world crossing situations. And as stated above, they address only one group of road users, albeit a group that arguably faces the greatest challenge in interactions with traffic.

3.2.3. Problems with some types of messages

There are some substantial drawbacks to some of the proposed e-HMI solutions for addressing pedestrian needs:

- Text messages in a specific language or alphabet may not be universally understood. If proposed recommendations and standards are to have a global remit, this is a significant shortcoming.

- Not all pedestrians can be assumed to be literate. It is estimated that one in five Europeans over the age of 14 have reading difficulties.[7]
- Text messages may not be readable at certain distances or angles and also may not be readable in conditions of glare.
- Instructions to road users to move or walk have clear safety risks: there is no assurance of safe passage across the road, in that there may still be a vehicle moving in an adjacent lane or from the opposite direction. Therefore, the situation cannot be considered to be analogous to a signalised crossing, where it can be assumed that other vehicles will comply with the signals, or even to a zebra crossing, where, again, other drivers are aware of the rules, and in any case pedestrians are likely to check for traffic. Vehicles should not be telling pedestrians (or indeed any road users) that it is safe for them to proceed when it may not be.
- Apart from indicator lights, all headlights on the front of new vehicles are limited under EU regulations[8] to white (fog lamps may be yellow). Similarly, apart from indicators and reversing lights, rear lights are required to be red. Thus, showing red or green at the front would be illegal. The main consideration here is that, especially at night, other traffic participants could become confused about the direction of the vehicle's travel if red lighting were used at the front.

Thus, in terms of universality, there are substantial deficiencies regarding messages in text targeted at pedestrians. Positive instructions, e.g., "Walk" or a green man symbol might also create safety risks, as might the use of coloured LEDs showing messages or symbols in green or red, which is currently illegal.

3.2.4. How do pedestrians currently determine what a vehicle is doing?

There are many statements made about eye contact, such as "eight of 10 people seek eye contact with the driver before they cross a busy road."[9] While there is no denying that eye contact (or gestures) might be helpful in some situations, studies of pedestrian-vehicle interactions have increasingly shown that implicit communication is more important than explicit communication. This is what Dey and Terken (2017) concluded from video observations of pedestrian-vehicle interactions at a zebra crossing and a mid-block location in the Netherlands: eye contact did not play a significant role in such interactions and explicit communication was rare. They found that vehicles' movement patterns did play a significant role.

Similarly, Risto et al. (2017, p. 186), drawing on observations in Southern California, state: "Our observations of real-world human road user behaviour in urban intersections indicate that movement in context is a central method of communication for coordination among drivers and pedestrians." They term the various movement patterns "movement gestures" and conclude that it is important for AVs to replicate such patterns, so as to prevent miscommunication. They acknowledge, however, that cultural norms for such communication may vary from one area or country to another. The observation studies for

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7 www.eli-net.eu/fileadmin/ELINET/Redaktion/Factsheet-Literacy_in_Europe-A4.pdf.

8 The requirement for headlights to be white is set by UNECE Regulation No 48, which came into force on 8 October 2016.

9 https://semcon.com/smilingcar/.

the European project interACT came to the same conclusion: "Road users mostly rely on implicit cues — this is consistent over the three countries, in which the observation took place (Greece, UK and Germany)" (Dietrich et al., 2019, p. 20).

Ackermann et al. (2019b) conducted a study using pre-recorded videos of a vehicle moving on a campus. Participants had to indicate when they observed a vehicle deceleration. Reaction times were shorter for lower speeds and larger decelerations. This points to how AVs could be given desirable behaviours for their interactions with pedestrians.

It is well-known that vehicle speed is a very important factor in how encounters between pedestrians and vehicles unfold. Thus, at zebra crossings, the presence of pedestrians has little or no influence on the speed of approaching traffic (vehicles under an ADS could well perform better in this regard). Drivers of slower-moving vehicles are more likely to stop for pedestrians (Sucha, 2014; Sucha et al., 2017).

As mentioned above, studies of direct communication in the form of e-HMI have been typically carried out in one-on-one situations (a single pedestrian interacting with a single AV). Such situations do indeed occur in real traffic, but they are by no means typical. It is more likely that a number of pedestrians wish to cross the road, and that they have to interact with a number of vehicles. With direct signalling, how is a pedestrian to know that a message is targeted at her/him as opposed to someone else? It is possible to hypothesise many situations in which such messages might not be helpful or might instil false confidence in a pedestrian. Pedestrians currently manage to interact with vehicles at night when direct eye contact and communication is virtually impossible. Thus there is a substantial risk that in complex traffic situations, where there are multiple pedestrians and multiple vehicles present or approaching, extra HMI providing additional information about detection of road users by the AV and indicating the intention of the AV could lead to confusion. The salience of such signals could also lead to pedestrians not detecting the approach of a human-driven vehicle, in other words it could have a kind of masking effect.

Cyclists and motorcyclists could also perhaps benefit from e-HMI solutions. But here again the same issues arise. Text messages would be hard for cyclists and motorcyclists to read while travelling at speed, while messages indicating that they should pass ahead in the form of virtual traffic signals have the same issues of lack of authority and guarantees of safety as such signals for pedestrians. The workload of cyclists and motorcyclists could be increased if they have to pay attention to signals for several AVs simultaneously, and again, there would be a risk that signals from AVs would have a masking effect on the detection of human-driven vehicles.

There is even less argument in favour of a general need for new e-HMI to assist in interactions between AVs and human drivers of other vehicles. These latter will expect AVs to behave in a human-like manner, and able to interact smoothly and without any special attention.

3.2.5. Is direct communication by e-HMI useful in specific circumstances?

There are nevertheless situations in which an indication by e-HMI might be helpful. Currently, road users are normally able to resolve difficult situations in which both parties hesitate, e.g., when priorities are equal, such as at an unmarked intersection. Here, direct communication, such as a gesture, can help resolve the impasse. However, the introduction of AVs could make this more difficult and thus create stand-offs in which neither party has the confidence to move first. Such stand-offs have already occurred in real-world driving of AV prototypes, with the most notorious being the interaction between a Google car and a cyclist at a four-way stop sign in Austin, Texas (McFarland, 2015). The cyclist was unsure whether the Google car would move first and likewise the AV was unsure whether the cyclist would move first. The event continued for some two minutes before the AV started to move and then stopped again in the middle of the intersection, unsure about whether it was safe to continue.

Such events could proliferate, causing delays and even risk if both parties decide to move off at the same moment. And they are relevant not just to interactions with vulnerable road users, but also to interactions between AVs and conventional vehicles, e.g., in urban intersections where priority rules are not always clear. In such situations, confirmation from the AV as to whether it is moving first could be helpful. It will, however, be important to ensure that the message could not be misconstrued by road users other than the one for whom the message is intended.

Providing AVs with the possibility to signal their intentions in such limited circumstances will require the AV to be able to detect that it is in a situation that requires such a signal. That will impose an additional requirement on the sensing system of AVs: they will need to detect that another road user is in a state of uncertainty about whether to proceed or not. Research and development is needed to provide AVs with the ability to make such intelligent observations.

There are also specific cases of AV technology where an e-HMI might be advantageous. One such case is truck platooning. An indication on the rearmost trailer, showing that the trailer is coupled to a platoon, might reduce surprises for drivers or riders following the platoon; hence, reducing traffic disturbances in the vicinity of the platoon, such as attempts to cut in. The concept could be extended to other vehicles in the platoon. However, studies of the need for this are inconclusive (Andersson et al., 2017).

3.2.6. Exterior indication of being driven by an ADS

Whether there is a need for an external indication of a vehicle being driven by an ADS is hotly debated. Some hold that it is desirable for those on the outside to know that a vehicle is under the control of an ADS. For example, it might help explain why the vehicle is fully compliant with traffic rules – not speeding, not amber-gambling at traffic lights, yielding to pedestrians where they have priority, etc. Thus, such an indication might reduce close following by other vehicles and rear-end collisions when an AV "unexpectedly" stops.

Others argue that such an external indication of being driven by an ADS would lead to gaming by other traffic participants: they might act aggressively towards AVs, knowing that AVs are programmed to be cautious. This could lead to unnecessary traffic disturbances and delays.

Our considered view is that the advantages of such an external indication outweigh the disadvantages and that the indication should be provided as an enhancement to the safe interaction of AVs with other road users. There is little evidence from automated shuttles of any gaming by pedestrians and cyclists in the vicinity. Very quickly, the automated shuttles come to be accepted as just a normal part of the traffic environment. The external indication could take the form of an exterior LED light mounted on the roof of a vehicle. Placement on large vehicles could be more of a challenge: multiple lights might be required in order for the indication to be visible from all sides.

3.2.7. Outcomes of stakeholder consultations

There was general agreement with the interim findings presented to the external stakeholders in the project workshop on HMIs. In particular, it was agreed that an external indicator of ADS control was desirable.

3.3. Recommendations to the Commission regarding HMI and e-HMI

3.3.1. HMI

1. In order to prevent confusion when switching from one vehicle to another, it is recommended to promote the "commonality" (see glossary) of on-board HMIs across vehicle types and manufacturers. This commonality should cover the functional logic of ADS, the control elements and the information presented. This needs to be taken up in GRVA and its subgroups under UNECE WP.29.

2. In order to promote user understanding and trust, minimum requirements for information to be presented to the driver by the vehicle should be established. Specific elements are ADS availability, status and safety-critical situations. This task falls within the remit of the UNECE Functional Requirements (FRAV) sub-group.

3. Establish and regulate minimum take-over times for specific situations in which the driver is requested to take back control from automated driving. This again falls within the remit of GRVA and its subgroups (FRAV and VMAD).

4. Monitoring of driver position, driver attention and driver engagement is needed for all vehicle types that can request the driver to take over control. There are some serious technical challenges to achieving this.

5. Establish agreed standardised testing procedures and evaluation criteria for HMI evaluation. This is a task that falls within the remit of the VMAD sub-group under UNECE WP.29. However, specialised skills and knowledge are required here, since the criteria and procedures need to be developed. A dedicated task force may be necessary, along the lines of the group that developed the European Statement of Principles (ESoP) on in-vehicle HMIs.

6. Platooning is a special function on top of automation. Further research is needed on the information needs of the drivers in the following trucks in a platoon. This should be addressed in Horizon Europe.

3.3.2. e-HMI

1. In interacting with other road users, automated vehicles should in general use existing e-HMI (headlights, indicators, horn, etc.) in order to avoid confusion and to avoid making the task more complicated. The frequent need for road users to be able to interact with multiple vehicles simultaneously is the main justification

for not making the situation more complex by means of additional external HMIs to indicate detection and intention.

2. In the special case of confusion in interactions with a road user such as a pedestrian, the use of a dedicated e-HMI to communicate the ADS's intentions is recommended since it could be helpful. The e-HMI should be standardised. This need is limited to a one-to-one situation, an example being when nobody is moving, i.e., a standoff. In designing any extra indications, there is a need to consider special user groups (e.g., vision impaired, hard of hearing, etc.). There is also a need for an ADS to detect that another road user is confused, i.e., is not moving when such movement would be expected, so that the e-HMI can be activated. Research will be needed on how best to address this, both in terms of the nature of the signal and in terms of detection by the ADS of the situational requirement. This topic should become a work item in Horizon Europe.

3. An exterior indication that a vehicle is driving in automated mode is recommended, both for other road users and for enforcement authorities. This could be achieved by a small LED light. The appearance of this indication should be standardised and GRVA under UNECE WP.29 should be tasked with developing the standard.

4. An e-HMI is needed for platooning on rural roads to inform the drivers behind the platoon that the rearmost truck is in a platoon and there might be a short distance between it and the set of trucks it is following. This also falls within the remit of UNECE WP.29, with the relevant sub-group being the Working Party on Lighting and Light-Signalling (GRE). There may be a need to amend UNECE Regulation 48 on vehicle lighting.

4. TRAFFIC RULES

Now that automated vehicles are entering European roads, we need to look at current traffic rules and provisions to see if they still apply or whether existing rules might need to be adapted and/or expanded. Another challenge for the deployment of automation is that currently there are differences in traffic rules between Member States that could confuse automated vehicles. In order to ensure both the safety of all road users and undisrupted traffic with the deployment of automation, there might need to be more traffic rules and provisions. Here, we discuss the consequences of the expected deployment of automation, using the current general traffic rules in Europe as a baseline and taking into account an increasing number of automated vehicles. The analysis looked at where the expected deployment of automation, operational domains (i.e., motorway, urban setting, etc.) and subsequent scenarios would make it appropriate or necessary to adapt traffic rules and/or provisions. The literature available on traffic rules is very scarce. Most of the literature reviewed focused on vehicle systems (e.g., the steering system). In the most relevant publication (Law Commission and Scottish Law Commission, 2018), one of the major concerns is the ability of highly and fully automated vehicles (Levels 4 and 5 of automation) to adhere to existing traffic rules, including police direction/command.

The literature shows that automated driving has not resulted yet in much of a change in current traffic rules. There is one accepted amendment to the Vienna Convention (UNECE, 1968). Article 8 states that "Every moving vehicle shall have a driver," and "Every driver shall at all times be able to control his vehicle or to guide his animals." A proposal was accepted to add the following: "Vehicle systems which influence the way vehicles are driven shall be deemed to be in conformity with paragraph 5 of this Article and with paragraph 1 of Article 13, when they are in conformity with the conditions of construction, fitting and utilisation according to international legal instruments concerning wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles" (UNECE, 1968: amendments).[10]

This means that an automated driving system can be the "driver" and that the driver therefore does not have to be human.

The white paper "Safety First for Automated driving, 2019" emphasised the necessity of having machine-interpretable traffic rules, especially for highly and fully automated vehicles because they should obey traffic rules. These machine-interpretable traffic rules are also referred to as the *digital traffic act*, which is the translation of the current traffic rules into exact and measurable traffic rules. Mobileye has already made an attempt at modelling such rules (Shalev-Shwartz et al., 2017).

One of the major concerns here is that current traffic rules are not "all-inclusive" and leave room for multiple interpretations. An option could be to have different rules for human drivers (current traffic rules) and for automated vehicles (digital traffic act). In this way the exact and measurable rules would only be for automated vehicles and the current rules with multiple interpretations would be only for human drivers. An example might be the rules regarding minimal-risk manoeuvres. Human drivers can be creative and decide on

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[10] www.unece.org/info/media/presscurrent-press-h/transport/2016/unece-paves-the-way-forautomated-driving-by-updating-un-international-convention/doc.html.

an appropriate manoeuvre to avoid a dangerous situation. This poses a real challenge to creating the digital traffic act, but it is important for the digital traffic act to indicate how to deviate from the rules in emergency situations.

Another concern is the variation in traffic rules between member states and between regions within a member state. It is recommended that those variations be included in the digital traffic act. An ADS can easily recognise by GPS location in which region or state it is and therefore it should not be a problem to switch to specific regulations when available in digital traffic (comparable to a navigation system switching digital maps when crossing a border).

Related to the topic of the digital traffic act is the issue of how the ADS should deal with speed limits, the boundary to follow it and the possibilities to “know” the current speed limit. This refers mainly to the proper functioning of an intelligent speed assistance (ISA) system, which aids the driver in maintaining the appropriate speed for the road environment by providing dedicated and appropriate feedback. This does not require traffic rules to be changed, but it is of importance for the ISA to be able to recognise speed-related road signs. Seidl et al. (2020) provide some recommendations regarding relevant road signs, the information available on the speed limit and feedback modes.

At the moment, there is a draft amendment from UNECE WP.1 on the concept of activities other than driving for vehicles with an automated driving system (ECE/trans/WP.1/2020/x).

It states that the following principles will be applied by the contracting parties to the 1968 Convention on Road Traffic as well as considered/followed by those applying the 1949 Convention’s equivalent requirements in Articles 7 and 10:

> *When the vehicle is driven by vehicle systems that do not require the driver to perform the driving task, the driver can engage in activities other than driving as long as:*
>
> *(a) these activities do not prevent the driver from responding to demands from the vehicle systems for taking over the driving task, and*
>
> *(b) these activities are consistent with the prescribed use of the vehicle systems and their defined functions.*

Given these conditions, it is therefore recommended that engaging in currently not permitted non-driving-related activities during automated driving be allowed. However, this depends on the automation level and the type of the other activity. When the automation level still requires the driver to be able to respond to emergency situations immediately (driver responsibility), engaging in other activities is not recommended. Other activities that take the driver out of the loop for a relatively long time, like sleeping, are also not recommended as long as the automation level is below Level 4 and/or the ODD of the Level 4 system is very limited.

4.1. Scenarios: relation matrix for traffic rules

A first step in developing a scenario vs. traffic rule matrix was to identify the different implementation scenarios from the work done in chapter one (see also Figure 4). The following scenarios have been identified and taken as a basis for the matrix as shown in Table 6:

1. "Increasing penetration of Level 2" (estimated to already be ongoing): more and more manufacturers offer SAE Level 2 systems, and thus penetration is expected to increase. In the near future that will mainly be support systems for non-urban settings. Moreover the systems will be bounded by the performance of the sensors used (e.g., cameras and low-sunlight or snow conditions).

2. "Onset of Level 3": some of the very first Level 3 systems are already available in vehicles. However, not all countries allow their use, and some are uncertain how to handle these systems legally or technically. However, it is expected that this is a temporary situation, as many institutions (UNECE, EC, national authorities, etc.) have already been working on this for several years and the first steps have been taken (see UNECE WP.29). As in the case of Level 2, it is expected that these systems will mainly operate in highway settings, as urban environments are too unstructured and have less predictable road users, like cyclists and pedestrians.

3. "Onset of Level 4": technologies have already been developed to bridge the take-over time when the driver has to take over control. These technologies are also very beneficial for Level 4 automation systems. Due to continuous developments in the field, it is expected that urban areas will also become part of the ODD of Level 4 systems.

4. "Beyond cooperative driving": in parallel to the developments of automated driving, cooperative driving will continue to be developed as well. Initially, this will be mostly "services", based on cooperative information. However, in the far future, this might also result in cooperative control where the car is no longer in control, but another entity, like a road operator, is. In this way, traffic can be made more efficient or local areas may be used differently/more dynamically, depending on traffic state, weather, local events, etc.

These four scenarios are the columns in the scenario/traffic rule matrix of Table 6 (below).

The rows in the matrix are formed by the traffic rules, which have been based on the Convention on Road Traffic (UNECE, 1968). To reduce the number of articles (56) and make the table more manageable, the rules were grouped as follows:

- "General, behave safely" rules
- Position on carriageway rules: includes in-line driving and overtaking, passing oncoming traffic and slowing down. These are basic manoeuvres current Level 2 systems have already mastered.
- Speed and headway rules
- Standing and parking rules
- Drivers' rules
- Pedestrians' rules
- Maneuvering rules: includes taking turns, driving through intersections and giving way
- Level-crossing rules

- Sign and signal rules
- Special rules: e.g., tunnels, processions

Table 6: Scenarios: Relation Matrix for Traffic Rules

		Cooperative information	Cooperative control		
	increasing L2	**onset L3**	**onset L4**		**'Beyond'**
			Highway	**Urban**	
General: behave safely			1	1	1
Position on carriageway			2, 3	3, 4	3, 4
Speed and distance		5		6	6
Standing and parking		7	7	7	
Drivers	8	8	9	9	9
Pedestrians					?
Manoeuvring				4	4
Level crossings					10
Signs and signals		11		4	4
Tunnels, processions, …		12			12

The numbers indicate possible changes to the current rules and are discussed below.

In regard to the specific rules (see Table 6):

1. When automated driving is as safe as stated ("vision zero", etc.), then whether seatbelts should still be used can be discussed. However, it is now recommended to keep the rule of mandatory seat belts. This means also, in the case of automated taxis, that children can only use these above a certain age, as the parents/guardians remain responsible for the use of the seatbelt while driving.

   In order to adhere to the general traffic rule of behaving safely for automated vehicles, they should always only function within the operational domain that they can handle. ODDs differ for different automated functions; therefore the automated vehicle itself (and not the driver) should make sure that the functionality of an ADS shall not be available outside its operational domain. This could be implemented as a traffic rule for ADS, but could also be seen as a recommendation for the design of automated vehicles.

2. Regarding the traffic rules on the safe position on carriageways, the platooning of vehicles carrying heavy goods on rural roads is important. For other vehicles

to recognise this, and be able to judge if overtaking is possible, platoons should have a specific sign, signalling other road users about the active platooning. This also depends heavily on what is nationally defined as a safe following distance for platooning (e.g., a fixed distance in meters or a time gap in seconds can make a big difference) and whether another vehicle can still fit in the gap between the platooning vehicles. This is a specific recommendation that has already been discussed in the section on e-HMI. E-HMI is needed for platooning on rural roads to inform the drivers behind the rearmost truck that it is in a platoon and might have a short gap in front.

3. Traffic rules on how to behave around emergency vehicles is an issue for automated vehicles. Whereas human drivers normally make an expert judgment about the situation and where best to make space for an emergency vehicle (e.g., when to go off the road onto a bicycle path, for example, or into a pedestrian zone), automated vehicles need to be programmed on what to do when encountering an emergency vehicle. These rules are sometimes specified per country but are mainly dependent on the current situation. It is therefore recommended to translate basic traffic rules on how to behave around emergency vehicles into the *digital traffic act*, including an indication as to how to deviate from the rules.

4. Effective use of limited space in packed cities: automated vehicles may give us a new opportunity to rearrange traffic in order to deal with limited space in crowded urban areas. For example, it might be desirable not to have fixed areas for any traffic participant, like sidewalks for pedestrians, parking spaces, bus lanes. Automated vehicles that are centrally directed by a road operator could adjust the situation to current needs. Since this touches upon the topic of different rules for automated and human-driven vehicles, it only becomes an option when there is a very high number of automated vehicles, or no human-driven vehicles at all.

5. Platooning (under Level 3): shorter following distances due to cooperative information may be possible.

6. Platooning (above Level 3): even shorter following distances due to cooperative control.

7. Minimum-risk manoeuvres (MRMs): to avoid unsafe situations like standing vehicles on a highway lane, current rules only describe where it is forbidden to stand and park. The resulting MRMs to avoid this are not described. Where human drivers can be creative and decide on the appropriate manoeuvre themselves, automated vehicles need to be programmed on what to do in each situation. These MRMs will probably depend on road type, current road layout, road conditions, traffic, being in a tunnel, etc. They are therefore dependent on the quality of this information from, for instance, a high-definition map.

8. A driver should possess the knowledge and skills needed to steer a vehicle: vehicles that have Level 2 and 3 systems may require more knowledge/skills from the driver to avoid incorrect use or misuse). The reader is referred to chapter 5 on driver licensing and training, where this topic is discussed and recommendations are given. In itself, the traffic rule requiring each driver to

possess the knowledge and skills to steer an automated vehicle should not be changed. The challenge is how the driver will obtain this knowledge and these skills.

9. Every moving vehicle or combination of vehicles shall have a driver: this traffic rule has now been redefined such that the automated system may also be seen as a driver (see discussion above on the amendment to article 8 of the Vienna Convention on Road Traffic). The former driver (and potential driver of the vehicle in the near future) is then considered as the "user in charge" (currently discussed on UNECE Working Group 29). Rules need to be set up for the user in charge to assure good transitions of control (e.g., addressing the use of smart phones).

   Regarding traffic rules for the professional driver when not actively driving, but being a "user in charge": the legal requirements regarding driving and rest periods in European law may become more relaxed. How much relaxation can be given to the now strict driving and rest periods depends on what is expected from the "user in charge" in terms of attention and reaction times.

10. Efficient traffic, e.g., directed by road operator, may lead to different ways of handling traffic at level crossings. As for topic 4, this requires a very high penetration rate of Level 4 vehicles.

11. Precedence of infrastructure-to-vehicle (I2V) instructions: with cooperative information becoming available in cars, the precedence of this information with respect to the other two sources of information (signs and signals on the roads) must be made clear. So, in a case where the information of the I2V source does not match the information from the road signs and signals, it should be clear to the user in charge (human driver or automation) which of those prevails. There was a difference of opinion between the experts and the results of the questionnaire. The experts recommended letting the road signs prevail over the I2V information, whereas the external stakeholders thought that the I2V information should be ranked higher than the road signs. The authors of this study conclude that road signs (dynamic and static) should always prevail over in-car I2V information (if contradictory). But, in the future, where I2V is provided reliably by authorities and all vehicles receive I2V, then the I2V should prevail.

12. Shorter following distances in tunnels for cargo vehicles stopping in tunnels (MRM): currently vehicles carrying heavy goods are obliged to keep a very long distance from each other in tunnels (200 meters). Due to the availability of platooning and V2V and I2V information, the following distances in tunnels may be reduced, keeping the same level of safety, but resulting in much more efficient use of tunnel capacity.

4.2. Comparison of EU Member States and US

While the US Department of Transportation and NHTSA periodically update their guidelines for autonomous vehicles, individual states are already passing relevant laws. However, there are still differences between them on the definitions of basic terms, such as "vehicle operator".

According to the database of autonomous vehicle legislation from the National Conference of State Legislatures, 29 states have enacted legislation related to autonomous vehicles and 11 state governors have issued executive orders regarding the operation of autonomous vehicles.

The most popular topic, for many of these sates, is exemptions to rules on following distance that allow for truck platooning. For instance, the state of Michigan specifies that the requirement that commercial vehicles maintain a minimum following distance of 500 feet (152 m) does not apply to vehicles in a platoon.

In general, the states that are leading the deployment of automation in traffic have not altered their traffic rules, but they do offer rules for testing and operating AVs on public roads. For example, in the state of California, existing traffic rules have not been changed with the appearance of automated vehicles; however, additional rules have been defined, mainly concerning the manufacturer's insurance, identification of the test vehicles, testing permits, who is allowed to operate the vehicle, requirements and qualification of test drivers, etc.

In Europe, several countries (e.g., Germany, Netherlands, Sweden, Estonia, Hungary) have already taken steps towards the introduction of self-driving cars. Similarly, as in the US, none of these countries have altered their traffic rules; instead, they only offer rules for testing and operating of automated vehicles on public roads.

In the Netherlands, for instance, road traffic rules have been amended; since summer 2015, the wide open-road testing of self-driving vehicles (both cars and buses) is possible with a permit from the competent authority.

In Germany, the German Road Traffic Act was amended in 2017[11] (Juhász, 2018). With this amendment, the German legislation established a legal framework in which the participation of self-driving cars on the road is possible. The framework focuses on defining the basic rules for the relationship between the driver and the highly or fully automated vehicle and provisions regarding data management.

For the introduction of (partly) automated vehicles in Europe, the main difficulty is the difference in the rules allowing or exempting these types of vehicles. It means that a specific ADS is either only allowed in a limited region or country, or it needs to be in compliance with the total of all different rules regarding allowances and exemptions. It is therefore recommended that the allowance and exemption rules for the EU Member States be aligned.

4.3. Outcomes of stakeholder consultation

This section describes the inputs from the stakeholders as collected by the survey and the workshop in January 2020. It should be noted that the results have also already been

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[11] www.bmvi.de/SharedDocs/EN/Documents/DG/eight-act-amending-the-road-traffic-act.pdf?__blob=publicationFile.

integrated in the sections above (i.e., the relation matrix for traffic rules and the safety and flow assessment).

Prior to the workshop in January 2020, a survey was circulated amongst stakeholders, containing 12 questions on traffic rules and automation (see Appendix 11.6). Sixty-seven completed the survey, with the following results:

1. The majority (72%) think that automated vehicles should be allowed to mimic human behaviour, e.g., breaking the speed limit.

2. On the topic of "major" and "minor" traffic rules (where "minor" traffic rules are those that may be broken to avoid dangerous/emergency situations), the majority think that these are necessary and should, first, be installed by international institutions like UNECE and, second, on an EU level.

3. With regard to switching the automated system on/off, the respondents are very much in favour (80%) that there should be clear rules for this, adapted (66%) to the circumstances at hand. Whether the driver should always be able to take back control (switch automation off), the respondents are undetermined.

4. In a situation where the driver misunderstands the limitations of the system, most respondents would hold the driver responsible when an accident occurs, but many also think that the car manufacturer or the provider of the automation system has a major role (42% and 34%, respectively) in this as well. As one respondent commented: "It depends on the cause of the accident and the cause of the misunderstanding."

5. A majority of the respondents (73%) think that there should be exact and measurable traffic rules (i.e., digital traffic act). However, the respondents differ in their opinion as to whether this is feasible (36% yes; 46% no).

6. Regarding information received from road operators through I2V communication, this should lead when it involves information like minimal following distances between vehicles, but should not prevail over traffic light information and variable speed limitations.

7. According to 71% of the respondents, the MRM should be prescribed depending on location, traffic and weather. Just stopping in a safe place is not thought of as always the best option when automation fails or outruns its operational domain.

The detailed reactions from the participants of the January 2020 workshop can be found in the workshop report. The following are worth mentioning here:

1. There was a discussion on having different rules for the automated system than for the human driver. On the one hand, "automation" can do tasks better than the human driver (e.g., during lengthy and dull parts of the drive), but on the other hand, it may take more time to understand scenarios due to sensor restrictions. Moreover, it can demonstrate how to break the rules in emergency situations. On the other hand, it might become difficult for other road users to predict the automated vehicle's behaviour.

2. It was stressed that local implementation/interpretation of the Vienna Convention must be taken into account, as this is how traffic is working now (expected behaviour): "Such as, for example in Norway, where the Vienna Convention is applied with provisions: the interaction between cyclist and car differs from the official texts (e.g., cars will yield if a cyclist wants to cross the road).

During the workshop three questions were answered by the participants through the active poll:

1. Should the driver always be allowed to override the system? Most of the participants answered with "Yes" (69%), although the ability of the human driver to judge the right course of action was questioned. It was also mentioned that some ADAS are easy to override but others are very difficult, so the difference should not be on allowing a system to be overridden or not but on designing a safe process to override it (e.g., in the case of a false positive, or when an external institution such as the police should do it).

2. If a driver misunderstands the limitations of the system and causes an accident, is (s)he considered responsible? Here also the majority answered with "Yes" (83%). An attendee from an OEM association said that the question is biased, and that no matter what, the person will be liable under the law. If the driver misuses the system, then the driver is responsible, unless there is a clear failure in the system. A last comment was made on the need to enhance education and raise awareness at an early stage. Doing so will allow drivers to understand all the procedures and decisions, thus enabling them to master and understand the limitations of the system.

3. Sixty-seven percent of the participants did not agree that there should be rules for pedestrians because of automated driving.

4.4. Recommendations to the Commission regarding traffic rules

In conclusion, the following is recommended in relation to updating the traffic rules (preferably at the UNECE level) for automated driving systems:

1. Current traffic rules need to be translated into exact and measurable traffic rules that can be programmable for ADS (sometimes also called the *digital traffic act*). Local variations in traffic rules and variations between Member States should be included in the digital traffic act. In this way, an ADS can switch to specific regulations when crossing a border, comparable to switching digital maps for a navigation system.

2. The digital traffic act should indicate how to deviate from the rules in case of emergency situations.

3. The functionality of an ADS shall not be available outside its operational domain. In order for automated vehicles to adhere to the general traffic rule of behaving safely, they should always only function within the operational domain that they can handle. ODDs differ for different automated functions. Therefore, the automated vehicle itself (and not the driver) should make sure that the ADS's functionality shall not be available outside its operational domain. This could be

implemented as a traffic rule for ADS, but could also be seen as a recommendation for the design of automated vehicles.

4. During automated driving, engaging in non-driving-related activities that are currently not permitted might be allowed (following the current draft amendment from the UNECE WP.1 on the concept of activities other than driving for vehicles with automated driving system). This depends on the automation level and the type of other activity. When the automation level still requires the driver to be able to respond to emergency situations immediately (driver responsibility), engaging in other activities is not recommended. Other activities that take the driver out of the loop for a relatively long time, like sleeping, are also not recommended as long as the automation level is below Level 4 and/or the ODD of the Level 4 system is very limited. Please also refer to the draft amendment from the UNECE WP.1 on the concept of activities other than driving for vehicles with an automated driving system (ECE/trans/WP.1/2020/x).

5. Road signs (dynamic and static) should always prevail over in-car I2V information (if contradictory). In the future, where I2V is provided reliably by authorities and all vehicles receive I2V, then the I2V should prevail.

6. Regarding traffic rules for the professional driver: when not actively driving, but being a "user in charge", the legal requirements for driving and rest periods under European law may become more relaxed. How much relaxation can be given to the now strict driving and rest periods depends on what is expected from the user in charge in terms of attention and reaction times.

7. Currently, commercial cargo vehicles are obliged to keep a very long distance from each other in tunnels (200 meters). Due to the availability of platooning and V2V and I2V information, the following distances in tunnels may be reduced, keeping the same safety level, but resulting in much more efficient use of the tunnel capacity.

8. It is recommended that the allowance and exemption rules for the EU Member States for the introduction of (partly) automated vehicles in Europe be aligned. The main difficulty is that a specific ADS is either allowed only in a limited region or country, or it needs to be in compliance with the total of all the different rules regarding allowance and exemptions.

5. DRIVING LICENSING AND TRAINING

5.1. Background to EU driver licensing and training

In 2003, the European Commission adopted Directive 2003/59/EC, which lays down the initial qualifications and periodic training requirements for professional drivers of trucks and buses, and replaced the 110 different models that were then in existence throughout the EU/EEA. The European Parliament adopted Directive 2006/126/EEC in 2006, and it was published in the Official Journal of the European Union on 30 December of the same year (European Commission, 2006). Furthermore, since 19 January 2013, the look and feel of driving licences issued by EU countries have been harmonised to the size and shape of a credit card. Licence categories have also been harmonised in all EEA Member States for mopeds, motorcycles, motor vehicles, heavy-good vehicles and buses, with a total of 15 categories across the five vehicle types. There are also national categories in the EEA Member States for, for example, tractors, large motorcycles, motorised wheel boats and motor tricycles. These national categories have not been harmonised and are only valid within the issuing country (in contrast to the five categories mentioned above where the licence is valid in all EEA Member States). As well as being physically harmonised, validity periods were also standardised, enabling authorities to regularly update the driving licence with new security features to resist tampering by unqualified or banned drivers.

While progress has been made in the harmonisation of licensing, there are wide disparities across Member States with regard to training the drivers of passenger cars. There are no EU standards on driver training, driving schools or driving instructors. In some countries, it is possible to prepare for the practical exam without the engagement of a professional driving instructor (Sweden, Finland); in others, such training is mandatory, along with a minimum number of training hours (Poland, Bulgaria, Portugal) See

Table 7. Whilst each EU Member State can choose how to design and structure driver training, there are minimum EU standards for the following:

- the driving test: drivers need to pass both a practical and a theory test
- the driving examiners: initial qualification, quality assurance and periodic training are required

To quantify the differences in testing, the TEST project examined the testing procedures across six European countries (Baughan, 2005) and found differences between driving tests, mainly in the duration of the test and the topics covered. In addition, the differences between different types of test centres (on the basis of their location) were greater than the differences between countries. Whilst it was found that driving tests rarely cover all elements listed in the European Driving Licences Directives, they did in general cover most items listed as compulsory.

Table 7: Relationship between Driver Training and Exam

System	Description	Examples
1. No mandatory on-road formal driver training	Learners can prepare themselves for the driving test without mandatory on-road driver training from a professional driving instructor.	Belgium, UK, Sweden, Finland (However, in Finland and Sweden risk-awareness training is mandatory.)
2. Traditional model	Mandatory formal driver training by a certified driving instructor. No informal training with lay instructor. After having passed the driving test, drivers can drive without supervision.	Denmark, the Czech Republic, Poland, Bulgaria, Romania, Portugal, Hungary, Greece, Slovakia, Malta
3. Test-led mode	The test dictates the content of training. There is no national curriculum. What is not tested is mostly not trained by private driving schools.	The UK, the Netherlands, Sweden, Cyprus, France, Spain
4. Training-led model	A national curriculum with obligatory training modules, also modules that are important for road safety but that cannot be tested during the driving test.	Germany, Croatia, Belgium
5. Two-phase model	Mandatory post-licence training (in first year or two after the test).	Finland, Luxembourg, Austria, Estonia, Slovenia, Latvia, Lithuania
6. Structured training + accompanied driving	Package of minimum driving school training + minimum mileage (with feedback sessions with instructor in between).	France, Austria
7. Post-test accompanied driving	Learner has to be accompanied by designated person when they have passed the driving test if under 18 years of age.	Germany, the Netherlands

Source: Helman et al. (2017).

The 2006 Directive states that drivers of all power-driven vehicles must at any moment have the knowledge, skills and behaviour described in the Directive, with a view to being able to:

- Recognize traffic dangers and assess their seriousness
- Have sufficient command of their vehicle not to create dangerous situations and to react appropriately should such situations occur
- Comply with road traffic regulations, particularly those intended to prevent road accidents and to maintain the flow of traffic
- Detect any major technical faults in their vehicles, particularly those posing a safety hazard, and have them remedied in an appropriate fashion

- Take account of all the factors affecting driving behaviour (e.g., alcohol, fatigue, poor eyesight, etc.) so as to retain full use of the faculties needed to drive safely
- Help ensure the safety of all road users, particularly the weakest and most exposed by showing due respect for others

The Directive also states the following:

> *Member States may implement the appropriate measures to ensure that drivers who have lost the knowledge, skills and behaviour....can recover this knowledge and these skills and will continue to exhibit such behaviour required for driving a motor vehicle.*

5.2. What skills and knowledge do drivers need in order to operate non-automated vehicles?

In order to truly capture the entire set of skills required by drivers to maintain safe travel, one would be required to carry out both a cognitive task analysis (which focuses mainly on decision making and memory) and a hierarchical task analysis (which decomposes a high-level task into subtasks). However, even for a simple task such as "making a cup of tea", the process of defining and sequencing all the necessary steps is long-winded. For this reason, there is no task analysis of the complete task of driving, although attempts have been made for sub-tasks. For example Richard et al. (2006) present task analyses for urban intersection scenarios such as "left turn on green light". A full task analysis required 20 pages of explanation and a table comprising 30 different sub-tasks.

Given the magnitude of undertaking a full task analysis of driving, a more generic approach is usually adopted, which describes it in a more functional way. Both Michon's (1985) and Brown's (1986) models of driving describe the knowledge, skills and behaviours required by drivers (where no driver support or automation exist). Michon (1985) proposed that driving is constituted of strategic, tactical and operational tasks, ranging from those that require milliseconds to execute, to those requiring minutes or even days. Brown's model is slightly different and describes six functional requirements that the driver needs to perform, those being route finding and following, steering and velocity control, collision avoidance, compliance with road rules and vehicle monitoring. Whilst both models provide a high-level description of the driving task, they do not provide a complete task-focused list of requisite skills. The models have, however, been used to some extent to guide the content of training programs, notably the GDE Matrix, which is one of the most referred to frameworks for driver training (Table 8).

Each of the four levels described in the table above are relevant for the training of skills for automation. For example, the first level refers to personal motives and tendencies that might influence attitudes, decision making and behaviour in driving and, consequently, crash involvement. Examples of such tendencies are a person's desire to experience thrills or to impress others. Whilst automation may in part reduce the opportunities for drivers to engage in thrill-seeking and risky behaviour such as speeding or following too closely, during periods where drivers are hands and/or feet off, they have the opportunity to engage in non-driving related activities. The extent to which drivers are willing to do this and the activities in which they engage might be detrimental to safety. For example, whilst a quick look at one's phone during a period of automated driving might not be an issue, compiling one's grocery list on a supermarket website could be considered as more engrossing and more liable to result in a loss of situation awareness.

Table 8: Goals for Driver Education

Level	Knowledge and skills	Risk-increasing aspects	Self-assessment
Goals for life and skills for living	Lifestyle, age, group, culture, social position, etc.	Sensation seeking Risk perception Group norms Peer pressure	Introspective competence Own preconditions Impulse control
Goals and context of driving	Modal choice Choice of time Role of motives Route planning	Alcohol, fatigue Low friction Rush hours Young passengers	Own motives influencing choices Self-critical thinking
Driving in traffic situations	Traffic rules Cooperation Hazard perception Automaticity	Disobeying rules Close following Low friction Vulnerable road users	Calibration of driving skills Own driving style
Vehicle control	Car functioning Protection systems Vehicle control Physical laws	No seatbelts Breakdown of vehicle systems Worn out tyres	Calibration of car control skills

Source: Hatakka et al. (2002).

The goals and context of driving focus on the goals behind driving and the context in which driving is performed. Examples include car preference, the trips one makes, and the choice to drive after consuming alcohol or not. With respect to fatigue and alcohol in particular, the temptation to drive in an impaired state might become more attractive to some, if they are over-reliant on the automation technology.

Driving in traffic situations concerns the mastering of driving in specific traffic situations. The ability to adjust one's driving to constant changes in traffic, as well as the ability to identify potential hazards and to act correctly in order to avoid them, are both included in this level. What is also relevant to automation is the retention of hazard-perception skills, which are known to improve with experience. This is especially relevant where the driver is required to resume control when the automation reaches its limits, drivers will need to quickly assess the information that is available to them from both the internal HMI and the road environment.

The final level, vehicle control, includes the ability to control the vehicle, even in difficult situations, as well as the functioning, use and benefits of injury-prevention systems such as seat belts. Knowledge of the limits of the automation and the maintenance of various sensors would be expected at this level of training for automation.

5.3. Current approach to training for Level 1 and 2 automation

Advanced driver assistance systems are grouped under Level 1 automation and, as such, are pervasive in today's vehicles. ADAS were introduced onto the market in the early 2000s and penetration into the market has been gradual. For example, Restrepo et al. (2019) modelled the penetration rate of various electronic control systems over the period 2000–2025. They found that some engine control systems, typically those affected by regulations on safety, fuel efficiency and/or emissions, such as stop-start systems and electronic stability programs (ESP) have increased rapidly to high levels of penetration. On the other hand, those that are unaffected by regulation, such as comfort systems (e.g., cruise control) have been stable at intermediate penetration levels for many years. They remain below 40% penetration even after 14 years on the market. See Figure 10.

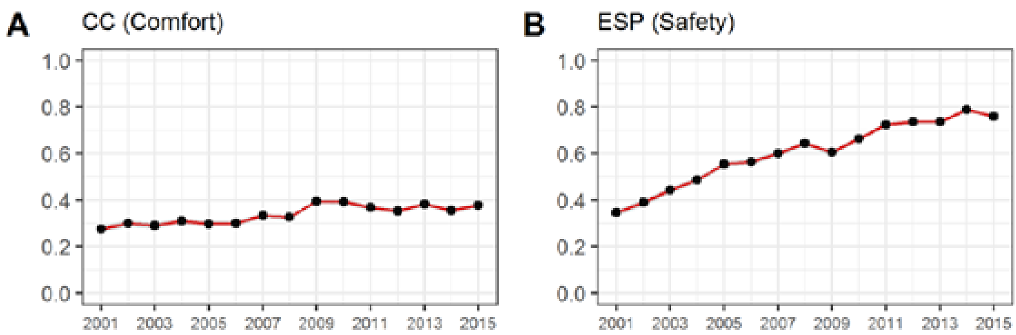

Figure 10: Penetration rate of two ADAS (cruise control and ESP)

The Highway Loss Data Institute (HLDI, 2012–2017) have reported that it typically takes decades after introduction before most vehicles on the road have a given feature. Furthermore, by taking into account the fact that some features are "optional extras", penetration rates can be even slower (HLDI, 2017).

With regard to changes in driver training and licensing, Level 1 automation features did not warrant a change in EU licensing procedures because the fundamental driving task remained unchanged and little driver action was required. However, it should be noted that "the lack of full standardisation of vehicle controls and the driver interface with driver assistance systems means there is often a 'human factors' deficit in which drivers are forced to use systems they do not necessarily fully understand" (Helman and Carsten, 2019). Indeed, Noble et al. (2019) report that even for Level 1 automation, the information in owner's manuals is not sufficient to teach drivers how systems work, particularly with regard to system limitations.

How quickly will Levels 2 and 3 penetrate the market? Many drivers do not buy or use new cars. In the EU, the average age of a passenger car is approximately 11 years, and the average age of vehicles has been increasing for several years now. There will therefore be inherent (and increasing) differences in vehicle equipment, coupled with the fact that young people who gain experience on the road use older cars. Indeed, as vehicles become more crashworthy, they might remain on the market longer.

Historical modelling of automation systems at Level 2 and above has shown that the rate of uptake is around 5% (using parking pilot, traffic jam assist, and highway autopilot as examples), even though parking pilot (automation Level 4) was present in newly registered cars during the whole study period of 2000–2015 (Restrepo et al., 2019). The authors conclude that this is in line with the early state of innovation for these technologies as well as the fact that current safety regulations restrain the broad use of autonomous cars (European Commission, 2017c; International transport Forum, 2015).

5.4. Knowledge and skills required for Levels 3 and 4 automated driving

As referred to in the previous section, drivers have been expected to use Levels 1 and 2 without specific changes in licensing and training, in spite of the fact that vehicle manufacturers refer to essentially the same technology by varying names (Helman and Carsten, 2019):

> *Adaptive Cruise Control (ACC), the system that matches the speed of a vehicle directly in front is actually called Adaptive Cruise Control by Fiat, Ford, GM, VW, Volvo and Peugeot, but is termed Intelligent Cruise Control by Nissan, Active Cruise Control by Citroen and BMW, and DISTRONIC by Mercedes.*

Under increasing levels of automation, the extent to which the driver engages in all four levels of the GDE Matrix will diminish, if not for the entirety of a journey but for parts of it. The driver will have less of a role in manoeuvring but will instead be required to supervise the automation systems and retain situational awareness of the environment.

Vehicle manufacturers have been able to rely on some aspects of intuitive design at these lower levels of automation, but Level 3 and above will fundamentally change the nature of the driving task. The high-level needs, some of which are defined by the Safe-D project, apply to all levels of automation (Manser et al., 2019), but become particularly pertinent at higher levels. These high-level needs build on those already identified by the GDE Matrix and are summarised as follows:

- The purpose of the ADAS and understanding the varying levels of ADAS (i.e., level of automation) such that users are aware of their own level of responsibility. This is from a survey that found that drivers held incorrect views about what they are free to do once the automation is turned on (Marinik et al., 2014). Another study found that almost half of respondents reported their vehicle had acted in a manner they did not expect (Stewart, 2018), and another found that experience with automation surprises increased drivers' desire for training (McGehee, 2016).

- Transitions between automation and manual modes and how to handle vehicle takeover requests. In such situations, the driver has to (re)place their hands and feet into the correct positions for vehicle control, regain awareness of the operating environment and then execute the appropriate response. Research studies dedicated to defining the time required to safely deactivate the automation and regain control of the vehicle have reported times between 1 and 15 seconds, largely depending on what the drivers are otherwise engaged in, e.g., non-driving related tasks (Naujoks et al., 2018; Eriksson and Stanton, 2017).

- Familiarity with system components, such as sensors and their placement, and knowledge regarding their maintenance. Drivers probably do not know about some of the technical limitations of Level 1 automation, such as ACC and lane-keep assist (LKA), or, for example, that ACC only functions if the grill-mounted radar sensor is not obstructed (by, e.g., mud) and that an LKA camera can be blocked by anything mounted on the roof.

- Understanding of the internal and e-HMIs. See section 3 for a discussion on commonality and intuitive design with regard to HMI. In particular, the stakeholder consultation revealed that respondents agreed that commonality in HMI across manufacturers will increase user acceptance and trust, ease of use, safety and ease of learning.

- Understanding of any new traffic rules. See section 4.4.

- Self-awareness of own capability. Knowing the limits of one's capability should form part of the training for automation (Loeb et al., 2018); however, we cannot expect that drivers, having been informed that vigilance (for example) might decrease after a period of fully automated driving, will necessarily either remember this or mitigate against it. Humans are also prone to many biases, distractions and overestimations of their ability to complete tasks successfully. This is particularly applicable at higher levels of automation, when drivers are able to engage in non-driving related activities. For example, reading (books or screens) whilst checking periodically on the road ahead requires the eyes to accommodate (the process by which the eye changes optical power to maintain a clear image or focus on an object as its distance varies). Many people suffer from presbyopia (the irreversible loss of the accommodative ability of the eye that occurs due to aging) sometime between the ages of 35–45 and require corrective lenses. However, people can be unaware that there is a problem and use strategies to minimise the symptoms (holding a book further away, for example). In addition to their gaze being diverted away from the road, users might have the option to shift their body position and rotate to face passengers in the rear of the vehicle. A recent study reported that facing rearwards in an autonomous vehicle leads to a sevenfold increase in motion sickness compared to forwards, with urban driving being significantly problematic compared to highway driving (Salter et al., 2019).

- Ensuring the appropriate level of driver trust in the automation. Trust has been identified as a key factor influencing reliance on automation, particularly in determining the willingness of a human operator to rely on automation in situations of uncertainty (Muir, 1994). Lee and Kantowitz (1998) noted that trust is one of the most important characteristics of driver cognition that determine the appropriate use of driver-assistance systems. With regard to automation, research suggests that user trust not only predicts whether automation will be used, but also how it will be used. For example, low levels of trust might dissuade users from its use, whilst high levels of trust might encourage misuse and abuse (using it inappropriately) (Lee and Kantowitz, 1998; Lee and Moray, 1998). Relevant to driver training, initial trust, perceived reliability and driver experience can all influence feelings of trust (Payre et al., 2014; Walker, 2018). The level of trust and users' expectations must match the actual capabilities of the system. Muir (1994) introduced the concept of trust calibration as the "process of adjusting trust to correspond to an objective measure of trustworthiness." Mistrust and distrust are examples of poor trust calibration: when an operator's trust in the system is higher than its actual trustworthiness, mistrust occurs, whilst distrust occurs when the subjective level of trust in the system is less than the actual trustworthiness of the system. Research has shown that drivers have difficulties adjusting their level of trust in AVs according to system performance criteria (a key requirement for trust calibration) (Körber et al., 2018).

5.5. When should drivers receive training for Level 3 and 4 automation?

Understanding where drivers obtain or access the vehicles they drive allows us to begin considering where the different points of training delivery are required. It is necessary to consider learner drivers, experienced drivers and drivers hiring a vehicle or using Mobility as a Service products. A matrix of needs can then be assembled (see Table 9).

Table 9: Likely Purchasing Scenarios.

Vehicle obtained	Vehicle source	Information available
Second-hand	Private	In the worst-case scenario, owner's manual (paper copy) is missing.
Second-hand	Dealer	Owner's manual usually present
New	Dealer	Owner's manual provided and supplemented with dealer's knowledge
Hire/Mobility as a Service	Agency	Owner's manual provided; agent might have minimal specific knowledge

Vehicle dealerships sell lots of different makes and models of second-hand cars, so whilst they might be able to source a replacement owner's manual, they wouldn't know about the specifics of every technology that every vehicle is fitted with. Furthermore, multiple studies have indicated that currently many car buyers do not receive any (or insufficient) information about the safety or comfort systems installed on their new car at their dealership (Abraham et al., 2018; Boelhouweret al., 2020a). The driver education for automated systems might amount only to additional pages in an owner's manual (a seldom-used "glove box reference"). Owner's manuals may even be absent from second-hand cars (however, the website "Love to know cars" provides digital copies of many manuals).

5.5.1 Learner/newly licensed drivers

Using the UK as a case study, around 700,000 new driving licences are issued annually. Between March 2019 and March 2020, the total number of licence holders increased from 40.764 million to 41.178 million – a rise of around 400,000[12] (taking into account licences that have expired or been suspended). At any time, approximately 1.5% of the driving population can be considered as "new drivers." A large proportion (in the UK it is 50%) of these new drivers are aged between 17 and 20 years of age, and for many, the cost of insuring their first car will be an important factor when choosing what vehicle to buy. The average premium for a 17-year-old in the UK in 2018 was £1,964, which is around 46% of what drivers in 2018 spent on average for their first car.

[12] www.gov.uk/government/statistical-data-sets/driving-test-statistics-drt.

A new driver's first car purchase will therefore usually be pre-owned, and hence older, thus featuring less safety and comfort technology. Initially, Level 3 and 4 automation will only be featured on some (higher-spec) models but, given past experience with ADAS, could permeate quickly through to less expensive models. Teaching a new driver about specific automation features, which they might never purchase (or at least not in the next few years) is relatively pointless because the information will be forgotten and technology will progress. Also, if there is no standardisation between manufacturers in either function or HMI, current licensing procedures will be insufficient. Therefore, whilst defining, operationalising and updating a range of training regimes to support learning for the use of various levels of automation will be almost impossible to implement, training drivers in some of the generic issues associated with Level 1 and 2 features would provide at least some foundation knowledge. In addition, for those drivers obtaining their licence for the first time, training for automation could be achieved by supplementing existing theory training with issues related to new automation systems, such as those defined in section 5.4 above.

5.5.2 Experienced drivers

If the driver has no prior experience with Level 3 or 4 automation, and the vehicle has been purchased privately (not through a dealership), the driver would not be able to rely on gleaning appropriate and full information regarding automation functionality via the owner's manual (which might be missing from the vehicle) or the vendor (who might not provide correct information). If the vehicle is purchased through a dealership, the driver is more likely to have access to an owner's manual and to acquire some verbal information from the salesperson. Those drivers with experience with automation might find that their previous experience is useful (with the same model of vehicle and level of technology) or disadvantageous (if they have to rely on outdated or irrelevant knowledge).

5.5.3 Hiring a vehicle/using Mobility as a Service options

When hiring a vehicle or using Mobility as a Service options, there is often little choice regarding the exact make and model of the vehicle; rather, one pays for a "class" of vehicle related to size amongst other things. Requests for particular features such as automation might not be fulfilled, thus risking a driver using a vehicle that does not have the automation features that they are familiar with. Couple this with unfamiliar roads, traffic regulations, etc., with a driver in a heightened state of anxiety, and errors may be more common.

5.6. A potential approach to training for Level 3 and 4 vehicle automation

Assuming that no drivers (newly licensed and experienced) have been required to undergo formal training on Level 3 or 4 prior to the point of purchase of a vehicle, there are a number of options that can be considered.

5.6.1 Pre-purchase training

Drivers could be required to undertake formal, mandatory training before taking possession of the vehicle. The training provided would be specific to the automation functionality present on the vehicle, but not necessarily tailored to the manufacturer's branding. This would require collaboration between vehicle manufacturers and the licensing agencies of Member States such that proof of training would be provided at the point of sale. The advantage of this option is that it shifts the responsibility from the dealership to the vehicle owner, but with the disadvantages that it could be time consuming (i.e., requiring advance planning on the part of the vehicle purchaser) and would still require the development of a range of certified training programs. The need to undertake further training might also be unattractive to some drivers and hence they might opt for a Level 1 or 2 vehicle instead.

If such training were to be considered, the use of virtual reality, simulators and test tracks could be explored. Research has shown that experience with road driving can lead to a better understanding of a vehicle's limitations and to proper trust calibration of automated vehicles (Casner and Hutchins, 2019). The advantage of interactive learning is that trainees can pause and restart the video, allowing for the development of a more appropriate mental model (Arguel and Jamet, 2009) and deeper learning, compared to a verbal instructional format (Mayer, 2003). Driving simulators can provide a more controlled environment and can be effective in skill training (Sportillo et al., 2019), but the use of simulators for training automation skills has not been extensively explored, apart from take-over requests (Milleville-Pennel and Charron, 2015; Payre et al., 2017; Sportillo et al., 2018). Wizard of Oz applications have been used as a half-way measure, where drivers believe the vehicle to be autonomous, but it is actually still controlled by a human (Hergeth, 2017). Virtual reality and augmented reality offer further options for training. Whilst virtual reality creates an isolating experience, augmented reality can be used to enhance real-life driving skills, and some transfer of training into real-life autonomous driving has been reported (Casner and Hutchins, 2019). Currently, virtual reality technologies are primarily used to train safe driving habits, especially for young drivers (Wang et al., 2017; Lang et al., 2018). The training programs based on virtual reality are effective in improving the ability of inexperienced drivers to perceive hazards and in preparing them to function in real traffic (Agrawal et al., 2017; Toyota, 2019).

5.6.2 In situ coaching

An alternative to pre-purchase training would be to assign the vehicle as coach/trainer. Such an in-car tutoring system has been suggested and investigated in studies such as those by Simon (2005) and Boelhouwer et al. (2020b). Where a driver purchases a new or used car from a dealership, the following training regime could be instigated.

1. Forecourt introduction – high-level face-to-face introduction of the main vehicle-specific automation functions. Given that this relies on memory and there is no driving context, this introduction should be brief, nontechnical and provide an overview of the coaching facility.

2. Coaching period – when the driver takes possession of the vehicle, it runs in "coaching" mode, where drivers are required to engage/disengage automation, such that handover can be practiced. This is recorded and feedback provided at the end of each trip. The length (time or distance) of the coaching mode depends on driver performance.

3. Probation period – following the coaching period, the driver enters a probation period. Feedback can be provided to the driver based on his or her interactions with the automation and the errors/misuses recorded. When a minimum threshold is reached, the driver can proceed to the next stage.

4. Normal operation – no coaching (or a refresher course if a problem is flagged).

One possible scenario is that the driver becomes "stuck" in the probation period, in which case they could go back to the coaching period. Likewise, drivers could request to return to stage 2 or 3 at any point.

5.7. Inculcation and retention of manual driving skills

There are two main issues to be resolved with regard to the training and retention of manual driving skills (i.e., those that might become defunct in Level 3 to 5 automation).

First, should driver training and testing continue to be carried out in a vehicle without automation (even Level 1) to ensure that drivers learn all the manual skills necessary for the safe operation of a vehicle? Or should training keep pace with technological advances and thus incorporate the use of automation in the training program? Currently, the training system adopts the first ethos and drivers then follow an individual "skills and knowledge path", depending on the vehicle they choose to drive. However, in order to realise the safety benefits of AVs, drivers have to be trained in its proper use, whether that be via intuitive design or formal instruction (by either an instructor or the vehicle itself).

Drivers who have gained their licence in the traditional way (by undertaking their training in a vehicle that at the very most features Level 1/2 automation) are at risk of skill degradation as their reliance on Level 3/4 automation increases. Skill degradation has been a significant issue in aviation, and in order to counteract it, pilots are regularly required to disengage the automated systems in order to refresh their skills. In addition, the Federal Aviation Authority recommends that pilots fly in manual mode more than in autopilot mode.

With respect to car drivers, the types of skills that might be in danger of degrading include the maintenance of longitudinal and lateral control, parking, and handling weather conditions (e.g., rain, fog, snow, ice). Behavioural studies also indicate that following the use of AV technology, lane-keeping performance is reduced, shorter headways are accepted and reaction times delayed (Eick and Debus, 2005). Elvik's (2006) work on crash involvement suggests that hazard perception improves as the number of miles travelled increases. Not accruing such experience could therefore have a bearing on a driver's ability to detect and react appropriately to a hazardous situation in manual mode.

Not only might manoeuvring skills be lost, cognitive skills might also suffer from the lack of regular use. In a simulator study using experienced pilots, Casner et al. (2014) found that whilst their ability to scan instruments and manually control the plane was mostly intact following a period of flying with automation, cognitive skills, such as tracking the aircraft's position or recognising system failures, worsened.

Spulber (2016) suggests that, similar to the aviation sector, procedures for minimum periods of manual driving or recurrent training on simulators (for vehicles that will still offer the option of manual operation) might help to reduce the likelihood that drivers lose their skills, thereby retaining the ability to act appropriately when faced with an automation failure.

5.8. Fitness to drive and aging

The 2006 Directive suggests minimum standards of physical and mental fitness for driving a power-driven vehicle (essentially cars/bikes and larger/passenger-carrying vehicles) for two classes of drivers. The categories include sight, hearing and various other chronic and acute medical conditions. In addition, there might be "notifiable" medical conditions, where it is the responsibility of the affected person to inform the licensing body. Where driver intervention is still required (Level 3/4), there is no reason to relax any of these requirements. For those "drivers" who are unlicensed or have had their licence revoked due to these medical conditions, they become winners in Level 5 automation, given that it would be akin to public transport: the vehicle can make personalised and self-scheduled trips.

With healthy aging (i.e., no known underlying medical conditions), it is likely that automation will appeal to this demographic, given the trend towards an aging population and that research indicates that a significant reduction in older people's mobility can lead to increased social isolation, loneliness, depression and reduced self-esteem (Li et al., 2019; Charlton et al., 2006). Li et al. (2019) carried out a qualitative semi-structured interview study with 24 older drivers, investigating their requirements for highly automated vehicles. Participants required an information system and a driver-monitoring system as well as an adjustable, explanatory and hierarchical take-over request. In general, they were positive towards the concept of highly automated vehicles.

With regard to the critical safety scenario of a request to take over control, there is little research evidence to suggest that older drivers would be any less effective compared to their younger counterparts (Hakamies-Blomqvist and Wahlström, 1998; Miller et al., 2016). In fact, there is some evidence to suggest that the take-over performance of older drivers might be safer and more cautious (Molnar, 2017; Körber, 2016).

5.9. Outcomes of stakeholder consultation

The stakeholder survey (see Appendix 11.5) included nine questions related to driver training and licensing and was completed by 16 respondents. The results indicate the following:

1. The majority agree that the 2006 European Directive on driver licensing should be updated to include the skills and knowledge required to operate a Level 3 or 4 automated vehicle.

2. They were more neutral regarding whether that knowledge should be incorporated into the licensing process, via the theory test.

3. As regards issuing different levels of licence to newly qualified road users for different levels of automation, respondents were equally split between those who agreed and those who disagreed.

4. There was also a fairly even spread between those who agreed with the idea that all road users who purchase a new vehicle should undergo an on-road coaching period, those who were neutral about it, and those who disagreed.

5. However, the majority were either neutral or agreed with the proposition that road users should obtain skills for handling automation when they buy a vehicle.

6. The idea that drivers who purchase a second-hand car with automation should automatically have access to a coaching mode also split respondents fairly equally into those who agreed, disagreed or were neutral.

7. Moving on to whether drivers of hire cars or shared mobility should be exempt from automation training, respondents were clearly not in favour of this, although they were more undecided regarding the relaxation of minimum standards of physical and mental fitness for driving an automated vehicle.

8. Finally, respondents were evenly split with regard to their opinion about where training for automation should take place, with no clear preference for this to be undertaken on closed test tracks and simulators only.

In addition, the stakeholder workshop (January 2020) provided further discussion points on the topic of driver licensing.

1. With reference to the owner's manual, typically provided with a vehicle, it was noted that they are not detailed enough and would need to be supplemented with dealer's knowledge (noting also that this would need to be updated regularly, given the pace of technology development).

2. Related to this point about training, there was a discussion regarding the (safety) benefits of automation. Drivers are not yet using the full potential of Level 2 systems because, even if they have been introduced to these systems, they are not trained enough to use them, so the same could be true for Level 3 and 4 automation.

3. There was concern regarding loss of skills, such that if a driver used a Level 3/4/5 vehicle for any length of time, he or she might forget how to drive manually. This would imply the need for constant training and checking.

4. There was some agreement that regulations regarding fitness to drive should not be relaxed (i.e., no changes regarding alcohol levels and requirements around driving capability) if drivers were required to take control and drive manually at any point.

5. Some discussion regarding the type of coaching that could be provided ensued, with agreement that this should be simple and could be completed quickly (otherwise it would imply that the automation functions were complicated).

6. In the interactive polls, stakeholders clearly agreed with the idea that trainee drivers should be trained and tested in "skills for automation", but were split in their opinion as to whether vehicle manufacturers should be obligated to design and implement a coaching system. Again, stakeholders agreed strongly that regulations on fitness to drive should remain as they are for Level 3 vehicles, but that there could be some relaxation for Level 5. Opinions were less clear with regard to the issuing of different levels of licence to newly qualified drivers for

different levels of automation. Some thought this would be difficult to implement and enforce.

5.10. Recommendations to the commission regarding driver licensing

The advent of higher levels of automation in vehicles brings a series of changes that require action in several policy areas. From the analysis of the different areas of impact presented above, clear lines of policy action are required.

1. The 2006/126/EEC Directive on driver licensing, which describes the knowledge, skills and behaviour required of all drivers of power-driven vehicles should be updated in relation to those required for automated driving, as listed in section 5.4. This should be undertaken by the European Parliament and the Council of the European Union.

2. For new drivers, it is recommended that this new knowledge be incorporated into the training process, via the theory and practical tests. This is actionable by the licensing bodies of individual countries.

3. The means for drivers to successfully obtain skills for driving a car with any level of assistance and automation should be provided when they acquire/hire a vehicle. Vehicle manufacturers should be obligated to provide the necessary and appropriate level of training in their vehicles.

4. For new vehicles (zero or near zero miles on the odometer), drivers should have a coaching period, embedded in the automation by the vehicle manufacturer.

5. For second-hand vehicles, a reset option should be available, which, when triggered, would cause the vehicle to enter coaching mode again.

6. To facilitate the design and development of user-friendly coaching tools, research is urgently needed regarding the most effective and efficient way of learning and evaluating skills in a safe and convenient manner, such that the safety benefits of automation can be realised as quickly as possible. This research should form the focus of a workstream in Horizon Europe.

6. TRAINING OF PROFESSIONAL DRIVERS

The main objective of this chapter is to analyse the specific characteristics and issues that concern the deployment of automation in the professional environment. This directly ties into existing EU legislation, in particular Directive 2003/59/EC, which deals with the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers. An introduction to EU training of professional drivers (Section 6.1) is followed by Section 6.2, an analysis of the revised[13] Directive 2003/59/EC. In Sections 6.3 and 6.4, required knowledge and skills in the professional environment are explained in light of SAE automation levels 1/2 and 3/4, respectively, and Sections 6.5 and 6.6 provide suggestions for new approaches to the training of professional drivers in light of automation. This chapter concludes with the results of the stakeholder consultation (Section 6.7) and the final recommendations (Section 6.8) for training professional drivers.

6.1. Introduction to EU training of professional drivers

The evolution towards more automation requires new skills and routines involving the management and supervision of the vehicle operating in automated mode. These routines require new competencies, with respect to which, the question arises as to which competencies should be added to the training of professional drivers. Additionally, one could ask whether training in these new competencies requires special training methods and contexts. Training on the skills involved in automated driving can be incorporated into the initial qualification, as well as the periodic training of professional drivers obtaining or extending their certificate of professional competence (CPC). On the one hand, adding new subjects to the training curriculum provides an incentive to Member States to augment their national traffic safety regulations; on the other hand, training is expensive and can be a barrier to new drivers entering the profession. There has been a continued shortage of professional drivers in Europe for more than a decade, so, while new topics that encourage safe and skilful driving should be added to the training programme, it should be done in a cost-efficient and time-effective manner.

With the progression of automation technology, it is likely that the competencies required for automated driving will continuously evolve. Periodic training on automation would allow professional drivers to become familiar with new technologies and contexts in a timely manner. The context will continuously change to include new compositions of road users, and in turn, the infrastructure will follow these new traffic mixes with such facilities as vehicle-to-infrastructure (V2I) communication. Technology is rapidly evolving, so the requirements for new skills and knowledge could be addressed in the regular, periodic training of professional drivers once every five years. This would help drivers to familiarise themselves with the new regulations and skills involved in automated driving as they evolve.

There are some trends related to technical, social and economic factors in the deployment of automated vehicles that might significantly influence the transport sector. In contrast to conventional vehicles, AVs and CAVs will in a sense never leave the factory. The ability to wirelessly install upgrades or patches that completely alter vehicle behaviour is part of automation. Thus, it is important to have in place a dedicated platform to test updates,

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[13] Directive 2003/59/EC has been amended by Directive 2018/645.

and a test site with physical vehicles on a road, in order to test software before it goes into production. Truck and bus manufacturers will be able to monitor the vehicle in use and collect data about operational malfunctions. Drivers should be aware of updates and how these updates affect the system.

Contrary to conventional vehicles, AVs and CAVs may lead to new policies in mobility, one of which could be reduced personal car ownership. Cars might not be owned by individuals but by companies or local authorities. Individuals will then request transportation and will become customers paying for mobility services. Car manufacturers and governments would then be responsible for mobility and the safety of the passenger. However, these tendencies are less likely to apply to large transport vehicles, which carry greater liability and require human drivers to monitor the system in order to take over control in case of hazardous situations. Analogous to a train engineer or airplane pilot, the professional driver carries out a twofold task: driving the vehicle manually when the automated mode is not allowed, and monitoring the system when automated mode is operational. This latter task is a new one and will require knowledge of the system. A mental representation of the system is helpful in order to understand communication and interaction with the system (Carsten and Martens, 2018).

Before Directive 2003/59/EC went into effect, cross-border professional drivers and their transport firms were not required to invest in mandatory training, giving them a competitive advantage over domestic drivers and firms. Now, under Directive 2003/59/EC, training is obligatory in all Member States, which has improved the safety of European roads. International transport with heavy-goods vehicles represents more than 30% of the total cargo transported by road in the EU, and many drivers actively cross borders from one EU Member State to another. Because of this professional cross-border traffic, many countries are hesitant to implement the additional national requirements for driver training that are listed in Directive 2003/59/EC or to add the additional subjects, which would create an uneven playing field in which foreign drivers, with, perhaps, a lighter training programme, would have lower costs. This continues to be a hurdle in cross-border transport as there are still many differences between countries and regions in the cost, content and intensity of training programmes and training tools. For this reason, therefore, Member States should be eager for a more minimal reading of the directives in order to equalise driving competencies in the Member States that are lagging behind.

Another problem in the transport sector is the shortage of new people training to be professional drivers. The free movement of workers is a fundamental European principle, and it compensates for labour shortages in western Member States. The shortage of manpower in the road haulage sector has been partly solved by drivers from new Member States moving on a temporary basis to older Member States. In several Member States, local bus/coach operators employ drivers who were previously resident in other Member States. However, in recent years the shortage of professional drivers has increased and now affects all Member States. A poll of members of the International Road Transport Union and associated organisations in Europe from October 2018 to January 2019 revealed a driver shortage of 21% across the freight transport sector. Imposing substantial initial qualifications and high-quality standards carries the risk that young drivers will be discouraged from entering the profession. Although such high standards might elevate the reputation of the profession, this will not solve the problem in the short run.

Another goal of the directives relating to professional driver training was the estimated reduction of crashes by about 3%. However, this amount has been subject to debate, with some studies indicating that driver training has no measurable effect. Mayhew and Simpson (2002) pointed out that the effectiveness of courses might be improved through a more judicious selection of content, with emphasis being placed on those skills that have been shown to be related to collisions, such as hazard recognition and risk assessment. Young drivers are particularly vulnerable and could profit from the right content.

6.2. Directive 2003/59/EC

As discussed above, Directive 2003/59/EC is concerned with the initial qualification and periodic training of drivers of specified road vehicles for the carriage of goods or passengers and is part of the overall effort to increase safety on European roads. It defines the requirements for the qualification and training of professional drivers. The Directive was adopted because the qualification and training of drivers engaged in the transport of goods or passengers by road is highly relevant and important for all Member States. The purpose of the Directive is to raise the standard of new drivers and to maintain and enhance the professionalism of existing truck and bus drivers throughout the EU through continuous and timely updates of their capabilities.

6.2.1. History of driver training in Europe

Before the introduction of Directive 2003/59/EC, the training of professional drivers was not mandatory in most Member States and was not standardised in the few states that tried to improve competencies among professional drivers. Under Council Regulation (EEC) No 3820/85 of 20 December 1985, for example, some young drivers were required to hold a CPC, depending on the vehicle. In most Member States, there was no separate training scheme or initial qualification for professional drivers other than the training for the driving licence itself. Prior to Directive 2003/59/EC, only a very few professional drivers were periodically trained beyond the training for a normal driving licence.

Under Directive 2003/59/EC, every professional driver needs a CPC for carrying passengers or driving vehicles with a weight of 3.5 tonnes or higher. The standards for new drivers were raised, contributing to a focus on the driver’s awareness of risks and how to minimise them. The first step towards harmonising regulations for training and qualification throughout the EU has been established, and all Member States have started to implement the compulsory initial qualification and periodic training, which has enhanced the free movement of workers within the EU. The training is carried out by centres approved by the Member States and leads to the CPC.

The CPC is mandatory for drivers of vehicles for which a C or D driving licence is required. It certifies the initial qualifications for professional drivers and thereafter the completion of periodic training of 35 hours every five years. The initial qualification had to be implemented for new bus drivers by 2008 and for new truck drivers by 2009 in the Member States. Drivers with a CPC had until 2015 or 2016, respectively, to complete their first periodic training. After the requirements for the CPC have been satisfied, “Code 95” is then printed on the driver’s licence or qualification document.

A detailed post hoc evaluation of Directive 2003/59/EC was carried out in 2014 (Panteia and Transport & Mobility Leuven, 2014) to examine the relevance, effectiveness, coherence, utility, efficiency and EU added-value of the Directive. It provided input to

Directive 2018/645, amending Directive 2003/59/EC, which provided a foundation for adding new topics to the teaching curriculum, such as automation.

6.2.2. Analysis of Directive 2003/59/EC

Documentation obtained from the EC's webpage and other sources was analysed in order to deepen the Consortium's understanding of the Directive on professional training and its context. As mentioned above, an independent ex post evaluation of the Directive was carried out in 2014 (Panteia and Transport & Mobility Leuven, 2014), albeit with an eye for its impact on road safety, as well as economic, social and environmental effects.

Directive 2003/59/EC paved the way to the harmonisation of EU rules on the minimum level of training for the CPC and it modernised the subjects covered by the training of professional drivers.

Member States have a choice between options relating to the initial qualification. There are two procedural guidelines for standardising initial professional qualifications:

- A course (mandatory attendance) followed by a test

  The training takes at least 280 hours. Each trainee driver should drive for at least 20 hours individually, accompanied by an instructor, in a vehicle that meets the requirements concerned. The topics covered in the training and tests are defined in Annex I of Directive 2003/59/EC. The minimum requirements for the initial qualification and the periodic training concern the safety rules to be observed when driving and while the vehicle is stopped.

- Theoretical and practical tests without compulsory course attendance

  The practical test consists of a 90-minute driving test and a practical test showing the driver's ability to load the vehicle in the correct way (driving licences C and D) and to ensure the comfort and safety of passengers (D). Other practical abilities that are tested include such things as the ability to assess emergency situations (C, D). The subjects of the tests are listed in Annex I, section 1 of Directive 2003/59/EC.

Some Member States have adopted the second procedure and organise tests. The quality of the training content is easier to evaluate by assessing the subjects and their responses. Other Member States have adopted the first. They have the advantage that trainees are receiving more hands-on practice. In light of automation, hands-on training and practice in simulators might be a good approach for teaching the motor and cognitive skills needed for interaction with the ADS and for performing smoother transitions of control. However, these skills will only be transferable to other vehicles or ADS when the major features of the HMI are harmonised (see *commonality* in chapter 3). (The skills concerning the major HMI features are discussed in more detail in section 6.4, below.) Note that research on training with a simulator suggests that simulators are fine for teaching basic skills, but retention is not great. Training higher-order skills is better done on-road, with context and a proficient trainer (Vlakveld, 2005).

Directive 2003/59/EC set minimum ages that depend on the kind of training and the category on the driving licence. With automation, minimum age limits are not needed because there is no evidence that young drivers would need more time or practice to learn to interact with the ADS.

According to Directive 2003/59/EC, professional drivers shall undergo periodic retraining in the skills essential for their profession. The duration of the training must be 35 hours every five years, given in periods of at least seven hours. Periodic training is given on a sufficiently frequent basis and is aimed at updating the knowledge that is essential for the work. It can also be useful for providing updates to the latest state-of-the-art technologies, including ADAS. Because periodic training every five years is covered in the Directive, no further legislative action is needed. What will be required to update the knowledge and skills of the driver on ADAS and automation will depend on how new technologies have evolved over the five years.

The amendment to the Directive states (Directive (EU) 2018/645, Art. 7): "The training subjects shall take into account developments in the relevant legislation and technology, and shall, as far as possible, take into account the specific training needs of the driver." This provides a way to update the training and include new training subjects related to automated driving.

The following training objective can be cited from the amendment (Annex I):

> *…to know the technical characteristics and operation of the safety controls in order to control the vehicle…and prevent disfunctioning: limits to the use of brakes and retarder,… action in the event of failure, use of electronic and mechanical devices such as Electronic Stability Program (ESP), Advanced Emergency Braking Systems (AEBS), Anti-Lock Braking System (ABS), traction control systems (TCS) and in-vehicle monitoring systems (IVMS) and other, approved for use, driver assistance or automation devices.*

This makes the subject of the training more contemporary with the addition of ADAS and automation. Therefore, in our expert view, we believe that no immediate legislative actions are needed because the current directive provides the necessary means to extend the training curriculum to include automation.

6.3. Required knowledge and skills in light of Level 1/2 automation

Whether the training of professional drivers contributes to the reduction of road accidents is still an open question. It probably has contributed to reducing human error, which is believed to be the major cause of accidents. For instance, a lack of experience can result in improper manoeuvres and mistakes in braking. Accidents often occur because the human driver is distracted or inattentive. This is further mediated by fatigue, especially among professional drivers who follow itineraries of many hours. Learning to recognise the symptoms of fatigue is an important self-awareness skill for professional drivers. Unlike humans, however, automated systems can stay focused continuously.

A lack of vehicle knowledge can result in bad operational judgments or improper reactions. An example of this is believing that there is no risk of an accident with an automatic emergency breaking (AEB) system, leading to over-trust and overreliance. The physical reality is that a 40-tonne truck can have a longer breaking distance than the sensor range of the AEB system. The latest generation of forward collision warning (FCW) and AEB systems is designed to detect other vehicles, pedestrians and other vulnerable road users, while older-generation FCW or AEB systems are only capable of detecting other vehicles. Having these Level 1 and 2 systems on board does not mean that the driver can stop paying attention to the road. Vehicle knowledge implies that the professional driver knows that these ADAS are fallback systems in case of human error and that they are not designed to take over the driving task. Knowledge of vehicle performance prevents overreliance on these technologies. Drivers, and especially professional drivers, should be aware of the limitations of these technologies.

6.4. Required knowledge and skills in light of Level 3/4 automation

Over many decades, driving will evolve from active manual control functions to tasks involving programming and monitoring the ADS. As drivers spend less time driving, their proficiency at manual driving might degrade. Therefore, drivers should repeatedly monitor their ability to drive and voluntarily drive in manual mode regularly. Driving skills should be maintained and preserved, so, in addition to the compulsory CPC training, organisations and companies should support their professional drivers by encouraging on-the-job training and experience to help them cope with new challenges and maintain their driving capabilities.

Most current ADAS are designed to be effective within a specific range of speeds and might not function properly under certain environmental conditions (e.g., rain, fog, glare/bright background light), depending on the underlying technology. Level 3 automated driving and above differs from ADAS in many ways (Benson et al., 2018). One of these differences is that automated driving systems should be able to verify that the ODD conditions for driving safely in automated mode are met. When these conditions are not met, the automated system should initiate a take-over request.

The range of tasks is expanding. The human is part of the driving system as a supervisor and as a driver, so in addition to manual driving, the professional driver needs to know how to supervise control of the vehicle. Initial qualification could aim at teaching the driver to interact with the HMI. Although the nonprofessional driver should also have a basic understanding of the HMI, the greater responsibility of driving public transport or heavy goods led us to elaborate further in section 5.4 (Knowledge and skills required for Level 3/4 automated driving). Drivers should know how to interact with the HMI (Abascal and Azevedo, 2007; Carsten and Martens, 2018). This involves the following:

- In chapters 3 and 5, we discuss how drivers should be able to recognise the operational mode of the system (automated, semi-automated or manual). In addition, the driver should be able to recognise robust system behaviour and develop a sense for misbehaviour (e.g., a system that goes idle). The professional driver should learn in which situations he/she cannot override the ADS as well as rules on how a system can be overridden when necessary to conform to local regulations (see chapter 4).
- The driver should learn about the different categories of messages that the system displays. He/she should be able to distinguish messages that require immediate action, messages that require later action, and messages that have mere informational value. The driver should be able to recognise the alerts of the system and the meaning of these alerts. These messages and alerts can be different for buses and trucks compared to regular cars (for example, messages concerning the truck load).

- Some operations require back-and-forth interactions with the system. Drivers should learn to understand and carry out all necessary actions required for this form of communication and tasks. They should know how to check and use the instrument panel. If HMIs are not harmonised, these skills will hardly be transferable from one type of AV to another.
- Being part of the back-and-forth interaction, a major challenge for the first-generation AV is to manage handover requests in a timely manner (see also chapters 3 and 5).
    - The time needed to take over steering largely depends on the situational awareness of the driver at the time of the take-over request. Secondary tasks (e.g., the driver performing inventory or stock management behind the steering wheel) or recreational activities should be discouraged in the first generation of AVs because these activities reduce situational awareness and set the supervisory driver outside the loop of control. Because freight and passenger transport carry greater responsibilities, it is important that drivers keep their eyes on the road and keep monitoring the automated system. Except for platooning, the driver should not be involved in secondary tasks.
    - It was found that there were differences observed in reaction times based on the type of disengagement, type of roadway and automated miles travelled. Reaction times were found to increase with increased vehicle miles travelled (Dixit et al., 2016). Because professional drivers travel long distances, there is a higher potential risk of overreliance on the ADS, leading to a loss of focus on monitoring the ADS and the road. For SAE Levels 3 and 4, it is best to explain this effect frequently in the compulsory periodic training. Overreliance can result in a loss of situational awareness, leading to a longer reaction time in case of a takeover request. Although Regulation (EU) 2019/2144 is now in force and makes ADAS such as the driver drowsiness-and-attention warning and the advanced driver-distraction warning mandatory, these systems only cover overt kinds of inattention and distraction.
    - Another psychological effect of driving long distances is habituation. Professional drivers should be aware that behaviours related to automated driving might carry-over to manual driving. For instance, if ODD conditions allow platooning with short distances between the trucks, drivers could become habituated to platoon conditions. Simulator studies have shown that drivers who have driven in a platoon, relying on adaptive cruise control, tend to continue following more closely after having left the platoon (Skottke et al., 2014). Training to make drivers aware of this habituation bias can be helpful.

In light of objective 1.2 in Directive 2003/59/EC (Annex I), "…to know the technical characteristics and operation of the safety controls in order to control the vehicle,…" a driver should be able to understand the basics of data processing and ADS behaviour. This should be similar to how they learn the function of the most important vehicle parts and could consist of the following subtopics:

- How the system makes and carries out decisions and how the system prioritises decision making; how the system executes actions and how the system prioritises actions. In Level 3 automation and higher, object and event detection and response (OEDR) systems are the heart of the artificial intelligence, interpreting situations and carrying out decisions. Professional drivers can acquire a basic understanding of the OEDR, which would help them understand how the system behaves in complex and in ambiguous situations and how it deals, for instance, with different weather conditions.
- Professional drivers can acquire a basic understanding of controllers and how they maintain the task of driving. They can learn about the optimal values of the parameters that concern the automated driving task (e.g., maximum velocity, maximal deceleration, emergency braking deceleration, recommended time gap or gap distance, desired velocity, etc.). Some of these parameters may be customisable (e.g., eco mode <=> normal mode <=> sports mode), which would tie straightforwardly into the revised Directive 2003/59/EC, objective 1.2: "…making better use of speed and gear ratio, making use of vehicle inertia, using ways of slowing down and braking on downhill stretches…;" and 1.3: "optimisation of fuel consumption by applying know-how as regards points 1.1 and 1.2, importance of anticipating traffic flow, appropriate distance to other vehicles and use of the vehicle's momentum, steady speed, smooth driving style…".
- Drivers should be able to notice improper behaviour and malfunctions of the system and report these to authorised persons or organisations. They should be able to notice shortcoming and they should be encouraged to report these shortcomings to the OEMs.
- Sensory information is provided by radar, lidar, near and far infrared devices, ultrasound sensors, and cameras in addition to other informational sources such as GPS and C-ITS messages. All these informational sources carry out specific measurements that lead to different kinds of sensory input. Recognising the different sensors (or antennas) and knowing their location on the vehicle, their maintenance guidelines and basic functions should become general knowledge. Drivers are better prepared when they know in which contexts the sensors operate well or may fail. A proficient ADS supervisor or monitor forms a mental image of the kind of sensory information the system collects and processes. This mental image is helpful in recognising contexts in which takeover requests might be issued. The range of on-board systems is limited, so the driver should also know the limits of the sensors. The configuration of the sensors installed today is very specific to the OEM.

Other useful topics include the following:

- Drivers might benefit from learning about the different systems/vendors available on the market and the major differences between those systems with respect to their professional activity. Driver training should be customised with respect to the system deployed in the automated vehicle. Harmonisation of the HMI principles, such as the display position and style of the alerts that require immediate action is an important step in terms of safety and can prevent a sprawl of emerging HMI systems on the market. Common, harmonised principles would allow drivers to drive different types of vehicles, which would not only improve safety but would also help mitigate the shortage of professional drivers. One possible method to improve harmonisation would be to converge towards a set of universal HMI principles and adopt this set in driver training programmes. OEMs that deviate from the standards might be held liable for their own system and for the required training of their deviating system (using pre-purchase training or in situ coaching).

- Drivers should learn about liability. ADAS are features designed to make the driving task easier and safer, but drivers are still liable if there is accidental damage or a violation of traffic rules. For SAE Levels 1 to 3, the professional and non-professional driver should be aware that they bear the ultimate responsibility while the system is driving in automated mode. Liability for SAE Level 4 and higher is still an open issue. However, reminding professional drivers of their responsibilities in the periodic training could be helpful to ensure that drivers understand the system functionality and their roles and obligations in automated driving. The subject of liability has already been covered in the revised Directive 2003/59/EC, but the legislative work on liability for automated driving is still ongoing.
- Proper training regarding remote driving/operation is necessary, and there are different levels to consider, depending on the context. For example, it has been shown that if remote operation is too much like a computer game, the operator might be more reckless.

In chapter 5, we discussed how traffic rules evolve and that a driving licence indicates that the holder is familiar with the rules and regulations related to the relevant vehicle. In the future, some of these regulations will concern automated driving and should be included in periodic training as well as initial training in order to ensure that drivers are up to date with new regulations as they evolve. For instance, there is still no decision regarding when I2V messages should be given priority over to road signs and signals (see chapter 4). With cooperative information becoming available in vehicles, the training of professional drivers should make clear how priorities are set.

6.5. Professional training of Level 1/2 automation

In section 6.3, we discussed how professional drivers should have knowledge about the vehicle’s performance. A lack of understanding of how the vehicle operates could lead to overreliance on the technology (e.g., believing that the AEB prevents collisions at all times). This issue is covered in objective 1.2 of the revised Directive 2003/59/EC:

> *…limits to the use of brakes and retarder... action in the event of failure, use of electronic and mechanical devices such as Electronic Stability Program (ESP), Advanced Emergency Braking Systems (AEBS)….*

This provides the legislative basis for including this in the training curriculum, but it seems, from conversations with people in the field, that there is too little awareness of the danger of overreliance on Level 1/2 technology. Our recommendation is to explicitly take this up in the periodic training as well as the initial qualification. If practical training is available (e.g., simulators and test tracks), it is best to make professional drivers experience these Level 1/2 limits in order to increase awareness.

6.6. Professional training of Level 3/4 automation

Humans develop skills to anticipate unexpected traffic conditions. In conflicting situations such as traffic deadlocks, human road users will always find a solution by using their imagination. In contrast, automated vehicles are programmed to follow traffic rules, and as a result they will display different behaviours than human drivers. Although automated vehicles follow traffic rules and might mimic human behaviour, their decisions can be unexpected in particular contexts. For instance, an automated truck might start to accelerate when entering the off-ramp leaving slow-moving traffic on the motorway. Through experience during the deployment phase of Levels 3 and 4 automation, ambiguous situations will be disambiguated, and infrastructure will be adapted accordingly. Likewise, professional driver training needs to be flexible in order to incorporate these changes in automation and to assimilate new practises as they develop. Today, there are only a few prototype automated vehicles on public roads in pilot experiments, so there is little practical experience with the impact of automated vehicles in traffic. It remains to be seen which contexts are ambiguous to machines. More research and experience is needed on Level 3/4 automation in order to extend the curriculum to cover the proper skills.

Developing regulations for automated vehicles is ongoing in policymaking, as we learn how traffic management and socioeconomic opportunities from automated driving will evolve. Our recommendation is that – before expanding the scope of training to include automated driving – all member states should ensure that the revised Directive 2003/59/EC is adopted in an ambitious way. Then, the curriculum can be extended with subjects tackling the shortcomings and pitfalls of driving in automated mode.

However, considering the additional costs, the shortage of professional drivers and the fact that the deployment of Level 3 ADS or higher has still to take off in the professional environment (while legislative action on liability issues and harmonisation of HMI is ongoing), staying in the preparation phase of new subjects concerning Level 3/4 automation is recommended until more evidence is gathered on the training methods and skills needed for automated driving. For instance, it is still an open debate whether the transitions of control can always be carried out in a safe manner.

Depending on the general consent in this debate, hands-on training and practice is probably the best approach for learning to carry out transitions of control. This involves motor skills that can become automatic behaviourally so that humans can take over steering more quickly, with fewer errors and carry-over effects. However, the more habituated the driver is with one system, the more errors that will be made with another if HMIs are not harmonised.

Different displays, buttons and levers are used by different OEMs. Provided that the main features of the HMI are harmonised among suppliers of ADS (see *commonality* in chapter 3), driver training exercises in simulators can be set up. Some training subjects cover OEM-specific features, while others cover general knowledge that ties into abstract principles. However, many principles will become more concrete as the HMI and driving modes of automated vehicles are standardised. Making OEMs responsible for driver training when their system deviates too much from the standard, and shifting liability to OEMs for aberrant automated driving procedures, is a way to force them to cooperate on harmonisation to the degree of reaching commonality by adopting the same general HMI principles.

6.7. *Outcomes of stakeholder consultation*

On Level 2, an attendee mentioned that a large risk in truck platoons is distraction probably, because of the monotonous pastime. If your truck has been following another truck very closely for an hour, you might not be paying attention to the distance between you. If something happens, you will have little time to react, and it might be difficult to see what is going on because you are very close, having no line of sight. Attendees asked how to maintain the focus of the driver, and the panellist answered that the vehicle should inform the driver when it goes beyond the ODD, and the driver should take over in time or go through the MRM. One of the solutions to maintain focus would be to monitor the driver (e.g., waking up a sleeping driver with special alert). These features are compulsory on new vehicles by Regulation (EU) 2019/2144.

In the case of driver-monitoring systems, an attendee stated that there have been more technical requirements in these systems. So far drivers are only tracked to see if they have their eyes on the road, and it has been shown that this does not guarantee safety because you might not be focused even if you are looking through the window. The attendee asked Mr. Maerivoet if there would be more solutions in the future. The answer was that OEMs and specific working groups might have a comprehensive understanding of upcoming solutions. Mr. Carsten closed by saying that minimum standards will come quickly, and then a more complex framework will be implemented in the upcoming four years. Mr. Lopez-Benitez added that this process of developing a more complex framework will evolve gradually since a tool might be defined at the EU level. The licensing of professional drivers should complement the training for a regular licence.

To maintain a driver's focus when there is platooning, simple tasks can be given to make sure he/she pays attention to the road. However, some privacy issues might arise (e.g., especially tachography, measuring the heart rate). Does "safety prevail above privacy" in all cases? Another attendee suggested having short monitoring that tracks the drivers' eyes but is not recorded, for example.

An attendee wanted to understand whether there were specific challenges for professional drivers. The answer is that professional and regular drivers are not included under the same regulatory framework because professional drivers might carry dangerous cargos and could inflict more damage, for example.

Real-life driver training cannot be fully replaced by simulated driving. Research suggests that simulators are fine for teaching basic skills, but retention is not as good. Training higher-order skills, it has been suggested, is best done on-road, with context and a proficient trainer. Transfer of training is indeed a very interesting research topic that will no doubt be revived within the current context of automation.

Regarding issues, training and HMI during the testing period of automated vehicles, the case of driver safety is likely to be relevant for a long time (real-life mile-gathering, fine tuning automated sensors for specific routes, etc.). This thus may require specific regulations and is currently a very under-researched area.

6.8. Recommendations to the commission regarding the training of professional drivers

We anticipate that the designers of trucks and buses will take the specific dynamics of these types of vehicles into account in their ADS design.

The recommendations below refer to updates needed in the education/training of professional drivers.

1. Professional drivers need to be able to check their automated driving system and understand its basic components. Therefore, they need to learn about the sensors of the ADS, about how the ADS interprets situations and makes decisions (OEDR) and the optimal settings for the automated driving task. This knowledge can be learned in theory courses as part of the initial CPC qualification. Compulsory periodic training is helpful to keep knowledge up-to-date.

2. Like regular drivers, professional drivers should learn about the correct operational status of the ADS system and its interactions with the HMI, such as carrying out transitions of control. Considering that there are different types and systems, we recommend that this training is best provided by means of pre-purchase training or in situ coaching if there is no harmonisation among suppliers. This kind of training would be developed by the supplier of the technology, who should bear the final responsibility for the training. However, if the main features of the HMI become more harmonised, certified training on ADS systems could be developed at a general level. A great deal of research is still needed into the best training techniques for mastering the HMI of the automated driving system.

3. Professional driver training should include the following: (1) the different systems/vendors available on the market and the major differences between them with respect to the driver's professional activities, and (2) liability issues and responsibilities (which, for professional drivers, also include the load and the passengers).

4. The European Union should encourage ambitious implementation of the revised Directive 2003/59/EC in all Member States. The EU should promote more harmonisation between vendors.

7. CODE OF CONDUCT FOR THE TRANSITION TO AUTOMATION

In this chapter we discuss the issues identified in the previous chapters and the actions that the authorities at all levels would need to take in order to ensure a safe transition to connected and automated mobility. We elaborate upon the discussions and insights in previous chapters concerning the likely effects on the behaviour of road users, changes needed in traffic rules, driver licensing and the training needs of professional drivers. These have been put into a list of actionable topics aimed at developing a roadmap to guide the transition to automated driving. A list of actions, responsible actors and timing is presented for integrating a code of conduct for the safe deployment of automation, as mentioned in the Strategic Action Plan on Road Safety 2021-2030 (European Commission, 2018a). Following the sequence of the previous chapters, the key issues identified for the transition serve as guidelines to actions and the key stakeholders that would be in place to entrepreneur, promote and coordinate the contributions of other stakeholders.

7.1. Human-machine interface (HMI in vehicles)

The major issues identified in HMI in vehicles were the need for harmonised commonalities in the control of car functions, user trust in new ADS, take-over times, monitoring driver awareness, platooning of trucks with cargo in highways, and remote control of vehicles. The key stakeholders guiding the transition include OEMs, the European Commission (DG R&I and DG Grow), UNECE-VMAD,[14] European Community Whole Vehicle Type Approval (ECWVTA),[15] and driver and logistic associations. Most of the actions required to bring automated cars to the road can be completed within one to three years for Level 3 automation. This time horizon is in agreement with the deployment projections outlined in chapter one. It must be emphasised that the time horizon is valid for the implementation of automation Level 3. The actions outlined are required to bring automated cars to the road as the next step in the automation roadmap. The target of implementation is to move forward when higher automation levels are being considered. Table 10 next page presents the results of discussions concerning responsibilities of key stakeholders concerning changes and issues involving HMI in vehicles.

7.2. External HMI

The following issues concerning the interaction of the vehicle within its context of operation for e-HMI were identified: to make clear that no additional e-HMI for interaction with the environment is needed (thus, no new standards are required); the need to have a signal that the vehicle is under ADS control; and rural platooning for safe overtaking. The key stakeholders to lead the necessary actions outlined in Table 11 (further below) are the European Commission (DG Grow and DG R&I), OEMs, logistic companies and UNECE WP.29 Similar to external HMI, the actions required and outlined in the table can be completed within one to three years for Level 3 automation.

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[14] VMAD validation method for automated driving.

[15] European Community Whole Vehicle Type Approval (www.vehicle-certification-agency.gov.uk/vehicletype/ecwvta-framework-directive.asp).

Table 10: Human-Machine Interface (in Vehicles) – Key Elements for a CAD Transition Code of Conduct

Key issues	Key actions	Stakeholders	Roles and Responsibilities	Implementation time
Commonality: major features harmonised	Ensure highest commonality possible without unnecessary limitations on design	OEMs, EU COM	DG R&I – commonality must be defined via research DG Grow – to promote recommendations of design in Geneva OEMs implement guidelines for commonality	When CAD Level 3 is allowed on roads (1-3 years)
Information and user trust	Define driver information requirements (e.g., always display the current automation level)	DG RTD DG Grow OEMs	DG R&I – commonality must be defined via research DG Grow – to promote recommendations of information requirements in Geneva OEMs implement guidelines for information provision	When CAD Level 3 is allowed on roads (1-3 years)
Take-over times	Regulate minimum take-over times for specific situations in which the driver is requested to take back control from automated driving	DG Grow	Promotion	When CAD Level 3 is allowed on roads (1-3 years)
Driver monitoring; ensuring attention, position and engagement	Ensure driver's attention to road and safety	DG Grow OEMs UNECE-VMAD	DG Grow (regulation) OEMs – install driver-monitoring system VMAD – establish test procedures and certify readiness	When CAD Level 3 is allowed on roads (1-3 years).
Harmonisation of standards	Standardisation of HMI elements (universal design solutions that include various user groups)	VMAD ECWVTA		When CAD level 3 is allowed on roads (1-3 years)
Platooning	Research on (platooning) positioning	DG R&I OEMs Driver/logistic associations	DG R&I – Need to know the types of communication requirements with other vehicles in the platoon and with other road users	When CAD Level 3 is allowed on roads (1-3 years)
Remote control of vehicle	Vehicle control Need for further investigation of HMI requirements for operator workstation as well as for users on-board	DG R&I	DG R&I	When CAD Level 3 is allowed on roads (1-3 years)

Table 11: e-HMI – Key Elements for a CAD Transition Code of Conduct

Key issues	key actions	Stakeholders	Roles and Responsibilities	Implementation time
No Additional e-HMI for interaction	Existing e-HMI is adequate and no major additional e-HMI for interaction with other road users, including VRUs. Thus no action is needed, with the exceptions below. No new standards are required.	DG Grow OEMs UNECE WP.29	DG Grow – to endorse the recommendation that, with two exceptions (see below), no new regulations for e-HMI are required. OEMs take this on board and do not install extra features that might cause confusion for road users. UNECE WP.29 – endorse and agree no action.	When CAD Level 3 is allowed on roads (1-3 years)
Active ADS signal for road users (Exception 1)	Exterior light indication that vehicle is under the control of ADS. Could explain behaviour to VRUs and useful for enforcement	DG Grow OEMs UNECE WP.29	DG Grow – decide and recommend type of exterior light signal (e.g., LED, colour) OEMs to agree to fit UNECE WP.29 to agree on standard signal and, if necessary, amend vehicle lighting regulations	When CAD Level 3 is allowed on roads (1-3 years)
Active ADS signal (Exception 2)	Exterior signal to assist in stand-off situation with VRUs	DG Grow OEMs UNECE	DG Grow – decide and recommend type of exterior light signal (e.g., LED, colour). Note the recommended signal from the interactive project OEMs to agree to fit UNECE WP.29 to agree on standard signal and, if necessary, amend vehicle lighting regulations	When CAD Level 3 is allowed on roads (1-3 years)
Rural Platooning	Safety on overtaking on single-lane roads	DG RTD DG Grow OEMs Logistic company[16]	Need to notify those intending to overtake a long platoon ahead DG RTD (e-HMI research needs) DG Grow (regulations)	When CAD Level 3 is allowed on roads (1-3 years)

7.3. Traffic rules

With the advent and deployment of automation Level 3, ideally few traffic rules will need to be adapted to ensure road safety. The key issues identified are the need for a digital traffic act, the definition of a new architecture for emergency situations, the need for ADS functions to operate within their respective ODD, the need to define what activities are to be allowed in the vehicle as ADS transforms drivers into passengers, and the need to set priorities to minimise risk, according to context and situation, and for providing dynamic versus static information. The actions demanded by each of these issues are outlined in Table 12.

[16] Most probably the e-HMI will be on the trailer and not on the tractor; hence, it is something a logistic company/driver would be responsible for.

Table 12: Traffic Rules – Key Elements for a CAD Transition Code of Conduct

Key issues	key actions	Stakeholders	Roles and Responsibilities	Implementation time
Digital traffic Act	Translate current traffic rules into digital form for ADS applications	UNECE WP.1 Member States ECWVTA	UNECE provides the digital form, maybe in some kind of pseudocode, or just in writing MS – check compliance for local variations (or traffic rules) and provide digital version of these	When CAD Level 4 is allowed on roads (4-7 years)
Emergency choice architecture	Digital traffic act must provide indication if/how to *deviate from traffic rules* in emergency situations	UNECE WP.1 Member States ECWVTA	This is closely related to the topic above	When CAD Level 4 is allowed on roads (4-7 years)
ADS functions within ODD	Testing of functionality of ADS for approval	ECWVTA DG R&I	DG R&I research on testing procedures and methods UNECE defines testing and certification requirements	When CAD Level 4 is to be allowed on roads (8-10 years)
ADS transforms driver into passenger	Define What activities are allowed when driver is transformed to passenger/potential driver ('user in charge')	DG R&I UNENCE WP.1 & WP.29	DG R&I research on what activities not related to driving can be allowed UNENCE WP1 What are the new rules. maker of the new rules/updating existing rules	When CAD Level 3 is allowed on roads (1-3 years)
Minimum-risk manoeuvres (MRMs)	MRMs must be prescribed (e.g., in case one of the supporting systems, like radar/lidar, fails)	DG R&I New independent authority	New independent authority for approval might be necessary given the considerable challenge of achieving a reliable system in a standard way for all current European authorities to verify compliance DG R&I must support research on minimal-risk manoeuvres OEMs comply with rules dictated	When CAD Level 4 is allowed on roads (8-10 years)
Information priority (static vs. dynamic)	Define sequence and priority of signs and signals in normal and emergency situations, as well as new/future information sources (I2V, local dynamic maps, 'cloud')	UNECE WP.1 Infrastructure owners (municipalities, traffic authorities)	UNECE WP.1 Define priorities on sources of information to ADS and drivers (dynamic and static signs in road, emergency infrastructure to vehicle [I2V])	When Communication from roadside and dynamic maps comes to the market, maybe along 5G (5– 10 years)

The primary stakeholders to lead such actions include UNECE WP.1 and WP.29, traffic authorities in European Member States, ECWVTA, European Commission DG R&I, and in the case of MRMs, a new authority must be defined. OEMs are expected to comply with the new traffic rules enacted by traffic authorities. The time horizon for the implementation of actions associated with these issues is three to 10 years; some actions are primarily associated with automation Level 4, which is still largely under development and not expected to be deployed for at least seven years.

7.4. Driver licensing

As discussed in previous chapters, automated vehicles transform the driver into a passenger, and there were a few key issues identified concerning changes in driver licensing. These include updating the directive 2006/126/EC on drivers' licences, updating licensing theory tests, training drivers on ADS functions and capabilities, and facilitating the reset of ADS after resale of used automated vehicles to a second or third owner. Key stakeholders involved in updating driver licensing include the European Commission (DG MOVE and DG R&I), Member States, OEMs and ADS suppliers. Some of the actions required could be ready between one to three years, but this shift in licensing should be ready when Level 3 automated vehicles are allowed on the road in about three to five years. The licensing protocols and new areas of testing are strongly linked with the new professional training required by the professional operation of automated vehicles discussed in chapter six and detailed further below. Table 13 presents the results of discussions concerning the responsibilities of key stakeholders in guiding the necessary changes in driver licensing in the European Union.

Table 13: Driver Licensing - Key Elements for a CAD Transition Code of Conduct

Key issues	key actions	Stakeholders	Roles and Responsibilities	Implementation time
Update Directive 2006/126/EC	Update requirements for knowledge, skills and behaviour of ADS users	DG MOVE and Member States	DG MOVE guide update process in changing the EU Directive	When CAD Level 3 is allowed on roads (3-5 years)
Update licensing theory tests	Update theory and practical tests for operating ADS	DG MOVE to coordinate and guide Member States	DG MOVE guide update process in EU institutions. Define levels of licensing. Member States to define content update of theory tests	When CAD Level 3 is allowed on roads (3-5 years)
Driver's training	Training on ADS functions and states	OEMs or ADS suppliers DG R&I	OEMs should provide clear instructions for the operation of their new ADS in new cars DG R&D research on effective methods of training, including VR	When CAD Level 3 is allowed on roads (1-3 years)
ADS-reset training of vehicle dealers	ADS-reset training option trigger in the acquisition of an unfamiliar vehicle	OEMs or ADS suppliers	Set up automated procedure for reset ADS into "Coaching mode" when new owner/driver gets car for the first time	When CAD Level 3 is allowed on roads (1-3 years)

7.5. Professional driver training

The advent of automated vehicles in professional transport services for passengers and goods brings a host of new requirements for knowledge and training in professional drivers. Following insights discussed in chapter six of this report, the driver for automated driving Levels 3 and 4 is a highly skilled technician who understands not only the technical aspects of the operation of the vehicle's ADS but also the legal aspects of liability and the regulations governing the vehicle's operation. The issues and areas of professional training required for a certificate of professional competence to operate automated vehicles include the following: capacity to communicate with the ADS in operation, understanding ADS decisions and actions, understanding the role of the system's key components and information processing, being knowledgeable about the liabilities and regulatory issues associated with the operation of automated vehicles. Additional issues concerning the training of professional drivers include training curricula, transposition of EU Directive 2003/59/EC, and a check of vehicle operational readiness. Primary stakeholders relevant to lead the actions indicated in Table 14 are European Member States, DG Move, ADS suppliers, OEMs, vehicle owners and professional drivers. Table 14 presents the results of discussions concerning responsibilities of key stakeholders to guide the necessary changes and issues regarding the certification of competence for professional drivers.

Table 14: Driver Training – Key Elements for a CAD Transition Code of Conduct

Key issues	**key actions**	**Stakeholders**	**Roles and Responsibilities**	**Implementation time**
Professional training curricula	Development and harmonisation of professional training curricula and CPC	European Member States, DG Move, ADS suppliers, OEMs, and professional drivers		When CAD Level 3 is allowed on roads (2-3 years)
Transposition of Directive 2003/59/EC and its most recent update	Promotion of adoption and implementation of directive in Member States	DG MOVE Member States	Promote adoption of directives and amendment Implement directive	When CAD Level 3 is allowed on roads (3-5 years)
Operational readiness check	Check that functions and associated equipment of ADS work before vehicle operation	Vehicle owner, vehicle driver Insurance company	Vehicle owner Vehicle driver	When CAD Level 3 is allowed on roads (1-3 years)

7.6. Towards a code of conduct for the safe deployment of automation

The elements needed to comprise a code of conduct for the transition to CAD should be based on the fact that its deployment concerns a transition of control and responsibility from the individual driver to third parties and that, to a large extent, the performance of a vehicle with an acting ADS is beyond the control of the individual driver. This is especially the case for CAD Level 3 and above, is based on three general categories of human behaviour that are affected by ADS: skills, rules and knowledge (Rasmussen, 1983).

- Skill-based behaviour concerns acts or activities that take place without conscious attention or control, and which are automated and highly integrated.
- Rule-based behaviour is defined as routinely executed acts or activities that follow a stored rule or procedure, often based on instruction or preparation.
- Knowledge-based behaviour concerns the performance of an act or activity during unfamiliar situations and is goal-controlled. Here, a person needs to plan his/her actions, evaluate them and consider the best response through functional

reasoning, usually by performing a sequence of rule- or skill-based behaviours, piecing together a novel reaction to a novel situation.

The distinction between skill-based and rule-based behaviour depends on the level of training and attention of the person: where skill-based behaviour is unconscious, rule-based behaviour is consciously based on an explicit recollection of facts. ADS are aimed to substitute primarily for skill- and rule-based behaviour. In the long run, ADS Level 3 will de-skill drivers and contribute to the deterioration of rule-based behaviour. There is an expectation that the driver can take over in unexpected situations, where value judgements and fast reaction times are required; however, it has been argued that this is self-defeating because the skills needed for a fast reaction might be lost over time and the driver's attention might be on other tasks (reading, conversing, napping, etc.). According to Heikoop et al. (2019), in SAE Level 3 of automation the ADS requires more than the human driver can prepare for, let alone perform. At a higher level of automation, the way the ADS is designed to execute its tasks becomes more important than how human drivers *ought* to execute their tasks.

7.6.1. Preliminary Guidelines for the transition to automation

The following guidelines for CAD deployment can be considered in relation to the actions, roles and responsibilities identified above. The idea is to check the ethical implications for those stakeholders involved in the transition to automated mobility against the guidelines listed below. We expect that, upon reflection, perhaps more issues and actions will be thought of than those the research team has identified in the list of policy recommendations already outlined. The guidelines given below refer primarily to four domains where moral hazards might arise: the first concerns the general principle of safety and autonomy of road users (Luetge, 2017), the second refers to the shift in responsibilities and liabilities (Geistfeld, 2017; Riehl, 2018; Milakis, 2019), and the third concerns the security and safety of the data flowing between the car and the user (EDBP, 2020; SWIPO, 2019; SAAS, 2019). This brings up issues of connectivity, cybersecurity and privacy that the transition code would need to address. The last domain points out questions that the drafters of the code of conduct will face while aiming to guide innovation and the behaviour of diverse stakeholders through the transition to automated mobility.

Domain 1: General principles of safety and autonomy of road users

Guideline 1 – Principles

- *Safety*: The primary purpose of partly and fully automated transport systems is to improve safety for all road users.
- *Personal autonomy*: individuals enjoy freedom of action for which they themselves are responsible. The way in which technology is statutorily fleshed out is such that a balance is struck between maximum personal freedom of choice in a general regime of development and the freedom of others and their safety.

Guideline 2 – Benefits of automated driving

The protection of individuals takes precedence over all other utilitarian considerations. The licensing of automated systems is not justifiable unless it promises to produce at least a diminution in harm compared with human driving; in other words, a positive balance of risks.

Domain 2: Shift in responsibilities and liabilities

Guideline 3 – Design of preventative rules

Automated and connected technology should prevent accidents wherever this is practically possible. Based on the state of the art, the technology must be designed in such a way that critical situations do not arise in the first place. Traffic environment control, vehicle sensors, braking systems, signals for persons/vehicles at risk, intelligent road infrastructure, etc., should be used and continuously evolved with precautionary principles.

Guideline 4 – Public sector – Guarantor of public safety

Driving systems require official licensing and monitoring. An official licence for cars is needed for automated driving and cannot be left to the responsibility of car manufacturers alone.

Guideline 5 – Liability shift

In the case of damage to human life, goods and infrastructure, liability is removed from the motorist. The liability shifts to the manufacturers, operators of the technological systems and the bodies responsible for taking infrastructure, policy and legal decisions.

Guideline 6 – Shifts in HMI-human accountability

It must be possible to clearly distinguish whether a driverless system is being used or whether a driver retains accountability through the option of overruling the system. In the case of non-driverless systems, the human-machine interface must be designed such that at any time, it is clearly regulated and apparent on which side the driver's responsibilities lie, especially the responsibility for control. The distribution of responsibilities (and thus of accountability), with regard to the arrangements for timing and access, for instance, should be documented and stored. This applies especially to the human-to-technology handover procedures. There should be international standardisation of these procedures and their documentation (logging) in order to ensure the compatibility of logging or documentation obligations as automotive and digital technologies increasingly cross national borders.

Guideline 7 – Information transparency

The public, along with private and professional drivers, are entitled to be informed about new technological features and capabilities as well as shifts in principles and liabilities. Information should be provided in a clear and transparent manner. Communication protocols should be reviewed by a professionally suitable independent body.

Domain 3: Security and safety of the data flows

Guideline 8 – Cybersecurity

Automated driving is justifiable only to the extent to which conceivable attacks (particularly manipulation of the IT system) or innate system weaknesses do not result in such harm as to shatter people's confidence in road transport. It is necessary to identify potential vulnerabilities through which personal data could be compromised. Unlike most devices on the Internet of Things, connected vehicles are critical systems where a security breach could endanger the life of its users and people around them.

Guideline 9 – Privacy and data protection of ADS users

It is the vehicle keepers and vehicle users who decide whether the data their vehicle generates are to be forwarded and used. Business models that are permitted to avail themselves of the data generated by automated and connected driving and that are relevant to vehicle control are limited by the autonomy and data sovereignty of road users.

The voluntary nature of such data disclosure presupposes the existence of acceptable alternatives and practicability. Action should be taken at an early stage to counter normative forces, as in the case of access by operators of search engines or social networks.

Guideline 10 – Cross-border data security
A key factor in improving legal certainty for companies, in regard to compliance with security requirements, is enhancing trust in the security of cross-border data processing.

Guideline 11 – Cross-border data processing and security
Consideration must be given to data processing and place of compliance whether this be Union law or the Member State of residence or establishment of the natural or legal persons whose data are concerned (for several types of data, i.e., geolocation, traffic and road infractions, and biometric). This should continue to apply to the processing of that data in another Member State.

Guideline 12 – Data portability
Professional users should be able to make informed choices and to easily compare the individual components of various data-processing services offered in the internal market, including in respect to contractual terms and conditions around the portability of data upon the termination of a contract.

Domain 4: Coordination of stakeholder actions

Guideline 13 – Coordination of stakeholders in CAD
Any code of conduct is a guideline concerning values for structural change in human technical and economic behaviour. The coordination of stakeholder actions in the transition to automated mobility must be done under the understanding that human values have a spurious relationship with behaviour (Schwartz et al., 2012; Punzo et al., 2019; Schmidt, 2019).

Guideline 14 – Self-regulation
The technical and operational requirements for the transition to automated mobility should be defined by all stakeholders through self-regulation. This should be encouraged, facilitated and monitored by the Commission in the form of "codes of conduct" that appropriately address the specific technical requirements of specific actions (HMI, traffic rules, professional training, driving licences, data flows, etc.) and types of service within the new digital environment. The code must fulfil the common requirements of stakeholders in order to become credible and functional and to ensure fair competition and a balance of interests at all times.

Guideline 15 –Implementation of supervision and review of code
The application and supervision of compliance with the code of conduct must be conducted by parties not directly involved in the transition to automated mobility.

Guideline 16 – Stakeholder actions guided by values but determined by circumstances
Actual human behaviour is guided by values but determined by the interaction of stakeholders on a given issue (Schwartz et al 2012; Montalvo 2007). In turn, the rationale and intent of each stakeholder is determined by the expected outcomes (what is in it for me and my group), the prevailing social norms (group, peer and regulatory pressures) and the level of agency (knowledge, resources and timing) to actually perform what any

stakeholder is intending (Montalvo 2006, 2007). The alignment of these three factors across the pool of stakeholders will determine whether the code guides a safe transition to connected and automated mobility.

8. CONCLUSIONS

Over the last five years, with the first wave of vehicles featuring some automated driving features and a further diffusion of electric vehicles, a technological shift is occurring in the automotive sector. In the case of automated vehicles (AVs), these advances have been enabled by the integration of new technologies, such as sensors, software and computing platforms. Although, due to technical and regulatory challenges, the advent of a fully automated vehicle able to operate in most road and traffic environments remains a distant prospect, it is possible to foresee the co-existence of partially automated and non-automated vehicles over the short term. Given the nature of AV technology and to ensure the interoperability and safety of road users, supporting rules and technologies that demand coherent coordination in different areas of regulation and standards are required. The transition to automated driving will affect the behaviour and performance of the driver and will influence the way road users interact with each other. This transition raises questions about policies related to the new forms of active (as driver) or passive (as passenger) behaviours during the use of the vehicle; the interaction of an AV with other vehicles and the roads; the adequacy of current traffic rules and infrastructure requirements; and the curricula for licensing and training drivers.

This study addresses a wide range of issues, and we have built upon the information acquired and the consultations undertaken to provide major conclusions. We have also identified the gaps in knowledge that should be considered in updating current regulatory structures and standards to support the transition to automated driving. The actionable topics identified, responsible entities proposed, and estimated time horizons are summarised in the tables presented in chapter seven. Here, the most relevant topics are highlighted. The overarching principle guiding all conclusions is to enhance the safety of all road users (i.e., pedestrians, cyclists, motorcyclists, and car and truck drivers).

8.1. HMI

The new human-machine interfaces (on-board HMI) create new forms of active or passive behaviours (as driver or as passenger, respectively) when an automated vehicle is being used. In today's conventional vehicles, drivers are used to gathering information about the vehicle's functions and their status from an on-board HMI, where the driver uses visual information from the display, auditory information from various auditory signals and motion and haptic feel from the vehicle. Since most operator errors are a result of insufficient or inadequate information, it will become extremely important for the HMI to deliver sufficient information, provided by the ADS, in order for the driver to understand the underlying functional logic of the ADS and the handling of the new control elements. To restrict operator confusion, therefore, it is important that the "commonality" of an on-board HMI be promoted and agreed upon. This includes the functional logic of ADS, the control elements and the information presented across vehicle types and manufacturers. More specifically, there needs to be agreement regarding the minimum requirements for the information to be presented to the driver in order to promote user understanding and to enhance user trust in automated vehicles.

Taking over control from an ADS remains a major issue to be addressed. With ADS, the role of the driver changes significantly because the ADS can take over partial or even full control of the vehicle. The fact that different functional modes are available in one and the same vehicle makes a comprehensive and efficient interaction strategy very important.

Depending on the role of the driver, different information is needed to fulfill the requested task. The HMI needs to be designed to be adaptable in order to provide the user with optimum support. One of the most important tasks is the avoidance of known operator errors such as mode confusion, automation surprises and overreliance.

Three major technical and regulatory issues remain open: first, it is critical to monitor the driver's position, attention and engagement levels for all vehicle types that can request the driver to take over control; second, it is necessary to establish and regulate minimum take-over times for situations in which the driver is requested to take back control; and last, monitoring the driver and establishing take-over times will require agreement about standardised testing procedures and criteria for HMI evaluation – and these will need to be established. Specialised skills and knowledge are required for the development of these criteria and procedures; therefore, a dedicated task force might be necessary, along the lines of the group that developed the European Statement of Principles (ESoP) on in-vehicle HMIs.

For AVs with external HMIs (e-HMIs), an overall conclusion is that they should use the e-HMI that is currently found on conventional vehicles (indicators, brake lights, horn, etc.) because new and different solutions could cause confusion when road users have to interact with multiple vehicles, both conventional and automated. A signal light to indicate that a vehicle is being driven by an automated driving system is advocated, as are some specific solutions to address specific needs.

8.2. Traffic Rules

Regarding the adequacy of current traffic rules and provisions when applied to AVs (along with potential changes), such adequacy is compounded by the differences in traffic rules between the Member States that might confuse AVs. The analysis of potential changes started from the hypotheses that either there is a need for more traffic rules and provisions, or that existing rules need to be adapted. The potential consequences of AVs were assessed, using the current general traffic rules in Europe as a baseline. The assessment and the literature consulted indicated that automated driving has not resulted yet in much need for a change in current traffic rules. However, one amendment to the Vienna Convention (UNECE, 1968) has been accepted: Article 8 states that "Every moving vehicle shall have a driver" and "Every driver shall at all times be able to control his vehicle or to guide his animals." The amendment implies that an automated driving system can be the "driver" and that the driver therefore does not have to be a human.

A major conclusion is that traffic rules for AVs do not need to be different from existing traffic rules. The main task ahead in updating current traffic rules is the translation of existing code into exact and measurable rules that can be programmable for ADS (sometimes also called the "digital traffic act", which can, in fact, be considered a digital version of traffic rules). Local variations in traffic rules and variations between Member States should be included in the digital traffic act. In this way, an ADS could switch to specific regulations when crossing a border, comparable to switching digital maps for a navigation system. This digital traffic act should indicate how to deviate from the rules in emergency situations. Also, during automated driving, engaging in non-driving-related activities that are currently not permitted might be allowed, but this would depend on the automation level and the type of activity.

8.3. *Driver's licenses and professional driver training*

Regarding the need to review potential changes in the knowledge required for drivers to operate AVs and use roads safely, there are a number of issues that connect the licensing of drivers and training of professional drivers. Regarding the issuing of driver's licenses, whilst there is a harmonised approach to driver licensing in the EU Member States, there is a wide variety of approaches to driver training and testing. Thus, the training of new skills, where identified to be of importance for the safe operation of AVs, would be nationally devolved. Through consultations with stakeholders, this study identified a number of suggestions or concerns with regard to the updating of licensing procedures. Drivers have been expected to use Level 1 and 2 automation without specific changes in licensing and training procedures; however, the literature review indicated that drivers are not always knowledgeable about the Level 3 or 4 automation functionalities present on their vehicles.

In order to reap the benefits of AVs, drivers should be familiar with the purpose of the automation, particularly their role and responsibilities in interacting with it. With regard to drivers yet to obtain their licenses, they could theoretically be given the choice of being trained to drive either a standard vehicle or one with autonomous features (or both). The subsequent testing and licensing of those drivers could also be adapted to lead to newly qualified drivers holding different types of licences that would restrict their driving to specific types of vehicles. However, the timely legislation and enforcement of such an approach could prove to be insurmountable, and given the rapidity of technological advances, such an approach might not be agile enough to cope with changes. The stakeholder consultation indicated that drivers could glean the requisite skills and knowledge via an interactive in-vehicle coaching tool, over and above what is provided by a typical owner's manual, and implemented on hired or shared vehicles for drivers to access. Further discussion with vehicle manufacturers is required in order to understand the limitations and barriers of implementing this. Not losing "manual" driving skills after an extended period of AV driving is an additional concern, and the in-vehicle coaching approach could be adapted to help mitigate this. Research in virtual reality environments is needed as a way of developing knowledge about training new skills. The relaxation of regulations around fitness to drive should also be considered as a possibility, especially in Level 5 vehicles.

With respect to professional training, Directive 2003/59/EC and its amendments set the framework for harmonising the training of professional drivers in the EU and the certification of professional competence every five years. The legislation improves harmonisation of driver training in the EU to a great extent, but still leaves room for Member States to organise professional driver training differently. In light of AVs, the mandatory periodic training, along with the topic of automation prescribed in Directive 2003/59/EC (amended by Directive 2018/645) provide all the necessary handles to acquire new knowledge and competence on evolving technologies such as ADS and advanced driver-assistance systems (ADAS). The topic of automated vehicles can be included in the theoretical part of the training, where learning about the technical characteristics of the safety controls of AVs can be covered. Training should help professional drivers to have a basic understanding of the main components involved in ADAS and ADS.

If ADS suppliers reach agreements on "communalities" and standardise the main HMI features, operational competence will be better covered by practical training organised by the training centres that have been approved by the competent authorities of the Member States. If ADS suppliers bring different systems and types to the market (i.e., no commonality), they should inform their customers and organise an adequate level of training (e.g., by in situ coaching embedded in the HMI) under the control of the EU. Based on the stakeholder consultations, it can be suggested that, whilst driver simulators can be helpful, especially for basic skills, higher-order skills are best trained on-road, with context and a proficient trainer. These topics are mainly related to driving or monitoring the vehicle, but some topics are not directly linked to the task of driving. One of these is liability. Although it is still an open issue in automated driving, professional drivers should learn about their liability with regard to automation, especially in relation to heavy loads and the transport of many passengers.

8.4. Towards a code of conduct for the transition to automated mobility

The reflections and discussions on the likely effects of automated mobility on the behaviour of road users, the changes needed in traffic rules, driver licensing and training of professional drivers led to a list of actionable topics to be addressed when a road map to guide the transition to automated driving is being developed. Such actions will require the involvement of key stakeholders that include the European Commission, OEMs, the road authorities in Member States, UNECE, etc. Most actions could be accomplished in the course of three years, with some exceptions for automation Level 4, which is expected to take up to 10 years. The elaboration of the code of conduct to guide the participation of stakeholders in the transition process would require addressing at least four domains of moral hazard: The first concerns the general principle of safety and autonomy of road users. The second refers to the shift in responsibilities and liabilities from the driver to other entities. The third concerns the security, safety and privacy of the data flowing between the car and the user. The last highlights issues that the drafters of the code of conduct will face while aiming to guide innovation and the behaviour of diverse stakeholders through the transition to automated mobility. Despite its normative connotation, the code of conduct must be seen as a contract that guides the coordination of diverse intents and strategies across stakeholders: it clarifies the roles and duties of all participants.

As a final conclusion, we are witnessing a major technological shift and structural change in the automotive sector. The concept of automated mobility has triggered strong competition across the sector, bringing in new players from information and telecommunication technologies sectors. Such competition implies a sectoral restructuring that will demand changes in regulatory systems in order to ensure mobility and road safety. Major trading partners in Asia, North America and Europe are taking steps to facilitate the deployment of self-driving cars by testing on public roads, while enacting policies to support such a technical shift in coordination between major brands. The insights provided by this study indicate that the impact on industrial leadership, employment and safety, as well as overall social impact depend as much on leadership in technical and service innovations as it does on the coherence and adequacy of the policy and regulatory steps taken to structure the transition to automated mobility.

As a final note, the current knowledge on automated vehicles indicates that there are still large gaps where more information relevant to policymaking is required. Further research and expert consultations are needed to fill these gaps in order to increase our understanding of the impact of automated driving on the safety of roads and traffic. This includes the harmonisation of the HMI and the updating of traffic rules, requirements for drivers’ licenses and training. This increased knowledge and understanding will better enable the transition to automated mobility.

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10. ANNEX 1: HMI STANDARDS

Standards and guidelines relevant to HMI

Standard	Issuing body	What it addresses
ISO 15622:2018	ISO	Intelligent transport systems -- Adaptive cruise control systems -- Performance requirements and test procedures
IS0 15008	ISO	Specifications and test procedures for in-vehicle visual presentation”
ISO/TR 21974- 1	ISO	Human state, performance in human state and performance in automated driving systems (ADS) – Part 1: terms and definitions of human state and performance
ISO 15007	ISO	Measurement and Analysis of driver visual behaviour with respect to transport information and control systems
SO/TS 14198	ISO	ergonomic aspects of transport information and control systems – Calibration tasks for methods which assess driver demand due to the use of in-vehicle systems
ISO/TR 21959-1	ISO	Road vehicles Human state, performance in human state and performance in automated driving systems (ADS) – Part 1: terms and definitions of human state and performance
ISO/TR 21959-2	ISO	Human state, performance in human state and performance in automated driving systems (ADS) – Part 2: experimental guidance to investigate human takeover state and performance
ISO/TR 23049	ISO	ergonomic aspects of external visual communication from automated vehicles to other road users
SAE J3134™	SAE	ADS equipped Vehicle Signal and Marking Lights (work in Progress)
SAE J 3016-2018	SAE	Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles
SAE J2802_201506	SAE	Blind Spot Monitoring System (BSMS): Operating Characteristics and User Interface
SAE J2988_201506	SAE	Guidelines for Speech Input and Audible Output in a Driver Vehicle Interface

11. ANNEX 2: STAKEHOLDER SURVEY

11.1. Introduction to the Survey

As part of the consultation strategy, a written consultation in the form of an online survey has been designed to address specific questions arising from the analysis, in order to support the team in drafting conclusions. The online survey also aimed to validate, where feasible, conclusions already taken based on literature review and interviews. Dividing the online survey into three sections has allowed specialists to answer questions from their main domain of expertise and to cover study tasks from 2 to 5 with dedicated sections.

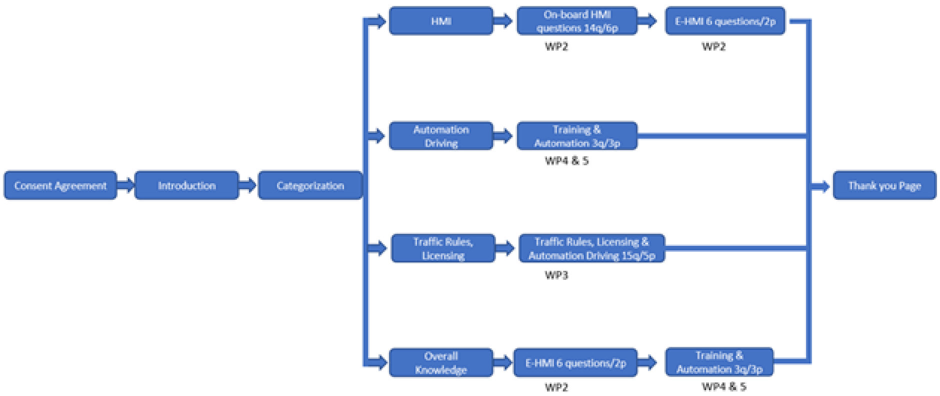

Figure 1: Survey question tree

11.2. Generic data collected by the survey

Up to date, January 15 2020, and survey's closure, **255 stakeholders**[1] **have answered the survey out of over** 450 persons contacted.

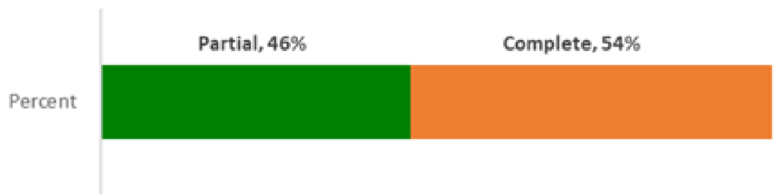

Figure 2: Percentage of respondents to the survey

Figure 3: On which of the following categories do you best identify yourself

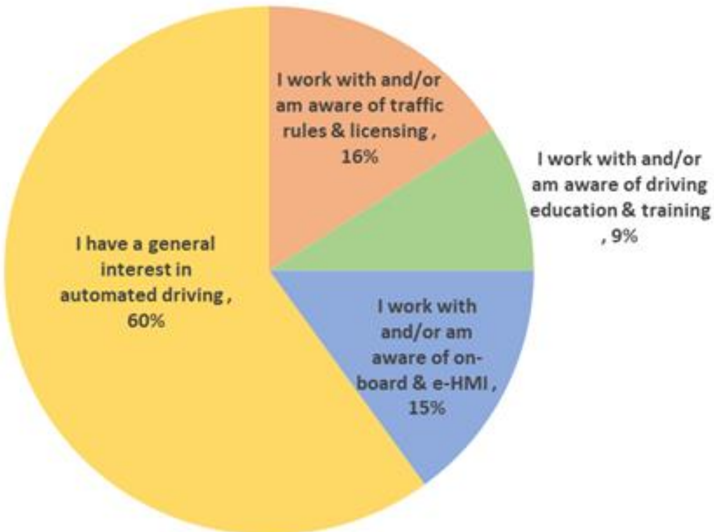

Figure 4: Which of the following statements best describes you?

11.3. HMI – ADAS Sub-Section

28 respondents have chosen to take the HMI – ADAS specific sub-survey

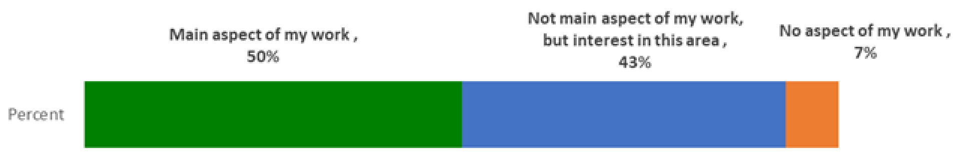

Figure 5: How much experience do you have with the design of on-board HMI for ADS?

	Yes - %	No - %	I don't know - %	Responses - Count
Commonality in HMI design will increase user trust and acceptance.	**83%**	4%	13%	23
Commonality in HMI design will increase ease of use.	**92%**	4%	4%	23
Commonality in HMI design will increase safety.	**83%**	13%	4%	23
Commonality in HMI design will increase ease of learning.	**83%**	4%	13%	23

Table 1: Which of the following statements do you agree with

Main comments received from respondents:

- *Common HMI design must be derived from a user perspective with traffic safety in focus:*
- *Common robust HMI can compensate for autonomous technology complication thus increase speed of AV's entry on public roads despite technical issues of automation*
- *Commonality can increase the above but can/will possibly stall progress to reach better and improved ways of interaction*
- *I have marked "I don't know" since my answer is "It depends" on what the HMI design turns out to be, how prescriptive, what is mandatory, what is left up to individual vehicle brand*

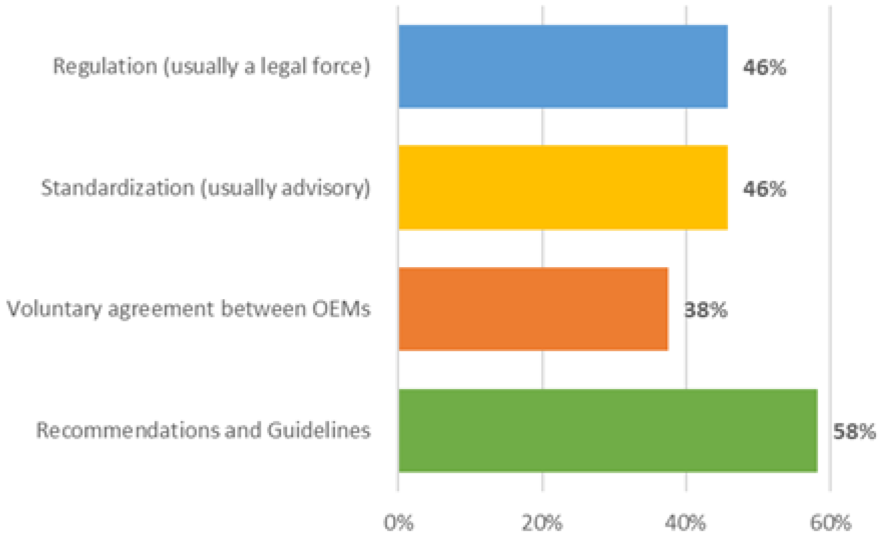

Figure 6: What we need for the design of the "functional logic" of an ADS is (multiple options)

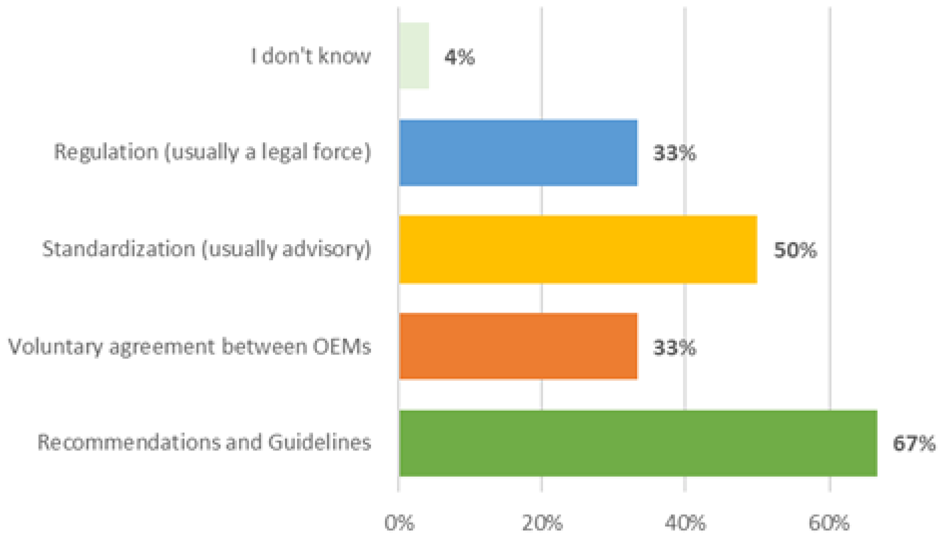

Figure 7: What we need for the design of "control elements" of an ADS is (multiple options)

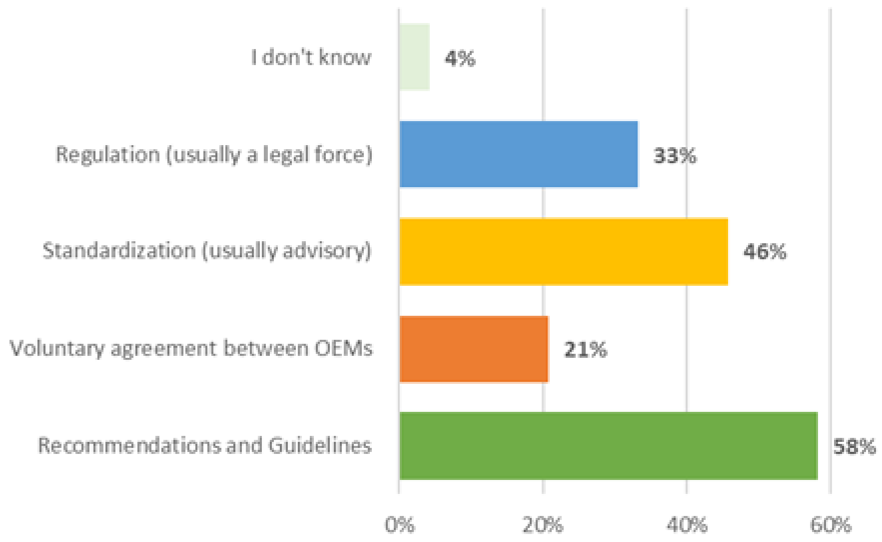

Figure 8: What we need for the "information" given by an ADS is (multiple options)

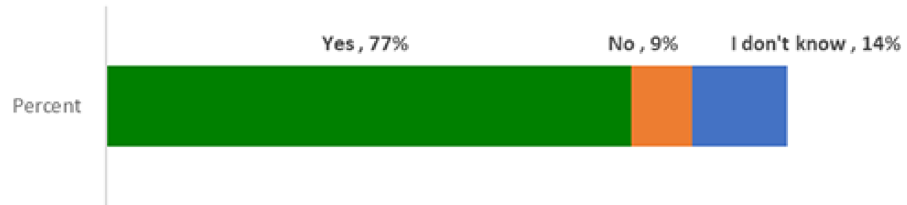

Figure 9: Do you agree with the following assertion: Authorities should ensure that the ADS (offering SAE L3 and lower) should provide some kind of driver monitoring to check for the appropriate level of user attention

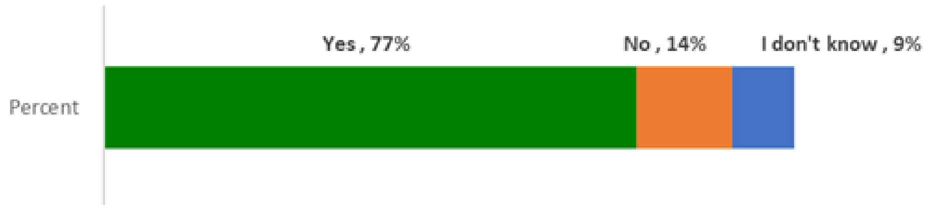

Figure 10: Do you agree with the following assertion: Authorities should ensure that the ADS (offering SAE L3 and lower) needs to provide appropriate and timely measures to alarm and re-activate the driver such as a hands-off warning?

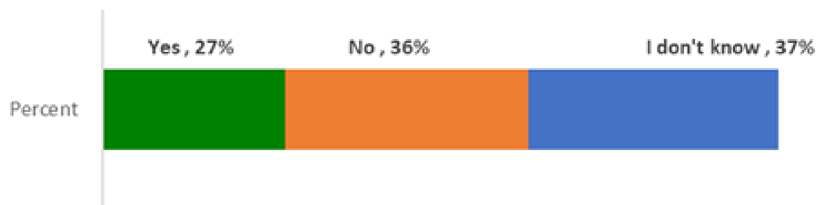

Figure 11: SAE level 3 automation that requests the need for the user to take back control is considered by some as unsafe. Should authorities forbid this level?

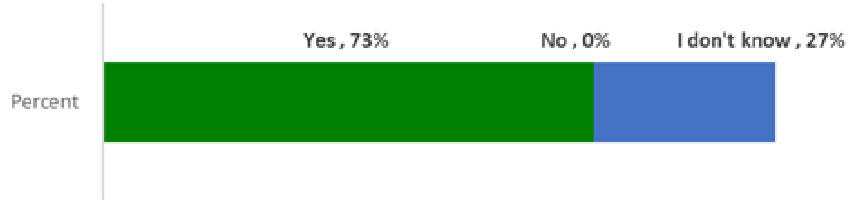

Figure 12: Do you agree with the following assertion: There should be common control elements for similar ADS functions across manufacturers.

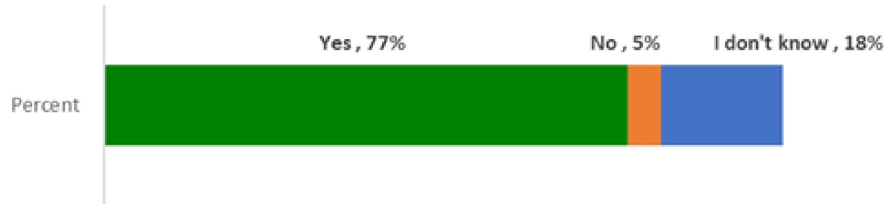

Figure 13: Should the minimum amount of information presented to the user be standardized across manufacturers?

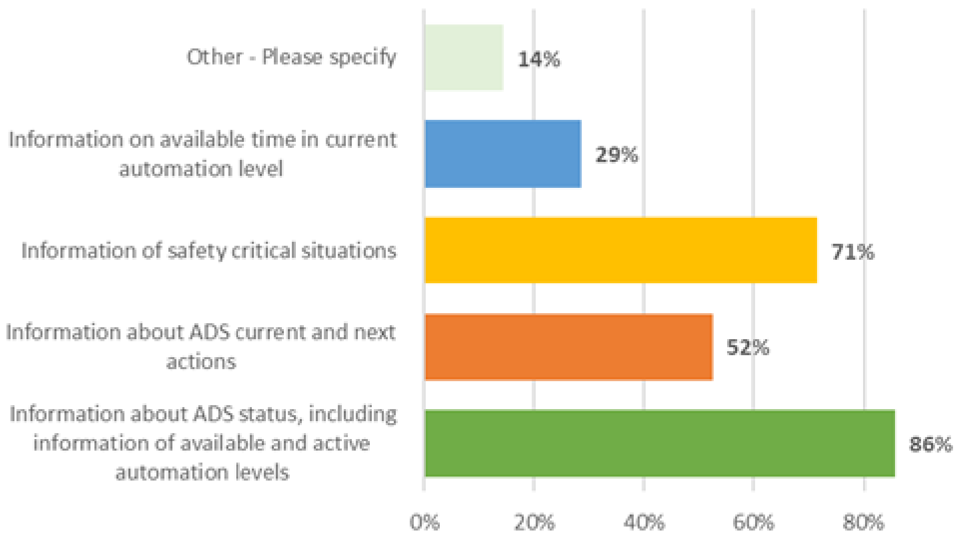

Figure 14: According to you, authorities should ensure that the ADS continually provides (multiple options)

Main comments received from respondents:

- *AS must remind driver regularly that system is active*
- *AS must permanently state how "certain" AS is*

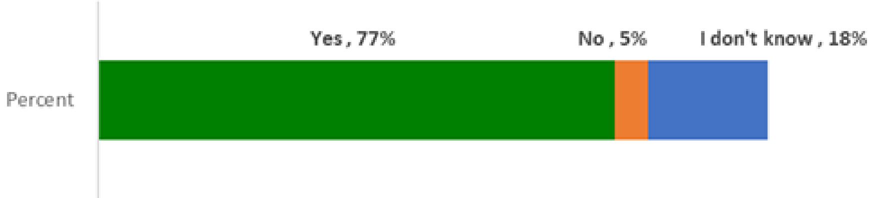

Figure 15: Should identical ADS functions have standardized icons across manufacturers?

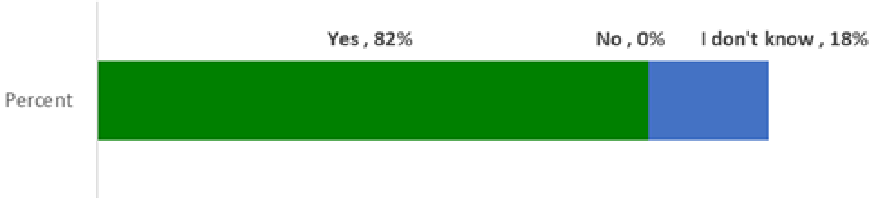

Figure 16: Do you agree that, an agreement on common testing standards and identification of important test scenarios for HMI is important?

11.4. E-HMI Sub-Section

115 respondents have taken the e-HMI specific sub-survey

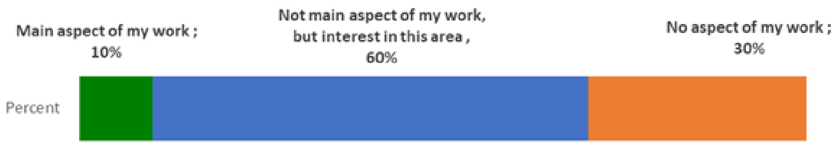

Figure 17: How much experience do you have research on and/or design of e-HMI?

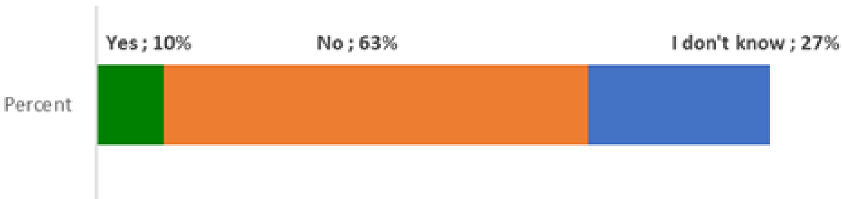

Figure 18: Do you think that, today's external HMIs are sufficient for future interactions between vehicles driven by an ADS and other road users?

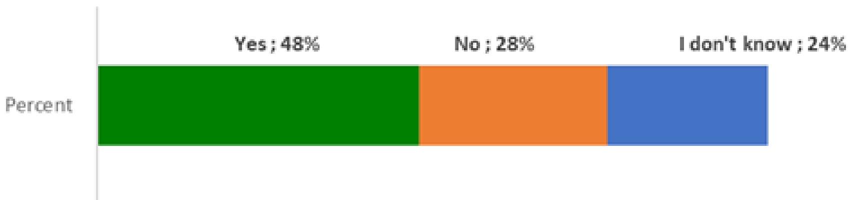

Figure 19: Do you think indication of being detected by an ADS is desirable?

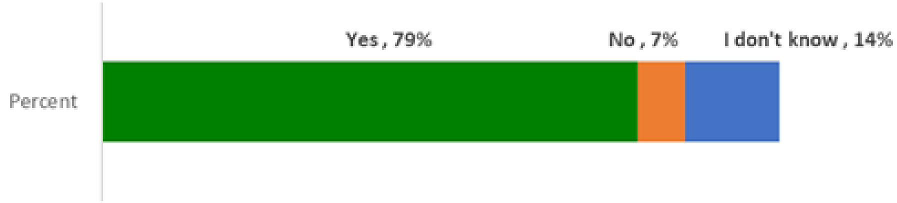

Figure 20: Do you consider that there are likely to be some special circumstances which might require new e-HMI?

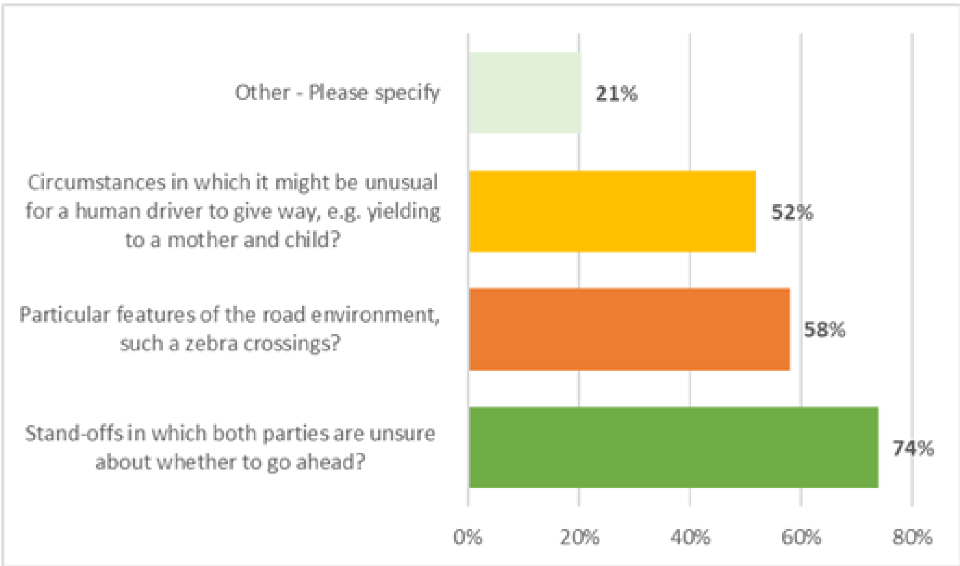

Figure 21: What specific situations do you think are relevant(multiple options)?

Main comments received from respondents:

- *Express the behaviour of the vehicle. If the vehicle is to signal that it has recognized a person, how should it handle situations with several pedestrians, bicyclists, etc? Therefore, better to show what the vehicle is actually doing (stopping, yielding, etc)*
- *Blind spot manoeuvres, in particular with trucks: we learn that if you can see the driver, the driver can see you. With an automated vehicle this rule of thumb no longer applies.*
- *When approaching a dual mode vehicle to ensure its safe to enter/approach and possibly enter.*
- *When interacting with priority vehicles (e.g. police officer, fireman, etc.)*

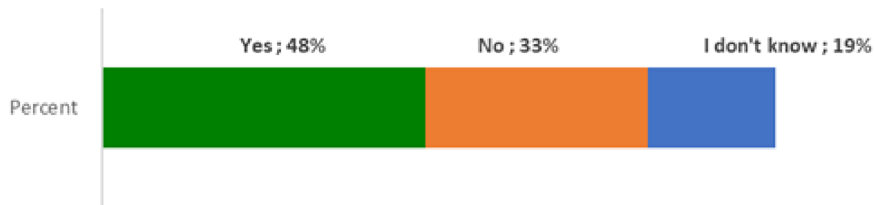

Figure 22: Do you think that, for e-HMI, existing vehicle lighting regulations should be altered to allow the use of colours other than white on the front of a vehicle? (i.e. existing vehicle regulations need to be changed to allow new designs. Existing regulation

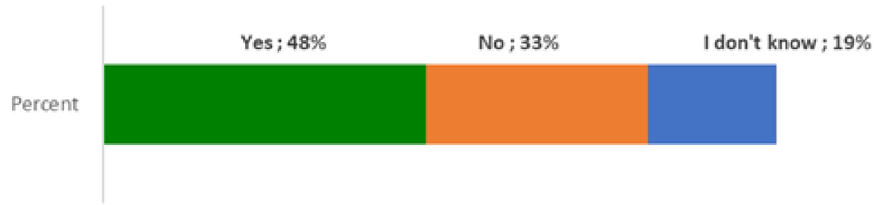

Figure 23: Do you think there should be an external indication of being driven by an ADS, rather like a taxi "for hire" sign?

11.5. Training & Automation Sub-Section

22 respondents have taken the Training & Automation specific sub-survey

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Responses - Count
The 2006 European Directive should be updated to include skills and knowledge required to operate a Level 3 or 4 automated vehicle	-	9%	9%	**68%**	14%	22
New knowledge should be incorporated into the licensing process, via the theory test	-	5%	24%	**57%**	14%	21

Issuing different levels of licence to newly qualified road users for different levels of automation is not practical	-	28%	14%	**42%**	18%	22

Table 2: What do you think about the following assertions

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Responses - Count
All road users who purchase a new vehicle should undergo an on-road coaching period, designed into the automation features	10%	29%	19%	**38%**	5%	21
Road users should obtain skills for handling automation when they buy a vehicle	5%	9%	24%	**52%**	10%	21
All road users who purchase a new vehicle should undergo an on-road coaching period,	5%	38%	14%	**43%**	-	21

designed into the automation features						

Table 3: What do you think about the following assertions

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Responses - Count
Road users of hire cars or shared mobility should be exempt from automation training	19%	**48%**	23%	10%	-	21
Training in automation should be done on closed test tracks and simulators only	5%	24%	**52%**	19%	-	21
Minimum standards of physical and mental fitness for driving an automated vehicle should not be relaxed	5%	19%	33%	**38%**	5%	21

Table 4: What do you think about the following assertions

11.6. Traffic Rules

94 respondents have taken the Traffic Rules Licensing & Automation specific sub-survey

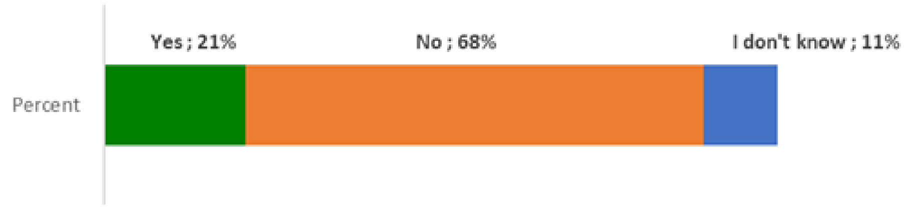

Figure 24: Should automated vehicles be allowed to mimic normal driving behaviour (e.g. violate the speed limit but stay under the limit of getting fined)?

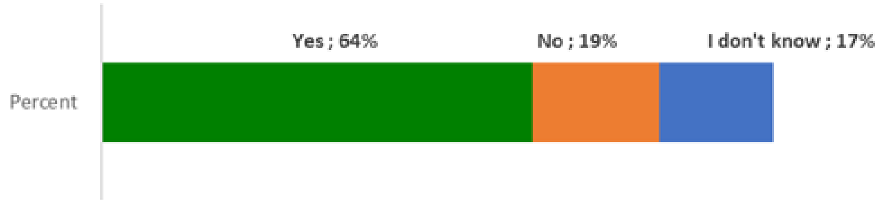

Figure 25: Do you think a distinction should be made between minor and major rules, where minor rules may be broken to avoid an accident?

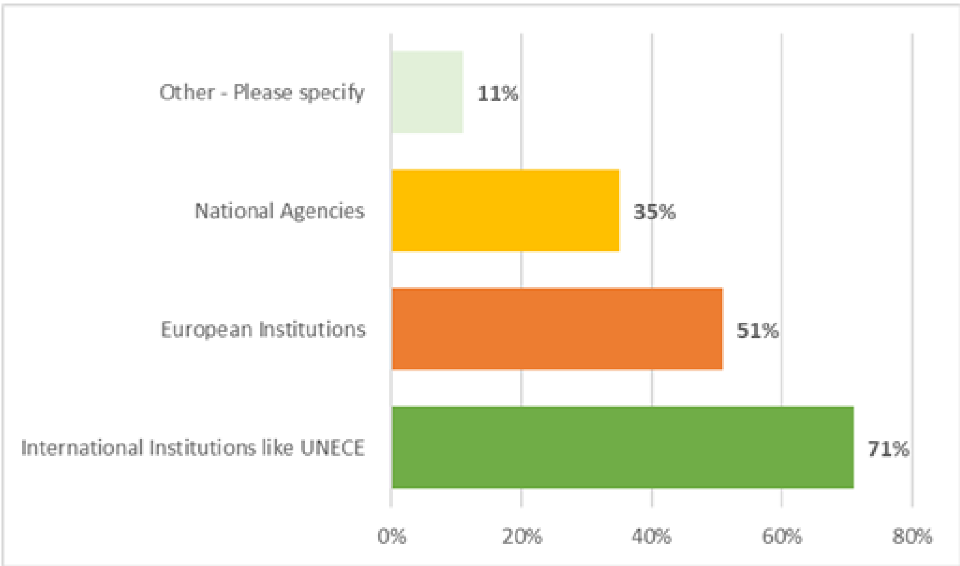

Figure 26: Who should determine what are these minor and major rules (multiple options)?

Main comments received from respondents:

- *These rules need to become part of Traffic Acts. Already today you are allowed to cross a continuous traffic line in certain circumstances. These parts need to be clearly formulated.*
- *A digitalisation of the traffic acts is necessary to produce a digital traffic act as basis for automated (as well as conventional) vehicles*

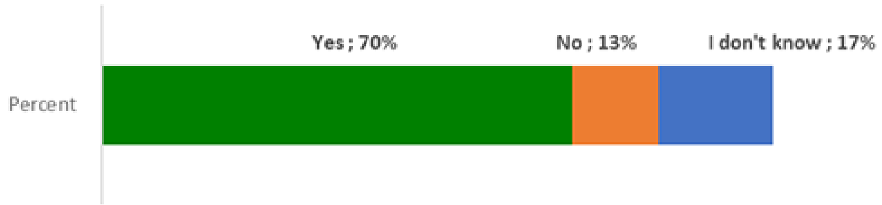

Figure 27: Should an automated vehicle break a traffic rule to avoid a crash even if the other vehicle is at fault?

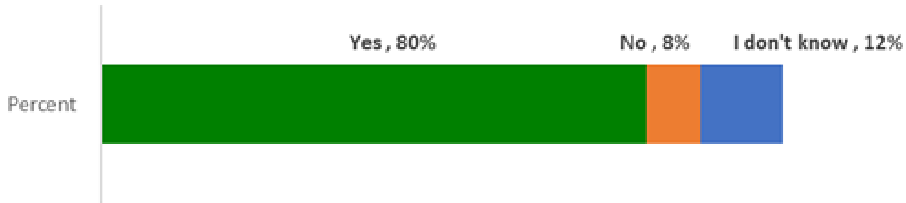

Figure 28: Should there be rules for switching on/off automation (e.g. in location, circumstances, …)?

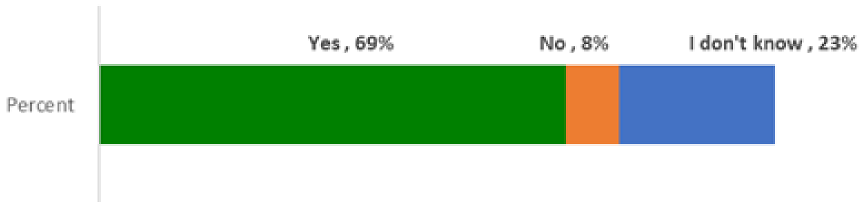

Figure 29: Should these rules be adapted to specific automation systems (e.g. different system capabilities, like SAE level of automation supported by the system)?

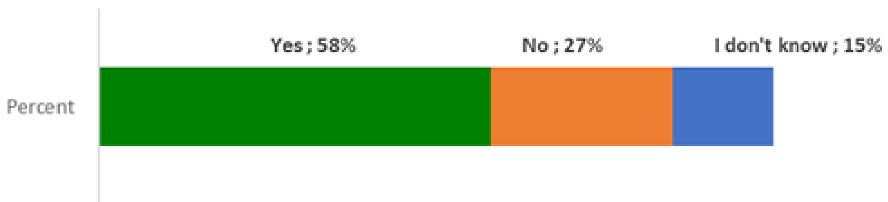

Figure 30: Should the driver always be able to take back control immediately from the automation?

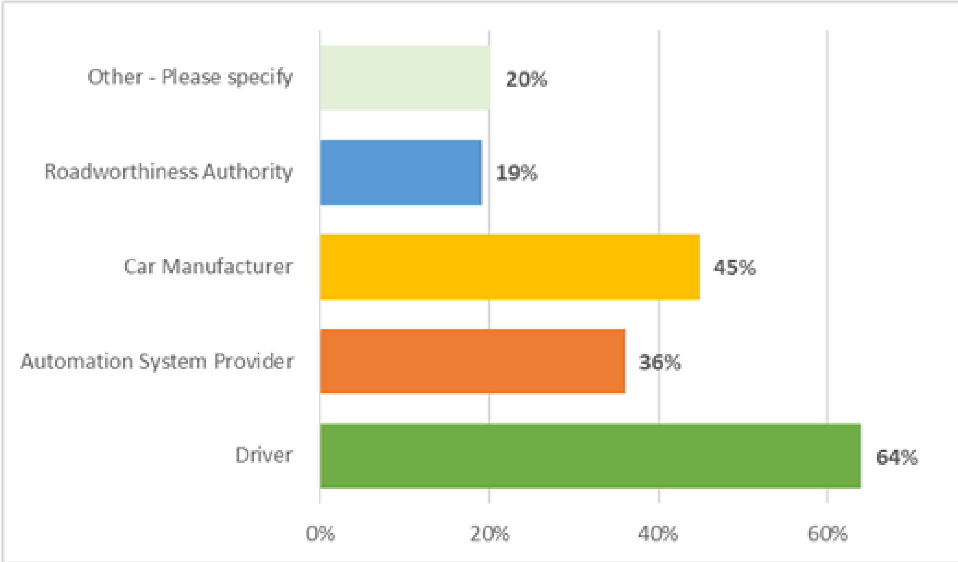

Figure 31: Who is responsible when a driver misunderstood the limitations of the system and an accident occurred (multiple options)?

Main comments received from respondents:

- *For SAE 1-3 it is the driver, from SAE 4 to 5 it is the OEM. It is always the actor who is in the "driving seat".*
- *Public authority who issues the driving licence for these specific functionalities*
- *It depends of the cause of the accident and the type of misunderstanding. Misunderstanding could be caused by lack of education or explanation at the specific automated system.*
- *Regulation should be in accordance with a safe system approach and hence forgive human failure. Hence, misunderstanding of the driver has to be taken into consideration when the systems are designed (fail safe). In the end, the responsible party is the road authority who provides the vehicle approval.*

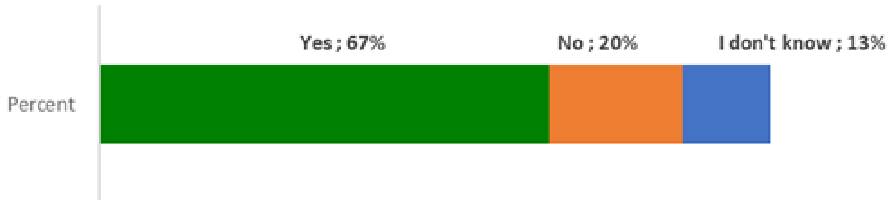

Figure 32: Should all traffic rules be made exact and measurable?

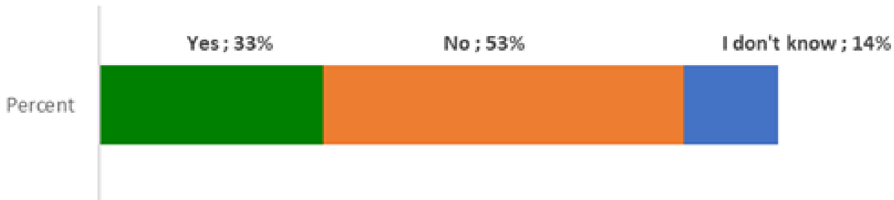

Figure 33: Do you think this is feasible?

	Overall Rank	Score	Total Respondents
Traffic light information	1	28	11
I2V information	2	18	11
Road signals	3	16	11

Table 5: In case of speed limitation what should be the precedence for this kind of information? Please classify from the highest (1) to the lowest priority (3)

	Overall Rank	Score	Total Respondents
I2V information	1	25	11
Traffic light information	2	22	10
Road signals	3	15	10

Table 6: In case of minimal distances between vehicles what should be the precedence for this kind of information? Please classify from the highest (1) to the lowest priority (3)

	Overall Rank	Score	Total Respondents
Traffic light information	1	31	11
I2V information	2	18	10
Road signals	3	13	10

Table 7: In case of traffic light information what should be the precedence for this kind of information? Please classify from the highest (1) to the lowest priority (3)

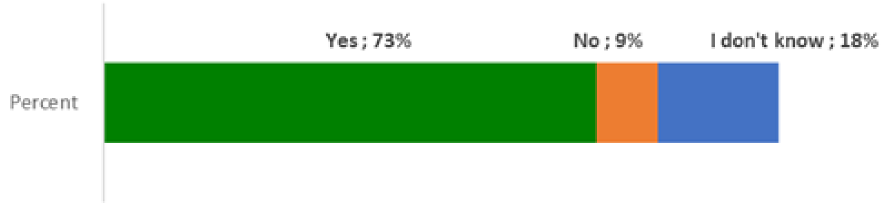

Figure 34: Should these minimum risk manoeuvres be prescribed (e.g. depending on location, traffic conditions, weather conditions, etc.)?

11.7. Other comments received from respondents

- *We need to safeguard kids and other sensible road users, falling under the principle of reliance. For ODDs there is currently no harmonized definition on what exactly is needed from the road authorities. What parts of the traffic acts need to be delivered in digital format? How to deal with areas, where we have different rules all over Europe (e.g. green flashing traffic light in Austria).*
- *Situations where an accident is unavoidable and the software needs to make a choice on who to harm and who to protect.*
- *Many situations can be expected that are not yet covered. There is far too little (hardly any) experience now which enables us to anticipate everything that can (and will) happen.*
- *If "Minimum risk manoeuvre" means stopping in a safe place, the "Safe place" concept needs to be thought through, and put into a system perspective.*
- *I am afraid the complexity of decision making while driving with regard to rules and safety is larger than we are aware of.*
- *Traffic rules may need to change to accommodate the complex interactions of multiple new road users (e-scooters, personal mobility devices, etc.) and also of pedestrians of different characteristics (the elderly, children, visual impaired, etc.).*
- *In my opinion, automated vehicles and human drivers and vulnerable road user should not be mixed in an urban environment. This will lead to conflicts and poor traffic flow/efficiency.*
- *If the vehicle is outside the ODD (for example because of weather conditions or difficult traffic situations) it is not enough to just go to a standstill. It could be extremely dangerous for other road-users. Adding to that there will not always be a "safe-spot" to go to. There are not safe-shoulders at any given stretch of road.*
- *In reference to question 19: Level 3 automation will never work. Drivers will become inattentive and mentally too unprepared to be able to take over driving in a short while when the car asks for take-over.*

[1] In fact, 238 respondents completely answered the survey once.

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