REPORT

How to maximize the road safety benefits of ADAS?

Client: Fédération Internationale de l'Automobile

Reference: BH3649-RHD-ZZ-XX-RP-Z-0001

Status: S0/P01.01

Date: 23 October 2020

HASKONINGDHV NEDERLAND B.V.

Laan 1914 no.35
3818 EX AMERSFOORT
Transport & Planning
Trade register number: 56515154

+31 88 348 20 00 **T**
+31 33 463 36 52 **F**
info@rhdhv.com **E**
royalhaskoningdhv.com **W**

Document title:	How to maximize the road safety benefits of ADAS?
Document short title:	
Reference:	BH3649-RHD-ZZ-XX-RP-Z-0001
Status:	P01.01/S0
Date:	23 October 2020
Project name:	BH3649-101-100
Project number:	BH3649-101-100
Author(s):	Anastasia Tsapi, Marco van der Linde, Maria Oskina, Jeroen Hogema, Frans Tillema, Arno van der Steen
Drafted by:	Anastasia Tsapi
Checked by:	Peter Morsink

Classification
Internal use only

MANAGEMENT SYSTEM CERTIFICATION DNV·GL ISO 9001 = ISO 14001 ISO 45001

Executive Summary

Advanced Driver Assistance Systems (ADAS) promise to deliver a substantial contribution to road safety. In May 2019, the European Parliament agreed that several safety systems like driver drowsiness and intelligent speed assistance must be present on new car models from July 2022 and on all existing models from 2024. To reap the potential safety benefits of ADAS, a variety of conditions should be met. The technical optimization of ADAS is crucial, both in terms of system limitations and Human Machine Interface (HMI). At the same time, measures should be taken to increase drivers' awareness of ADAS.

Fédération Internationale de l'Automobile (FIA) has set up a research project to examine the optimal way for the deployment of six ADAS technologies mandated for cars in the European Union from 2022: Advanced Emergency Braking (AEB), Intelligent Speed Assistance (ISA), Emergency Stop Signal (ESS), Adaptive Cruise Control (ACC), Lane Keeping System (LKS) and Driver Monitoring (DM) for drowsiness detection / distraction recognition. This research has been carried out by a partnership between Royal HaskoningDHV (lead), HAN University of Applied Sciences and TNO (Dutch Organisation for Applied Scientific Research). This research provided insight in the features, functionality, and potential of the six selected systems and aimed to provide policy recommendations to tackle the challenges that hinder reaching the full safety potential of ADAS. In other words, the aim was to answer the following question:

"Which policy recommendations can be formed to maximize the benefits of ADAS on road safety, taking into account the systems' current functionality, limitations and user awareness?"

A variety of research methods has been deployed to seek answers to the research questions. *Desk research* has been the main research tool to provide the state of the art in ADAS functionality, limitations, and safety risks as well as HMI and technical implications. A *Round Table meeting* with international experts from different ADAS fields has taken place to provide more insight in the findings of literature research on HMI, while *expert interviews* were conducted to complement literature findings on costs of ownership. With regards to user awareness, an *online survey* has been issued in six European countries (The Netherlands, Germany, Italy, Denmark, France, and Austria) to gather information on user's knowledge, expectations, and satisfaction of ADAS. This research step has been complemented with *expert interviews*. In parallel, an *online assessment of car manuals* and a scan of car websites have been used as input for a *"mystery shopping assignment"* at exclusive and independent car dealerships.

The results of this study have confirmed the conclusions of previous literature studies and managed to get insights in knowledge gaps in ADAS' functionality and limitations, HMI issues, user's knowledge, awareness, quality of available information as well as safety assessment procedures relevant to On Board Diagnostics and Lifetime Safety and Security. The main findings can be summarized in the following policy recommendations.

1. **Better information supply on ADAS functionality needed**
   To begin with, a good explanation to end users of the systems' limitations and Operational Design Domain (ODD) are significant in determining the expected contribution of ADAS to road safety. The desired insights into the limitations of the selected ADAS, however, do not appear to be sufficiently available.

2. **Improved accuracy in systems' functioning needed**
   Furthermore, accurate functioning of the systems is of utmost importance as it affects the consumer's trust in the latter. This study's findings indicate that the accuracy level of the studied systems is yet insufficient. There is, therefore, a lot of space for the improvement of the ADAS' accuracy.

3. **Improved fail-safe communication needed**
   Potential safety risks (like failure to detect threats) may arise. This study concludes that even in case the systems fail to function, potential road safety risks can be avoided by proper fail-safe communication. However, for the six studied ADAS, a failure to function is (almost) never communicated to the driver. As a result, drivers expect to be assisted when they are not. Inability to react to a traffic situation because of false expectations from the systems can be the cause of road accidents.

4. **Prerequisites for HMI design should be followed more closely**
   Concerning Human Machine Interface (HMI), ADAS that rely on a good (human centred) interface for their basic functionality are LKS, ISA and ACC. In the other three systems (AEB, drowsiness detection and ESS), a user interface is not (or hardly) involved. The findings on the prerequisites for the HMI framework (e.g. the system should react and behave predictably and the driver should be informed about any malfunction within the system that is likely to have an impact on safety) can be applied to any ADAS system for which an HMI framework is eminent and can be a base for creating policy guidelines for the ADAS HMI design.

5. **Clear maintenance and calibration processes needed**
   With regards to the impact of the ADAS' age on the systems' functionality, age-related issues can be solved with clear maintenance and calibration processes, making the latter increasingly important. In case ADAS gets damaged, the broken sensors mostly do not get repaired but get replaced as a whole. This increases the individual damage repair costs, because of the need for specialized equipment, qualified personnel, and higher spare part prices.

6. **Better instruction and training to drivers needed**
   The online survey, which collected responses of more than nine thousand drivers in six European countries, showed that most users do not receive training, but rely on information from the car seller, the user manual or they apply the 'trial-and-error' method. The quality of both information and instruction via these learning methods is found to be imperfect, which means that drivers are provided with incorrect and/or incomplete information and instruction. Compared to the respondents' trust in the six ADAS, it seems that a great number of respondents highly trust the systems, although they have insufficient knowledge of them. This is a type of overtrust in the systems which can lead to unsafe traffic situations. The mystery shopping assignment showed that car dealers are more aware of the ADAS' functionality, capabilities and limitations than shown in previous studies. However, the dealers' knowledge is transferred to the car buyer only under certain and limited conditions. These findings highlight the necessity of ADAS in training as well as the improvement of information and instruction given to all ADAS users.

7. **Safety assessment procedures: more accessible and updated in time**
   The last part of this research regarded On-Board Diagnostics (OBD) and Lifetime Safety and Security. This part makes clear that importance should be given to accessible safety assessments of ADAS. In this way, the correct operation and degradation can be identified and diagnosed, and the driver can be notified in time of the malfunction. However, the functionality of these systems cannot be currently quantified through OBD as there is no data to diagnose them. Moreover, serially produced passenger cars that use public roads must meet certain type approval requirements and regulations. This approval applies to vehicles as well as to vehicle systems, components, and separate technical units. However, once approval is obtained, it remains valid even if admission requirements are changed later. The current directives for type approval admission requirements need to become stricter and receive frequent updates.

8. Need for an integrated safe system approach

An integrated multi-channel “driver-vehicle-infrastructure” approach is needed to embrace and increase the safety potential of ADAS. To begin with the *driver*, focus should be given on the role of the driver, the existing limitations of the systems and on the aspects of the systems that are still unknown. Also, minimum harmonization requirements should be applied for the information car dealerships should provide to their customers during the purchase process of an ADAS equipped vehicle. Regarding *vehicle* related improvements, minimum (technical) requirements must be set and all ADAS should comply with the same standards that state what the system is capable of and more importantly what it is not capable of. Also, a clear standard must be set for lifetime guarantee of ADAS. Regarding the Human Machine Interaction, improvements should not focus on interface (controls and displays) as a stand-alone item but consider it in combination with the rest of the ADAS functions. Finally, the systems’ functionality should ideally be reflected through the names of the systems. According to the present study, there are both advantages and disadvantages regarding uniform ADAS names. Therefore, it should be still researched and discussed if this reflection should happen together with terminology unification. As for *infrastructure*, national road operators and traffic agencies should collaborate towards a uniform “future proof” road network with priority to the highway and provincial roads. Such a network facilitates the necessary physical and digital infrastructure, considering and compensating for dangerous "hotspots" and gaps in the systems’ ODD. Finally, the current legislation should be complemented and provide clarity in all three aspects of this integral approach to ensure the beginning of initiatives and the application of regulations.

Table of Contents

Executive Summary **i**

1 Introduction 1

1.1 Research aim and research questions 2

1.2 Report outline 3

2 Research Methodology 4

2.1 ADAS state of the art 4

2.1.1 ADAS functionality 4

2.1.2 User communication (Human Machine Interface) 5

2.2 Users' awareness & understanding of ADAS 6

2.2.1 Survey on users' understanding of ADAS 6

2.2.2 "Mystery shopping" exercise on users' information at car dealerships 7

2.3 Technical Implications 9

2.3.1 On-board diagnostic functionality for the repair and maintenance of ADAS 9

2.3.2 Technical type-approval and roadworthiness regulatory requirements 9

3 ADAS state of the art 11

3.1 Factors affecting ADAS' road safety potential 11

3.1.1 Driving behaviour changes 12

3.1.2 Operational Design Domain (ODD) 12

3.1.3 ADAS' accuracy 13

3.1.4 Fail safe communication 13

3.2 ADAS' functionality, limitations and safety risks 14

3.2.1 Advanced Emergency Braking (AEB) 14

3.2.2 Intelligent Speed Assistance (ISA) 15

3.2.3 Emergency Stop Signal (ESS) 16

3.2.4 Adaptive Cruise Control (ACC) 17

3.2.5 Lane Keeping System (LKS) 18

3.2.6 Driver Monitoring (DM) for Drowsiness detection / distraction recognition 20

3.3 Cost of Ownership 24

3.4 Conclusions state of the art 25

4 Human Machine Interface 26

4.1 Literature research outcomes on the HMI designs of ADAS 26

4.1.1 Penetration rates and usage rates of ADAS 26

4.1.2 Generic HMI design principles and standards 27

4.1.3 Advanced Emergency Braking (AEB) 29

4.1.4 Intelligent Speed Assistance (ISA) 29

4.1.5 Emergency Stop Signal (ESS) 30

4.1.6 Adaptive Cruise Control (ACC) 30

4.1.7 Lane Keeping System (LKS) 32
4.1.8 Driver Monitoring for detection of driver drowsiness/distraction 33
4.2 Scan of car brands websites on the frequently used ADAS terminology and warning methods 33
4.3 Accident database overview for ADAS safety assessment 34
4.4 Round table meeting outcomes 35
4.5 Conclusions and recommendations on HMI 37
5 User awareness & usage of ADAS 39
5.1 User knowledge and awareness survey 39
5.1.1 Survey set-up 39
5.1.2 Block 1: Background questions 41
5.1.3 Block 2: Information & expectations 41
5.1.4 Block 3: Trust and satisfaction 43
5.1.5 Block 4: Knowledge assessment 44
5.1.6 Clarification of survey findings 46
5.1.7 Conclusions on ADAS user awareness 47
5.2 Information & instruction quality 47
5.2.1 Online car shopping assignment 47
5.2.1.1 Online car shopping assignment UK websites 47
5.2.1.2 Comparison of scans of UK and Netherlands web pages. 48
5.2.2 Scan of User Manuals 48
5.2.3 Mystery shopping assignment 49
5.2.3.1 Results per visit 49
5.2.3.2 General findings 51
5.2.4 Conclusions on information and instruction quality 52
6 Technical implications 54
6.1 Harmonised on-board diagnostic functionality for repair and maintenance of ADAS 54
6.1.1 Limitations and safety risks per ADAS 54
6.1.2 V-tron study 57
6.1.2.1 Data logging 57
6.1.2.2 ADAS monitoring 58
6.1.3 Conclusions and recommendations on Technical Requirements and OBD 59
6.2 Technical type-approval and roadworthiness regulatory requirements necessary to guarantee ADAS lifetime technical safety and security 61
6.2.1 Type approval 61
6.2.2 Lifetime guarantee safety (maintenance) 62
6.2.2.1 Recommendations for Requirements of maintenance on ADAS 63
6.2.3 Security 64
6.2.3.1 Conclusions and recommendations on security 64
6.2.4 Remaining findings 64

6.2.5 Regulations per ADAS 65
6.2.5.1 Conclusions on Regulations 66

7 Conclusions and recommendations 67
7.1 ADAS features and road safety impact 67
7.2 Human Machine Interface 70
7.3 User awareness 71
7.4 Technical implications 74
7.5 ADAS oriented infrastructure 74

References 76

Appendix I: Online user awareness survey 84

Appendix II: Qualitative analysis of four car User Manuals 92

Appendix III: Survey results 95

Appendix IV: Online car shopping assignment 104

Appendix V: Detailed outcomes of Round Table Meeting 105

Appendix VI: User awareness studies used as basis for awareness online survey 110

List of Tables

Table 1 Participants Round Table meeting. 5
Table 2 Selected car brands for online car shopping assignment. 7
Table 3 Criteria for assessment of car brand websites. 7
Table 4 Explanation of hits, false alarms, misses, and correct rejections. 13
Table 5 AEB's Operational Design Domain (ODD) 15
Table 6 ISA's Operational Design Domain (ODD) 16
Table 7: ESS's Operational Design Domain (ODD) 17
Table 8 ACC's Operational Design Domain (ODD) 18
Table 9 LKS's Operational Design Domain (ODD) 20
Table 10 Driver Monitoring's Operational Design Domain (ODD) 24
Table 11: Estimation of ADAS penetration rates 26
Table 12: User influence on usage rates of ADAS 26
Table 13: Scan of car brands websites on the ADAS terminology 33
Table 14: Scan of car brands websites on the ADAS warning methods 34
Table 15: Estimation of the effect of the automated vehicle level 2 on the accidents reduction. 35
Table 16 Magnitude of correlation coefficients (all correlations are positive and significant at the 0,01 level) 44
Table 17 Visited car-dealerships during mystery shopping assignment 49
Table 19 OBD2 modes of operation. 59
Table 20 Goals for Driver Education matrix (Hatakka, et al.,2003). 72

List of Figures

Figure 1 Main research question and sub-questions in relation to project deliverables. 2
Figure 2 SAE levels of driving automation (source: sae.org). 11
Figure 3 Every situation outside the ODD causes an interruption in the operation of the ADS, which will lead to a Transition-of-Control (TOC) (Alkim, 2017). 12
Figure 4 AEB most used sensor types and input. 14
Figure 5 ISA most used sensors, input and event notification. 15
Figure 6 ESS's sensors, input and event notification (to the following vehicle). 16
Figure 7 ACC's most used sensors and input. 17
Figure 8 LKS's most used sensors, input and event notification. 18
Figure 9 Most used sensors for drowsiness detection and distraction recognition, input and event notification. 22
Figure 10: Developments in the expected damage repair volume without (left) and with (right) correction for increased parts & labour prices (BOVAG, 2019). 25

Figure 11: 4-blocks design user survey. 40
Figure 12 Penetration rates per ADAS as resulted from the online survey. 41
Figure 13 Information/learning channels for ADAS’ functionality, use and limitations, 42
Figure 14 Perceived understanding of the systems. 43
Figure 15 ADAS level of knowledge. 45
Figure 16 Comparison between level of trust in ADAS and knowledge about ADAS. 45
Figure 17 Relation between current experiences/ expectations with ADAS and number of correct answers. 46
Figure 18 Example of the web page analysis. 48
Figure 19 Left: eOBD port, Right: Data logging through PEAK CAN. 57
Figure 20 Test setup. 57
Figure 21 Peak CAN USB logger. 58
Figure 22 OBD2 message format. 58
Figure 23 Flowchart for application for type approval [4]. 62
Figure 24 “Multi-channel” ADAS road safety approach “driver-vehicle-infrastructure”. 67

Royal HaskoningDHV HAN_UNIVERSITY OF APPLIED SCIENCES TNO innovation for life

1 Introduction

The automotive sector is radically developing with the aim to continue assisting drivers to perform a wide range of driving tasks, from simple to more complex ones. This support is provided with the development of new and the optimization of the current Advanced Driver Assistance Systems (ADAS).

As support of this deployment, the European Commission published in May 2018 a strategy that includes the use of ADAS as a step towards fully autonomous vehicles, while it aims at establishing Europe as a leader in the sector (European Commission, 2018). While ADAS technologies are still under optimization, they are already sold either as standard or as an option in the market. In May 2019, the European Parliament agreed that several safety systems like driver drowsiness and distraction warning, intelligent speed assistance, lane-keeping assistance and advanced emergency braking must be present on new car models from July 2022 and on all existing models from 2024 (European Commission, 2019). This is expected to accelerate the share of cars with safety systems in the near future.

The promised potential of ADAS in contributing to road safety is great. ITS and ADAS have made cars safer, but the effect of the various systems differs greatly. A variety of conditions should be met to realize the full potential of them. Such conditions are optimization of the systems' technical functions, driver's knowledge of the systems' capacities as well as appropriate road infrastructure to support the safe and comfortable functioning of ADAS. While road authorities in different countries (e.g. the Netherlands and Germany, see https://www.rijksoverheid.nl/actueel/nieuws/2019/06/03/eu-landen-en-autofabrikanten-delen-informatie-voor-meer-verkeersveiligheid) are updating road infrastructure to meet the requirements of ADAS and the automotive industry is working on the optimization of the systems, the safety risks of the systems (due to their limitations) are still discussed in a general manner. At the same time, recent studies have shown that a great number of drivers are not aware of the existence of the systems in their cars, not even in case the systems are constantly activated (Connecting Mobility, 2017).

Even when drivers are aware of the systems, some experience difficulties on how to properly interact with the available systems: from activation to signal understanding and reaction. Even though it is suggested that human error (partially) contributes to about 90% of the motor vehicle crashes, and ADAS can potentially compensate for a great part of that, the changing role of the driver (from driving to monitoring) could potentially increase cognitive workload and decrease situational awareness, thus introducing new risks (Dutch Safety Board, 2019). Thus, the overall safety benefits of ADAS might be lower than initially expected.

It is therefore obvious that improvement is necessary from all perspectives. The technical optimization of ADAS is crucial, both in terms of system limitations and Human Machine Interaction (HMI). At the same time, measures should be taken to increase the awareness of drivers on ADAS. What are the necessary steps for this improvement? In other words:

How to maximize the road safety benefits of ADAS?

Fédération Internationale de l'Automobile (FIA) has set up a research project to tackle different aspects of this question. This research, taking into account the results of ongoing European studies and the "FIA Region I" policy position, will result in an inventory of the capabilities and issues of ADAS and will provide insight into the user awareness level in European countries. The outcomes will be used to produce policy recommendations at the European level to address the identified challenges.

This report presents the outcomes of the research of the partnership between Royal HaskoningDHV (lead), HAN University of Applied Sciences and TNO. It is used as a technical report and basis of the executive summary with the key findings and recommendations for the optimal use of ADAS by drivers.

1.1 Research aim and research questions

This research examines the optimal way for the deployment of ADAS technologies mandated for cars in the European Union from 2022. Focus will be given on the following six ADAS:

1. Advanced Emergency Braking (AEB)
2. Intelligent Speed Assistance (ISA)
3. Emergency Stop Signal (ESS)
4. Adaptive Cruise Control (ACC)
5. Lane Keeping System (LKS)
6. Driver Monitoring (DM) for rowsiness detection / distraction recognition

The aim of this research is to provide in-depth insight in the features, functionality, and potential of these systems. This knowledge is of paramount importance for exploring how to maximize the road safety gains for society. The study ultimately aims to provide policy recommendations to tackle the challenges described in this report.

This aim can be translated into the following main research question:

"Which policy recommendations can be formed to maximize the benefits of ADAS on road safety, taking into account the systems' current functionality, limitations and user awareness?"

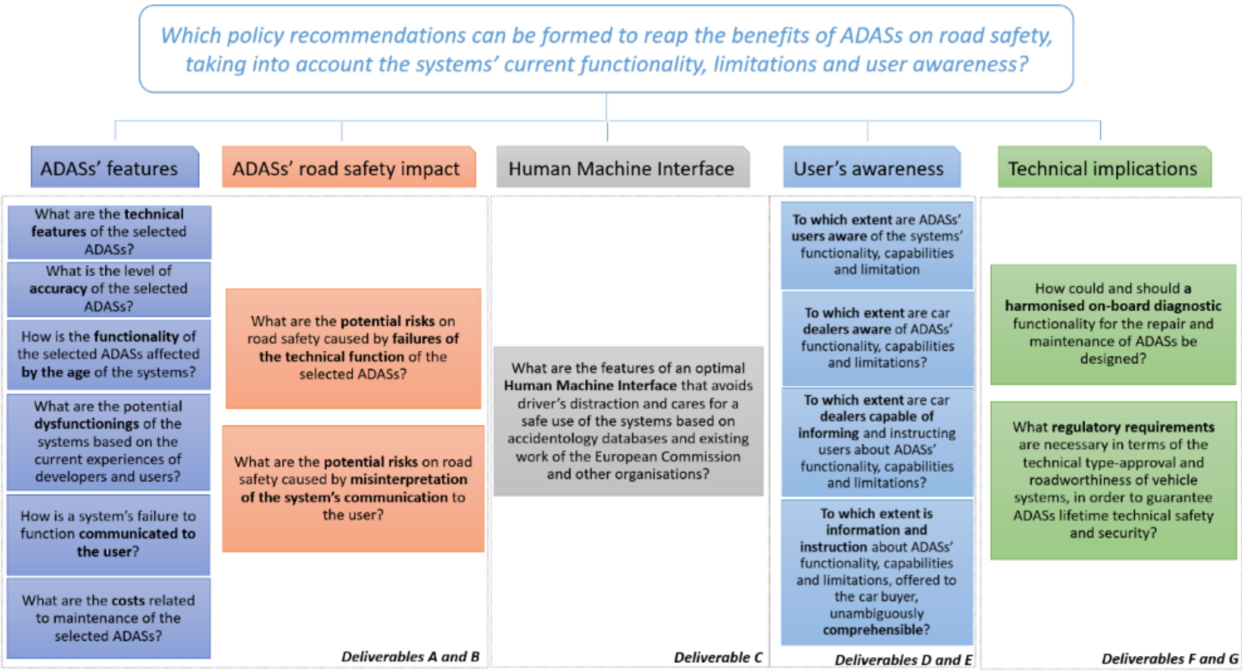


Figure 1 Main research question and sub-questions in relation to project deliverables.

1.2 Report outline

The formation of the main research question and its sub-questions is followed by the research methodology in *chapter 2* of this report. *Chapter 3* presents the results of the literature research, being the answers to deliverables A and B. *Chapter 4* outlines the findings of literature research and an expert session about Human Machine Interface (Deliverable C). In *chapter 5* the knowledge and awareness of ADAS users and car dealers are discussed based on the findings of this research. Finally, the ADAS technical limitations regarding On Board Diagnostics and Lifetime Safety and Security are described in *chapter 6*. The conclusions and recommendations of this study are presented in *chapter 7*.

2 Research Methodology

This chapter presents the steps that were followed in all stages of the study to answer the sub-questions per deliverable.

2.1 ADAS state of the art

Desk research has been carried out to provide a full overview of the capabilities, the relevant safety risks, practical issues and necessary elements of Human Machine Interface of the following ADAS:

1. Advanced Emergency Braking (AEB)
2. Intelligent Speed Assistance (ISA)
3. Emergency Stop Signal (ESS)
4. Adaptive Cruise Control (ACC)
5. Lane Keeping System (LKS)
6. Driver Monitoring (DM) for Drowsiness detection / distraction recognition

The desk research has been split into two parts:

- Scientific literature research on the technical capacities, limitations, and safety risks of the ADAS.
- Desk research on experiments, workshops, interviews, and studies which have been carried out in a commercial context.

2.1.1 ADAS functionality

In this first phase of the desk research, literature research was carried out to create an inventory of the technical functionality and safety risks of the selected ADAS.

More specifically, the literature research will focus on scientific studies about:

- The **Operational Design Domain (ODD)** of each system, meaning the conditions under which each system is expected to successfully perform;
- The **used sensors** for each system (like camera's, lidars, radars, ultrasonic, et cetera) and what kind of information source each ADAS needs for it to be detected by its sensors;
- The **accuracy** of each system for false positives and negatives and to detection range. The role of the type of sensors of each system will also be discussed;
- The **communication of the system** towards the driver when it **fails to function** (if any).

A research inventory that has been made recently in the Netherlands (Vlakveld, 2019) as well as in the United States by IIHS (Weast, et al., 2020) have been used as a basis and have been supplemented by findings of other scientific studies. To select the key studies, we focused on:

- Scientific studies with the following characteristics:
  - Recent publication date
  - Use of field experiments
- Commercial studies focused on:
  - Use of field experiments
  - ADAS' Operational Design Domain (ODD)

The second phase of the desk research was related to ADAS' technical limitations. Studies from both the scientific community and commercial studies have been used to provide insight in any potential differences existing between experimental settings and real-life experiences:

- Results of field experiments and workshops of commercial parties were used to analyse the potential limitations of the ADAS as a result of the vehicle's age but also any other dysfunctions that have been noticed. In the same way, the costs of repair and other effects of ADASs on vehicle maintenance businesses were researched.

- Experiences of systems' users were explored along with the opinions of experts of the automotive industry. Regarding the Cost of Ownership of a (lease)vehicle fleet, car insurance experts (e.g. AON, AXA Belgium) were interviewed about effects of a higher ADAS penetration rate on decreasing insurance claims.

2.1.2 User communication (Human Machine Interface)

Literature research has also focused on collecting information from state-of-the-art studies regarding Human Machine Interfacing. The search aimed to create a list of elements that are necessary for an optimal Human Machine Interface. Such an interface enables easy and clear communication between the ADAS and the driver, while avoiding the risk of any distraction or confusion. The latter can be significantly important for specific groups of drivers who have different driving experience, physical capacities, and needs, like young novice drivers and elderly drivers. The desk research into Human Machine Interfacing included the following:

- Overview of relevant user groups and their characteristics, focusing on how this influences system operation;
- Overview of distracting or unambiguous factors of existing HMI designs;
- Analysis of papers on the traffic accident databases;
- Overview of frequently used terminology and a proposal for simplified & uniform terminology;
- Proposal for an "HMI framework" that focuses on the prerequisites for safe HMI design.

To confirm and strengthen the research findings an online "Round Table" meeting with representatives from expert organisations took place on June 26th 2020 The meeting aimed to receive feedback on the findings of the literature research as well as prioritize the elements of an HMI in terms of importance.

Representatives from the different areas of ADAS expertise that jointly need to work on a European level on an "integrated safe system approach" to accelerate the benefits of ADAS were invited. Table 1 shows the experts that took part in the Round Table session.

Table 1 Participants Round Table meeting.

	Organisation	Name
1	CIECA/CBR	Eef Jonkers (R&D, CBR)
2	Prodrive Academy	Mark Maaskant
3	Bundesanstalt für Straßenwesen (BASt)	Roland Schindhelm
4	Delft University of Technology	Joost de Winter
5	Leeds University	Natasha Merat
6	ACEA	Johannes Peter Bauer
7	European Association of Automotive suppliers (CLEPA)	Annika Larsson van Veoneer
8	VUFO	Thomas Unger
9	Chalmers University of Technology	Lars-Ola Bligård
10	FIA	Lone Otto Chris Hottentot Javier Morales Diogo Pinto
11	Royal HaskoningDHV & TNO	Anastasia Tsapi Maria Oskina Jeroen Hogema

2.2 Users' awareness & understanding of ADAS

Recent studies have suggested that there is a potential discrepancy between users' awareness and understanding of ADAS and the actual presence and capabilities of ADAS. This study continued to build upon these previous studies to investigate how users' awareness and understanding of ADAS can be improved.

2.2.1 Survey on users' understanding of ADAS

To achieve an improvement of users' awareness about the availability and correct usability of ADAS, an awareness survey was performed. To build a survey, the answers to which can provide sufficient insights in users' knowledge and awareness, three steps were carried out.

First, previous studies were assessed focusing on their findings as well as current knowledge gaps. Second, the insights of step 1 were used to design the new, international, users online survey. The survey questions (see Appendix I) addressed the following topics:

- Awareness of ADAS ownership/availability
- Knowledge of how to use ADAS correctly
- Users' attitudes/ preferences towards vehicle automation

The third step of the process consisted of the selection of four (4) European countries, where the recruitment of participants would take place (aiming at 1000 participants per country). The country selection criteria related to the presence of a car industry, the state of infrastructure, the use of lease cars and the average age of vehicle fleet per country. In agreement with FIA and its partners, the following countries were selected:

- Germany
- France
- Italy
- The Netherlands

Given the great challenge of reaching 1000 participants in 4 weeks, it has been decided to additionally distribute the questionnaire in Denmark and Austria. In these six countries, national automobile federations and insurance companies have been asked to distribute the survey through direct e-mails to their members, placement of recruitment texts on their websites, social media, and newsletters. The selection of these channels has been made because of their large, relevant group of members: insurance tend to have clients who drive modern cars and/or are most likely to know what type of vehicle the users are driving, while automobile federations have access to our target group and local/national companies. A weekly reminder has been sent by these organisations to increase the number of responses.

It must be noted that initially France was chosen as the main country for analysis and Denmark was chosen as an additional country for analysis. However, during the responses collection phase, it appeared that there were not enough responses in France and that there were enough responses in Denmark. Denmark, therefore, replaced France in the list of 4 main countries for analysis. Although the responses from France and Austria were only a few, the data of these two countries was added to the data of the four main countries with the large data sets for the sake of a larger sample.

2.2.2 "Mystery shopping" exercise on users' information at car dealerships

Discrepancies between users' knowledge about the presence of ADAS and how to use it correctly is largely influenced by how drivers are informed and instructed about these systems. This step has focused on the information quality and instruction quality a car buyer/owner receives.

FIA's request for proposals included the suggestion of performing a "mystery shopping" exercise. The expected results of this method in one country are not directly representative for the situation in other countries. Not only can a car dealer in country A be very different from a car dealer in country B but there can be differences between car dealerships of the same brand within one country. For more representative outcomes, two extra research steps have taken place before visiting car dealerships:

1. **Online car shopping assignment.**

This step included website visits of seven car brands (Table 2). The selection of the car brands was based on the list of most sold brands in Europe in 2019.

Table 2 Selected car brands for online car shopping assignment.

Brand	Visited model
Peugeot	Peugeot 508
Renault	Kadjar
Volkswagen	VW Golf
Toyota	Toyota Corolla (hatchback)
Ford	Ford Focus
Mercedes	B 200 AMG Line
Volvo	Volvo S60

This step aimed to assess the availability and the clarity of information that was provided at the website of each brand regarding the brand's ADAS existence, function, ODD and limitations. A set of criteria has been established (Table 3), based on which the assessment took place.

Table 3 Criteria for assessment of car brand websites.

Criteria	Type of answer (per ADAS)
Criterion 1: Availability of information	
Did you find any information about the ADAS?	YES/NO
Criterion 2: Easiness to find information	
Number of clicks until the information appears	#
Was the information clearly visible from either the homepage and/or the car model page?	YES/NO
Existence of relevant keywords at the search button	YES/NO
Criterion 3: Quality of information	
Is a description of the system provided?	YES/NO
Are there videos/photos to assist the description?	YES/NO/What
Is there clear description of the system's ODD / systems limitations?	YES/NO/only ODD/ only limitations
Is the system information unambiguous?	enter NO when you can interpret the info in more than one way
Is there a warning stating that the system does not replace a human driver and that the driver has to pay attention at all times?	YES/NO
Is there a reference to the instruction manual?	YES/NO
Is the content recently updated (within the last 12 months)	YES/NO/unknown

The online search was conducted by visiting the British websites of these brands. Next to this, the Dutch websites of Volkswagen, Toyota, Ford, and Volvo were visited. The latter aimed to identify any potential differences in the provision of information across different countries.

2. Assessment of User Manuals.

This step focused on the qualitative assessment of User Manuals of four car models. The qualitative assessment was focused on searching explanatory statements within the user manuals about ADAS system operation, limitations, ODD, and more. Consequently, these statements were categorized into several segments and assessed on multiple criteria. For each statement, it was decided whether the explanatory function of the statement was ambiguous or not (*"can it be interpreted in more than one way?"*). By using a three-colour coding scheme, the qualitative assessment of the user manuals was completed. This assessment focuses only on one of the six ADAS systems, namely the LKS. It was found that the descriptions of the other ADAS systems are quite like one another, in terms of structure, the used language, and the level of detail of the information and instructions concerning the systems' ODD.

The assessment focused on all information that addresses system (LKS) operation, limitations and ODD. The assessment therefore included all the criteria as stated below:

1. Speed range:
   a. Activation speed
   b. Deactivation speed
   c. Max. functional speed
2. Intended area of use:
   a. Road category
   b. Road profile
   c. (Ambient) conditions that need to be met
3. Influencing factors:
   a. (Ambient) conditions that negatively impacts the functioning of the LKS
   b. Functioning in combination with other ADAS
4. Warnings:
   a. General warnings
   b. Curve specific warnings
5. Operation when LKS is inside its ODD

If a car owner reads the User Manual, he/she should be able to get a good impression about what the system can and cannot do and where and when it can and cannot be deployed. How thorough this impression of the systems' ODD is, will of course depend on the accuracy and completeness of the information and whether it is easy to comprehend this information (is it unambiguous or not?).

3. Live Mystery Shopping Exercise.

The last step of the "Mystery shopping" exercise consisted of the physical visit of car dealerships in the Netherlands. Based on the conclusions of recent mystery shopping experiments (Boelhouwer, et al., 2020), car seller information improvements could be most effective when directed at independent dealers. For this reason, both exclusive and independent car dealers have been visited.

The "Mystery shopping" exercise was built in 3 steps (Weast, et al., 2020):

- **Step 1**: Researchers introduced themselves, without revealing the true purpose of their visit, and explained that they were shopping for their new company lease car. At this point, researchers showed interest in specific car models, without raising any questions about ADAS.
- **Step 2**: Researchers indicated that they have heard and seen advertisements on different "in-car" systems. They raised questions like "Are such systems available in this car?" but did not ask more in-depth questions.
- **Step 3**: Researchers asked specific questions on the systems' functionality, limitations, and the role of the driver, like "Can you please explain how this system works?".

The information provided by the car dealers was assessed based on the following questions:

- Does the car dealer mention the existence of the systems without being asked?
- Does the car dealer know how to answer the questions?
- To which extent does the car dealer know if the systems focus more on safety or comfort?
- To which extent does the car dealer explain/demonstrate the functionality of the systems?
- To which extent does the car dealer explain the limitations of the systems?

2.3 Technical Implications

2.3.1 On-board diagnostic functionality for the repair and maintenance of ADAS

This step focuses on the analysis of current diagnostic functionality and the desired functionality concerning the repair and maintenance of ADAS. Stepwise the following aspects have been researched:

- Based on the given list of ADAS, five (5) high-level goals of a harmonized On-Board Diagnostics functionality were defined, for repair, maintenance, security and ‘safety monitoring’. The high goals are related to aspects of ADAS such as (sensors), interface to drivers and driver notification:
  - Based on the functional goals, the ideal and necessary data records to be diagnosed were defined.
- High level functional requirements have been added to the analysis, based on the necessary data records, like:
  - Frequencies;
  - Accuracy;
  - Pass/Fail Criteria.
- Literature review into the existing data records in cars available through E-OBD. Specifically, two (2) cars (VW Golf and Toyota CHR) were reviewed. Both mentioned cars are representative of middle (c) class popular cars/ SUV.
- Confrontation of step 2 and step 3. Conclusions were drawn on high level whether existing E-OBD functionality concerning ADAS, in the two reviewed cars, can satisfy (pass/fail) functional requirements.

Based on the outcomes and synthesis of the aforementioned steps, conclusions were drawn on whether existing E-OBD is suitable to be used for high- level goals and policy advice was given for discussion with the European Commission and ACEA.

2.3.2 Technical type-approval and roadworthiness regulatory requirements

Regarding lifetime safety and security, emphasis has been given on the existing legal framework and the necessary additions to guarantee ADAS lifetime technical safety and security. The following process has been followed:

- Desktop research on high-level goals concerning lifetime safety and security (set of five (5) goals in agreement with FIA)
- Desktop research to analyse the current legal framework concerning ADAS:
  - 2007/46/EG, art. 20 and 29
  - 2018/858/EG
  - UN R.79
  - Consumer rights directive
- Desktop research was complemented by specialist consultation (together with experts from our network at technical approval agencies RDW and TüV) to analyse and summarize the current standards concerning lifetime safety and security:

- ISO 26262 for functional safety of road vehicles;
- ISO PAS 21448 for safety of the intended functionality in road vehicles;
- ISO/SAE 21434 for cybersecurity in automotive.

- The confrontation of current legal framework with high-level goals led to a set of conclusions, based on which advice is given on whether existing law fits high-level goals or that changes should be made.

3 ADAS state of the art

Advanced Driver Assistance Systems (ADAS) support the driver in performing primary driving tasks. Depending on the level of automation (see Figure 2), they can inform or warn the driver, partially take over the driving task from the driver, and/or intervene in critical situations (Dutch Safety Board, 2019).

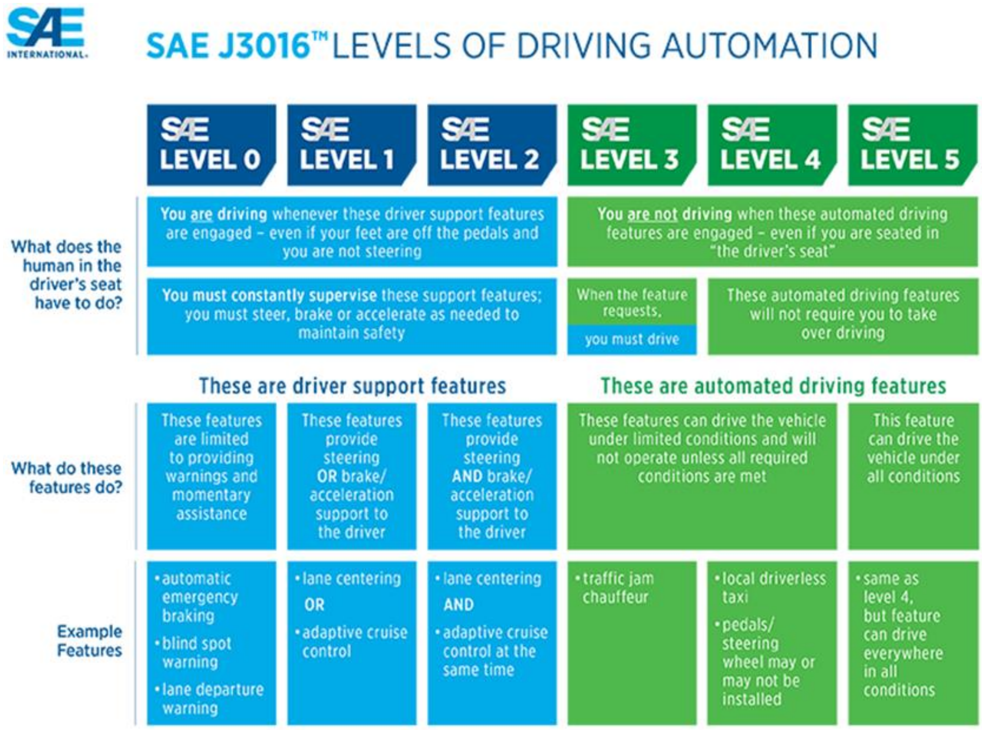


Figure 2 SAE levels of driving automation (source: sae.org).

ADAS are not only intended to make driving safer, but also to make it more comfortable for the driver. Some ADAS are more focused on safety, such as systems that intervene in emergency situations (e.g. AEB and Emergency Stop Signal), while others are more focused on comfort, such as systems that partly take over the driving task (e.g. ACC).

Systems that only intervene in critical situations are often permanently on. The driver does not notice anything while driving. Systems that partially take over the driving task, such as ACC or systems that automatically keep the car in the center of the lane (LKS), must be switched on by the driver. The driver experiences that the system is activated while driving. In case of systems that only warn in emergency situations (e.g. drowsiness detection), the driver does not notice their presence during regular driving. It sometimes happens, however, that the driver should switch this ADAS on every time he drives (e.g. ISA). Systems that provide continuous information are usually switched on automatically. Some of the ADAS that are automatically on, can be switched off (Vlakveld, 2019).

3.1 Factors affecting ADAS' road safety potential

Research has shown that drivers in highly automated cars have a hard time staying alert and tend to commit to other activities while driving, even when they have been told that the ADAS in their car is not 100% reliable (Carsten et al., 2012). Drivers also cope with multitasking, that comes from receiving and understanding a warning, without losing attention from the surrounding traffic conditions. A Swedish study (Victor et al., 2018) found that after driving for half an hour in a highly automated car, 28% of participants crashed into a parked inflatable car, despite keeping their hands on the wheel and being warned when off-road. It should also be considered that because of automation, drivers gradually stop practicing part of their skills. This can, therefore, result in them not acting properly in the few situations where this is necessary, being ADASs failures (Vlakveld, 2019).

3.1.1 Driving behaviour changes

On the one hand, ADAS can prevent accidents. On the other hand, new reasons for accidents by ADAS arise. Safety gains can be only achieved if the number of accidents prevented by ADAS is greater than the number of accidents it causes (Vlakveld, 2019). These new accidents can be caused, among other things, by:

- a decrease in situational awareness; since drivers become less attentive to traffic, they do not know what is going on around them and where this may lead in the following seconds (Endsley & Kaber, 1999);
- a reduction in workload, leading drivers to become distracted by non-driving tasks;
- overreliance in ADAS, which results to the drivers not checking if the systems function properly; and
- "mode confusion": when people are mistaken about the state of the system (e.g. "off" or "on"), drivers may (incorrectly) expect the systems to intervene or take over while they do not (Endsley, 2017);
- Behavioural Adaptation (Rudin-Brown & Jamson, 2013) .

3.1.2 Operational Design Domain (ODD)

Whether or not an Automated Driving System (ADS) is capable of functioning largely depends on its Operational Design Domain (ODD).

> *The ODD defines the operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics (SAE International, 2018).*

Users' knowledge of every system's ODD is crucial for managing the system's expectation and therefore, for the safe and efficient use of the system. The ODD is a result of various factors, all of which together define the capacity of the system in different driving environments, weather, and traffic conditions.

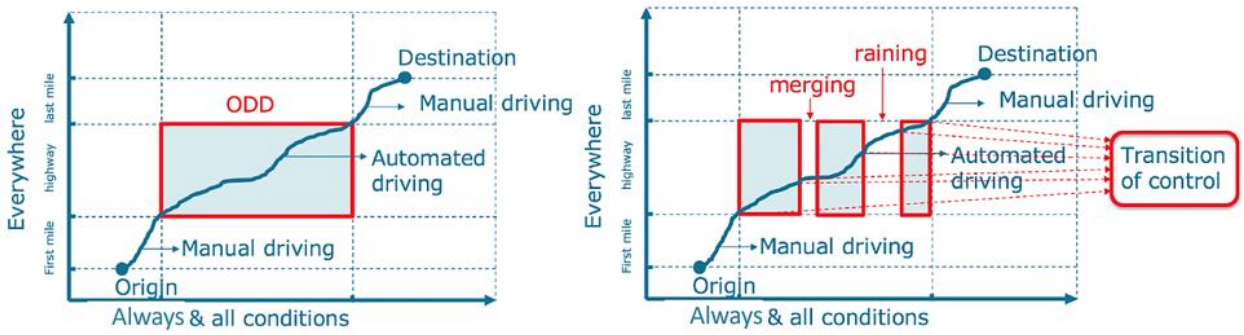


Figure 3 Every situation outside the ODD causes an interruption in the operation of the ADS, which will lead to a Transition-of-Control (TOC) (Alkim, 2017).

3.1.3 ADAS' accuracy

Software and hardware are possible to malfunction or crash. Possible electronic malfunctions (e.g. sensor malfunctioning) or system limits (e.g., missing lane markings or bad visibility conditions) may lead to false or missing interventions by ADAS (Naujoks, et al., 2015).

The ratio between hits and misses/ false alarms is of utmost importance as it affects the consumer's trust in the systems (Table 4). The number of misses and false alarms should be as low as possible and the number of correct rejection, but especially the correct hits, should be as large as possible. If a driver is warned for something that was not experienced to be dangerous (false alarm), the system will lose credibility points, decreasing acceptance. The same holds for misses; in case the system does not warn for something that was indeed experienced to be dangerous and did not fulfil its task in the first place, the system will not be accepted (Sayed et al., 2012).

To date, there have not been studies that provided ratios of accuracy for ADAS. Even in experimental studies where the numbers of false negatives and false positives have been measured, conclusions about accuracy cannot be drawn for the systems of all brands, since these can differ in both capabilities and limitations. As a result, there are no hard numbers indicating how reliable a system is compared to another system. In his study, Vlakveld (2019) has characterized the accuracy of different systems as good, reasonable (fair, average) and (presumably) insufficient. Out of the 14 systems analyzed in his study, only 2 systems (ISA and Alcohol Lock) are found to have good accuracy, while the other 12 systems have reasonable or insufficient accuracy. Although the accuracy is not presented in the form of hard numbers, there is a lot of space for the improvement of the ADAS' accuracy.

Table 4 Explanation of hits, false alarms, misses, and correct rejections.

Warning/Situation	Dangerous	Non-dangerous
Warning	Hit	False alarm
No warning	Miss	Correct rejection

3.1.4 Fail safe communication

Studies show that human performance degrades in a situation of automatic system failure compared to dealing with the same situation in a manual driving condition. Similar findings have been reported in other industrial settings, where higher human response time was observed in an automated operations scenario compared to a non-automated operations scenario during system failure (Dey, et al., 2016; Young & Stanton, 2001).

According to SWOV (2019), to date, there are no (national and international) legal design requirements for ADAS and other ITS. There are, however, recommendations and general design principles focusing on the safe use of ADAS/ ITS. The European Commission's Statement of Principles on human-machine interface is relevant (EC, 2008).

> *The content of the information should not induce the driver to engage in behaviour that increases the risk of an accident while driving. Dangerous behaviour can also influence the behaviour of other road users. Other road users are involved if the dangerous behaviour occurs when the driver interacts with those other road users or if the system gives signals that are perceptible from the outside and that may lead to misinterpretations and potentially dangerous manoeuvres of other road users.*

With regards to display elements, it is important that all the following elements, including failure to function, are displayed to the driver (UNECE, 2010):

- System active status shall be displayed to the driver. Drivers should be provided with clear feedback informing them when the system is actively controlling the vehicle.
- Drivers should be notified of any transfer of control between the driver and the vehicle.
- If action or information is not available due to a failure, the driver should be informed.

Finally, the Dutch Safety Board (2019) included as one of their recommended safety principles:

“Safe designs of new technology in relation to road safety should be such that the technology will safely shut itself down in case of a failure (failsafe)”.

3.2 ADAS’ functionality, limitations and safety risks

In the following paragraphs, the state of the art is presented regarding the ADAS functionality, Operational Design Domain (ODD), limitations and safety-related risks caused by sensor failures. Information is provided per system for each one of the following ADAS:

1. Advanced Emergency Braking (AEB)
2. Intelligent Speed Assistance (ISA)
3. Emergency Stop Signal (ESS)
4. Adaptive Cruise Control (ACC)
5. Lane Keeping System (LKS)
6. Driver Monitoring (DM) for Drowsiness detection / distraction recognition

3.2.1 Advanced Emergency Braking (AEB)

Advanced Emergency Braking (AEB) warns and/ or intervenes to perform an emergency stop. A collision cannot always be prevented, but hard braking will reduce the impact of that collision. The combination of Forward Collision Warning (FCW) features[1] (which alert a driver to take action when a collision appears possible) with first-generation AEB has shown dramatic reductions in rear-end collision rates (up to 80%) and pedestrian collision rates (up to 50%) when compared to similar models without the technology (https://www.bikewalknc.org/2018/02/autonomous-driving-and-collision-avoidance-technology/).

Figure 4 AEB most used sensor types and input.

Some AEB systems are designed to detect only cars and significant differences in performance are found among the products designed to detect pedestrians. The European New Car Assessment Program (Euro NCAP) began performing standardized tests for pedestrian AEB systems in 2016. The test results, published online, show how fast each vehicle can drive and still have the AEB system stop effectively for a pedestrian walking across the roadway. Tested performance varies even among implementations using the same sensor types. Most use some combination of cameras and radar since lidar has historically been very expensive. Some of the systems performed well at relatively high speeds, but the takeaway is that even with autonomous braking, pedestrians and crossing the road are safer if vehicle speeds are limited. (Bikewalk, 2018, see https://www.bikewalknc.org/2018/02/autonomous-driving-and-collision-avoidance-technology/; Tan et al., 2020).

---

[1] *FCW is a separate form of ADAS. It warns a driver for potential collisions, whereas AEB can apply the brakes when it senses the driver reacts too late, too little, or not at all.*

With regard to cyclists, a typical AEB system is likely to detect and brake for a cyclist riding in the centre of the lane on a low-speed city street, but may fail to slow down in time for a bicyclist riding on the edge of a narrow, high-speed rural highway – which unfortunately is the most common scenario for car-overtaking-bicycle crashes (Bikewalk, 2018). Finally, AEB can be vulnerable to fog or heavy rain as well as to the glare of sunlight and sunrise (Table 5).

Table 5 AEB's Operational Design Domain (ODD) (NA= Not applicable means that the system is not affected by these parameters, so it is expected to perform under all these conditions).

Physical infrastructure				Operational Constraints			Environmental conditions			Connectivity/ Digital infra	Zones
Roadway types	Roadway surfaces	Roadway edges and markings	Roadway geometry	Min speed limit (km/h)	Max speed limit (km/h)	Traffic density	Weather	Weather-induced Roadway Conditions	Illumination		
Depending on road conditions, stopping distances may vary Not always successful in detection of cyclists on highways	NA	NA	NA	20-60	- In high speeds not always successful in the detection of pedestrians)	NA	Ice and snow may affect the sensors, reducing functionality of the system	NA	Some systems vulnerable to fog and the glare from sunrise and sunset	NA	Not operating in very low speed zones (<20km/h)

3.2.2 Intelligent Speed Assistance (ISA)

Intelligent Speed Assistance (ISA) is a system which informs, warns, and discourages the driver to exceed the statutory local speed limit or other desired speed thresholds below this limit at safety-critical points. The in-vehicle speed limit is set automatically as a function of the speed limits indicated on the road. GPS allied to digital speed limit maps and speed traffic sign recognition allows ISA technology to continuously update the vehicle speed limit to the road speed limit. There are three types of ISA (European Commission, 2018):

- The open ISA warns the driver (visibly and/or audibly) that the speed limit is being exceeded. The driver him/herself decides whether to slow down. This is an informative or advisory system.
- The half-open ISA increases the pressure on the accelerator pedal when the speed limit is exceeded (the 'active accelerator'). Maintaining the same speed is possible, but less comfortable because of the counter pressure.
- The closed ISA limits the speed automatically if the speed limit is exceeded. It is possible to make this system mandatory or voluntary. In the latter case, drivers may choose to switch the system on or off.

The currently available ISA systems are based on fixed speed limits. They may also include location-dependent (advisory) speed limits. It will become increasingly possible to include dynamic speed limits that take account of the actual circumstances at a moment in time (EC, Mobility and Transport, 2020).

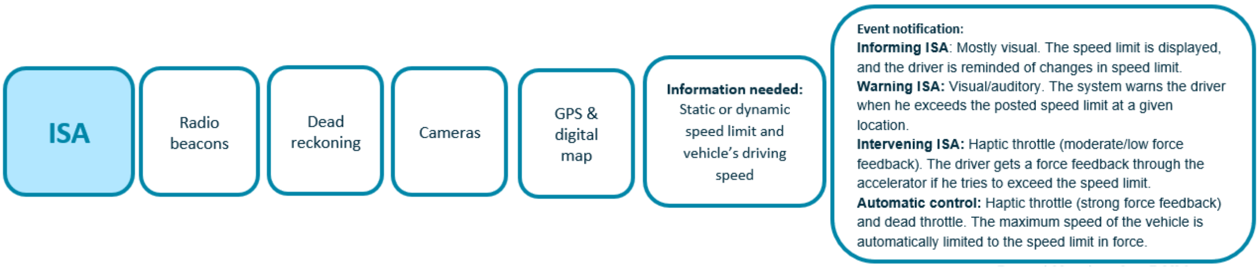


Figure 5 ISA most used sensors, input and event notification.

The most common problem experienced with ISA is that speed limits in some locations are incorrectly displayed by the ISA system (Paine et al., 2007). These inconsistencies are due to a. the limitations of the

GPS receiver in case it has limited accuracy in detecting the position of the vehicle and b. wrong information on the digital map. The vehicle's location information is matched with the digital map and the speed limit displays. When there is a loss of GPS signal or the digital map contains incorrect information (in terms of the road network and/or speed limits associated with it), this incorrect information is displayed to the driver, which could mislead the driver. In more advanced versions of ISA, the system could maintain the wrong speed limit. In both cases, ISA is not functioning as it should. These issues are often compensated using dead reckoning (however, positioning errors still play a role). In other cases, such inconsistencies are the result of wrong traffic sign recognition by in-car camera systems, such as when the system reads and informs about signs of parallel roads to the main road.

ISA has no further physical, operational, and environmental constraints that limit its function and accuracy.

Table 6 ISA's Operational Design Domain (ODD) (NA= Not applicable means that the system is not affected by these parameters, so it is expected to perform under all these conditions).

Physical infrastructure				Operational Constraints			Environmental conditions			Connectivity/ Digital infra	Zones
Roadway types	Roadway surfaces	Roadway edges and markings	Roadway geometry	Min speed limit (km/h)	Max speed limit (km/h)	Traffic density	Weathe r	Weather-induced Roadway Conditions	Illumination		
NA	NA	Vegitation, walls and other obstacles can obscure traffic signs, traffic signs on parallel roads read by cameras instead of the needed sign	Road curvature can obscure sightlines to traffic signs	NA	NA	In heavy traffic, signs might be obscured from view	NA	Functionality can be affected if traffic signs covered by snow/ice (does not apply for GPS-based systems)	Functionality can be affected if traffic signs covered by sunlight/sunrise/fog (does not apply for GPS-based systems)	Limitations of GPS connection may affect the functionality of the system	NA

3.2.3 Emergency Stop Signal (ESS)

Emergency Stop Signal (ESS) is designed to reduce the risk of accidents by warning following vehicles that the lead car is braking hard (e.g. by use of AEB and/or ABS);

The ESS system is not intended to replace the stop or brake lights fitted on the vehicle, consequently, its operation alone is not enough for proper brake signalling.

ESS activates when the driver brakes hard while driving at 50-60 km/h or above to alert drivers behind about sudden braking by rapidly flashing hazard warning or brake lights. The system works either with a sensor that detects rapid/sudden deceleration, or an electronic signal of the ABS activation triggers the flashing of the lights (https://www.hondacarindia.com/ownersmanual/webom/eng/jazz/2016/details/106278046-296438).

Figure 6 ESS's sensors, input and event notification (to the following vehicle).

The system is expected to work on all types of roads, speed ranges and weather conditions (Table 7). However, the system has its limitations and no safety system or combination of such systems can prevent all accidents. ESS is dependent on the car's AEB and/or ABS. If AEB/ABS stops working, the ESS will not activate. Furthermore, to avoid "too many" false positives in the use of ESS, which leads to unnecessary signals under "normal" driving circumstances, certain limit values have been set by manufacturers that must be met before activation, leading to a higher rate of false negatives (the following vehicle might not receive any signal of hard braking).

Table 7: ESS's Operational Design Domain (ODD) (NA= Not applicable means that the system is not affected by these parameters, so it is expected to perform under all these conditions).

Physical infrastructure				Operational Constraints			Environmental conditions			Connectivity/ Digital infra	Zones
Roadway types	Roadway surfaces	Roadway edges and markings	Roadway geometry	Min speed limit (km/h)	Max speed limit (km/h)	Traffic density	Weather	Weather-induced Roadway Conditions	Illumination		
NA	NA	NA	NA	50-60	-	NA	NA	NA	NA	-	Not operating in low speed zones (<50km/h)

3.2.4 Adaptive Cruise Control (ACC)

When Adaptive Cruise Control (ACC) is switched on, a pre-set speed is maintained (like with a conventional Cruise Control), and this speed is automatically reduced if a slower vehicle in front is approached too close. The ACC can operate at any speed if the Stop and Go function is available and for speeds above 30-50km/h (depending on the vehicle model) if the function is not available.

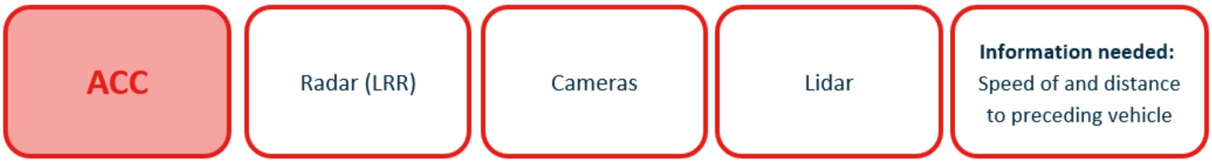


Figure 7 ACC's most used sensors and input.

The following limitations and safety risks of ACC have been reported in literature and field test studies:

- ACC may malfunction under adverse weather conditions or because of dirt on the sensors (confirmed by OEM's with regard to the radar and camera sensors);
- ACC systems may suffer from target detection loss due to sensor and environment issues (a radar sensor has a limited angle of view and can miss targets, i.e., the preceding vehicle, on curvy roads). This can lead to failure to detect preceding vehicles;
- ACC occasionally provides false notifications or unneeded braking intervention (e.g. using a vehicle in the adjacent lane as the target to follow);
- ACC may simply accelerate up to the set speed when a lead vehicle turns on a roundabout;
- By design, ACC does not work at low speeds or at very high speeds.

Table 8 ACC's Operational Design Domain (ODD) (NA= Not applicable means that the system is not affected by these parameters, so it is expected to perform under all these conditions).

Physical infrastructure				Operational Constraints			Environmental conditions			Connectivity/ Digital infra	Zones
Roadway types	Roadway surfaces	Roadway edges and markings	Roadway geometry	Min speed limit (km/h)	Max speed limit (km/h)	Traffic density	Weather	Weather-induced Roadway Conditions	Illumination		
NA	NA	NA	In bends, the sensor may detect the wrong vehicle or lose a detected vehicle from view	30-50*	Differs per system. Some ACC's work far above the speed limit	For high densities only ACC with Stop and Go function is functional**	Ice and snow may affect the sensor, reducing functionality of ACC. At very high temperatures the camera and radar unit can temporarily be switched off for about 15 minutes	Sometimes the sensor does not work on a very wet or snowy road surface	Dirt or non-reflective paint of the preceding vehicle may affect the functionality of laser or radar based ACC.	NA	Not operating in very low speed zones (<30km/h)*

*for ACC without Stop and Go function
**Sometimes the radar unit is late at detecting vehicles at close distances - e.g. a vehicle that drives in between your car and the vehicle ahead. Small vehicles, such as motorcycles, flat bed trailers or vehicles not driving in the center of the lane can remain undetected.

Concerning ACC's fail-safe communication[2], according to Volvo (2018), notifications are given to the driver in case of malfunction of the radar and camera sensors of ACC systems. However, no information has been found about communication to the driver in case ACC fails to function.

3.2.5 Lane Keeping System (LKS)

Lane Keeping Systems (LKS) and lane-departure-warning (LDW) systems have been a subject of intensive research and development (Amditis et al., 2010). LKS not only warns the driver in case of course deviation (like Lane Departure Warning) but takes over the task of returning the vehicle to the centre of the lane. LKS keeps track of the road and the lane boundaries. Some versions of LKS will only steer the vehicle when it comes too close to the lane edge, causing the vehicle to steer away from that lane edge and towards the centre of the lane. This causes the vehicle to swerve in its lane. Other versions of LKS steer the vehicle continuously, keeping the vehicle centered in its lane and thus causing less swerving. The trajectory to be followed is simply the middle of the lane, which can be easily computed based on the knowledge of the lane boundaries. Since an LKS only works if it can detect the lane boundaries, there is a direct relationship between the vehicle (system) and the road infrastructure.

Up to now, the most common techniques in lateral support systems are based on lane trackers using monocular video sensors to detect the lanes up to 50 m ahead (Zomotor & Franke, 1997; Clanton, et al., 2009). Laser scanners (Kirchner & Heinrich, 1998), high-resolution radar (Polychronopoulos et al., 2004), and infrared cameras (Fardi & Wanielik, 2004) are also used (Cheng, et al., 2006; McCall & Trivedi, 2006). More efficient approaches propose fusion techniques to complement the yaw rate- based road geometry, and estimate and predict changes in the curvature of the road ahead using a digital map and Global Positioning System (GPS) receivers and video cameras (Clanton et al., 2009) (Figure 8).

Figure 8 LKS's most used sensors, input and event notification.

Light Detection And Ranging (LIDAR) represents another major possible modality for lane and road detection. The LIDAR, being an active Time Of Flight (TOF) device, can measure the 3D structure of the vehicle surrounding. Besides, most LIDARs can report reflected intensity as well, providing a substitute to

[2] *Fail-safe communication is discussed only for ACC, since (almost) no information has been found for the other studied systems.*

a visual camera with an advantage of being an active light source and thus independent of natural light issues. This specifically helps in coping with shadows and darkness. Since lane marks have only intensity information and no 3D structure, intensity measurement is required if the LIDAR is to be used as the only modality. Also, LIDAR can be used to detect host vehicle pitch and road angles (most notably slopes) to improve image to world correspondence. The use of 3D data instead of 2D image allows for greater robustness and success rates: curbs, berms and road roughness are strong road markers. Obstacles are more easily detected in 3D, as well as road geometry (Hillel et al., 2014). The major drawback of the LIDAR modality is the relatively high cost of such sensors. The current high cost prevents such sensors from becoming wide-spread commodities for automotive applications.

While different warning channels are generally used, including haptic vibrations on the steering wheel and directional audio signals, active actions are generally delivered as an additive steering torque. It should also be noticed that some decoupled additive steering-angle solutions such as Advanced Front Steering systems are also available.

LKS's accuracy with respect to false positives and negatives and to detection range

Many studies have observed that the Time to Lane Crossing (TLC) based methods tend to have a higher False Alarm Rate (FAR) when the vehicle drives close to the lane boundary than when it drives closer to the middle. This is primarily due to using an oversimplified model to reduce computational complexity, neglecting drivers' steering characteristics and vehicle dynamics. The problem, however, is that most LKS systems cannot predict the forthcoming driver behaviours or vehicle trajectories (Wang et al., 2018).

Systems that use image processing can be complemented by GPS and map data providing information on where the road is expected to be and thereby improve lane positioning and reduce false alarms (Bishop, 2005).

Radar modality, while useful for other tasks, lacks the resolving power to observe lane marking or even delicate 3D structures. The relevance of RADAR sensors is twofold:

1. Detect obstacles (i.e. other vehicles) that obscure the lane marking and road boundaries.
2. Discriminate between road and off-road regions based on their large reflectivity difference.

Both properties form only a limited subset of the capabilities a LIDAR has, although with different related cost and other technical parameters.

Stereo imaging, the use of two cameras to obtain 3D information, represents a step between single camera modality and 3D LIDAR. Stereo imaging is typically much cheaper to implement than LIDAR and it inflicts smaller footprint on the host vehicle. On the other hand, stereo imaging generally cannot reach the same range accuracy and reliability that a LIDAR can. Unlike LIDAR, successful depth measurement is texture dependent, with extremely uniform surfaces posing a challenge. The range accuracy is a function of the stereo baseline (the distance between the two cameras) (Hillel et al., 2014).

The integration of sensing functions leads to improvements in performance superior to the sum of the contributions of each of them, since it increases the individual functionality of the systems, as well as reducing the false alarms. Detection by a single sensor has limitations inherent in the characteristics of that sensor.

Taking into account the sensors' accuracy constraints, field experiment studies have concluded to the following LKS limitations listed below (Klem & Gorter, 2016; Gorter et al, 2019; Morsink et al, 2019; Prins et al, 2019; Van der Linde, 2020). These limitations define LKS's ODD as shown in Table 9.

- Performance strongly fluctuates with changing environmental conditions;
- False detection can happen on surfaces that look like lane borders;

- Night-time urban light pollution may degrade detection of lane markings by cameras;
- In S-curves, LKS may not function in the second curve;

In his research, Van der Linde (2020) has studied the lower and upper limits of the ODD of Lane Keeping Systems in curves. During the field tests conducted within this study, it became clear that none of the test vehicles used was able to drive the curve with the LKS at the maximum permitted speed (except for one). From this it can be concluded that the compatibility between the LKS of the vehicle and the road design is not yet at the same level as the compatibility between the human driver and the road design. Road design that today is classified as "safe" for use by the human car driver is not necessarily "safe" for the LKS. The study results suggest that the ODD limit of the best performing test vehicle in the present study appears to be smaller what expected.

Furthermore, the various measured performance indicators show an image showing that the LKS of the vehicles perform better at lower driving speeds. This is in line with the visualized relationship between speed and arc radius (van der Linde, 2020). In addition, the average lateral position of the vehicle in relation to the centre lane before the turn was found to potentially influence the ability of the LKS to successfully turn a corner.

It also appeared that with a continuous marking configuration in the outside bend, the LKS was better able to take the bend; the deviation from the lane centre and the winding behaviour both decreased. It also appears that making more and smaller steering interventions translates into better LKS performance (van der Linde, 2020).

Table 9 LKS's Operational Design Domain (ODD) (NA= Not applicable means that the system is not affected by these parameters, so it is expected to perform under all these conditions).

Physical infrastructure				Operational Constraints			Environmental conditions			Connectivity/ Digital infra	Zones
Roadway types	Roadway surfaces	Roadway edges and markings	Roadway geometry	Min speed limit (km/h)	Max speed limit (km/h)	Traffic density	Weather	Weather-induced Roadway Conditions	Illumination		
Directly linked with road edge markings and geometry	-	Might miss not-continuous marking and special types of markings, vegitation	Issues at curves and S-curves. Minimum lane width differs per car.	Usually between 50-65 km/h	Differs per system. Some LKS work far above the speed limit	When too close to lead vehicle the lane marking might be missed.	Rain, snow, sunlight, dirt	Cameras and radar may not read lane marking in adverse weather conditions	Nighttime or light angle can affect the function of sensors	-	-

The desired insights into the boundaries of the ODD of LKS do not appear to be sufficiently available. Own observations of manuals from Subaru (2018) and Ford show that the Lane Assist may not work (properly) in certain situations, such as snowfall or a sharp turn. However, what exactly is a sharp turn is not defined. Also, Tesla has not included a clear description of the capabilities and limitations of its driver assistance systems in the manual (Bhusari, 2018).

The lack of knowledge about the ODD means that both car drivers and road authorities do not have (complete) insight into the capacities and limitations of driver assistance systems and therefore cannot know in which situations the systems function properly. Car drivers and road authorities will therefore have to experimentally determine what driver assistance systems can and cannot do. An incorrect estimate or a moment of inattention can potentially lead to very dangerous situations (van der Linde, 2020).

3.2.6 Driver Monitoring (DM) for Drowsiness detection / distraction recognition

Within this study, drowsiness detection / distraction recognition is studied as part of this group of driver monitoring systems. Driver inattention might be the result of a lack of alertness when driving due to driver drowsiness and distraction. Both driver drowsiness and distraction might have the same effects, i.e., decreased driving performance, longer reaction time, and an increased risk of crash involvement (Mbouna et al., 2013).

The existing monitoring systems can be divided into two branches: drowsiness and distraction detection systems. However, the distinction between them is not clear since cognitive distraction may in some cases be linked to the driver's vigilance (e.g. daydreaming). Intrusive driver monitoring techniques are not suitable for an in-vehicle environment and therefore, camera-vision-based systems are preferred by the automotive industry. A driver is not expected to wear special equipment when driving a car.

Driver drowsiness

Driver *drowsiness detection* is a car safety technology which aims to prevent accidents due to the driver getting drowsy. Various studies have suggested that around 20% of all road accidents are fatigue-related (AWAKE, 2002), up to 50% on certain roads. Unlike driver distraction, driver drowsiness involves no triggering event but, instead, is characterized by a progressive withdrawal of attention from the road and traffic demands.

Driver drowsiness is often caused by four main factors: sleep, work, time of day, and physical (Saini & Saini, 2014). Drowsiness detection can be divided into three main categories:

1. Vehicle based: Several metrics, including deviations from lane position, movement of the steering wheel, pressure on the acceleration pedal, etc., are constantly monitored and any change in these that crosses a specified threshold indicates a significantly increased probability that the driver is drowsy. When drowsy, the number of micro-corrections on the steering wheel reduces compared to normal driving (Saini & Saini, 2014). Based on small steering wheel movements, it is possible to estimate the drowsiness state of the driver and thus provide an alert if needed. It should be noted that ADAS (especially LKS) affect the steering behaviour and lane keeping performance, making this source of information less useful fort drowsiness detection (Schwarz et al., 2019).
2. Behavioural based: The behaviour of the driver, including yawning, eye closure, eye blinking, head pose, etc. is monitored through a camera and the driver is alerted if any of these drowsiness symptoms are detected:
    - LBP (local binary pattern): Local binary patterns (LBPs) have aroused increasing interest in image processing and computer vision. This technique is mostly used for detecting emotions on the face like, happiness, sadness, excitement etc. LBP (local binary pattern) is used in drowsiness detection for detecting face of the driver, it divides the image into four quadrants then the top and bottom part are detected (Saini & Saini, 2014).
    - Optical detection: In this eye blinking rate and eye closure duration is measured to detect driver's drowsiness. In this system the position of irises and eye states are monitored through time to estimate eye blinking frequency and eye close duration (Lenskiy & Lee, 2012). This system uses a remotely placed camera to acquire video and computer vision methods are then applied to sequentially localize face, eyes and eyelids positions to measure ratio of closure (Malla et al., 2010).
    - Yawning Based Technique: Detection of drives' drowsiness based on yawning measurement. This involves several steps including the real time detection and tracking of driver's face, detection and tracking of the mouth contour and the detection. (Hariri et al., 2012).
    - Head Nodding Detection: This technology simply determines the head tilt angle. When the head angle goes beyond a certain angle, an audio alarm is transmitted in the driver's ear.
3. Physiological based, where the drowsiness estimation is done based on physiological signals: ECG (electrocardiogram), EOG (electrooculogram) or EEG (electroencephalogram). Drowsiness is detected through pulse rate, heartbeat, and brain information (Saini & Saini, 2014).

Finally, time-on-task is an easily obtained measure relevant for drowsiness estimation (Soares et al., 2020). Relying on several of the measures discussed above can yield a better drowsiness detector than a single-source system (Schwarz et al., 2019).

These systems act to warn the driver when a safety-critical events such as a fatigue episode, has been detected, and depending on the device settings, parties external to the vehicle can also receive auditory warning information (Figure 9). There are, few on-road studies examining the effectiveness of fatigue auditory warnings, with some evidence that haptic warnings can be as effective as auditory feedback. When a fatigue event is detected, the vehicle operator is given an auditory warning ("fatigue detected") or an auditory tone (depending on vehicle), and/or a haptic warning (Fitzharris et al., 2017).

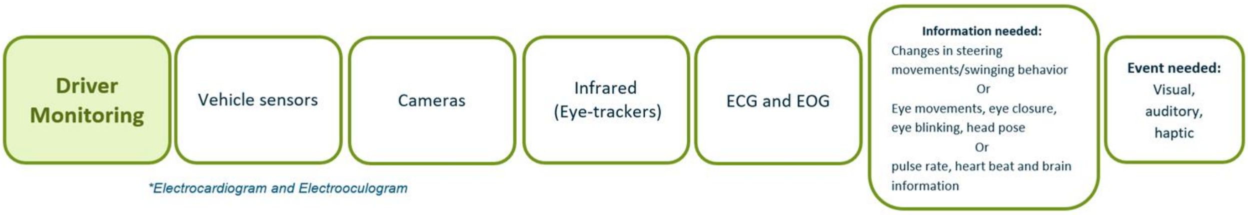


Figure 9 Most used sensors for drowsiness detection and distraction recognition, input and event notification.

Driver distraction

Distraction detectors measure whether the driver has turned his eyes off the road for too long. If a certain threshold value of "looking away from the road" has been established, an alarm is triggered. Even in a normal driving environment, e.g., straight road, minimal traffic, etc., distraction will increase the response time of the driver and hence reduce driver's readiness in responding to emergencies. In case of texting, the distraction is often severe and can lead to a loss of vehicle control, even without presence of external hazards. During texting, the driver reaction or available response time is too short to provide corrective action even in normal (nonemergency) cases of lane departures or negotiating curves, etc. The driver ability to formulate (decide) the corrective action could be drastically influenced by a distracting cognitive load alone (Sayed et al., 2012).

Distraction may also be caused by external factors, billboards, unusual traffic patterns, undesirable lighting, etc. The inattention of drivers and distractions are among the most important causes of accidents. 20%-30% of all car crashes were found to involve some form of driver distraction or inattention (Dragutinovic & Twisk, 2005).

> *"Driver distraction is the voluntary or involuntary diversion of attention from the primary driving tasks not related to impairment (from alcohol, drugs, fatigue, or a medical condition) where the diversion occurs because the driver is performing an additional task (or tasks) and temporarily focusing on an object, event, or person not related to the primary driving tasks. The diversion reduces a driver's situational awareness, decision making, and/or performance resulting, in some instances, in a collision or near-miss or corrective action by the driver and/ or other road user" (Australian Road Safety Board, 2006).*

Regarding driver distraction detection, now, the same systems can be used for driver distraction as for driver drowsiness (Kutila et al., 2007; Jin et al.,2012). However, much research is still needed to determine technology-based countermeasures for distracted driving. These technologies must incorporate the driver condition in complex situations (e.g., in presence of multiple stimuli) and the human response capacities. Among valuable areas of investigations are those that focus on the driver cognitive and physiological capacities and performance during driving (Sayed et al. 2012). However, eye closure and eye blinking are less relevant for driver distraction.

Driver Monitoring's accuracy with respect to false positives and negatives and detection range

The systems' accuracy can be summarized as such:

- Steering wheel direction reversals, vehicle path deviations and standard deviation of lateral position most sensitive for drowsiness detection;
- Visual road-ahead detection has around 84% accuracy for the visual distraction detection; more than 15% of the alarms can be false alarms (also dependent on driver characteristics);
- Eye trackers may lose tracking accuracy when vehicles are traveling on rough roads or when the lighting conditions are variable;
- Delay of detection is possible (related to sensor or data computation).

In more detail:

- Friedrichs and Yang (2010) compared 31 metrics of driving performance and found that among these metrics, the average steering angular velocity was the most sensitive.
- Sandberg et al. (2011a) compared 18 metrics and reported that variability of lateral velocity was the most sensitive.
- In a joint effort, Berglund (2007) and Mattsson (2007) compared a set of 17 metrics and found that a linear combination of steering wheel direction reversals, vehicle path deviations, and standard deviation of lateral position was most sensitive to driver drowsiness. These examples illustrate that no consensus exists regarding which metric or combination of metrics would be the most sensitive to driver drowsiness (Forsman et al., 2013).
- Limited sensitivity and reliability of the systems results in failure to communicate with the driver. This means that the system does not always warn when there is fatigue and sometimes it warns when nothing is wrong (Vlakveld, 2019).
- According to Hu and Zheng (2009), more than 15% of the alarms can be false alarms. However, this does not only depend on the system's capabilities but also on the driver's facial features and expressions.
- The reported accuracies of automatically detecting driver drowsiness varies across studies, however it is generally increased when algorithms have an inbuilt calibration/referencing system for each subject. It has also been suggested that the ability to accurately detect driver drowsiness would be increased using independent input signals (Pritchett et al., 2011).
- Similar to driver drowsiness, the sensitivity and specificity of driver distraction systems still need to be improved. However, the most important according to the experiment of Kutila et al. (2007), the visual road-ahead detection can be performed with some 84% accuracy, which promises a good outcome for the visual distraction detection. However, the issue is very different when false warning messages are provided since even 5% false alarms would frustrate human (Kutila et al., 2007).
- Eye trackers may lose tracking accuracy when vehicles are traveling on rough roads or when the lighting conditions are variable. More robust eye tracking techniques are needed to make these detection systems a reality. Second, delay of detection needs to be accurately measured to evaluate whether it is appropriate for the application (Liang et al., 2007).

In comparison to eye tracking, steering data can be obtained directly from the angle of the steering wheel and some have developed robust measures of lane position in real driving environments (Liang et al., 2007; Jin et al., 2012). Thus, driving performance can be used alone to detect driver cognitive state. The specificity is up to 99%, and false alarm rate for this system is low, which increases the system acceptance (Jin et al., 2012). On the other hand, a notable advantage of facial monitoring systems over the steering date ones is their compatibility with partial and conditional autonomous vehicles. Since in such scenarios the driving task is performed by the vehicle itself, the driver's performance cannot be assessed, and consequently, the systems are not able to infer the driver's state, which is preponderant in a fallback situation (Costa et al., 2019).

Finally, there is currently no system monitoring all types of reactions of driver. To expand the ODD of driver drowsiness and driver distraction monitoring systems, Costa et al. (2019) have proposed new approaches for these two aspects. They proposed a feature set that considers the vehicle's automation level for fatigue supervision. In terms of distraction assessment, the proposed (i) a holistic system that covers the full range of driver distraction types and (ii) a monitoring unit that predicts the driver activity causing the faulty behaviour. Based on their simulator experiments, their system can predict the driver's state with an accuracy ranging from 89% to 93%. However, the system only under research and development.

Table 10 Driver Monitoring's Operational Design Domain (ODD) (NA= Not applicable means that the system is not affected by these parameters, so it is expected to perform under all these conditions).

Physical infrastructure				Operational Constraints			Environmental conditions			Connectivity/ Digital infra	Zones
Roadway types	Roadway surfaces	Roadway edges and markings	Roadway geometry	Min speed limit (km/h)	Max speed limit (km/h)	Traffic density	Weather	Weather-induced Roadway Conditions	Illumination		
-	Eye trackers may lose accuracy	-	-	-	-	-	-	-	Eye trackers may fail to function under various light conditions	-	-

3.3 Cost of Ownership

In general, there is a lack of (detailed) information and literature about the cost of ownership with concerning ADAS, especially at the level of an individual vehicle owner. Cost benefits (cost savings) of ADAS are unknown because they are attributed to the expected decrease in vehicle crashes: the more crashes the ADAS prevent, the more the accident costs are reduced. It seems logical that sale prices of vehicles increase when the amount of new ADAS technology in the vehicle also increases. It is unknown what the actual effects of ADAS are on the vehicle sale prices. Some brands present prices for optional safety equipment on their online car configurator tools, but it is unknown if these prices represent the actual value of the ADAS. For example, for an additional €290, a Dutch VW Golf can be equipped with ACC, AEB and some other ADAS.

It is, however, possible to assess the monetary effects of an increase or decrease in road crashes on the damage repair and maintenance industry. The Dutch industry organization for car dealerships and garages, BOVAG, has conducted such a research (BOVAG, 2019).

They concluded that, on the short term, ADAS is suspected to have a low impact on the total amount of maintenance and repair jobs. The costs of these activities will however increase, putting pressure on the profit margins of garages (BOVAG, 2019). On the longer term, ADAS will mainly have an impact on the damage repair activities. Four types of ADAS are expected to have a substantial potential to decrease vehicle damage (GDV, 2017; BOVAG, 2019):

- Automatic Emergency Braking (AEB)
- Lane Change Assist (LCA) / Blind spot monitoring (BLIS)
- Lane Keeping System (LKS)
- Parking Assist (PA)

BOVAG calculated that, in a realistic scenario (in terms of market penetration), these four systems together will lead to a 23% reduction of damage repair volumes[3]. Corrected for increased prices for spare parts and calibration activities, the revenue of damage repair garages is expected to decrease by ~9% until 2030 (BOVAG, 2019). Since the European Parliament in the meantime has decided that an array of ADAS will

[3] *A decrease in damage repair volume is not the same as a decrease in crashes/injuries/fatalities.*

become mandatory on new cars, the AEB and LKS will decrease vehicle damages even further (because of higher penetration rates). In this case, the ‘high scenario’ should be expected.

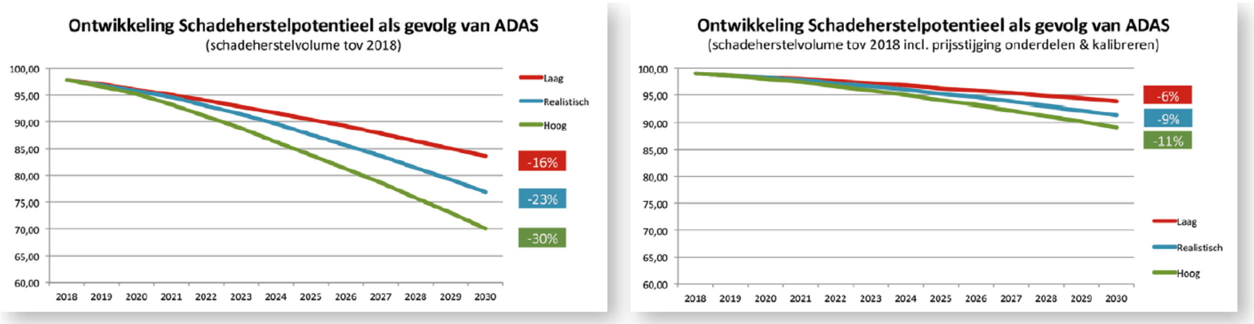


Figure 10: Developments in the expected damage repair volume without (left) and with (right) correction for increased parts & labour prices (BOVAG, 2019). Numbers represent all four ADAS systems (mentioned above) together. Lower decreases in damage repair volume apply for individual ADAS systems.

According to the BOVAG report, a 30% increase in costs can be expected for windscreen repair jobs. This is mainly caused by the increased complexity of the windscreen and the sensors behind it. There is a need for calibration of the sensors, which amplifies the necessity of high-tech tools, software, and qualified personnel to perform these repair and calibration jobs.

3.4 Conclusions state of the art

Functionality

- System definition and names differ between organizations;
- System definition includes (very) limited information on the Operational Design Domain (ODD).

ODD

- The desired insights into the boundaries of the selected ADAS do not appear to be sufficiently available; more ACC related information is available compared to the other systems;
- This lack of knowledge about the ODD means that both car drivers and road authorities do not have (complete) insight into ADAS capacities and limitations;
- Car drivers and road authorities will therefore have to determine experimentally what driver assistance systems can and cannot do.
- Discrepancy between driver expectations and vehicle capabilities: need for both (i) expectation management, and (ii) technological developments

Failsafe communication

- General design requirements based on European Commission, UNECE and Dutch Safety Board;
- System specific information: limited information only for ACC.

Cost of Ownership

Individual damage repair jobs are likely to increase, because of the need for specialized equipment, qualified personnel, and higher spare part prices. When penetration rates increase, the damage repair volume will, however, decrease. Four types of ADAS together are expected to cause a 23% decrease in damage repair volume (~9% if corrected for increased prices). Mainly AEB and LKS are expected to contribute to this decrease in vehicle damages.

4 Human Machine Interface

One of the important elements of the ADAS is the Human Machine Interface (HMI). An optimal HMI enables easy and clear communication between the ADAS and the driver, while avoiding the risk of any distraction or confusion. Such a HMI can contribute to the safer use of ADAS and support specific groups of drivers who have different driving experience, physical capacities and needs, like young novice drivers and elderly drivers. This chapter presents the literature research, the round table discussion, and conclusions on a framework with a list of elements that are necessary for an optimal HMI.

4.1 Literature research outcomes on the HMI designs of ADAS

This section presents the results of the literature research on the HMI features. The literature scan was conducted using available literature within TNO (including many reports from EU projects), www.scopus.com, https://trid.trb.org, and https://scholar.google.com/ and a scan of the car brand webpages.

The following paragraphs present the literature findings on the penetration rates of ADAS systems and HMI design principles for the systems in general and each ADAS separately.

4.1.1 Penetration rates and usage rates of ADAS

Although it is expected that ADAS contribute to the increase in of road safety, ADAS are efficient only if they are present in the vehicle (have high penetration rate) and if they are activated (high usage rate). Besides straightforward connection with the effectiveness, penetration and usage rates are important indicators for the level of attention that the systems require. If the systems are widely used – a clear policy recommendation should be given to ensure that users have a high level of understanding of ADAS' functionality, capabilities and limitations and can use the systems their vehicle is equipped with.

The table below gives a found estimation of the penetration rates for three out of the six ADAS.

Table 11: Estimation of ADAS penetration rates (L3Pilot, Deliverable D3.3 (2019); Bovag (2019))

Estimation of ADAS penetration rates in EU28 (2017; 2018)	AEB	ACC	LKS
Equipped % of new passenger vehicles sold	49 %		
Equipped % of new passenger vehicles as standard		16 %	14 %
Equipped % of vehicle stock	7.3 %		

It should be mentioned that usage rates do not correspond to penetration rates. Systems that can be disabled by a driver have lower usage rates. The following table gives an overview of the ADAS disabling possibilities.

Table 12: User influence on usage rates of ADAS

ADAS	Usage rate
ACC	User-selected
LKS	
DM (DD; DR)	Default on (but possibly can be deactivated)
ISA	
AEB	100 % time on
ESS	

The main reasons for using or not using ACC, LKS and Driver Monitoring (DM) are presented below. This analysis is not applicable for AEB, ESS and ISA since these systems are always activated.

ACC (Alkim et al., 2007; Niklas Strand, 2011)

- ACC is used mainly on uncongested motorways and rural roads;
- Reasons for using the system were that users found them: quick, predictable and comfortable;
- Reasons for deactivating the system were:
  - the functional limitations in the distance measuring system;
  - functional limitations connected to factors in the driving environment, such as specific road designs and weather conditions;
  - Harsh, abrupt control behaviour.

LKS (Niklas Strand, 2011; Reagan, Cicchino, Kerfoot, & Weast, 2018)

- The available information shows that LKS is relatively not used much. Reported reasons for that are low inconsistent lane tracking and discomforting steering, i.e. more about the control performance of the systems than strictly on the Human Machine Interface;
- Drivers who had lane maintenance systems turned off, believed warnings were *distracting and unnecessary;*
- Furthermore, a high frequency of perceived false positives and false negatives contributed to not using these systems;
- Increases in mileage were associated with significant decreases in the likelihood that a lane maintenance system would be turned on.

Driver Monitoring (Niklas Strand, 2011)

- Here the main reason mentioned for deactivating the system was drivers' inability to understand what triggered the warnings.

4.1.2 Generic HMI design principles and standards

On a high level, there is the "European Statement of Principles on human-machine interface (HMI) for in–vehicle information and communication systems", or ESOP in short (EC, 2008). Given the importance and relevance of these principles, they are listed below.

Design goals

- The system supports the driver and does not give rise to potentially hazardous behaviour by the driver or other road users.
- The allocation of driver attention while interacting with system displays and controls remains compatible with the attentional demand of the driving situation.
- The system does not distract or visually entertain the driver.
- The system does not present information to the driver which results in potentially hazardous behaviour by the driver or other road users.
- Interfaces intended to be used by the driver while the vehicle is in motion are consistent and compatible.

Installation principles

- The system should be located and securely fitted following relevant regulations, standards, and manufacturers' instructions for installing the system in vehicles.
- No part of the system should obstruct the driver's view of the road scene.
- The system should not obstruct vehicle controls and displays required for the primary driving task.
- Visual displays should be positioned as close as possible to the driver's normal line of sight.
- Visual displays should be designed and installed to avoid glare and reflections.

Information presentation principles

- Visually displayed information presented at any time by the system should be designed in such a way that the driver can assimilate the relevant information with a few glances which are brief enough not to adversely affect driving.
- Internationally and/or nationally agreed standards relating to legibility, audibility, icons, symbols, words, acronyms and/or abbreviations should be used.
- Information relevant to the driving task should be accurate and provided on time.
- Information with higher safety relevance should be given higher priority.
- System-generated sounds, with sound levels that cannot be controlled by the driver, should not mask audible warnings from within the vehicle or the outside.

Interaction principles (controls and displays)

- The driver should always be able to keep at least one hand on the steering wheel while interacting with the system.
- The system should not require long and uninterruptible sequences of manual-visual interface. If the sequence is short, it may be uninterruptible.
- The driver should be able to resume an interrupted sequence of interface with the system at the point of interruption or at another logical point.
- The driver should be able to control the pace of interface with the system. In particular, the system should not require the driver to make time-critical responses when providing inputs to the system.
- System controls should be designed in such a way that they can be operated without adverse impact on the primary driving controls.
- The driver should have control of the loudness of auditory information where there is likelihood of distraction.
- The system's response (e.g. feedback, confirmation) following driver input should be timely and clearly perceptible.
- Systems providing non-safety-related dynamic visual information should be capable of being switched to a mode where that information is not provided to the driver.

System behaviour principles

- While the vehicle is in motion, visual information not related to driving that is likely to distract the driver significantly should be automatically disabled.
- The behaviour of the system should not adversely interfere with displays or controls required for the primary driving task and road safety.
- System functions not intended to be used by the driver while driving should be made impossible to interact with while the vehicle is in motion, or, as a less preferred option, clear warnings should be provided against the unintended use.
- Information should be presented to the driver about status and any malfunction within the system that is likely to have an impact on safety.

Information about the system

- The system should have adequate instructions for the driver covering use and relevant aspects of installation and maintenance.
- System instructions should be correct and simple.
- System instructions should be in languages or forms designed to be understood by the intended group of drivers.
- The instructions should clearly state which functions of the system are intended to be used by the driver while driving and those which are not.
- Product information should be designed to accurately convey the system functionality.

- Product information should make it clear if special skills are required to use the system as intended by the manufacturer or if the system is unsuitable for specific users (e.g. senior drivers, drivers with disabilities, etc.).
- Representations of system use (e.g. descriptions, photographs, and sketches) should neither create unrealistic expectations on the part of potential users nor encourage unsafe use.

The ESOP and NHTSA (National Highway Traffic Safety Administration) Guidelines refer to various existing standards and standard documents in preparation to which the principles implicitly refer. These include:

- Concerning **dialogue management**: ISO 15005:2017 (ISO, 2017a). This European standard includes generic requirements (e.g. with respect to timing: "… the … device shall respond … to driver input on time"). It also gives many examples of what these generic requirements mean for ACC (in this case: "A vehicle's response to deactivation of … ACC… is immediately and clearly perceptible")
- Concerning the presentation of **visual information**: ISO 15008 (ISO, 2017b). This standard covers perceptual, and some basic cognitive, components of the visual information. It deals with visual contrast in different light conditions, font size etc., aimed at safe and quick and correct perception and recognition of visual information.
- Concerning the presentation of **auditory signals**: ISO 15006 (ISO, 2011). This standard covers basic perceptual aspects of auditory signals, at the level of sound levels and frequency content, aimed at ensuring auditory signals that will be clearly perceptible, but not startling.
- ISO TR 16352:2005(E). Literature survey about the **HMI of warning systems** in vehicles. It covers different modalities (visual, audio, and tactile) in terms of efficiency and acceptance, as well as recommendations for how to combine them (ISO, 2005).
- ISO TR 12204:2012(E) also relates to warnings, more specifically: **safety critical and time critical warning signals** (ISO, 2012). The TR covers the 'ACC overload' situation, i.e. the ego vehicle is approaching another vehicle and the braking capabilities of ACC are such that the system cannot cope with the situation (i.e. the driver must take control and brake or steer to avoid a collision).
- ISO 2575:2010 (ISO, 2010) specifies symbols for use on controls, indicators and tell-tales applying to passenger cars, light and heavy commercial vehicles and buses. The aim is to ensure identification and facilitate use.

The Dutch Safety Board has identified bottlenecks in terms of design, policy, regulation and supervision, data availability and learning capacity.

4.1.3 Advanced Emergency Braking (AEB)

Kidd and Reagan (2019) did a survey on, amongst others, Front Crash Prevention (FCP) systems, which is the combination of Forward Collision Warning (FCW) and Advanced Emergency Braking (AEB). Since they study this specific bundle, it is hard to separate the effects of the individual systems. When asked about keeping FCP on all the time, the average score was around 4 on a scale from 1 = strongly disagree to 5 = strongly agree, with some variation between car brands and types. "Drivers were more likely to agree to keeping FCP on, provided that it gave warnings they understood and warned infrequently".

4.1.4 Intelligent Speed Assistance (ISA)

ISA comes in many forms. These forms range from advisory/warning systems to intervening systems (overridable or not), see for instance (Carsten, 2002). An active gas pedal (where the return force under the foot is adjusted based on the relationship between actual speed and speed limit) can be in between these extremes, where the applied off-force determines the extent to which the limit can still be (comfortably) overridden (Rook & Hogema, 2005).

Lai and Carsten (2010) analysed results from extensive UK fields trials on ISA, distinguishing various driver groups (young/old, male/female, intending to speed / not intending to speed…). Their results showed that ISA tends to be overridden on roads where it was perhaps needed most. Further, behavioural differences among driver groups also suggests that ISA "tends to be overridden by those drivers who in safety terms stand to benefit most from using it".

Rook and Hogema (2005) compared various HMI alternatives in a driving simulator study: a dead throttle, a throttle with tactile feedback (vibrating when the speed limit was exceeded), and an active gas pedal with a 'low-force' or 'high-force', and a dead throttle. The results showed a trade-off between acceptance and effectiveness: the more restrictive the ISA, the lower its acceptance.

Finally, ISA has the longest adaptation period from the six studied ADAS. The adaptation to the system can take over a year, which can be a serious limitation for novel and elderly drivers.

Trade-off between acceptance and effectiveness: The more restrictive the ISA, the lower the acceptance rate.

4.1.5 Emergency Stop Signal (ESS)

The Emergency Stop Signal is an ADAS that is always activated by-default in the vehicle. However, it is active only when the car detects an emergency or heavy breaking situation and automatically deactivates once the situation has cleared and the car drives off again.

The literature study revealed no sources where Human Machine Interface or Human Machine Interaction processes with respect to ESS were covered.

4.1.6 Adaptive Cruise Control (ACC)

In addition to the general HMI guidelines and standards, there is a specific International Standard for ACC: ISO 15622 (ISO, 2018). This standard includes the basic control strategy, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures ACC systems (ISO, 2018). The 2018 version of the standard distinguishes between Full Speed Range Adaptive Cruise Control (FSRA) and Limited Speed Range Adaptive Cruise Control (LSRA) systems.

"*Adaptive Cruise Control is fundamentally intended to provide longitudinal control of equipped vehicles while travelling on highways (roads where non-motorized vehicles and pedestrians are prohibited) under free-flowing and for FSRA-type systems also for congested traffic conditions. ACC can be augmented with other capabilities, such as forward obstacle warning. For FSRA-type systems the system will attempt to stop behind an already tracked vehicle within its limited deceleration capabilities and will be able to start again after the driver has input a request to the system to resume the journey from standstill. The system is not required to react to stationary or slow-moving objects*". From an HMI perspective, this high-level distinction is highly relevant: users should know what the ACC can and what it cannot deal with.

The standard also prescribes the required reaction to system failures. Essentially, failures shall result in immediate notification to the driver and the notification shall remain active untill the system is switched off. Furthermore, (re)activation of the system shall be prohibited until the failure has been resolved.

Along similar lines, SAE Standard J2399_201409 (SAE, 2014) "contains the basic minimum recommended practices for the control strategy, functionality, driver interface elements, system diagnostics, and vehicle response to recognized failure for Adaptive Cruise Control (ACC) systems, with a focus on the ACC system operating characteristics and elements of the user interface".

The standards list what should at minimum be present in the HMI but does not prescribe how the controls and displays should be implemented.

Several sources in the literature provide information with respect to different ***user groups.***

- Ward, Humphreys, and Fairclough (1996) performed a field study with two groups of participants that differed in terms of sensation seeking disposition. Perceived safety benefits of ACC were higher among High Sensation Seekers (compared to Low SS). Driving with ACC, speeds were slightly higher, and headways were slightly shorter compared to manual driving, but interaction effects were not reported (suggesting that these changes in behaviour occurred in both groups).
- Hoedemaeker and Brookhuis (1998) did a driving simulator study with several groups of drivers that differed in driving style. This study also revealed higher speed and smaller minimum time headway when driving with ACC but driving style group made little difference to these behavioural adaptations.
- Within the group of ACC users, Gorter (2015) reported a correlation between the ACC ratings and driving style characteristics. Drivers which consider themselves more decisive and careful, or maintain a larger headway in manual driving, are more positive about ACC. "ACC-users overall are positive about ACC-usage on the highway, especially at higher speeds. In congested situations, an ACC-system with a full speed range is much more appreciated than a system which deactivates below a certain speed."
- Viti, Hoogendoorn, Alkim, and Bootsma (2008): "aggressive" drivers (defined as using relatively short THW when driving manually) used the shortest time gap settings exclusively, whereas non-aggressive drivers also used larger settings.
- Wu and Boyle (2015) conducted a survey among ACC owners in Washington State. From their analysis, four clusters of users emerged, ranging from those who rarely used ACC in any situation (low engagement group) to those who used it for almost all situations regardless of whether it is appropriate or not (high engagement group).
- Eichelberger and McCartt (2016): survey among Toyota Prius users with various ADAS (ACC, forward collision avoidance, and lane departure warning and prevention). Males were more likely than females to receiving a warning from ACC (when the system's max deceleration was not enough).

Another aspect relevant for different user groups is the **experience with ACC**. Experience is studied by comparing non-users with experienced users, and by exploring how much time is needed to develop from novice to experienced user, or how ACC usage develops over time.

- Gorter (2015), comparing ACC users with non-users: "ACC users tend to be older, male, drivers, with a lot of driving experience. (…) They consider themselves 'fast' drivers compared to non-ACC users, which is underlined by their tendency to drive too fast, perform secondary tasks while driving, and receive more penalties for traffic violations."
- Xiong, Boyle, Moeckli, Dow, and Brown (2012) investigated how experience with ACC and geographical location influenced ACC use patterns and acceptance. They found that "novice users intervened more often and set lower speed with ACC when compared with experienced users."
- Larsson, Kircher, and Andersson Hultgren (2014) compared driver with and without ACC experience in critical situations. Their results showed an increase in response times when driving with system support for both ACC-experienced drivers and ACC-novices (in line with several other sources). However, this effect was significantly lower for those previously experienced with ACC.
- In EuroFOT, Sanchez et al (2012) reported an increase of the ACC usage rate over time (footnote: this was ACC combined in one bundle with FCW). Acceptance (defined in terms of perceived

usefulness and driver satisfaction) was high and stable (i.e. did not increase or decrease over time). Close to 80 % of drivers state that driving comfort increases when they use ACC and 94 % of drivers feel that ACC increases safety. In terms of behaviour, driving with ACC resulted in a slight increase of average THW and a reduction of % of critical THWs.

- An increase of usage rate was also reported by Pereira, Beggiato, and Petzoldt (2015), however on urban roads only, leading them to the conclusion that the development of ACC usage over time might have distinct patterns in different road environments.
- Which is in line with Eichelberger and McCartt (2016): usage of ACC increased over time, but only for roads with “lower speed limits”.
- Viti et al. (2008) reported ‘fast learning’ in terms of choosing time gap settings in a Field Operational Test, observing only small variations after one month of using ACC.
- Beggiato, Pereira, Petzoldt, and Krems (2015) conducted a longitudinal study on learning and development of a mental model with ACC. “Results show that learning, as well as the development of acceptance and trust in ACC follows the power law of learning. All processes stabilize at a relatively high level after the fifth session, which corresponds to 185 km or 3.5 h of driving.”
- They identified three clusters of participants, based on the ACC usage (in terms of speed and time gap choice, number of warnings and frequency of deactivations): Conservative (C), Moderately risky (M), and Risky (R). Subjective and objective.

Kidd, Cicchino, Reagan, and Kerfoot (2017) investigated trust in various ADAS types in several production vehicles. They claimed that trust is a strong predictor of use. ACC was “in the middle”. Harsh control behaviour or late changes to vehicle speed were system behaviours that seemed related to lower trust scores. Similar, a questionnaire study by De Winter, Gorter, Schakel, and Van Arem (2017) found that unnecessary or abrupt braking (possibly surprising following vehicles) were mentioned by participants who disliked ACC. In contrast, among those who found ACC pleasant, the quick and predictable response of ACC to traffic events were mentioned.

In short, in addition to the general HMI guidelines and standards, there is a specific International Standard for ACC: ISO 15622 (ISO, 2018). This standard includes the basic control strategy, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures ACC systems (ISO, 2018). SAE Standard J2399_201409 (SAE, 2014) “contains the basic minimum recommended practices for the control strategy, functionality, driver interface elements, system diagnostics, and vehicle response to recognized failure for Adaptive Cruise Control (ACC) systems, with a focus on the ACC system operating characteristics and elements of the user interface”.

Most consider this to be a comfort system that may have some safety benefits (where behavioural adaptation may negate the benefits to a certain extent).

Not the HMI, but rather the control behaviour of ACC is a factor that strongly influences acceptance and trust (and therewith, in the end, usage).

4.1.7 Lane Keeping System (LKS)

Kidd, Cicchino, Reagan, and Kerfoot (2017) investigated trust in various ADAS types in several production vehicles. They claimed that trust is a strong predictor of use. LKS scored the lowest of the five ADAS types in the study. “Participants frequently complained about the functionality and/or performance of active lane keeping, but complaints about the user interface were most common”. “This included complaints about inconsistent recognition and tracking of lane markings and that steering inputs from the system were inappropriate or discomforting”.

Reagan, Cicchino, Kerfoot, and Weast (2018) investigated usage of various ADAS types of production vehicles (via surveys and by collecting system state data at service departments when customers brought in vehicles for service). Vehicles from five OEMS, from a total of 35 models with some form of lane maintenance systems, only one model had LKS. In terms of usage, the LKS did not differ from lane departure warning or lane departure prevention systems. A significant effect was found showing increases in mileage were associated with significant decreases in the likelihood that a lane maintenance system would be turned on.

LKS scored the lowest in users' trust among the studied ADAS, leading to the conclusion that LKS is expected to be used less that other ADAS. Most of the trust issues are relevant to the system's HMI.

4.1.8 Driver Monitoring for detection of driver drowsiness/distraction

Wilschut, Caljouw, and Valk (2009) presented an overview of methods for drowsiness detection behind the steering wheel using non-intrusive systems. Systems were subdivided into four types based on: physical activity, ocular measures, driving performance, or a multiple-measure approach. The same approach also covers distraction detection (Regan, Lee, & Young, 2008).

Drowsiness and distraction detection perform, as the name says, *detection* of driver states and thus do not have an HMI. In addition to the direct warnings to the driver (as discussed in Section 3.2.6), the output of such a system can be used in various ways during driving (Victor, 2011).

- Interaction managers (also dialogue or workload managers): by monitoring the driver-vehicle-environment state, the type or timing of information presented to the driver can be adapted, to ***prevent*** distraction or excessive workload.
- In terms of ***mitigating*** actions,
  - performance or state feedback can help the drivers realise that they are being distracted or getting drowsy. These are the warnings / suggestions to take a break.
  - Also, other types of ADAS (such as lane departure warnings or forward collision warnings) could adapt their warning thresholds to the driver state, i.e. warn a bit earlier when a driver is drowsy or distracted.

4.2 Scan of car brands websites on the frequently used ADAS terminology and warning methods

The overview of frequently used terminology is based on the scan of car brands webpages. The following table presents names of ADAS for different car brands and information on ADAS alarming systems.

Table 13: Scan of car brands websites on the ADAS terminology

	Volkswagen	Renault	Peugeot	Ford	Mercedes	Toyota	Volvo
Advanced emergency braking	Front Assist	Automatic Emergency braking system	Automatic Emergency Braking System	Emergency break assist	Active braking assist		City Safety with Steering Support
Intelligent speed assistance	Sign assist	Traffic sign recognition	Intelligent speed adaptation	Intelligent speed assist	Active speed limit assist	Road sign assist	Road sign information
Emergency stop signal							Emergency break light and hazard warning
Adaptive cruise control	Adaptive cruise control	Adaptive Cruise Control with Stop & Go		Intelligent adaptive cruise control	Active distance assist DISTRONIC	Intelligent adaptive cruise control	Adaptive cruise control

Lane keeping system	Lane assist	Lane keeping assist	Active lane keeping assistance	A lane-keeping system.	Active lane keeping assist	Lane departure alert with steering control	Lane keeping aid
Driver monitoring system	Driver alert system		Driver attention alert				Driver alert control

The car dealership webpages analysis shows that ADAS presented at all car dealers are: Intelligent Speed Assistance and the Lane Keeping System. The least presented systems are the Emergency stop signal and the Driver monitoring system. The analysis highlights the lack of consistency in the ADAS names since all the systems have different names for different car brands. An overlap is found in the names of Adaptive Cruise Control and Lane Keeping System between different brands.

The variety of names assigned to the rest of the ADAS can be explained by the need to reflect the functionality of systems in their names because the name of ADAS can influence the user's expectations regarding the system's capabilities. For example, some car brands decided to use assistant instead of system (e.g.: Road system assist; lane assist), which reflect the fact that systems assist human in driving but do not take full responsibility and control on the driving process.

Besides the naming of the relevant systems on the webpages, the car brands websites were also scanned for the warning methods of systems. The results of this scan are presented in Table 14.

Table 14: Scan of car brands websites on the ADAS warning methods

	Volkswagen	Peugeot	Ford	Toyota	Volvo
Advanced emergency braking	-visually and audibly				- audible, visible and brake pulse warnings
Intelligent speed assistance	-traffic signs are displayed on the multifunction and on the navigation system unit display.			-a visual warning -an acoustic warning	
Adaptive cruise control	- first with visual and acoustic signals, -then with a short braking jolt.				
Lane keeping system	-if Lane Assist is activated, a yellow control symbol lights up -when the camera has analysed the road markings, the symbol turns green -if driver takes hands off the wheel, the system makes a sound and displays a message.		-vibration on the steering wheel -a visual warning	-an audible and visual warning	
Driver monitoring system	- a visual display on the dashboard -a warning sound -if driver hasn't taken a break within 15 minutes, the system will repeat the warning.	-a message is displayed -a visual and audible alert			- a message display

Given the variability of warning signal types provided by several car brands, drivers who drive more than one car need to be able to recognize and interact with various types of warning signals. This can lead to potential confusion and/or misinterpretation. As a result, the reaction time of the driver to a warning can increase.

4.3 Accident database overview for ADAS safety assessment

A method for assessing the impact of ADAS on road safety is to check the statistics of road accidents. In general, limited information is provided on the statistics of accidents for the vehicles equipped with ADAS. A common reason for the lack of this information is that police rarely recreates the accident scene.

In this study, the research of accident databases has been based on two documents on accident statistics that have been provided by VUFO (Verkehrsunfallforschung an der TU Dresden GmbH). The first paper authored by Unger and Schubert (2018) focuses on ISA. Accidents related to speeding are particularly relevant for this system. The accident data shows that a proportion of 3% on average in Europe is related to excessive vehicle speed as the main cause. However, there is an issue with predicting the number of accidents due to not following the speed limits as all national accident databases are based on police reports. The police are usually not reconstructing accidents and thus, are not able to state the exact initial speed of the vehicles. Besides human factors contribution to accidents, the technical limitations of ISA are also present as accident causes. The traffic sign recognition error rates reach 10% under normal weather conditions and 15-25% under rain or during a night ride. In case ISA cannot read or misses traffic signs, changes in speed limit are not communicated to the driver. As a result, the driver might continue driving according to another speed limit, which is (much) higher or lower than the allowed one. Inconsistencies in driven speed among traffic users can lead to dangerous traffic situations, since they allow for hard decelerations, overtaking manoeuvres, etc.

The second provided paper by Liers and Unger (2019) considers the potential mitigation of accident scenarios for automated vehicles with level 2 of automation. According to the authors of the paper, the typical automated vehicle (AV) with level 2 has the following standard features:

- Antilock Braking System (ABS),
- Brake Assist System (BAS),
- Electronic Stability Control (ESC),
- Automatic headlamps,
- Traffic sign recognition
- Full speed range Adaptive Cruise Control (ACC) with Stop & Go function
- Forward Collision Warning System (FCW)
- Autonomous Emergency Braking (AEB) system
- Lane Keeping System (LKS) with lane centering function
- Blind Spot Detection (BSD), Blind Spot Information System (BLIS)
- Tire Pressure Monitoring System (TPMS)

Based on the accident statistics in 2017[4], an estimation was made of the reduction in the number of accidents. Table 15 shows the outcomes of this estimation.

Table 15: Estimation of the effect of the automated vehicle level 2 on the accidents reduction..

Market penetration rate	10 %	20 %	50 %
Estimated number of avoided accidents	653 ± 70	1308 ± 112	3271 ± 126
Potential effect on accidents avoidance	3.6 % ± 0.4 %	7.1 % ± 0.6 %	17.9 % ± 0.7 %

The estimation shows that if every fifth passenger car was equipped with the combination of the above-mentioned systems for AV level 2 (mainly ACC with stop and go, LKS, BSD, ESC, AEB front), a reduction of around 7% of all motorway accidents where a passenger car involved could be achieved.

4.4 Round table meeting outcomes

During the round table meeting, experts in different ADAS related fields shared their knowledge on three main questions (see 2.1.2), in the form of both closed questions (mentimeter survey (https://www.mentimeter.com/)) and open discussion. This section gives a short overview of the expert

[4] *https://www.destatis.de/EN/Press/2017/12/PE17_442_46241.html*

meeting's outcomes. For detailed information on the experts' answers to open and closed questions, see Appendix V.

With regards to creating uniformity in naming ADAS, there is no unified opinion of the Round Table meeting's experts but there is a general consensus that a system's name should reflect its functionality. One third (5 out of the 16) of the experts state that unified terminology and the reflection of functionality are not mutually exclusive. According to them, unified terminology that reflects the systems' functionality should be applied. The rest of the experts focus more on the fact that the ADAS names should reflect functionality. Finally, a minor part of this group (2 out of 16 experts) claims that it is too early to force names to be assigned to ADAS, because some ADAS are still maturing and are therefore subject to changes in their functionality. According to historical data, ADAS' names will gradually become similar once the penetration rate in the market has increased (e.g. ACC and LKS) or when their introduction will be mandated by the authorities.

The Round Table experts' views agree with the research results of Teoh (2019). His research has shown that the terminology used by car manufacturers to describe ADAS influences the users' expectations of those ADAS' functionality and operation. System names that seem to suggest that the vehicle's system will drive itself (e.g. "Autopilot", "ProPilot") were linked to higher rates of people who deem several behaviour types as 'safe'. "While a name alone cannot properly instruct drivers on how to use a system, it is a piece of information and must be considered so that drivers are not misled about the correct usage of these systems", Teoh (2019) states in his research. This highlights the necessity of correct regulation and evaluation of ADAS terminology in order not to mislead drivers about their proper use. The existing international guidelines provide "terms, definitions, abbreviations, and acronyms to enable common terminology for use in engineering reports, diagnostic tools and publications related to active safety systems." These descriptions focus on the functionality aspects of the systems, instead of technical specifications. These guidelines are, however, designed for use by the professional automotive community and might be too complex for the general public to comprehend.

According to the experts of the Round Table, wider use of the systems will provide more clarity in the exact function of the systems. As a result, names will gradually become similar. For example, a great overlap is seen in names for Adaptive Cruise Control and Lane Keeping System, which are used more widely than others. Additionally, it can be seen that the systems with uniformed names are those with the strongest connection to the HMI interface.

Euro NCAP has been mentioned as the organisation that is responsible for taking the lead in unifying ADAS' names. According to the latter, working towards a unified terminology starts from clarifying to the drivers whether the system is Safety based (like AEB) or Comfort based (like ACC).

Concerning increasing drivers' awareness levels on ADAS, most of the round table meeting's experts claim that the drivers should be informed on ADAS' functionality, capabilities and limitations during the purchase or while renting a vehicle. In this case, car dealers, leasing and renting companies should be in the lead in ensuring that sufficient ADAS information is provided to the drivers. The latter comprises a challenge for these types of companies, since the variety of names that is used for different ADAS would require them to know all different names and functionalities as well as the differences between them. In addition, nowadays, the process of renting a car often does not require any interaction between the user and the rent-a-car personnel. In these cases, the provision of information about the car's ADAS from the personnel to the user is not possible. Further, the round table meeting's experts are against using knowledge on ADAS as a requirement for someone to drive an ADAS equipped vehicle. According to them, ADAS knowledge can be acquired after the drivers get familiar with their vehicle and its functions.

Regarding drivers' education, the participating experts consider that voluntary training has added value in embracing the safety effects of ADAS. Driving training should come in the form of one-on-one training on public roads (not on a track); broad awareness campaigns and ADAS test drives. According to these experts, training should be provided by importers or lease companies and it should be given by skilled, certified trainers from training & driving academies. A short theoretical and practical introduction to specific ADAS used in specific vehicles or car models should be also provided by the car sellers. Regarding the content of training, the latter should include the following elements:

- Demonstration of all in-car available systems
- Explanation of the capabilities and limitations of the systems
- Explanation of the safety potential of the systems
- Demonstration of the ways to use comfort ADAS, where to use them and where not to use them

Finally, infrastructure is very important for the smooth and safe operation of ADAS. The systems' functionality is highly affected by the road infrastructure and the available road elements that are used to explain the current traffic rules. The participating experts agree that infrastructure is currently not ready for wide and safe use of the systems. The unification of road infrastructure and traffic elements is clearly needed, at least in Europe (mid-term) and worldwide (long-term). However, there is no organisation that can take all the responsibility for infrastructure policies across Europe. Some organisations that can take a lead in collaboration with each other are the European Commission together with Euro NCAP. Additional support can come from UNECE WP1 and WP29, OICA, FIA.

4.5 Conclusions and recommendations on HMI

- The findings on **the prerequisites for the HMI framework** can be applied to any ADAS system that has HMI framework and can be a base for creating an exact policy for the ADAS HMI design. The two main sides of the HMI consist of:
  - User to System: the controls. These consist of the way the driver can provide input to the system (e.g., activating, deactivating, change a mode or setting). In the context of ADAS, mainly buttons or levers on or near the steering wheel are used for this.
  - System to User: the displays. These can be visual, auditory, haptic, or tactile: any modality through which the system can inform the user (regarding states, modes, settings, detected objects), or warn the user.
- On a lower level, the HMI framework can be summarised as: “Watch your basic ergonomics”. The HMI design should consider the limitations of the user in terms of perception, information processing and task execution. This is the level of how and where the controls and displays are realised around the driver.
- On a higher level, the ADAS should not introduce excessive workload for the driver or cause distraction. At this level, timing, frequency, and duration of interaction between the system and the user play an important role.
- Both these levels are covered in the ESOP, not only in terms of design goals (“the system does not distract the driver”) but also in terms of what this means for the presentation of the information and for interaction principles (controls and displays of the HMI). Regarding the detailed level, various existing standards and standard documents in preparation exist that are all relevant to HMI design of ADAS. These cover aspects like the presentation of visual information, presentation of auditory signals, HMI of warning systems, dialogue management, and safety-critical and time-critical warning signals. All of these should be adhered to enable easy and clear communication between the system and the driver while avoiding the risk of any distraction or confusion.
- Regarding types of warnings, the most common methods of **ADAS warnings** are visual and audible warnings. The basis to develop and adopt a warning strategy is to eliminate situations when drivers are distracted by too many warnings or mental overloaded.

- It is advised to visually inform the driver about the live state of the systems, preferably in a Head Up Display (HUD). Also, a clear message should be always provided about the status of the systems: enabled/disabled. Now, most systems only give information about the failure of the sensor and do not inform the driver when the system fails to function or when it has been deactivated.
- **The system must react and behave predictably**. The driver should be able to understand how the system works. Additionally, the system should be flexible to adjust to driver preferences. Some drivers experience difficulties to incorporate ADAS into proactive driving (systems are reactive).
- In line with the previous point**, the driver should be informed about any malfunction within the system** that is likely to have an impact on safety. This is directly in line with the generic ESOP (EC, 2008) principles. Furthermore, for ACC, the ISO 15622 explicitly requires notification of failure states to the driver. It seems straightforward to extend this requirement for a driver notification to any other ADAS of which the failure would impact safety.
- It is recommended not to focus on the HMI as a stand-alone item but regard it in **combination with the rest of the ADAS functions** (in terms of its logic and control behaviour). ADAS should be evaluated in terms of workload and distraction, but also trust and acceptance. This is not only determined by the HMI but by the overall system. A possible way to do this is via the “Code of Practice for the Design and Evaluation of ADAS” from the “RESPONSE 3” project (RESPONSE_3, 2009). The focus of the Code of Practice (CoP) is the system design against the background of system controllability and the total vehicle from the field of view of Human Machine Interaction (i.e., wider than the Human Machine Interface).
- With respect to **user groups**, no direct conclusions can be drawn on which HMI solutions are more suitable for specific user groups. As far as elderly drivers are concerned, it is known that many aspects of human task performance gradually decline. This should be considered when applying standard HMI guidelines for controls and displays.
- **Uniformity in naming ADAS,** according to the participants of the Round Table meeting**,** is not the only priority at the moment. All experts agree that the functionality of the systems should be reflected in the systems’ names. One third of the experts state that this should come together with unified terminology. The rest of the experts focus more on the fact that the ADAS names should reflect functionality. As historical data shows, ADAS’ names will gradually become similar once the penetration rate in the market has increased (e.g. ACC and LKS) or when their introduction will be mandated by the authorities. EuroNCAP has been mentioned as the organisation that should take responsibility in the potential uniformity of ADAS’ names.
- **Drivers should be informed** on ADAS’ functionality, capabilities and limitations during the purchase or while renting a vehicle. In this case, car dealers, leasing and renting companies should be in a lead in ensuring that sufficient ADAS information is provided to the drivers
    - Voluntary **training** is expected to have added value in embracing the safety effects of ADAS. Training should be provided by importers or lease companies and it should be given by skilled, certified trainers from the training & driving academies.
    - A short theoretical and practical introduction or instruction to specific ADAS used in specific vehicles or car models should be also provided by the car sellers.
- **Infrastructure** is currently not ready for wide and safe use of the systems. The unification of road infrastructure and traffic elements is clearly needed, at least in Europe (mid-term) and worldwide (long-term).
- Finally, this literature research reveals a knowledge gap about the exact penetration rate for the six studied ADAS.

Royal HaskoningDHV HAN_UNIVERSITY OF APPLIED SCIENCES TNO innovation for life

5 User awareness & usage of ADAS

Research among business drivers shows that they are often not aware that their cars are equipped with assistance systems. As a result, these systems are often not used. On the one hand, this is because they receive information about their car for only a short period of time. When this information is not actively offered, they do not learn about the systems available in their car. On the other hand, this lack of knowledge is caused by the absence of a universal description of the different ADAS. It is expected that young people, who probably use their car much less than business drivers, are even less aware of ADAS (Harms & Dekker, 2017; TeamAlert, 2020).

This chapter begins with the presentation of the results of the online users' knowledge and awareness survey and continues with the results of the "Mystery shopping assignment" on car dealers' knowledge and awareness of ADAS.

5.1 User knowledge and awareness survey

To build upon the findings of previous studies and find out more about the reasons for this lack of information, a survey has been created and distributed in six European countries, namely: Germany, France, Italy, The Netherlands, Denmark and Austria. The distribution in different countries aims at gaining insight into the problem on a European level. The outcomes of this survey will be used to form policy recommendations to increase the knowledge and awareness of both drivers and car dealers regarding ADAS.

5.1.1 Survey set-up

To formulate survey questions, recent studies have been assessed in order to find knowledge gaps that the current project can fill. The literature used for this step included the Connecting Mobility study (by Harms & Dekker, 2017), the L3Pilot project (https://www.l3pilot.eu/) and the study by Boelhouwer et al. (2020). Detailed information about the results of each study is found in Appendix VI.

Harms & Dekker (2017). This study by Connecting Mobility combined an online survey with 1,355 business drivers. The study was carried out amongst members of VZR, a Dutch interest group for business drivers.

The L3Pilot project includes experimental road tests that are being carried out with multi-brand instrumented vehicles in real traffic conditions on many predefined test routes throughout Europe. During the pilots, data is being collected through questionnaires, which were completed by participants testing the ADAS on the test site. The questionnaires used during the pilot studies covered information about sociodemographic information of participants, vehicle purchasing decisions, driving history, in-vehicle system usage and trip choice; participants' impression of the ADAS performance, including acceptance, safety and comfort, among others; willingness to pay for the specific ADAS. As of September 2020, data is still being collected and hence the results of the pilot studies are not yet publicly available. The L3Pilot study has been, therefore, mainly used as input for the formulation but not the content of the survey's questions.

Boelhouwer et al. (2020): This study from the University of Twente *("How are car buyers and car sellers currently informed about ADAS? An investigation among drivers and car sellers in the Netherlands")* covers questions on the general interest in innovative technologies, the way of receiving information about the system during the purchase, and the level and satisfaction of the information that customers have received; additional questions about sources of information that customers use to learn about functionality and limitations of systems.

Knowledge gaps

The studies give a good overview of the driver's awareness about the ADAS function of the vehicles, the information given during the purchase, acceptance of ADAS and the level of knowledge users have about ADAS symbols and functionality. However, these studies lack information about:

1. The level to which expectations before purchase matches the experience with the vehicle after purchase. While purchasing the vehicle, sellers are expected to be able to explain the functionality and limitations of the ADAS systems to the level that the customer will understand what level of assistance can be expected from the vehicle. The mismatch between expectations and real experience should be limited to not result in over-trust and unsafe behaviour of drivers.
2. The level of trust of users on the ADAS. As discussed in chapter 4, trust is one of the components that affect the correct use of the system and influence the final decision not only to keep using but also to purchase the system again in future.
3. Recognition of the functionality of ADAS in a range of real traffic situations.

Additionally, literature research in the framework of the deliverable C (chapter 4) showed that there is lack of information about the penetration rate of the 6 ADAS since literature studies provide information about usage rates of only ACC and LKS and not of other systems.

The choice of questions for the survey of the present study was made based on these literature gaps. The questionnaire has a 4-blocks design (Figure 11):

1. The first block consists of questions about the background of participants, including socio-demographic questions and questions about the respondents' vehicle equipment.
2. The second block covers questions about the six ADAS: self-assessment of the level of understanding of each ADAS system, reasons for choosing to buy an ADAS equipped vehicle, ways of learning about ADAS functionality and comparison between the before-purchase expectations with the after-purchase experience.
3. The third block asks questions about trust to each of the six ADAS and the overall level of satisfaction for each ADAS.
4. The fourth block is a true/false type of test, assessing the level of understanding of each ADAS. For each of the six ADAS, questions were asked about functionality, limitations, technical characteristics, and the role of the driver. Questions mimic situations that a driver may encounter on the road.

Figure 11: 4-blocks design user survey.

5.1.2 Block 1: Background questions

The recruitment of participants took place between 26th June and 31st of July 2020 (5 weeks) and resulted in 9.252 respondents[5].

The respondents in this survey are predominantly male (~90%) and 45 years of age or older (~83%). Although there are some country-specific differences, more than 60% of the respondents drive a vehicle that was built in 2016 or more recently. Most of these vehicles were bought new, except for the Netherlands where respondents buy mostly second-hand vehicles. Most respondents drive 10.000-20.000 kilometres per year.

Around half of the vehicles are equipped with AEB, ACC and LKS. ISA, ESS and DM systems are less frequently installed on the respondents' vehicles. Since ISA, ACC and LKS can usually be switched on and off by the user, the respondents were also asked how frequently they use these systems. Around 60% of the respondents who claimed to have ACC and LKS state that they use these systems during almost every drive. 30% of the respondents indicate that they almost never use the ISA system.

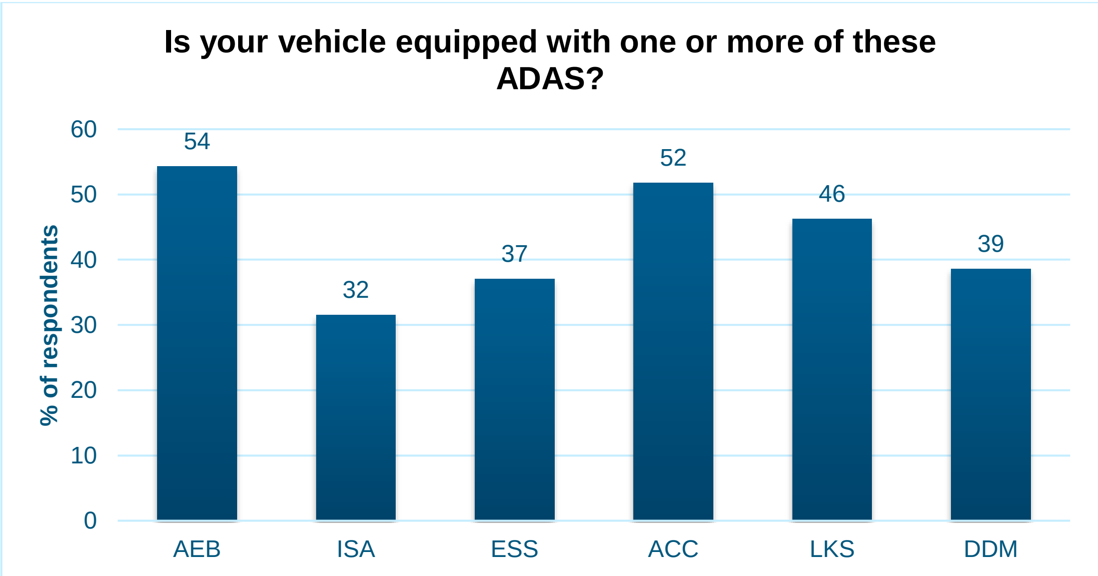


Figure 12 Penetration rates per ADAS as resulted from the online survey.

As shown by the Connecting Mobility study (Harms & Dekker, 2017), there is a discrepancy between what ADAS car owners think their vehicle is equipped with and what systems are present in the vehicle. To gain insight in the awareness of users into their vehicles' capabilities, extensive datasets (with information about the exact equipment per vehicle model or even per license plate) needs to be linked with the exact vehicle that the respondents claim to drive. This analysis has been set out of this study's scope given the difficulties in the acquisition of this data (relevant to time planning and involved costs). This analysis has, therefore, not been performed.

5.1.3 Block 2: Information & expectations

Results show that a lot of vehicles were already equipped with one or more ADAS, or that they are a standard option on a newly bought vehicle. This is especially the case with the AEB, ESS and DDM systems.

[5] *The numbers of respondents per country can be found in Appendix III.*

Respondents also indicated that (in about 20% of the cases) the ADAS was part of the 'safety package' the respondent wanted to have. About 20% of the respondents indicated that they wanted to have the ADAS to be able to drive more safely. Reasons to buy ACC, ISA and LKS also include the respondents' need to increase their driving comfort. For only ~10% of the respondents, an interest in new (vehicle) technology was a reason to buy an ADAS equipped vehicle.

A bit more than a quarter of the respondents (25-30%) indicate that they read the vehicle user manual to inform themselves about the ADAS functionality, use and limitations. For each of the six systems, about 20% of the respondents indicated that they have also received some information and/or instruction from the car seller. As shown later (paragraph 5.2.3) in the mystery shopping exercise, however, this information and/or instruction lacks the level of detail needed to fully comprehend the ADAS' workings. The third most used method to 'learn' about these six systems is the '*trial-and-error*' method. This is interesting since all three of these methods of 'learning' are found to be imperfect, as explained later in paragraph 5.2. Almost no respondents (less than 1%) have received training on ADAS. This highlights the absence of ADAS training from driver training schools and professional driver training organisations, as also shown by Morsink et al. (2017).

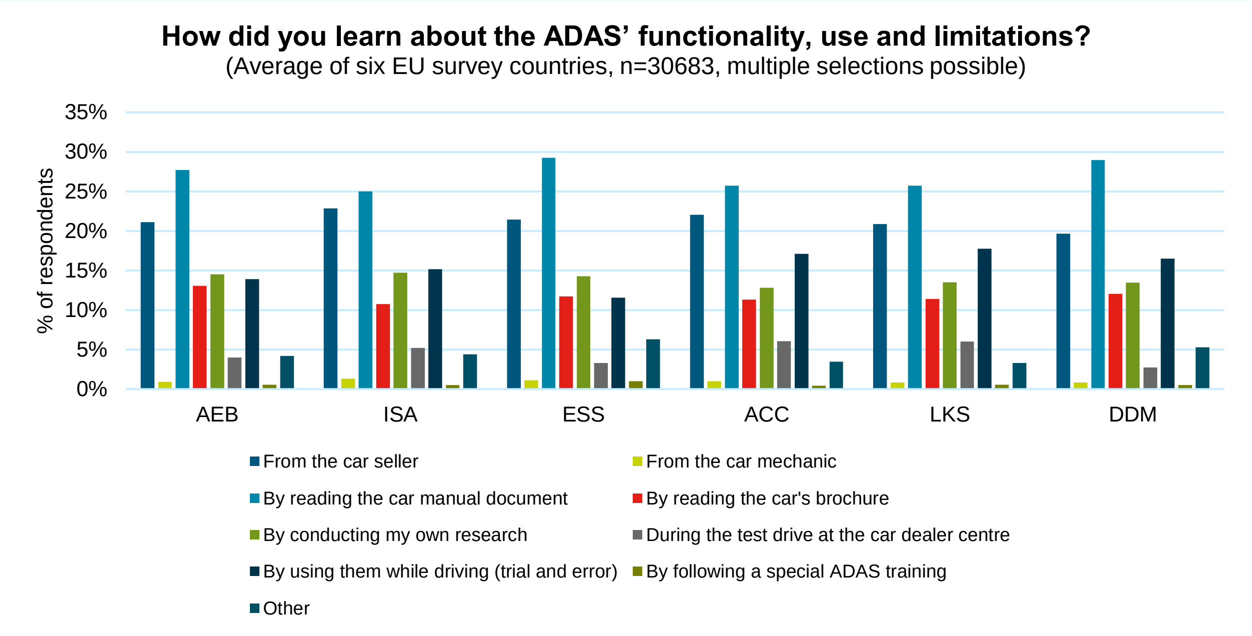


Figure 13 Information/learning channels for ADAS' functionality, use and limitations,

Nevertheless, most of the respondents state that the six ADAS systems perform as they expected. The respondents are most positively surprised by the ACC's performance, that performs better than expected according to 30% of the respondents who have experience with this system. The LKS disappoints around 20% of the respondents who own such a system, stating that it performs worse than expected. It is interesting to mention that the percentage of respondents who state the systems perform as expected is not closer to 100%. On average, only 69% of the respondents state that the systems perform as expected. This means that ~30% of the respondents were not able to get a clear enough picture of the systems' performance during the purchase process and that they have experienced unexpected performances (both positive and negative) by these ADAS.

5.1.4 Block 3: Trust and satisfaction

Despite some discrepancies between users' expectations about the ADAS and their experience with its performance, the user satisfaction is still relatively high: between 3,5 and 4,5 (on a 5-point Likert scale) for all six systems. The respondents are mostly satisfied with the ACC system, and least satisfied with the driver monitoring systems. Since few vehicles are equipped today with driver monitoring systems, it could mean that early versions of such systems do not function as well as they are supposed to do.
The graph below shows that the respondents perceive their level of understanding of how to use and interact with the six ADAS and in which situations the systems can function generally as high for each of the six ADAS.

- It is interesting to mention that the respondents are less sure about the situations when or where the ADAS cannot function.
- Especially in the case of ACC, LKS and AEB, many respondents think they can explain the system to other people.
- Respondents are less familiar with ISA, ESS and DDM systems, which might be caused by the fact that these systems are relatively new and/or that ESS and DDM systems require less interaction with the driver.

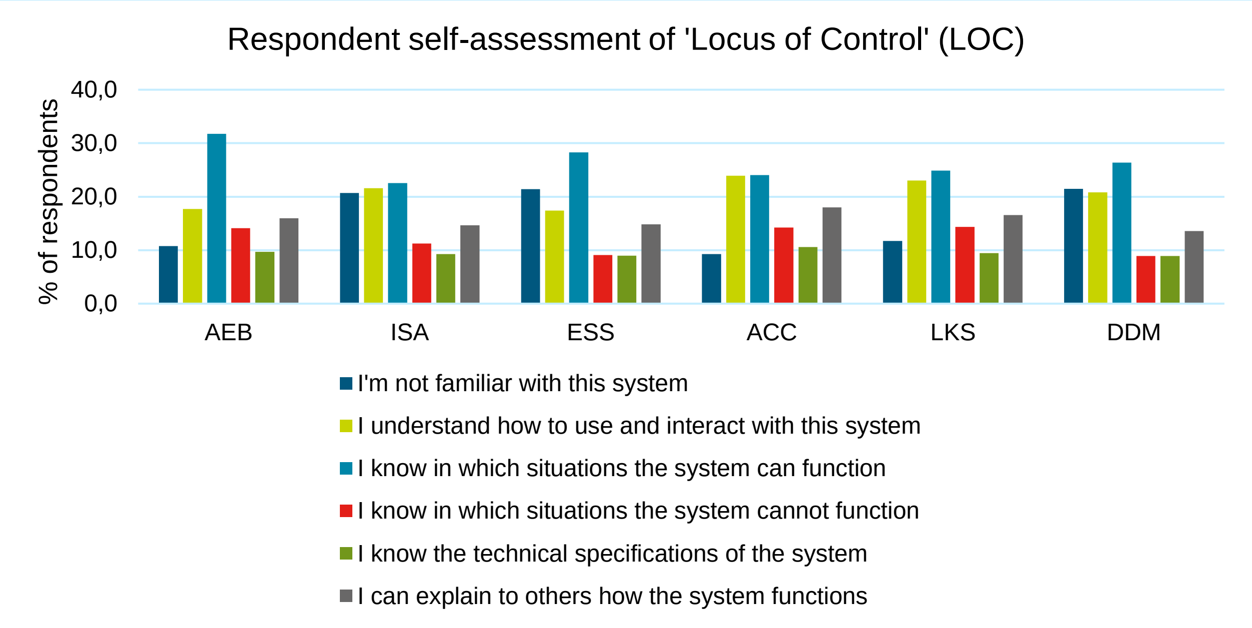


Figure 14 Perceived understanding of the systems.

A Spearman correlation analysis (for non-parametric data) between the number of correctly answered knowledge questions (paragraph 5.1.5) and the attitudes towards the ADASs was conducted.

For all six ADAS, there is a statistically significant positive correlation between all attitudes towards ADAS and the number of correct answers. This means that with the growth of knowledge about the ADAS, the trust, comfort and feeling of safety also increases.

It is interesting to point out that the statement "ADAS is annoying" also has a positive correlation for all six ADAS, most strongly with LKS, which means that with an increasing number of correct answers the irritation level towards the system(s) also increases. This contradiction could be explained by a potential discrepancy between user expectations of the ADAS and their experience with the ADAS at a later stage. It could mean that these respondents have learned about ADAS (hence the higher number of correct answers) by experiencing system operation that is different than they had expected, which in turn decreases their satisfaction of the system. The correlation between “LKS is annoying” and the number of correct answers is moderate and has a mean level of association (p=0,001, r_s= 0,347). For all other ADAS, this correlation has a weaker magnitude.

Among the parameters (Table 16), the strongest correlation “number of correct answers” has with the statement “The ADAS is useful” and with the statement “I trust the ADAS”. However, it is interesting to mention that LKS has the lowest magnitude among statements with the statement “I trust the LKS” (p=0,001, r_s= 0,330), which means that LKS users have limited trust for LKS.

Table 16 Magnitude of correlation coefficients (all correlations are positive and significant at the 0,01 level)

	Number of correct answers					
	AEB	**ISA**	**ESS**	**ACC**	**LKS**	**DM**
I trust the ADAS	0,183	0,265	0,348	0,307	0,330	0,291
The ADAS makes me feel safer	0,172	0,250	0,302	0,309	0,350	0,289
The ADAS is annoying	0,108	0,232	0,241	0,216	0,347	0,222
The ADAS is useful	**0,191**	0,262	0,347	0,328	0,359	0,284
The ADAS makes me feel more comfortable	0,151	0,254	0,300	0,325	0,358	0,288

5.1.5 Block 4: Knowledge assessment

To test the respondents’ knowledge of the six ADAS, several statements were formulated for each of the six systems. Respondents were asked to indicate if they believe the statements were either “True”, “False”, or that they were “Not sure” of the correct answer. The statements were designed to test the respondents’ level of understanding about:

- The systems’ limitations;
- How to operate the system;
- The role of the driver;
- The type of sensors the system might use.

For three out of the six ADAS, four statements were presented to the respondent. For the other three ADAS, three statements were presented. When a respondent selects “Not sure”, this is seen as an incorrect answer as well, since this also implies that the respondent does not fully understand the system. The results are presented in the graphs below. The main findings of this part of the survey are:

- For all six ADAS, only a minority of the respondents was able to correctly indicate whether the statements are true or false. This varies between 1 – 30%.
- This implies that 70 – 99% of the respondents (including those who own recent vehicles) do not fully understand the ADAS.
- These findings show that more than 70% of the respondents overestimate their own understanding of ADAS, as this is presented in Figure 14.
- ISA and ESS are better understood than ACC, AEB, DM and LKS.

Compared to the respondents’ trust in the six ADAS, it seems that there is a large discrepancy between the percentage of respondents that trust that the systems will work well and the percentage of respondents who are able to correctly answer all knowledge questions. Inadequate knowledge of ADAS prevents people from understanding how these systems should work, which can potentially be dangerous if people are confident that these ADAS will work well. Based on these results, it is unlikely that the respondents are in state to correctly estimate how these ADAS should work and when and where it is appropriate to use them.

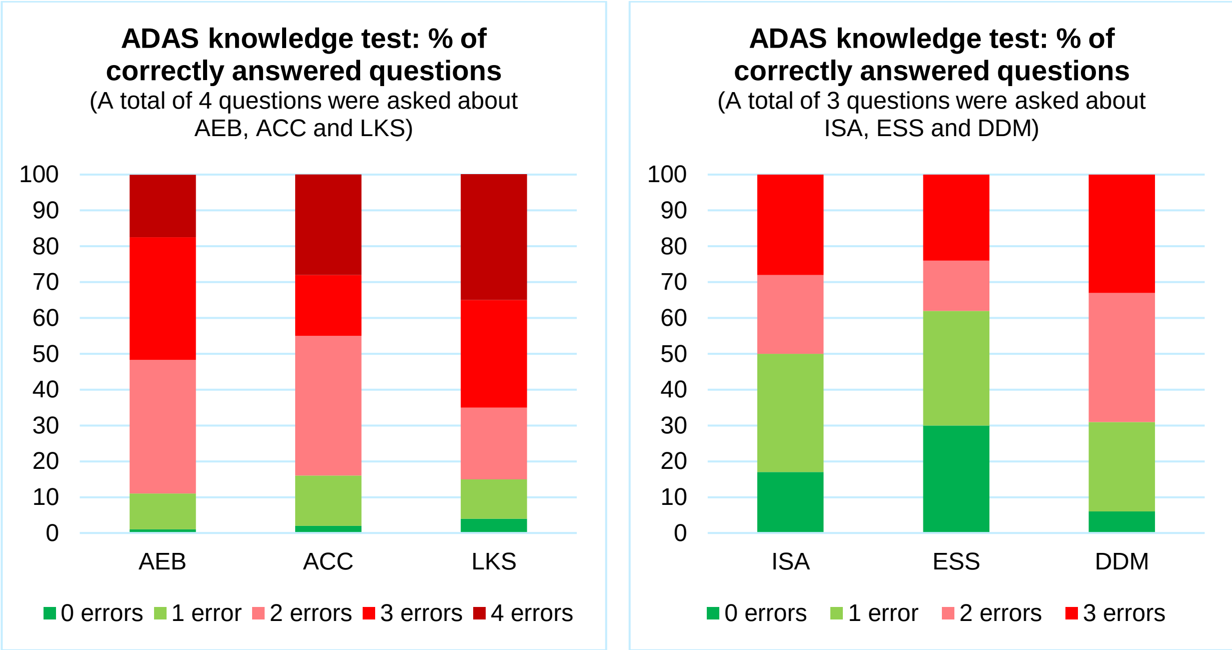


Figure 15 ADAS level of knowledge.

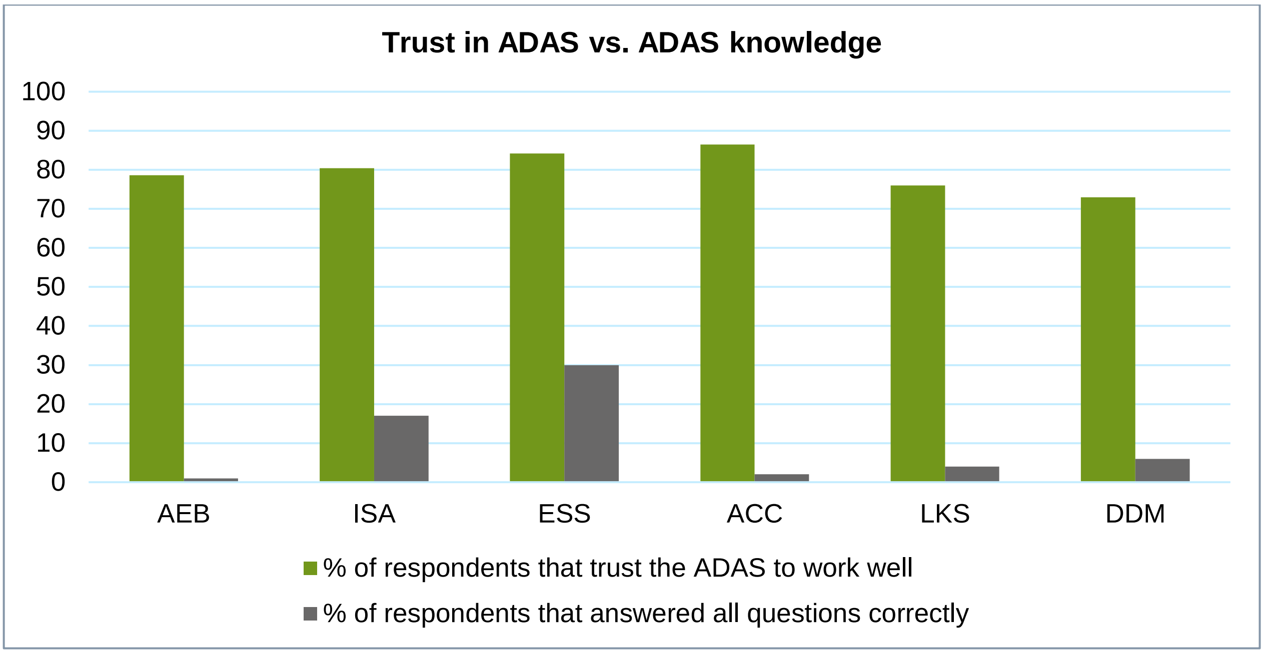


Figure 16 Comparison between level of trust in ADAS and knowledge about ADAS.

A boxplot analysis was conducted to evaluate the relation between the knowledge of respondents about the individual ADAS and their experiences with them. For all ADAS, except LKS, respondents who indicated that they do not have the ADAS in their vehicle were still able to correctly answer 1 knowledge question. This is also the case for the respondents who indicated that the system performed differently than expected. The respondents who reported that the ADAS performed better/worse/as expected in general have a mean value of 2 correct answers.

It can be concluded that the boxplot analysis of the relationship between current experiences with ADAS and the number of correct answers did not show a clear trend. Besides a lack of a clear trend, the non-symmetrical form of the boxplot itself and whiskers indicate that the data is not coherent and cannot lead to a clear conclusion. In general, the level of knowledge on the ADAS is low, which does not allow to make a differentiation between respondents with different experiences.

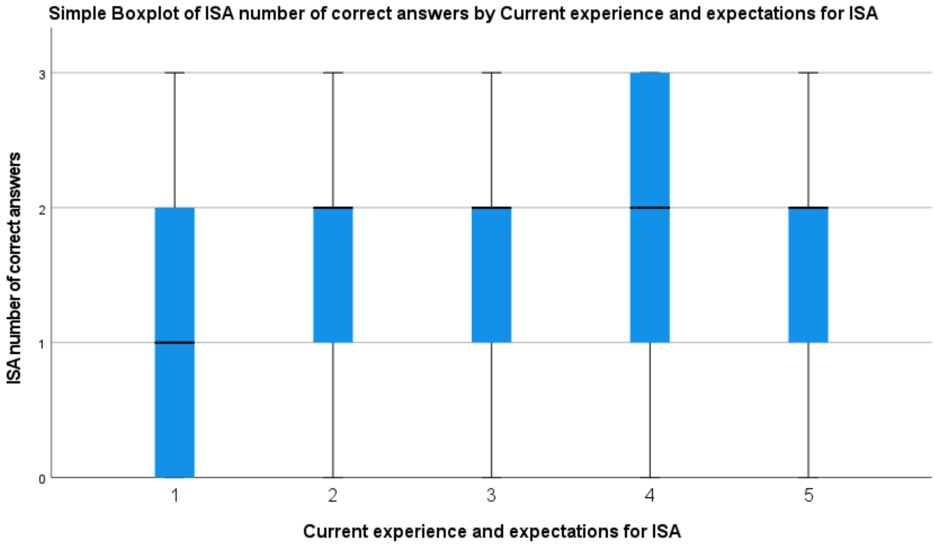


Figure 17 Relation between current experiences/ expectations with ADAS and number of correct answers. (1=I don't own this ADAS; 2-5=The ADAS performs better/as/worse/different than expected)

5.1.6 Clarification of survey findings

To clarify the survey findings, we have conducted an interview with Mr Mark Maaskant from ProDrive Training. Mr Maaskant is director of ProDrive Training, a company with experience in ADAS user training, both for new owners as well as for drivers who want to optimize the use of their vehicle. ProDrive is one of the few companies in the Netherlands that provides professional ADAS training at a large scale.

This training seems to have great impact on the extent to which drivers familiarize and decide to use the systems. Mr Maaskant claims that his 'students' have many questions about ADAS, ranging from the operation of Adaptive Cruise Control and uncertainties regarding the stopping distance of the Advanced Emergency Braking System. "The students are right to wonder whether the car brakes before the red traffic light, whether the vehicle always comes to a complete stop in other situations and whether or not brake lights come on when the car brakes itself". The most common questions asked during these trainings are:

- Does the car brake before a standing traffic jam?
- Does the system also react to motorcyclists?
- Does the car also brake for red traffic lights?
- Do I need to keep my hands on the wheel?
- How do I see if the system is activated?

Furthermore, confusion among the drivers originates from the names of the systems. "Lane Trace Assist of Toyota Corolla acts only as an assistant and should not be confused with a lane keeping system. While it helps you stay within the lane boundaries, as a driver you must stay more involved in with task than, for example, with Volvo's or Nissan's systems".

Finally, according to Mr Maaskant, a great number of drivers do not start using the systems independently without having had a good explanation. In case they receive a good explanation, they understand the benefits and learn to use the systems. During training, drivers are motivated and encouraged to use ADAS safely and under the right conditions. A new car is "explained" to the driver, so training and coaching are provided to teach drivers to recognize systems' limitations and relevant dangers. Specifically, the driver is taught about what the systems are and are not intended for.

5.1.7 Conclusions on ADAS user awareness

As the results of the survey have shown, it is very important to increase the level of understanding of ADAS. Almost all respondents (99%) indicated that they did not receive training, but rely on information from the car seller, the user manual or they apply the '*trial-and-error*' method. It has also been found that with an increase in correctly answered knowledge questions, trust and comfort levels in ADAS also increases. Nevertheless, the survey showed that the general knowledge of ADAS is low. It appears that the respondents tend to have a false sense of trust in the ADAS capabilities, compared to their level of knowledge about the ADAS. This highlights the importance of presence of ADAS training in driver training schools and professional driver training organisations.

5.2 Information & instruction quality

This paragraph aims to assess the quality of both information and instruction about the six ADAS. Firstly, an assessment was executed to assess the information quality on online webpages of several car brands. This is an important source of information before people buy a vehicle. The second phase of this part of the project consists of an assessment of the quality of user manuals. Finally, several car dealerships were visited during a 'mystery shopping' exercise experiment.

5.2.1 Online car shopping assignment

The online car shopping assignment covers website observations for seven car brands within three price segments (low, medium, and high price segment). For this part of the project, UK websites were used (Appendix IV). Each car brand has a dedicated website per country, which can differ from country to country depending on local marketing strategies. Because ADAS terminology can also differ per language, UK websites were chosen for this part of the project, since English is the most universal language and many ADAS terminology is also originally composed in English. The scan of the websites revealed what the level of the information is about ADAS accessible on the official car brands webpages.

Besides scanning United Kingdom webpages, analysis of Dutch webpages was also conducted to identify potential differences in information provision between countries.

5.2.1.1 Online car shopping assignment UK websites

The online car shopping assignment revealed a clear need for improvement of the level of the information provided online. Currently, information present on webpages focuses on the marketing and promotion of ADAS. As car brands create an impression of highly capable systems, situations of over-trust may appear which can lead to unsafe driving behaviour.

Higher-class car brands try to improve the quality of the provided information, by increasing the amount of information present on the webpages and providing educational videos. For example, Volvo has made clear progress by providing a description of all six ADAS and clearly stating that systems have assistant use and the human driver is still in charge of driving.

More specifically:

- Only one car manufacturer presented information about all 6 ADAS (Volvo). They are also the only one providing a video with a clear message that the system is only a driver aid system and that the responsibility lies with the human driver;
- Car companies of low- and medium-priced cars have the same amount of information about ADAS, while the higher segment brands provide more information about the systems;
- The majority (4/7) of the provided ADAS information on home pages and/or car model pages is very marginal and mostly focused on marketing purposes. It is mostly meant to show off technological advancement.
- The search button gave results for the ADAS only for 2/7 websites (medium-high price);
- For all ADAS present on the webpages, a description of the system was provided, illustrated with the picture.
- No brand provided an explanation about the ODD and the systems' limitations. It is mentioned that systems (should) enhance safety, but generally very little attention is given to actual functionality and limitations.
- Most mentioned ADAS are: LKS and ISA, while ESS is only mentioned by 1 brand only.
- The best "explained" ADAS are ACC and AEB, followed by the LKS (in terms of information clearly visible on the website, the explanation provided videos and/or pictures).

Volvo (high)	ISA	ACC	ESS	AEB	LKS	DriverMonitoring
Availability of information						
1. Did you find the necessary information? (YES/NO)	yes	yes	yes	yes	yes	yes
Easiness to find information						
1. Number of clicks until the information appears (#)	4	4	4	4	5	7
2. Was the information clearly visible from either the homepage and/or the car model page? (YES/NO)	no	no	no	no	no	no
3. Existence of relevant keywords at the search button (YES/NO)	yes	yes	yes	yes	yes	yes
Quality of information						
1. Is a description of the system provided? (YES/NO)	yes	yes	yes		yes	no
2. Are there videos/photos to assist the description? (YES/NO What)	yes (video	yes (video and photo)	yes (photo)		yes (video and photo)	yes (video)
4. Is there clear description of the system's ODD / systems limitations? (YES/NO/only ODD/ only limitations)	only ODD	no	no		no	no
5. Is the system information unambigious? (enter NO when you can interpret the info in more than one way)	no	no	no		no	no
6. Is there a warning stating that the system does not replace a human driver and that driver have to pay attention at all times(y	no	no	no		no	no
7. Is there a reference to the instruction manual (yes/no)?	no	no	no		no	no
8. Is the content recently updated (within the last 12 months) (YES/NO/unknown)	yes	yes	yes		yes	yes

Figure 18 Example of the web page analysis.

5.2.1.2 Comparison of scans of UK and Netherlands web pages.

For all considered car brands, except Volkswagen, the information provided on webpages is similar among British and Dutch versions. Volkswagen presents more information on the English webpage than on the Dutch one. To be more specific, the Dutch webpage provides a description of 2 ADAS (out of 7), while the English webpage provides a description of 5 ADAS (out of 7). Also, no brochures can be downloaded from the Dutch webpage. Reaching information on VW's webpage is easier through the English webpage, as it requires 4 clicks to reach ADAS descriptions, while it takes 15 (!) clicks on the Dutch webpages.

On the opposite of Volkswagen, Ford provides more precise information about the systems' limitations on the Dutch website. The Dutch webpage provides warning information that the ISA and LKS are assistant systems and should only be operated under the control of the human driver.

Volkswagen, Ford, and Toyota support ADAS functionality explanation with the video content only on the Dutch website.

5.2.2 Scan of User Manuals

As described in paragraph 2.2.2, a qualitative analysis was conducted to assess the information quality of the User Manuals of four car models. The extended results of this analysis can be found in Appendix II. The conclusions of this analysis are presented below.

Based on the information in the User Manuals, it becomes clear that it will be difficult for a car owner to form a good idea of what the systems' ODD is. The manuals mostly consist of all kinds of warning messages and legal disclaimers. The contents of the manuals seem to be focused more on shifting responsibility from the car manufacturer to the car driver, instead of informing the car driver. Moreover, the driver is expected to be aware of the vehicles' safety equipment since the available information sources can provide information about optional ADAS systems that might not be present on the users' own vehicle.

The changing role of the driver entails that the driver should be able to relate his/her knowledge about the ADAS and its limitations with whatever the driver sees on the road ahead. Until full automation is reached, the driving task will therefore increase in complexity compared to non-assisted driving, because of additional cognitive processing of incoming information and already present knowledge.

Many conditions and situations in which a system might not (properly) function are described but in a very ambiguous manner. The information presented in the manuals can often be interpreted in more than one way. For example, it is mentioned that LKS might not function in heavy rain or sharp curves, but it is not mentioned what a sharp curve or heavy rain is; the driver is expected to recognize these situations by him/herself. The problem with this is that the driver does not know in advance if the system will function or not.

It might also not be possible to describe these limitations in a very precise and unambiguous manner. Whether or not a traffic situation is within the ODD of the ADAS can depend on many factors, which is difficult to describe in advance in a manual. If car drivers can be made aware of the knowledge gaps on system limits, they might be able to alter their driving behaviour accordingly. For example: instead of thinking that the system will function as intended because the driver thinks that *"it is not raining hard enough"*, the driver should think *"I'm not sure if this amount of rain is too much for my ADAS to function properly"* and act accordingly. The four assessed User Manuals do not mention these knowledge gaps, so there is no warning that states that it is unknown when a system might fail to function.

It is therefore even more important that a car driver is not only made aware of possible limitations but also when it is unclear if/when the ODD limits are reached.

5.2.3 Mystery shopping assignment

The live car mystery shopping was the third step of the mystery shopping assignment. Based on the results of the online car shopping assignment and the study of the online user manuals, it has been decided to visit both exclusive and independent car dealers. In total, four dealerships were visited. Two members of the research team visited these dealerships, both alone and/or with their partner. Table 17 shows information about the four (4) visited car dealerships.

Table 17 Visited car-dealerships during mystery shopping assignment

Brand	Type of dealer	Car model
Volkswagen	Exclusive	Golf 8
Toyota	Independent	Corolla
Ford	Independent	Focus
Subaru	Exclusive	XV

5.2.3.1 Results per visit

Volkswagen

The researchers showed interest in the VW Golf 8 model, only mentioning that they aim to use it as their new lease car. The car dealer provided general information about the car, focusing on the upgrades in styling and engine in comparison to the previous model. The car dealer did not introduce any of the assistance systems to the researchers in the first 30' of the discussion.

At the second phase of this mystery assignment, the researchers mentioned that their current car offers the option of Cruise Control and asked if similar systems options are offered in this car. At this point, the car dealer started outlining the different ADAS that are offered with the car, while also explaining which of them come as standard and which of them come as an option. The car dealer described what the aim of each system is and in which driving tasks it helps the driver while emphasizing that the driver should be always alert and ready to take over the system and carry out any task.

To check further knowledge of the car dealer, researchers asked about the way the systems function (third phase). The car dealer was aware of all sensors used per available system, while he was able to point out where the sensors (like cameras) are placed on the car to read lane markings, driver distraction etc. In addition, the car dealer could make a distinction between systems that function more towards comfort and systems that function more towards safety, explaining that ACC is oriented more towards comfort than towards safety.

Finally, the car dealer provided some information regarding the limitations of the systems. This information was provided without any question of the researchers to trigger the discussion:

- The dealer initially pointed out that lane marking is necessary for the **LKS** to function since it cannot read physical road borders. He also indicated in case of the system's inability to function, the LKS signal on the driver's dashboard changes color (the system provides signal in three different colors based on its ability to function: can function as expected/cannot function as good as expected/ cannot function).
- Regarding **ISA**, the car dealer expressed his opinion to not activate the system since it can fail to function causing great inconsistencies in speed. According to him, great changes in the speed that can be caused by the limitations of ISA can hinder traffic safety. More specific, information was provided about the system's inability to read the traffic signs (example: double traffic signs on Dutch highways), which leads to either providing wrong speed information to the driver or too hard decelerating or accelerating, while it should not.
- With regard to **ACC**, the car dealer explained that there are 5 different options for the driver to choose his headway to the preceding vehicle while advising which one is better to use (according to himself) in order to avoid unnecessary accelerations and decelerations, which can become dangerous for the driver and the surrounding traffic.

Toyota & Ford

At an independent dealership that sells both Toyota and Ford in the same building (but in separate showrooms), the researchers showed interest in the business lease versions of the Toyota Corolla and the Ford Focus models. The car seller started talking about the practicality of the vehicles and which one was cheaper to lease. He kept pointing out positives about the more expensive vehicle though. At that point, the researcher asked about available options or option packages. The ADAS related options were not mentioned the first, but the seller did introduce the available ADAS on both vehicles. He mentioned what the systems were supposed to do and how the driver could activate them.

After asking if the driver will not have to steer the vehicle anymore, the seller indicated that the driver is still responsible for operating the vehicle safely and that the driver should always pay attention. The seller then started explaining that the ADAS (e.g. LKS) sometimes will not function properly or not function at all in case there was heavy rain or bright lights (e.g. headlights).

At some point, the seller had figured out that the researcher was not actually going to buy or lease a car, which resulted in a change of conversation. The researcher explained he was assessing whether the seller was providing certain types of information about ADAS for a research project. The conversation then continued about why it was important that a car buyer receives qualitatively good information about these systems. The seller was a bit surprised to hear that the cars' user manuals do not provide clearly comprehensible information (e.g. when is there too much rain, when is a curve too sharp, et cetera.).

Subaru
During the visit to the Subaru dealership, interest was outed towards the XV model which comes equipped with the brand's EyeSight system as standard. This is a package of multiple ADAS, including ACC, LKS and more. After a quick chat about the vehicle, the seller started explaining EyeSight, since the brand actively promotes this system in their marketing efforts. He told about the various ADAS that it entails and what these ADAS are meant to prevent. Then the seller got the keys and took the researcher out for a test drive. During this test drive, the seller started explaining what characteristics makes this car brand unique and why the Subaru brand chose to do things differently compared to other brands.

When the researcher redirected the conversation back to the EyeSight system by pointing out the two cameras behind the windscreen, the seller started explaining the car's ADAS by demonstrating some functionalities. Subaru uses a stereo camera setup, which the seller explained has some advantages compared to other brands in terms of vision. The seller kept talking about what the systems were doing in certain on-road situations. He also mentioned some risks if the driver was not using the system correctly, which in some cases he tried to demonstrate as well.

After the static and dynamic introduction to this vehicle, the researcher was handed the car keys for a private test drive. The seller mentioned that he always introduces people in this manner. However, it did seem that the car seller did try to explain the ADAS in more detail because the researcher showed interest in these systems.

5.2.3.2 General findings

Although all car dealerships provide at least some level of information about the ADAS equipment on vehicles, it seems that this information generally is quite limited in detail at first. Car sellers tend to tell more about ADAS when they notice that the car buyer is interested in it. Otherwise, they just tell the buyer that the vehicle comes equipped with these systems and maybe show how to turn it on and off, but they do not explain how these systems operate and what limitations they might have.

The researchers also got the feeling that information about ADAS was offered selectively. Car sellers try to figure out what kind of person the potential customer is and what his/her interests are. This might influence the type of information and the level of detail that the customer receives. This could potentially be a dangerous situation since the people who do not have an interest in the technology behind ADAS also have to understand when and why a system might not function (properly). Otherwise, these people might try to figure out the functioning of the systems with the trial-and-error method, which causes potential danger. Customers that have little (technical) understanding of these systems need extra information, regardless of their interest in the systems. Especially since some ADAS cannot be switched off. Customers that indicate that they do not need the information because they know how it works could also be drivers that overestimate themselves.

Dealerships are a bit divided when it comes to the dynamic instructions (the test drive). Some dealerships prefer to let the customer take the car for a test drive, without accompanying the customer during the test drive. They do not want to give the impression that they really want to sell a car. Other dealerships do go along with the customer on a test drive because they think it is an extra service to explain all the systems to the customer. Some dealers also indicated that there will be an extended instruction when the vehicle gets delivered to the customer.

In the first case, the customer has to figure out the ADAS present without any help or explanation when something unexpected happens. In the third case this also happens, but then the customer will at least receive instructions when he/she takes the vehicle home. In the second case, there is a possibility for professional instruction, but during this first encounter with the new vehicle, the customer might be unfocused because of he/she is still trying to get used to the new vehicle. A recent study showed that drivers who experienced an ADAS-equipped vehicle for the first time are more focused on how to operate the systems (eg. *"where is that button I need?"*) and that their situational awareness decreases during these first test drives (Prins, Voskuil, Van der Linde & Morsink, 2019).

It also seems that there are differences between several dealerships of the same car brand. In his study, Van der Linde (2020) found that a Volkswagen dealership did not talk about the available ADAS (options) until the seller was asked about it. This is different from the experience during this mystery shopping exercise, as described above. It, therefore, seems that the type of information that the customer receives, and the level of detail of that information, also depends on the individual car seller.

Some of the dealerships mentioned the possibility of returning to the dealership after a few weeks of car ownership, for extra instructions if needed. That seems like a good service, but the dealerships did not seem to realize that the customer had already been driving around while not fully understanding the system(s).

5.2.4 Conclusions on information and instruction quality

"The changing role of the driver entails that the driver should be able to relate his/her knowledge about the ADAS and its limitations with whatever he/she sees on the road ahead."

Online car shopping exercise:
Both Dutch and UK webpages revealed a clear need for improvement on the level of the ADAS information provided online. Currently, information present on webpages focuses on marketing and promotion of ADAS and is mostly not suitable for creating a thorough understanding of the system capabilities, as there is limited information about ODD and limitations. The higher-class car brands make an attempt to improve the quality of the provided information, by increasing the amount of information present on the web pages and providing educational videos. Besides the pure quality of the provided information, there is also a clear gap in the number of systems covered. Only one car manufacturer provides information about all six ADAS, and the most mentioned ADAS systems are LKS and ISA, while ESS is only mentioned by one brand.

Qualitative assessment of car User Manuals:
It is unlikely that a car owner can get a good understanding of the systems' functions, limitations and its ODD by reading the user manual. These manuals are filled with all kinds of warnings, that seem to shift responsibilities away from the car manufacturer and to the car owner for legal purposes. The information that is present in these manuals is first and foremost geared towards explaining how to turn on/off these systems. Information about system limitations and ODD often is written in a very ambiguous manner.

It might also not be possible to provide more precise information about system limitations and ODD, because there are still a lot of knowledge gaps concerning these systems' capabilities and limitations. It, therefore, is important that car drivers are made aware of these unknown capabilities and limitations. Neither of the four assessed user manuals offers descriptions about these knowledge gaps.

Mystery shopping exercise:
Car dealerships tend to provide quite limited amounts of information about ADAS until they notice that the customer has some level of interest in these systems. Some dealerships also offer more detailed information without being prompted, but this seems to depend on the individual characteristics of the car seller. This automatically leads to different levels of detail of instruction per customer. It is suggested that this could potentially lead to a decrease in safety.

It was also found that not all car dealers were aware of the importance of good instruction. Their primary focus is to sell vehicles, not to provide driver training. Some dealers did not even know about the ambiguous information in the user manuals.

6 Technical implications

The research in this chapter aims to determine the available information related to ADAS in cars that can be used for diagnosis. The two main goals of this study are:

- On-board diagnostic functionality for the repair and maintenance of ADAS.
- The technical type-approval and roadworthiness regulatory requirements necessary to guarantee ADAS lifetime technical safety and security.

The research questions formulated based on the objectives are:

- How could and should a harmonized on-board diagnostic functionality for the repair and maintenance of ADASs be designed?
- What regulatory requirements are necessary in terms of the technical type-approval and roadworthiness of vehicle systems to guarantee ADASs lifetime technical safety and security?

6.1 Harmonised on-board diagnostic functionality for repair and maintenance of ADAS

This paragraph is focused on analysing the diagnostic functionality of ADAS with respect to repair and maintenance. In the beginning, the limitations of the systems are revisited, while the reasons why drivers tend to deactivate the systems are described. The combination of this information leads to recommendations for technical requirements per system.

The desk research has been complemented by a study conducted by Vtron. This is conducted to identify and examine the available information related to ADAS from the vehicle’s On-Board Diagnosis (OBD) and, if possible, to use this information to assist in repair and service of these systems. The International Organization for Standardization (ISO), has defined a set of safety standards for the safe functionality for ADAS and data security. These safety standards must be followed by manufacturers when designing such a system.

6.1.1 Limitations and safety risks per ADAS

Advanced Emergency Braking (AEB)

As described in chapter 3, AEB’s function is limited by certain restrictions that play an important role in its potential safety contribution.

Limitations & Safety Risks:

- The performance of the system is related to environmental conditions, e.g. lighting, rain, fog, etc.
- The system can operate for a limited speed range, that varies per manufacturer.
- May fail to detect/slowdown in time for small road users (cyclists, pedestrians).
- May fail to detect/slowdown in time for stationary objects.
- An emergency stop may lead to rear-end collisions with the vehicle behind the braking vehicle.
- An emergency stop may happen when not needed (false positive) resulting in ghost braking.
- An emergency stop may not happen when needed (false negatives) resulting in a collision.

The motivation for a driver to switch off:

- Usually an AEB cannot be deactivated by the driver.
- If the system has too many false positives (too much ghost braking).
- In dense traffic situation (traffic jams, city), the system may activate too much.
- When the vehicles are overtaken and cut off, the system may activate too much.

Intelligent Speed Assistance (ISA)
The limitations of ISA are revisited to let the reader understand why ISA is often switched off by the driver.

Limitations & Safety Risks:
- GPS is heavily reliable on the strength of the signal (could differ a lot per country or region).
- GPS signals do not adapt to changing speed limits for example at traffic jams or road works. Therefore, the vehicle does not react to that kind of temporary/dynamic speed limits.
- Speed limit signs can be read incorrectly by the camera. Therefore, the car could maintain the wrong speed limit.
- ISA cannot be overruled by the driver (differs per manufacturer) and can therefore hinder safe takeover manoeuvres.

The motivation for a driver to switch off:
- If the system detects/maintains wrong speed limits (especially lower speeds) too often.
- If the system cannot be (temporarily) overruled.

Emergency Stop Signal (ESS)
Limitations & Safety Risks:
- The system may not work on all types of roads, speed ranges and weather conditions.
- In some applications, the system is completely dependent on a working ABS system. If the ABS system fails or is not working correctly, the ESS system does not work either.
- The system is tuned to have a high number of falls negatives which leads to no signalling when needed.
- False positives lead to ghost signalling (signalling when it is not needed). Resulting in braking of following vehicles (causing a chain reaction).

The motivation for a driver to switch off:
- The system cannot be switch off by the driver, however, a driver might want to switch off the system if too many false positives occur (signalling when it is not needed). However, this is more an inconvenience to the following traffic.

Adaptive Cruise Control (ACC)
Limitations & Safety Risks:
- ACC does not take road limitations into account. It will therefore also work on roundabouts and highway exits for example. This may lead to unwanted and dangerous situations. ACC also filters out a stationary object (like trees on the side of the road). However, this can also mean stationary pedestrians for example.
- ACC often does not work properly for very low or very high speeds.
- Not all (following) objects/vehicles may be detected. For example, motorcyclists or flatbed truck trailers.
- ACC reduces the workload of a driver which can cause drowsiness/distraction/fatigue.
- Occasionally provides false notifications or unneeded braking interventions.
- The vehicle can fail to follow lead vehicle which can be dangerous if a driver is distracted.
- The vehicle will maintain cruising speed in situations where it is not possible (roundabouts or highway exits for example). Unwanted acceleration action during exiting of highway can also occur.
- Unwanted deceleration actions during overtaking or when the vehicle gets cut off by another road user.

The motivation for a driver to switch off:

- In dense traffic situations, the system might react to much (braking and accelerating). System safety boundaries that lead to large following distances might invite other road users for cuttings (people will take the free space available).
- When initiating an overtaking manoeuvre and the vehicle detects the car that must be overtaken, the system will decelerate when changing lanes (unwanted).
- When changing lanes and the vehicle detects a car ahead (on the fast lane), the system will decelerate after changing lanes.

Lane Keeping System (LKS)

Limitations & Safety Risks:

- The performance of the system fluctuates with changing environmental conditions, such as lighting, rain, fog, snow, etc.
- The performance of the system is directly linked to (conditions of) road markings and geometry. Might miss not continues markings or too curved lines. Also, worn, or vague lines might be missed.
- The system may cause dangerous situations in road works due to other road markings (not following yellow lines for example.
- The system may not detect lane markings when driving close/too close to the vehicle ahead.
- The system may fail in small radius curves or 2nd curve of an S-curve.
- Different versions of LKS exist (only warning, steering correctively, or active steering), therefore wrong expectations of the system by the driver. The potential danger of overreliance.
- LKS reduces the workload of a driver which can cause drowsiness/distraction/fatigue.
- In many applications, the system will deactivate when reaching its limits or when no lane markings are detected without giving a warning to the driver (differ per manufacturer).
- Too much force needed from the driver to overrule the system.

The motivation for a driver to switch off:

- Unwanted or too much lane departure warnings.
- The system steers to abrupt which is not comfortable.

Driver Monitoring System (DM)

DM systems monitor the driver to detect drowsiness or distraction. However, the technology is relatively new and different variations exist for different manufacturers.

Limitations & Safety Risks:

- Eye-tracking may lose accuracy.
- Lighting conditions may affect the functionality of eye-tracking.
- Rough and bumpy roads may cause that the face and/or eyes are not detected.
- The system may have a delay for detection. At high speeds, this delay can lead to warnings that appear too late.

The motivation for a driver to switch off:

- Unwanted or too many warnings.
- Privacy issues of drivers.
- Not sure if the system can be deactivated but a driver can easily block the camera view with a sticker.

6.1.2 V-tron study

A study carried out by V-tron is described here to verify the desk research findings of the technical implications of using ADAS in a vehicle. The study is focused on analysing the diagnostic functionality of Advanced Driver Assistance Systems (ADAS) with respect to the repair and maintenance.

6.1.2.1 Data logging

As already described in Chapter 3, ADAS are electronic systems included in a vehicle to aid drivers to perform tasks in a smoother and safer way. They are also a key underlying technology in emerging autonomous vehicles. They use different sensors such as camera, radar, lidar, ultrasonic and others, individually or infusion to understand the environment and react to it when required. The type of sensor and fusion varies for different manufacturers.

The data flowing in the vehicle CAN bus can be accessed from the eOBD port available in all vehicles. The location of this port is mostly below the steering wheel compartment but can also be identified using the vehicle manual.

OBD code reader

A code reader is a simplified version of a scanner or scan tool. This reader allows to view the trouble code and clear them. The trouble codes are displayed in the reader only when there is some problem with the functioning of any sensor. When a system is not functioning, the reader will help to identify it, so checks can be made to correct the system.

OBD scan tool

On the other hand, a scan tool provides a wider range of operation. The live data can be logged and saved for future use. But the complexity of using a scan tool is higher compared to a normal reader. The tool will provide an output based on the input given to it, so it is important to know what information is required and how to access that specific information. The information can be accessed using Parameter IDs (PIDs). There are a set of standard PIDs for different functionalities.

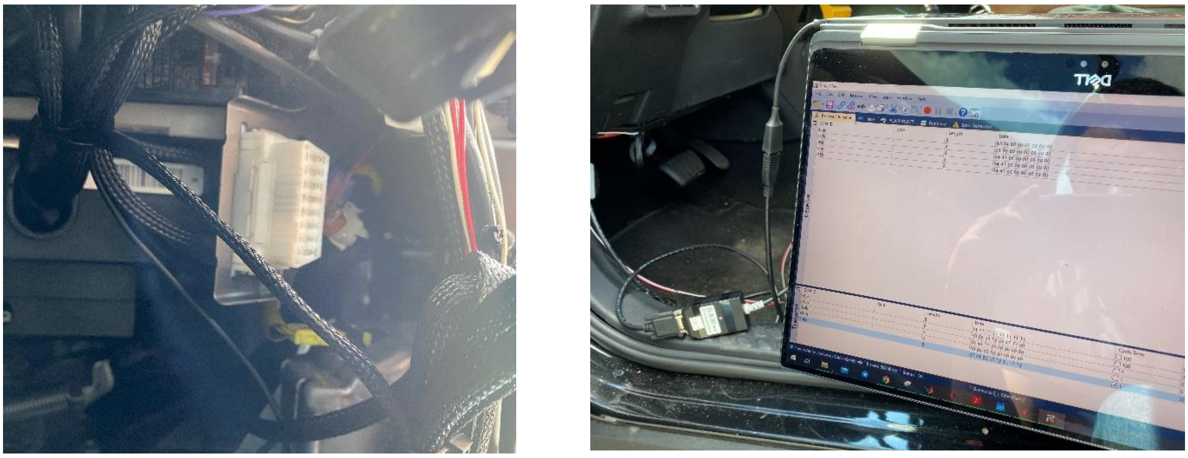


Figure 19 Left: eOBD port, Right: Data logging through PEAK CAN.

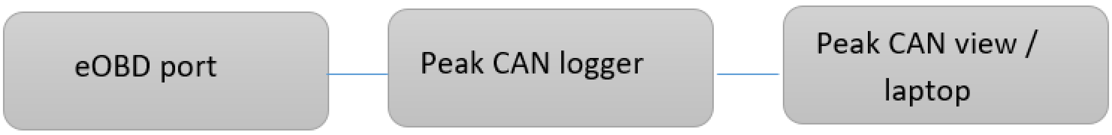


Figure 20 Test setup.

6.1.2.2 ADAS monitoring

As mentioned earlier prior knowledge about the specific IDs is required to log the required data. A lot of research has been done in the field of powertrains and there is a lot of information available about these codes. Because ADAS are recently developed systems and OBD is concentrated mainly on emission regulations not much information is available comparatively. This makes it difficult for logging and evaluating the ADAS related data.

Peak CAN

There are plenty of scan tools available in the market for logging the data. The scan tools provide output data based on the requested input information. For this study we used a peak CAN scan tool to monitor the ADAS data which we have used in previous projects and have prior experience with the software used. The test was performed in two-passenger vehicle, Toyota CH-R hybrid, and Volkswagen polo.

Figure 21 Peak CAN USB logger.

The tool is connected to the eOBD port on one end and the other end is connected to a laptop. Peak CAN view was used to transmit and receive messages. *Figure 22 OBD2 message format.* represents the general frame of the code that is used to communicate.

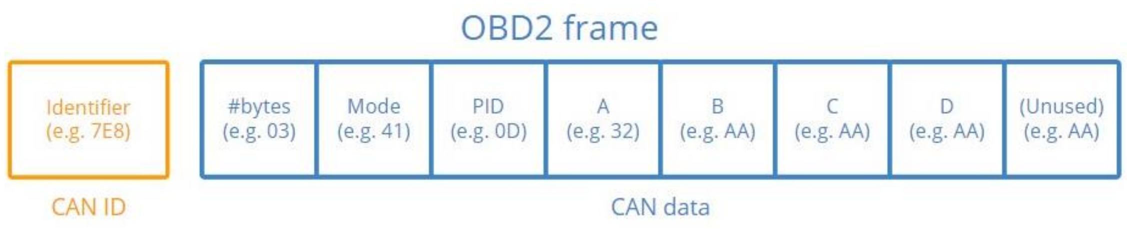


Figure 22 OBD2 message format.

It was found that there is no direct information available with respect to ADASs CAN PIDs. The standard codes are mostly available for powertrains and other basic operations such as throttle, brake, etc. This is because the PIDs are classified as standard and manufacturer specific and the manufacturer specific codes are not readily available. Without the knowledge of corresponding PIDs for ADASs, it is not possible to receive relevant data.

There are 10 diagnostic modes of operation described in the OBD2 standard, see *Table 18*. Most of the diagnosis is related to powertrain and emission data.

Table 18 OBD2 modes of operation.

Diagnostic service Mode of operation	Description
$01	Request Current Powertrain Diagnostic Data
$02	Request Powertrain Freeze Frame Data
$03	Request Emission-Related Diagnostic Trouble Codes
$04	Clear/Reset Emission-Related Diagnostic Information
$05	Request Oxygen Sensor Monitoring Test Results
$06	Request On-Board Monitoring Test Results for Specific Monitored Systems
$07	Request Emission-Related Diagnostic Trouble Codes Detected During Current or Last Completed Driving Cycle
$08	Request Control of On-Board System, Test or Component
$09	Request Vehicle Information
$0A	Request Emission-Related Diagnostic Trouble Codes with Permanent Status

6.1.3 Conclusions and recommendations on Technical Requirements and OBD

As the European Commission mandates ADAS in new vehicles in 2022, without giving (technical) requirements, adverse effects of ADAS on road safety can also be expected. Manufacturers can develop and define their own ADAS without any requirements, resulting in a very wide range of ADAS with different names, functionalities, limitations, and capabilities. Furthermore, manufacturers advertise their ADAS on the comfort level and therefore create dangerously wrong expectations for their customers (drivers).

- It is necessary that the ADAS become more generic.
- All ADAS should have the same standards that state what the system is capable of and more importantly what it is not capable of.
- This will result in safer ADAS and clearer expectations of the drivers on what the ADAS can do.

These recommendations are supported by a recent policy supported advisory research in collaboration with different organizations of the Automotive sector in the Netherlands (van der Steen et al., 2019) and another research executed by the Dutch Safety Board (2019). Both researches conclude that there is a very high demand from the Dutch Automotive industry on standardisation of both the names and functionality of ADAS.

Regarding On-Board Diagnostics, during the V-tron study, it was found that only continuity failure, such as circuit connection failure will be displayed in scan tool for diagnosis. The functionality or a calibration error cannot be diagnosed with the currently available resources. Even if the information is available it would be a big task to reverse engineer the information and to interpret the original meaning. This, in turn, means that it is not possible to measure the functionality of ADAS without proper resources which belong to the manufacturers. So, the way the information is available might vary depending on it which further complicates the process.

Like the standards and priorities given for the emissions, importance should be given to safety side of ADAS to make it more accessible. In this way, the correct operation and degradation can be identified and diagnosed. ADAS are common safety features present in the modern-day cars. But currently, the functionality of these systems cannot be quantified through OBD as there is no data to diagnose them. The capabilities, limitations, and boundaries of all ADAS must be made clear. Some minimum (technical) requirements must be set and the attached system information must be known. The following frameworks provide the suggested technical requirements per studied ADAS.

AEB Technical Requirements

The system should:
- Operate for a certain speed range of [x] – [x] km/h and have a minimum detection range of [x] m. The minimum detection range and maximum speed are correlated with each other. They depend on the safe braking distance of the vehicle (distance to stop without collision) and the minimum stated deceleration (7.2 m/s^2 for a vehicle).
- (Self)Check the working of the sensor every [x] km. Does the sensor detect an object at the minimum detection range within the speed range every [x] km?
- Provide the driver with information about the availability of the system, warning when the criteria aren't met and deactivate the system or confirm that the system is functionally operable.

ISA Technical Requirements

The system should:
- Detect all sorts of speed limit signs (fixed speed limits, matrix signs, advisory speed limits).
- Give (optical) signal/warning if a speed limit is not detected.
- Should work for speed limits of [x] – [x] km/h. (it is unwanted if the system works for speed limits of for example 30 km/h).
- Driver must be able to overrule the system by maintaining its own speed limit. Especially if speed limits are read/detected incorrectly or when dynamic speed limits are required at for example road works or traffic jams.
- Receive information from road managers, police, public services, etc. to be able to know what is going on in the surroundings of the vehicle (Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I)).

ESS Technical Requirements

The system should:
- Self-check if the system is still working (especially the ABS sensors/ wheel speed sensors).
- Work for the full speed range of the vehicle (same speed range for all manufacturers).

ACC Technical Requirements

The system should:
- Have a minimum detecting range of [x] m.
- Have a working speed range from [x] to [x] km/h.
- Minimum detection range and maximum speed are correlated with each other. Maximum speed range should be around the max speed of a country (the system should not work when over speeding). However, this differs per country.
- The maximum range of sensor results in a limitation of maximum cruise speed.
- Work for specific roads only (like highways and provincial roads, but not in the city for example). This can be realised using GPS fencing. This is a technique that determines where the car is via GPS. If the car is in a city, the ACC cannot be activated for example.
- Self-check if it is still working properly.
- Self-check if the sensor view is clear (no dirt/snow on the lens for example). And give a warning if the sensor view is blocked.

LKS Technical Requirements

The system should:

- Not work above a speed of [x] km/h which should be around the maximum speed limit of a country. The faster you drive the lighter steering corrections are needed to keep a vehicle in its lane. Therefore, the system might steer too much on high speeds which can lead to dangerous situations.
- Work for specific roads only (like highways and provincial roads, but not in the city or curvy roads for example).
- Work for specific lane markings (continuous lines, coloured lines for example).
- Self-check if it is still working properly.
- Self-check if the camera view is clear (no dirt/snow on the lens for example). And give a warning if the sensor view is blocked.

DM Technical Requirements

- Work all the time, but preferably works on long journeys or late hours.
- Take specific types of roads into account. In the city, you are aware most of the time as a driver. But at long stretches of highway with no other traffic around there is a higher risk of distraction/drowsiness.
- Work at all vehicle speeds.
- Request the driver for breaks between long drives.
- Should warn the driver when the face is not detected (on bumpy roads or with various lighting conditions).
- Self-check if the camera view is clear (dust for example). And give a warning if the sensor view is blocked or face is not detected.
- The driver should be able to switch off the system if it’s not working correctly or if the driver feels that his privacy is at stake.

6.2 Technical type-approval and roadworthiness regulatory requirements necessary to guarantee ADAS lifetime technical safety and security

This paragraph provides an overview of the legal aspects and frameworks of vehicles with ADAS. It provides information about the regulations for type approval, lifetime safety guarantee (maintenance) and security. First general findings are described followed by a more detailed description of type approval, lifetime safety guarantee (maintenance) and security. Finally, specific regulations for the six selected ADAS, if any, are given.

6.2.1 Type approval

Serially produced passenger cars that use public roads must meet certain type approval requirements and regulations. This approval applies to vehicles as well as to vehicle systems, components, and separate technical units. Once approval is obtained, it remains valid even if admission requirements are changed or tightened later. The approval requirements are included in the European Directive 2007/46/EG (European Parliament, 2007), which was updated in May 2018 (2018/858/EG) (European Parliament, 2018). General findings for approval regulations for (vehicles with) ADAS are listed below:

- ADAS is a subcomponent of a vehicle and is often used in multiple vehicle types. It can therefore get a subtype-approval that is later used for the type approval of a new vehicle (Dutch Safety Board, 2019). However, 2007/46/EG and 2018/858/EG have no admission requirements for ADAS (European Parliament 2007 en 2018).
- Components that have no admission requirements or do not meet these requirements can qualify for a subtype-approval, Article 20: Exemptions for new technologies or new concepts. The condition for granting is that vehicles must achieve at least the same level of safety (European Parliament 2007 en 2018).
- The directives do not describe the assessment of the safety level of an ADAS. Nowadays, it is stated that the effect of new ADAS on road safety cannot be demonstrated and therefore it is stated that it is not possible to say what effect new ADAS have on road safety. The condition of Article 20, the

same level of safety, is therefore met and a subtype-approval is granted, Figure 23 (Dutch Safety Board, 2019).

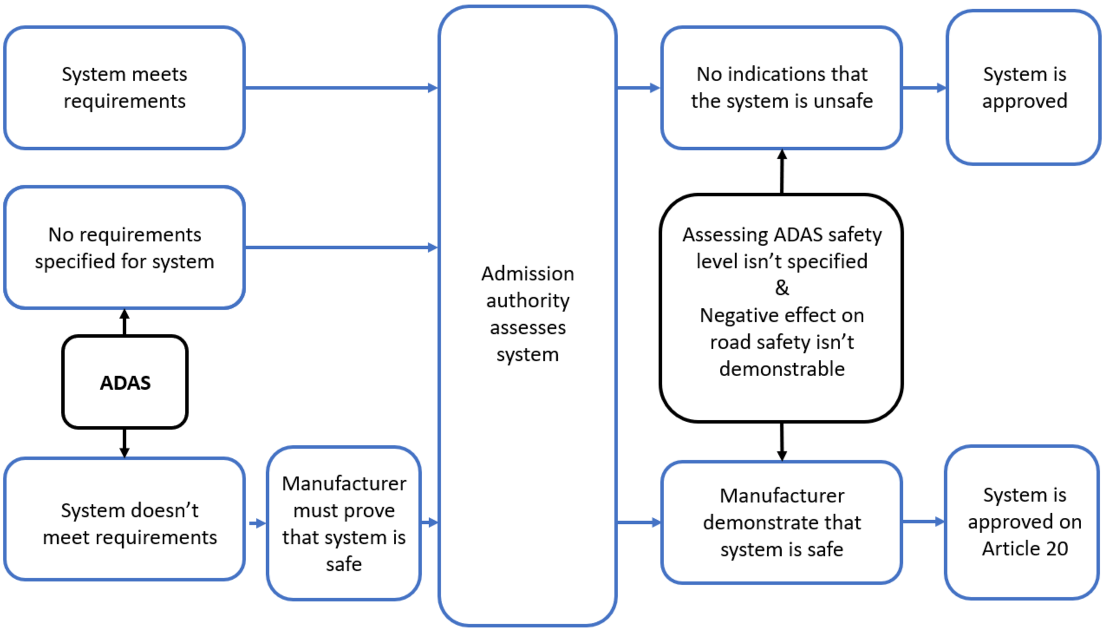


Figure 23 Flowchart for application for type approval [4].

- An approval remains valid once it has been obtained. However, the systems may be developed and updated further, with possible changing or added functionalities, after approval.
- Some specific ADAS have technical approval requirements, such as Automated Emergency Braking Systems for trucks or Lane Departure Warnings Systems for passenger vehicles.

So, there are no admission requirements for ADAS. And since it is stated that the effect of ADAS on road safety cannot be demonstrated, these systems are easily approved. However, studies show that the driver’s workload reduces when driving with (partially) automated driving systems where complete driving tasks are taken over by the system, i.e. ADAS. This can result in complacency and loss of situational awareness which will have a negative effect on road safety (Lu et al., 2016; Dutch Safety Board, 2019). Furthermore, after approval, the systems can be updated, with possible negative effects on road safety, but the approval remains valid.

6.2.2 Lifetime guarantee safety (maintenance)

With the ‘General Safety Regulation’ implemented by the EU that states that some types of ADAS will be mandatory by 2022, maintenance of ADAS is going to play a vital role in securing and maintaining the safety and functionality of these ADAS. In this paragraph, the current development, and trends of maintenance on ADAS are explained together with some requirements that should be met when the ADAS become mandatory (BOVAG, 2019).

Current state of maintenance on ADAS:

- A lot of unknowns and uncertainties regarding the functionalities of all ADAS in general.
- Replacing a bumper can already affect the ADAS, for example if the bumper is not replaced correctly and blocks the view of the radar sensor for ACC.
- Types of ADAS differ a lot per car manufacturer in terms of names, functionality, limitations, etc. This requires a specific maintenance approach per ADAS per manufacturer.

- Calibration of the system is becoming a big (extra) part of the maintenance service and costs.
- Reparation is much more expensive for cars with ADAS due to expensive materials and it requires more time to repair (due to calibration for example). Broken ADAS systems (sensors) mostly do not get repaired but get replaced as a whole.
- Due to constant updates that manufacturers apply to their ADAS, the functionalities of those ADAS may change. This affects the maintenance required as well.
- There is no clarity about the lifetime of the systems. How long will they be updated/supported by the manufacturer?
- Digital systems do not wear-out like mechanical systems. Continuous monitoring is required but not mandatory yet. Lifetime safety can therefore not be guaranteed.

Expected change of maintenance on ADAS:

- Due to ADAS, the roads become safer and cars get more efficient. Therefore, traditional maintenance and repair works will decrease over time. This also means less revenue for car dealers and garages.
- The maintenance/repairs that are needed will cost more money due to more expensive materials and more time needed by the mechanic. A part of the lesser revenue for car dealers and garages can be compensated by this effect.
- Windshield replacements will also get more expensive. Due to camera and sensor calibration that is needed after window replacement.
- Parties that manage to adapt to these changes the best (in calibration and good maintenance of ADAS) will benefit the most and increase their market share.
- The question remains which parties will execute the calibrations in the most efficient way and will benefit the most from these trends (car manufacturers, aftermarket dealers, maintenance garages).

6.2.2.1 Recommendations for Requirements of maintenance on ADAS

According to Van der Steen et al. (2019), the Dutch branch of garages and maintenance & repair shops unanimously agreed that ADAS should become part of the “Algemene Periodieke Keuring (APK)[6]”. It is, however, necessary that testing ADAS functionalities is achievable, measurable, and verifiable. To achieve that, several recommendations are proposed:

- ADAS database: during the check-up, a database that has information about the ADAS that are present on the vehicle is needed, which the mechanic can access via the vehicle’s VIN-number. It is preferred that this database is publicly available.
- Standardization: it is preferred that this database contains a uniform ADAS terminology and a uniform description of its functionality.
- Education: specialized educational programmes are therefore necessary for maintenance personnel.
- Inspectors: the inspectors who are responsible for inspecting the quality of the mechanics’ work should also have detailed knowledge about all ADAS and their way of operation for each car brand.

Further:

- A clear standard must be set for lifetime guarantee of ADAS (both maintenance and updates).
- A MOT (ENG) or APK (NL) should be introduced for all types of ADAS. In this way you introduce a (yearly) check-up if the ADAS is still functioning properly. Hence, you can guarantee a lifetime guarantee on the functionality of the ADAS.
- Requirements need to be set in case manufacturers are able to/willing to provide updates of their ADAS.

[6] *a mandatory yearly check-up for all motor vehicles that focuses on vehicle safety and emission regulations.*

- Manufacturers must make information available to independent companies to make the repair and maintenance process transparent so that it can be checked whether the processes lead to the required result.
- A lot of attention should go into reliable calibration since this is expected to be of key importance to a well-functioning ADAS.

6.2.3 Security

Safety of ADAS is not only about the safe functionality, approval, and maintenance of the systems, but is also about (cyber)security. Today's cars with multiple ADAS have more external connections and more digital inputs that must be protected against deliberate abuse (Dutch Safety Board, 2019). Furthermore, ADAS are interconnected digital and physical systems and provide a more direct link between the computer systems and the control systems (steering, braking, throttle) of the vehicle. Cyber risks can therefore have a major influence on physical safety (Dutch Safety Board, 2019). The main findings of (cyber)security regulations and standards are listed:

- The vehicle industry has designed guidelines for cybersecurity. For example, the SAE (Society of Automotive Engineers) has given a manual with guidelines for cybersecurity threats (SAE International, 2016) and are currently working on a standard (together with ISO) for cybersecurity in the auto-industry (ISO/SAE).
- In addition to the industry, different organizations, and government agencies, such as ENISA and NHTSA, have documented how cybersecurity should be arranged in IT-systems in general and, in particular, for IT in vehicles. Guidelines and best practices are published (McCarthy et al., 2014; NHTSA, 2016; ENISA, 2016; GOV.UK, 2017)
- However, there are yet no specific regulations on cybersecurity in and around cars. Cybersecurity is now described as a guideline in an appendix to approval requirements. Manufacturers can include the new cybersecurity principles as a standard in their design process, but these are not mandatory.
- No (independent) cybersecurity test is mandatory. Potential vulnerabilities of the system are therefore not exposed (Dutch Safety Board, 2019).

6.2.3.1 Conclusions and recommendations on security

The increasing number of external connections and the direct link between the computer systems and the control systems due to ADAS entails cybersecurity risks. However, no specific regulations for cybersecurity are defined, not for vehicle approval and not for maintenance/lifetime. Only guidelines and best practices are provided.

Given the risks, regulations and standards for cybersecurity should be introduced. Furthermore, this should be a continuous process during the lifetime of a vehicle since cybersecurity is a (fast) changing subject. A newly developed vehicle can have great cybersecurity while it is obsolete after a few years.

6.2.4 Remaining findings

- No regulations about the use of names/definitions (such as ABS) and symbols. However, partners of the ADAS alliance are creating proposals to the RDW (for European regulations) and Euro NCAP (for the manufacturers) for the development of generic names, generic symbols and, where possible, standardized operations/functionality of ADAS.
- Human-machine interaction is not an explicit part of vehicle regulation and type approval since the driver remains responsible. From a legal point of view, the ADAS only assist the human driver. However, ADAS takes over complete driving task under certain conditions (throttle, brakes, steering) until they come to a situation they are not designed for. This means that HMI legislation is also important for ADAS, nevertheless, it is not there yet.

- No regulations for driving exam with ADAS. There is no testing for the correct use of various (advanced) driver assistance systems installed in the vehicle. Furthermore, ADAS is not included in the theory exam.

6.2.5 Regulations per ADAS

Some ADAS have regulations, standards, or requirements. However, these regulations or requirements are often very generic and not specific, or they are provided for an ADAS that is not mandatory in new vehicles in 2022. For AEB, ACC and LKS, regulations have been found and brief information is provided. For the other systems, no regulations are defined.

Advanced Emergency Braking (AEB):

- There is a draft UN Regulation for AEB systems in passenger cars (UNECE, 2019) which is adopted at UNECE. This regulation will lay down the technical requirements for the approval of “vehicle-to-vehicle” and “vehicle-to-pedestrian” AEB systems fitted on cars. The draft Regulation is not yet entered into force. This is planned for early 2020 [18].
- “The new UN Regulation will impose strict and internationally harmonized requirements for the use of AEB systems at low speeds even in complex and unpredictable situations such as traffic in urban areas” – (UNECE, 2019).

Adaptive Cruise Control (ACC):

Nowadays, there are no admission requirements for an ACC, despite the broad applicability. However, there is an ISO standard, ISO 15622 Intelligent transport systems — Adaptive cruise control systems, for performance requirements (ISO, 2018). It contains the basic control strategy, minimum functionality requirements, basic driver interface elements, etc. Some findings from the standard are listed: ACC is an enhanced cruise control. The vehicle will follow a forward vehicle at an appropriate distance by controlling the engine and/or powertrain and brakes.

- An ACC system is not required to react to a stationary or slow-moving object. If the system is not able to do, it must be stated in the vehicle’s manual.
- Some functionalities are specific, others are more generic/general:
  - Transition to speed control (CC) and time control (ACC) shall be made automatically
  - The ACC system shall be able to determine the speed of the subject vehicle.
  - Time gap (distance/speed) shall be equal or greater than 1 sec.

Lane Keeping System (LKS):

Lane Keeping Systems can have different functionalities. The system can warn the driver for leaving the lane, Lane Departure Warning (LDW). Other systems can assist the driver to stay in the (intended) lane, but this is not an automated steering function (LKS). And the most advanced systems can keep the vehicle in the (intended) lane for a longer period as they are an automated steering system, Lane Keeping System (LKS).

For LDW, there is a regulation, Regulation No 130 – Uniform provisions concerning the approval of motor vehicles with regards to the Lane Departure Warning System (LDWS), (European Parliament, 2014). Some specific requirements are specified in this regulation, such as the minimum radius of the road/lane where the system is still able to provide a warning or the minimum speed where the system should be active. Furthermore, a test procedure is described for manufacturers.

For ADAS there is the Regulation No 79 – Uniform provisions concerning the approval of vehicles with regards to steering equipment, (UNECE, 2020). However, it is not certain if these systems are specified as comfort systems or safety systems. The main requirement in this regulation is that the system should increase the safety of the system. Or safety should not be negatively affected by the system.

- There is a UN Regulation proposal for LKS systems in passenger cars which is adopted at UNECE. This regulation will lay down the technical requirements for the approval of vehicles with regards to Automated LKS. The draft Regulation is not yet entered into force. This is planned for January 2021 (UNECE, 2020).

6.2.5.1 Conclusions on Regulations

Multiple sources indicate that there are limited legal regulations for ADAS (SWOV, 2019; Dutch Safety Board, 2019; Euro NCAP, 2020). In general, there are no legal requirements, national and international, (with the exception of a few specific systems) for the design of ADAS, only recommendations, general design principles and guidelines for the safe use of ADAS are provided (SWOV, 2019). It is therefore not guaranteed that new ADAS are adequately tested for risks and can contribute to increasing road safety (Dutch Safety Board, 2019) However, large efforts are made to obtain safety ratings of vehicles with ADAS in consumer testing (Euro NCAP, 2020). This results in the further development of such systems by car manufacturers since vehicle manufacturers appear to be sensitive to the EuroNCAP score (SWOV, 2019; Euro NCAP, 2020). Furthermore, organisations like EuroNCAP, make sure that safety ratings become available, for cars that enter the European market. Nevertheless, car manufacturers have no obligation to comply with the high EuroNCAP standards.

Although there are (almost) no regulations, there are different recommendations and design principles for ADAS (European Parliament, 2017; UNECE, 2017). However, this is very generic and not specific, for example:

- Driver assistance systems should improve road safety;
- Driver assistance systems, which are important for road safety, must be regularly checked;
- Drivers should be clearly informed when the assistance system is actively controlling the car;
- Calls on manufacturers and operators to:
  - Make the activation file of each driver assistance system visible to the driver.
  - Ensure that the active state of the ADAS is activated after each new start of the vehicle.

Some specific ADAS, such as Automated Emergency Braking Systems for trucks or Lane Departure Warnings Systems for passenger vehicles, have technical requirements; nevertheless, this is for a limited amount of systems and the vast majority of mandatory systems do not yet have legislation.

7 Conclusions and recommendations

This chapter provides an overview of the main conclusions and recommendations on the study topics presented in the previous chapters. This is done by listing out the most important conclusions of this study and providing a list of recommendations per studied aspect. First, the conclusions are given in the form of answers to the study's sub-questions, followed by relevant recommendations (❖) (if applicable/necessary).

The results of this study have confirmed the conclusions of previous literature studies and managed to get insights in knowledge gaps in user's knowledge, awareness, quality of available information and HMI issues. The international character of this study, which has drawn conclusions based on data of 6 different countries, shows what the needs are to increase the potential of ADAS on a European level. A multi-channel "driver-vehicle-infrastructure" approach is needed in order to embrace and increase the safety potential of ADAS (Figure 24). Such an approach tackles all current issues at the same time, in a connective way so that developments follow each other and avoid the issues that arise from excessive progress in specific fields and (almost) no progress in others.

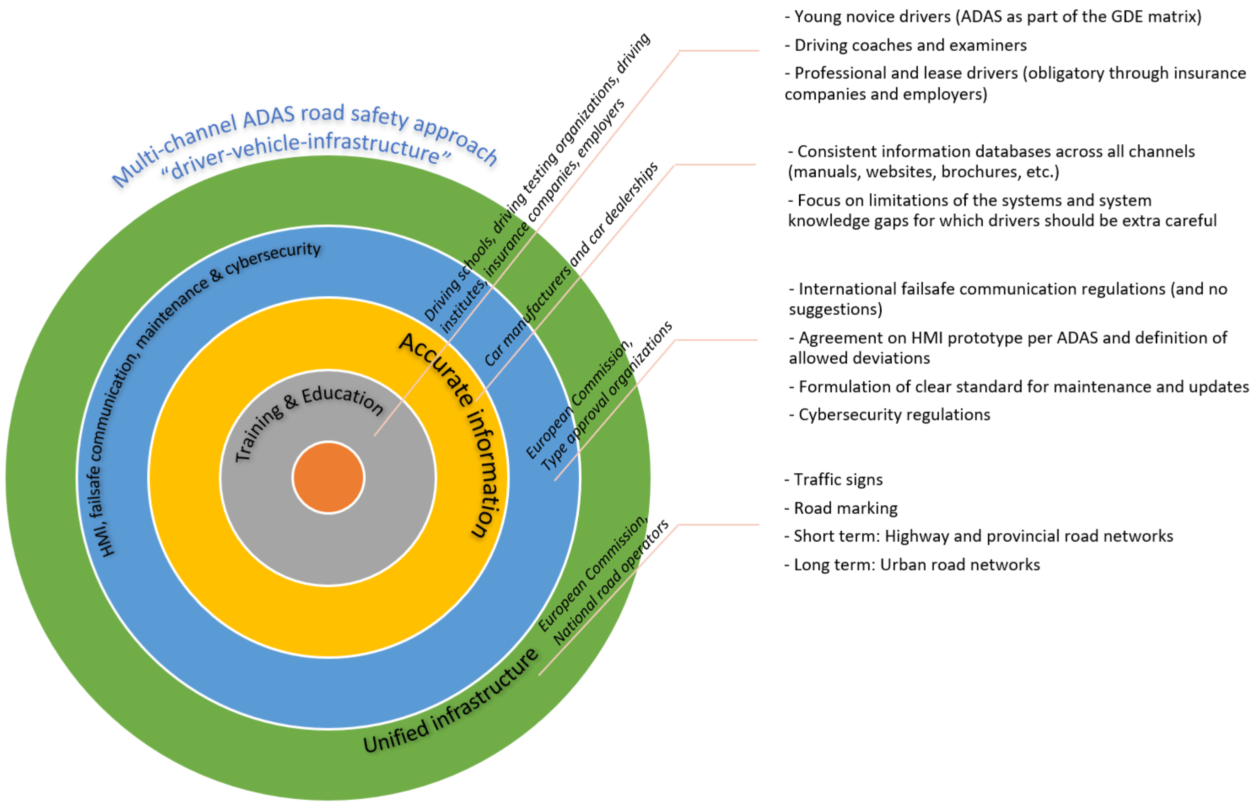


Figure 24 "Multi-channel" ADAS road safety approach "driver-vehicle-infrastructure".

7.1 ADAS features and road safety impact

What are the technical features of the selected ADAS?

ADAS function with the help of one or more sensors, aiming to assist the driver in performing different driving tasks. The capabilities of the systems vary depending on different factors (e.g. environmental, physical constraints, etc.)

Next to the capabilities of the systems, the systems' limitations and ODD are significant in determining their expected contribution to road safety. The desired insights into the limitations of the selected ADAS do not appear to be sufficiently available. ACC related information is more often available compared to the rest of the systems. This lack of knowledge about the ODD means that both car drivers and road authorities do not have (complete) insight into ADAS capacities and limitations.

What is the level of accuracy of the selected ADAS?
The ratio between hits and misses/false alarms is of utmost importance as it affects the consumer's trust in the systems. The number of misses and false alarms should be as low as possible and the number of correct rejection but especially the hits should be as large as possible.

To date, there have not been studies that provided ratios of accuracy (hard numbers) for ADAS. In the study of Vlakveld (2019), accuracy is characterized as good, reasonable (fair) and insufficient. Only ISA out of the six selected systems is reported to have good accuracy, while the rest of the systems have reasonable or insufficient accuracy. There is a lot of space for the improvement of the ADAS' accuracy.

How is the functionality of the selected ADAS affected by the age of the systems?
There is no clarity about the lifetime of the systems. How long will they be updated/supported by the manufacturer? The age of the systems itself is not seen as a problem; if the sensors are in a good state and adjusted properly, they will continue to function as intended by the vehicle manufacturer. These sensors are not perishable. However, as the age of both the car and the systems increase, maintenance and updates become increasingly important. Age-related issues (especially related to the software updates) can be solved with clear maintenance and calibration processes.

- ❖ A clear standard must be set for lifetime guarantee of ADAS (both maintenance and updates) (for more information see 7.5)

What are the potential dysfunctions of the systems based on the current experiences of developers and users?
Most of the systems' dysfunctions originate from the limitations of their sensors. These, often dependent on environmental and infrastructural conditions, may fail to:
- detect potential threats (e.g. failure of the ACC radar sensor to detect preceding vehicles),
- receive the necessary information and inform or intervene accordingly (e.g. ISA's camera failure to read traffic signs or GPS signal loss)
- detect (fast) small moving objects, like pedestrians and cyclists (see AEB's results on Euro NCAP tests)
- function because of dependency on other systems of the vehicle (e.g. ESS is dependent on the correct function of ABS).

Sensor improvements are necessary to create a wider range of the system's capabilities:
- ❖ OEMs should strive to increase the functional range of the sensors. The combination of multiple sensors for an ADAS should be able to minimize the limitations that are found in one sensor.

How is a system's failure to function communicated to the user?
There are currently general design requirements based on European Commission, UNECE and Dutch Safety Board. However, system-specific requirements refer only to the fail-safe communication of ACC. In practice, systems only communicate the sensors' inability to function (e.g. the system's sensors cannot work because of a technical malfunction). No information is communicated in case the systems fail to function or deactivate (e.g. the systems deactivate because operational criteria are not met, such as vehicle speed).

This research has shown that there is a great need for international regulations (and not suggestions), which will clearly outline what type of information, signals and messages should be communicated to the driver in case the ADAS fails to function.

- A detailed list should be provided with “dos and don’ts” per ADAS system, giving priority to the six systems that will be a standard part of all existing car models from 2024.
- Parts of these regulations should be also in user manuals (in a simplified language) for the ADAS user to learn what to expect in case of the system’s failure.
- The responsibility for the formulation of failsafe communication regulations lies with governmental organisations responsible for type approval. To be followed consistently, such regulations should follow under the umbrella of the European Commission.

What are the costs related to the maintenance of the selected ADAS?

Reparation is much more expensive for cars with ADAS due to expensive materials and it requires more time to repair. Broken ADAS systems (sensors) mostly do not get repaired but get replaced as a whole. Individual damage repair costs are likely to increase, because of the need for specialized equipment, qualified personnel, and higher spare part prices. Other contributing factors for this increase in repair costs are:

- Types of ADAS differ a lot per car manufacturer in terms of names, functionality, limitations, etc. This requires a specific maintenance approach per ADAS per manufacturer.
- Calibration of the system is becoming a big (extra) part of the maintenance service.
- Due to constant updates that manufacturers apply to their ADAS, the functionalities of those ADAS may change. This also affects the required maintenance.
- Digital systems do not wear-out like mechanical systems. Continuous monitoring is required but it not mandatory yet.

When penetration rates increase, the damage repair volume will, however, decrease. Four types of ADAS together are expected to cause a 23% decrease in damage repair volume[7] (~9% if corrected for increased prices). Mainly AEB and LKS are expected to contribute to this decrease in vehicle damages.

What are the potential risks on road safety caused by failures of the technical function of the selected ADAS?

Sensor failures to function are the most common reasons for failures of ADAS. Systems’ correct operation depends, among others, on software calibration and maintenance, which ensure safe operation if they take place regularly.

This study concludes that even in case the systems fail to function, potential road safety risks can be avoided by proper fail-safe communication. For the six studied ADAS, a failure to function is (almost) never communicated to the driver. As a result, drivers expect to be assisted when they are not assisted. Inability to react to a traffic situation because of false expectations from the systems can be the cause of road accidents. This, together with the fact that drivers often over-rely on the systems (and therefore expect that the system will always provide a warning or intervene), can aggravate the consequences of a dangerous traffic situation.

What are the potential risks on road safety caused by misinterpretation of the system’s communication to the user?

According to users’ experiences, the signals sent by the different ADAS through the Human Machine Interface are not always clear. Visual, audible, or haptic signals sent as a single message or as a combination can cause the driver to be distracted and/or confused. As a result, the driver cannot perceive

[7] *A decrease in damage repair volume is not the same as a decrease in crashes/injuries/fatalities.*

the traffic situation and potential threat as adequately as needed and may fail to react (in time) to avoid a dangerous situation. In this case, the assistance system(s) have adverse effects on traffic safety, instead of the intended positive impact.

In addition, the high number of false negatives and false positives some of the ADAS present, highly affect the level of trust of users on the systems. The more the number of false signals, the fewer users trust the systems. Therefore, users with such experiences tend to ignore the systems' signal and rely on their capacity.

7.2 Human Machine Interface

What are the features of an optimal Human Machine Interface that avoids driver's distraction and cares for the safe use of the systems?
ADAS that have a significant Human Machine Interaction in the first place are Lane Keep System (LKS), Intelligent Speed Assistance (ISA) and Adaptive Cruise Control (ACC). In the other three systems (AEB, drowsiness detection and ESS), a user interface is not (or hardly) involved.

The findings on the prerequisites for the HMI framework can be applied to any ADAS system that has HMI framework and can be a base for creating an exact policy for the ADAS HMI design. The two main sides of the HMI consist of:

- User to System: the controls. These consist of the way the driver can provide input to the system. In the context of ADAS, mainly buttons or levers on or near the steering wheel are used for this.
- System to User: the displays. These can be visual, auditory, haptic, or tactile: any modality through which the system can inform the user or warn the user.

The following recommendations apply for an optimal Human Machine Interface that avoids driver's distraction and ensures the safe use of the systems:

- ❖ It is recommended not to focus on the HMI as a stand-alone item but regard it in combination with the rest of the ADAS functions (in terms of its logic and control behaviour). ADAS should be evaluated in terms of workload and distraction, but also trust and acceptance. This is not only determined by the HMI but by the overall system. The focus of the Code of Practice (CoP) is the system design against the background of system controllability and the total vehicle from the field of view of Human Machine Interaction (i.e., wider than the Human Machine Interface).
- ❖ On a *lower level*, the HMI framework can be summarised as: "Watch your basic ergonomics". The HMI design should consider the limitations of the user in terms of perception, information processing and task execution. This is the level of how and where the controls and displays are realised around the driver.
- ❖ On a *higher level*, the ADAS should not introduce excessive workload for the driver or cause distraction. At this level, timing, frequency, and duration of interaction between the system and the user play an important role.
- ❖ The system should react and behave predictably.
- ❖ The system should be flexible to adjust to the drivers' needs and preferences.
- ❖ In line with the previous point, the driver should be informed about any malfunction within the system that is likely to have an impact on safety. This is directly in line with the generic ESOP (EC, 2008) principles. The existing explicit ISO 15622 requirements for ACC on notification of failure states to the driver, should be extended for a driver notification to any other ADAS of which the failure would impact safety.
- ❖ OEMs should take the responsibility to continue conducting experiments and pilots using different driver profiles and groups to constantly improve the interface between the driver and the system and reduce the driver's workload.

- The driver should be visually informed about the live state of the systems, preferably in a Head Up Display (HUD). Also, a clear message should be always provided about the status of the systems: enabled/disabled.
- With regards to uniform naming of the ADAS, focus should be given on the reflection of the systems' functionality through the names of the systems. It should be still researched and discussed if this reflection should happen together with terminology unification.
- Alignment between HMIs of different car manufacturers is desirable. However, the competitive character of this industry poses a great challenge for this alignment. Discussions on international level are necessary to agree on a “prototype” HMI for each ADAS, that will allow for several modifications across car manufacturers.

7.3 User awareness

To which extent are ADAS' users aware of the systems' functionality, capabilities, and limitations?
Most users do not receive training, but rely on information from the car seller, the user manual or they apply the ‘trial-and-error’ method. The quality of both information and instruction via these learning methods is found to be imperfect, which means that drivers are provided with incorrect and/or incomplete information and instruction.

Users indicate that the ADAS perform as they expected, which is interesting because the knowledge test has shown that most of the users are not able to correctly answer the majority of the questions. This implies that most of the respondents do not fully understand the ADAS. Among the systems, ISA and ESS are better understood than ACC, AEB, DM and LKS. Combined with the high levels of trust and satisfaction of these ADAS, this implies a potential road safety risk.

Compared to the respondents' trust in the six ADAS, it seems that there is a large discrepancy between the percentage of respondents that trust that the systems will work well and the percentage of respondents who actually have sufficient knowledge of the systems.

There is a significant need to improve the quality of the provided information and instruction:

- To avoid any adverse effects that can be caused by the incorrect use of ADAS on the group of young novice drivers, ADAS should be part of driver's training (see chapter 5). ADAS is taught on a voluntary basis in the Netherlands but it is not a part of the obligatory training in any European Country. The voluntary character of the ADAS courses in the Netherlands is responsible for the very low demand for these courses. Given the introduction of the six studied ADAS in all existing models from 2024, training schools and driving testing organisations across all European countries should strive towards a driver training curriculum that includes both theoretical and practical training on ADAS.
- In driver training, the driver's role should be very clearly taught and tested both when driving with and without ADAS. It is, therefore, very important that the drivers should first learn how to drive alone and later get introduced to driving with assistance systems. The Goals for Driver Education (GDE) matrix (Table 19) can be used as a basis for the placement of ADAS in the learning process. It is yet to be discussed if ADAS should be taught as part of 1 and 2 of the GDE matrix or as part of the high order skills (level 4).
- Driving testing examiners and driving training coaches should be trained and tested before the introduction of ADAS in the training of young novice drivers.
- Training in the form of (voluntary) seminars or “life-long” learning should be introduced for any new ADAS user. These should be provided by all driver training schools or by driving schools that offer ADAS dedicated courses to certain types of drivers, like lease drivers.
- Insurance companies and employers can boost the response and willingness of their customers and employees to attend ADAS courses by setting this as an insurance/lease requirement. As a

result, they should have an active role in the safe use of ADAS by creating incentives to this large groups of older drivers, who do not receive any ADAS training in the way young novice drivers should do.

Table 19 Goals for Driver Education matrix (Hatakka, et al.,2003).

		Knowledge and skills	Risk-increasing factors	Self-evaluation
Level 4	Goals for life and skills for living	Understanding the importance of lifestyle, age group, cultural and social circumstances, etc.	Understanding the importance of sensation-seeking, risk acceptance, group norms, peer pressure, etc.	Understanding the importance of introspection, competence, personal preconditions for safe driving, impulse control, etc.
Level 3	Goals for, and context of driving	Understanding the importance of modal choice, time of day, motives for driving, route-planning, etc.	Understanding the impact of alcohol, fatigue, low friction, risk hour traffic, peer-age passengers, etc.	Understanding the importance of personal motives, self-critical thinking, etc.
Level 2	Mastery of traffic situations	Mastering traffic riles, hazard perception etc. Automating elements of the driving process. Cooperating with other drivers, etc.	Understanding the risks associated with disobeying rules, close-following, low friction, vulnerable road users, etc.	Calibration of driving skills, developing a personal driving style, etc.
Level 1	Vehicle control	Mastering vehicle functioning, protective systems, vehicle control etc. Understanding the impact of physical laws	Understanding the risks associated with non-use of seat belts, breakdown of vehicle systems, worn out tyres, etc.	Calibration of car control skills

To which extent are car dealers aware of ADAS' functionality, capabilities and limitations?

In comparison to previous studies on this subject, the mystery shopping assignment showed that car dealers are more aware of the ADAS' functionality, capabilities and limitations than expected. The type and level of knowledge differ not only among car brands but also between individual sellers. It is important to note that sellers are not aware of how important it is that the knowledge they have, and transfer should be such that it is interpreted in one way only. Also, no major differences are found in the level of knowledge between exclusive and independent dealerships.

❖ Car dealerships personnel should receive theoretical and practical training and instruction on ADAS.

To which extent are car dealers capable of informing and instructing users about ADAS' functionality, capabilities and limitations?

The dealers' knowledge is transferred to the car buyer only under certain conditions. This means that the lack of knowledge of the car dealers (in case there is) is not the only problem. The information on ADAS is not openly and always addressed to the customers:

- Information on ADAS is generally limited in detail at first. Car sellers tend to tell more about ADAS when they notice that the car buyer is interested in it.
- Information on ADAS is offered selectively. Car sellers try to figure out what kind of person the potential customer is and what his/her interests are. This might influence the type of information and the level of detail that the customer receives.
- Dealerships are a bit divided when it comes to providing dynamic instructions (test drive). Some dealerships let the customer take the car for a test drive, without accompanying them. Others do go along with the customer on a test-drive, because they think it is an extra service to explain all the systems to the customer. A recent study showed that drivers who experienced an ADAS-equipped

vehicle for the first time are more focused on how to operate the systems and that their situational awareness decreases during these first test drives.

- There are differences between car dealerships of the same car brand. The type of information that the customer receives and the level of detail of that information highly depends on the individual car seller.

Finally, not all car dealers were aware of the importance of good instruction.

- ❖ Car dealerships should provide a short theoretical and practical introduction to specific ADAS used in specific vehicles or car models.
- ❖ Minimum harmonization requirements should be applied for the information car dealerships should provide to their customers during the purchase process of an ADAS equipped vehicle. This will eliminate the existing differences in the provided service among different and the same car brands. Car dealerships are obliged to:
  - inform the customer about the available ADAS in the car
  - explain the type of systems (safety or comfort-oriented)
  - describe how the systems function, what the systems can and cannot do (manage customers' expectations)
  - show (in practice, e.g. test drive) when and how to operate the systems
  - suggest that the customer reads the user manual carefully

To which extent is information and instruction about ADAS' functionality, capabilities and limitations offered to the car buyer, unambiguously comprehensive?
It is unlikely that a car owner can create a good understanding of the systems' functions, limitations and its ODD by reading the user manual or visiting the car brand's webpage.

On the one side, the manuals outline all kinds of warnings, that seem to shift responsibilities away from the car manufacturer to the car owner for legal purposes. The information that is present in these manuals is first and foremost geared towards explaining how to turn on/off these systems. Information about system limitations and ODD is often written in a very ambiguous manner. On the other side, information on webpages focuses on marketing and promotion of ADAS and is mostly not suitable for creating a thorough understanding of the system capabilities, as there is limited information about ODD and limitations. Higher-class car brands provide relatively more comprehensive (but still insufficient and ambiguous) information than medium/low class car brands.

The responsibility of the provision of accurate information does not only lie by governmental organisations and private driving institutes:

- ❖ Car manufacturers should work towards creating consistent information databases for their (potential) customers, which appear clearly and in the same way across all their channels (manuals, websites, etc.). A clear separation between marketing and educational material must take place.
- ❖ In all channels, focus should be given on the role of the driver, the existing limitations of the systems and on the aspects of the systems that are still unknown (like the reaction of the systems to specific traffic situations or weather conditions).
- ❖ All descriptions should be written in a very simple and direct way to be interpreted only in one way (unambiguous information).
- ❖ Minimum harmonization requirements should be applied for the structure, content, and language use of car manuals. These requirements should form a list of guidelines that should be followed by OEMs. This will solve the lack of information in the user manuals, the complexity of the texts and the differences among different car brands and models.

7.4 Technical implications

How could and should a harmonized on-board diagnostic functionality for the repair and maintenance of ADAS be designed?

Importance should be given to the safety side of ADAS to make these systems more accessible. In this way, the correct operation and degradation can be identified and diagnosed. The functionality of these systems can currently not be quantified through OBD as there is no data to diagnose them.

The capabilities, limitations, and boundaries of all ADAS must be made clear.

- ❖ Some minimum (technical) requirements must be set and the required information for the system must be known (see 6.1.3 for the detailed technical requirements per system).
- ❖ All ADAS should have to comply with the same standards that state what the system is capable of and more importantly what it is not capable of (uniform functionalities).
- ❖ The design of a harmonized on-board diagnostic functionality for the repair and maintenance of ADAS requires uniform names for all systems.

What regulatory requirements are necessary in terms of technical type-approval and roadworthiness of vehicle systems to guarantee ADAS lifetime safety and security?

- ❖ A clear standard must be set for lifetime guarantee of ADAS (both maintenance and updates):
  - A regular (e.g. yearly) check should be introduced to assess the correct functioning of each ADAS. This could be a part of the regular vehicle safety & emission check-ups (in the UK: the MOT, in NL: the APK).
  - Requirements need to be set in case manufacturers are able to/willing to provide updates of their ADAS, especially when such an update changes the performance and/or the way of operating of the ADAS.
  - Manufacturers must make information available to independent garages to make the repair and maintenance process transparent.
  - A lot of attention should go into reliable calibration since this is expected to be of key importance to a well-functioning ADAS.
- ❖ To minimize the cybersecurity risks that follow the development of the ADAS software, regulations and standards for cybersecurity should be introduced. This should be a continuous process during the lifetime of a vehicle since cybersecurity is a (fast) changing subject. A newly developed vehicle can have great cybersecurity while it is obsolete after a few years.

7.5 ADAS oriented infrastructure

Regarding the last element of the triangle “driver-vehicle-infrastructure”, there is a gap in the coherency of the environment in which ADAS operate. The lack of unified infrastructure in Europe, ranging from traffic signs to road marking, affects the operational efficiency of ADAS since ADAS are confronted with road conditions and traffic situations outside of their ODD. Although infrastructural analysis is out of the scope of this study, it came to the forefront of the discussions when studying the main study subjects.

- ❖ In parallel with initiatives in education and the technical optimization of the systems, national road operators and traffic agencies should collaborate to upgrade and maintain their road infrastructure under the same European guidelines.
- ❖ These European guidelines should clearly define the road infrastructure characteristics and standards that are crucial for the smooth operation of the systems on all European road networks.
- ❖ Road infrastructure updates should be first a priority for highways and provincial roads since most of the upcoming ADAS in 2024 have a minimum functional speed. In the long term, uniformity in infrastructure should also be the case within urban environments on a European level. However,

uniformity in urban environments is followed by great challenges that relate to special characteristics (cultural, architectural, type of traffic, etc.) that are met across different countries.

- Organisations that should take the lead in infrastructural policies are the European Commission and EuroNCAP. Additional support can come from UNECE WP1 and WP29, OICA, FIA, CEDR, ERF.

Harmonization

in system development, HMI, education, provision of information, infrastructure, On-Board Diagnostics as well as in maintenance and repair processes are the key to the effective and safe use of ADAS.

References

Alkim, T. (2017). Operational Design Domain Framework. Utrecht: Rijkswaterstaat, Ministery of Infrastructure and the Environment.
Amditis, A., Bimpas, M., Thomaidis, G., Tsogas, M., Netto, M., Mammar, S. & Etemad, A. (2010). A situation-adaptive lane-keeping support system: Overview of the safelane approach. IEEE Transactions on Intelligent Transportation Systems, 11(3), 617-629.
AWAKE, 2002. Awake Consortium (IST 2000-28062), System for effective assessment of driver vigilance and warning according to traffic risk estimation. September 2001–2004. Available: http://cordis.europa.eu/ (accessed on 13.10.11).
Bergasa, L. M., Nuevo, J., Sotelo, M. A., Barea, R., & Lopez, M. E. (2006). Real-time system for monitoring driver vigilance. IEEE Transactions on Intelligent Transportation Systems, 7(1), 63-77.
Berglund, J. (2007). In-vehicle prediction of truck driver sleepiness: Steering related variables.
Beggiato, M., Pereira, M., Petzoldt, T., & Krems, J. (2015). Learning and development of trust, acceptance and the mental model of ACC. A longitudinal on-road study. Transportation Research Part F: Traffic Psychology and Behaviour, 35, 75–84. doi:10.1016/j.trf.2015.10.005
Boelhouwer, A., Beukel, A. P. van den, Voort, M. C. van der, Hottentot, C., Wit, R. Q. de, & Martens, M. H. (2020). How are car buyers and car sellers currently informed about ADAS? An investigation among drivers and car sellers in the Netherlands. Transportation Research Interdisciplinary Perspectives. doi:10.1016/j.trip.2020.100103
BOVAG (2019) Het effect van ADAS op schadeherstel, onderhoud en reparatie [The effect of ADAS on damage repair, maintenance and repair jobs]. VMS Insight. The Netherlands.
Bhusari, S. (2018). A Methodology for the assessment of Operational Design Domain for lane keeping system equipped vehicles: The case of Tesla Model S. Delft University of Technology, Faculty of Civil Engineering and Geosciences, Department of Transport and Planning. Delft, The Netherlands: TU Delft.
Bishop. R. (2005) Intelligent Vehicle Technology and Trends. Norwood, MA: Artech House INC.
Cabrall, C., Janssen, N., Goncalves, J., Morando, A., Sassman, M., & de Winter, J. (2016, October). Eye-based driver state monitor of distraction, drowsiness, and cognitive load for transitions of control in automated driving. In 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC) (pp. 001981-001982). IEEE.
Carsten, O., Lai, F. C., Barnard, Y., Jamson, A. H., & Merat, N. (2012). Control task substitution in semiautomated driving: Does it matter what aspects are automated? Human factors, 54(5), 747-761.
Carsten, O. M., & Tate, F. N. (2005). Intelligent speed adaptation: accident savings and cost–benefit analysis. Accident Analysis & Prevention, 37(3), 407-416.
Carsten, O. (2002). European Research on ISA: Where Are We Now and What Remains To Be Done. ICTCT Workshop on Intelligent Speed Adaptation.
Cheng, H. Y., Jeng, B. S., Tseng, P. T., & Fan, K. C. (2006). Lane detection with moving vehicles in the traffic scenes. IEEE Transactions on intelligent transportation systems, 7(4), 571-582.
Costa, M., Oliveira, D., Pinto, S., & Tavares, A. (2019). Detecting Driver's Fatigue, Distraction and Activity Using a Non-Intrusive Ai-Based Monitoring System. Journal of Artificial Intelligence and Soft Computing Research, 9(4), 247-266.
Clanton, J. M., Bevly, D. M., & Hodel, A. S. (2009). A low-cost solution for an integrated multisensor lane departure warning system. IEEE Transactions on Intelligent Transportation Systems, 10(1), 47-59.
Dabral, S., Kamath, S., Appia, V., Mody, M., Zhang, B., & Batur, U. (2014, August). Trends in camera based automotive driver assistance systems (adas). In 2014 IEEE 57th International Midwest Symposium on Circuits and Systems (MWSCAS) (pp. 1110-1115). IEEE.
Davidse, R. J. (2006). OLDER DRIVERS AND ADAS: Which Systems Improve Road Safety? *IATSS Research*, *30*(1), 6–20. doi:https://doi.org/10.1016/S0386-1112(14)60151-5

De Winter, J. C., Happee, R., Martens, M. H., & Stanton, N. A. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. Transportation research part F: traffic psychology and behaviour, 27, 196-217.

De Winter, J. C. F., Gorter, C. M., Schakel, W. J., & van Arem, B. (2017). Pleasure in using adaptive cruise control: A questionnaire study in The Netherlands. Traffic injury prevention, 18(2), 216-224.

Dey, K. C., Yan, L., Wang, X., Wang, Y., Shen, H., Chowdhury, M., … Soundararaj, V. (2016). A Review of Communication, Driver Characteristics, and Controls Aspects of Cooperative Adaptive Cruise Control (CACC). IEEE Transactions on Intelligent Transportation Systems, 17(2), 491–509. doi:10.1109/tits.2015.2483063

Dragutinovic, N., & Twisk, D. (2005). Use of mobile phones while driving-effects on road safety: a literature review.

Dutch Safety Board (2019). Who is in control? Road Safety and Automation in Road Traffic. The Hague, November 2019.

Eichelberger, A. H., & McCartt, A. T. (2016). Toyota drivers' experiences with Dynamic Radar Cruise Control, Pre-Collision System, and Lane-Keeping Assist. Journal of Safety Research, 56, 67–73. doi:10.1016/j.jsr.2015.12.002

Endsley, M. R. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics, 42(3), 462-492.

Endsley, M. R. (2017). Autonomous driving systems: A preliminary naturalistic study of the Tesla Model S. Journal of Cognitive Engineering and Decision Making, 11(3), 225-238.

Euro NCAP, "Euro NCAP," [Online]. Available: https://www.euroncap.com/nl/veiligheid-voertuig/de-beoordelingen-nader-verklaard/. [Accessed 14 7 2020].

European Commission. (2008). Commission Recommendation of 26 May 2008 on safe and efficient in-vehicle information and communication systems: update of the European Statement of Principles on human-machine interface. Official Journal of the European Union, (2008/653/EC).

European Commission (2018). Communication on the road to automated mobility: An EU strategy for mobility of the future' (COM (2018) 283).

European Commission (2019) "New Safety Features in your car," European Commission, Brussels, 2019.

European Parlement, "Mensenlevens redden: verbeteren van de veiligheid van voertuigen in de EU," European Parlement, 2017.

European Parliament, Council of the European Union, "DIRECTIVE 2007/46/EC: Establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles," European Parliament, Council of the European Union, 2007.

European Parliament, Council of the European Union, (2018). REGULATION (EU) 2018/858: On the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repe.

European Parliament, Council of the European Union, (2019). REGULATION (EU) 2019/2144: On type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users

European Parliament, Council of the European Union (2014). Regulation No 130: Uniform provisions concerning the approval of motor vehicles with regard to the Lane Departure Warning System (LDWS).

European Parliament, Council of the European Union, (2018). Regulation No 79: Uniform provisions concerning the approval of vehicles with regard to steering equipment.

European Parliament, Council of the European Union, (2015). COMMISSION REGULATION (EU) 2015/562: Amending Regulation (EU) No 347/2012 implementing Regulation (EC) No 661/2009 with respect to type-approval requirements for certain categories of motor vehicles with regard to advanced emergency braking systems.

United Nations Economic Commission for Europe, (2020). Proposal for a new UN Regulation on uniform provisions concerning the approval of vehicles with regards to Automated Lane Keeping System, Geneva: Inland Transport Committee.

European Union Agency For Network And Information Security, 2016. Cyber Security and Resilience of smart cars; Good practices and recommendations, ENISA..

Fardi, B., & Wanielik, G. (2004, June). Hough transformation-based approach for road border detection in infrared images. In IEEE Intelligent Vehicles Symposium, 2004 (pp. 549-554). IEEE.

Fitzharris, M., Liu, S., Stephens, A. N., & Lenné, M. G. (2017). The relative importance of real-time in-cab and external feedback in managing fatigue in real-world commercial transport operations. Traffic injury prevention, 18(sup1), S71-S78.

Forsman, P. M., Vila, B. J., Short, R. A., Mott, C. G., & Van Dongen, H. P. (2013). Efficient driver drowsiness detection at moderate levels of drowsiness. Accident Analysis & Prevention, 50, 341-350.

Friedrichs, F., & Yang, B. (2010). Drowsiness monitoring by steering and lane data based features under real driving conditions. In 2010 18th European Signal Processing Conference (pp. 209-213). IEEE.

GDV (2017) Automatisiertes Fahren – Auswirkungen auf den Schadenaufwand bis 2035. Retrieved from https://www.gdv.de/resource/blob/8282/c3877649604eaf9ac4483464abf5305d/download-der-studie-data.pdf.

Gorter, M., Wien, J., Droogsma, J., & Klem, E. (2019). ADAS on the N59 provincial road: an assessment. Transport & Planning. Amersfoort, the Netherlands: Royal HaskoningDHV.

Gorter, M. (2015). Adaptive Cruise Control in Practice, A Field Study and Questionnaire into its influence on Driver, Traffic Flows and Safety (No. Thesis MSc Civil Engineering). TU Delft.

GOV.UK, “The key principles of vehicle cyber security for connected and automated vehicles,” GOV.UK, 2017.

Hariri, B., Abtahi, S., Shirmohammadi, S., & Martel, L. (2012). A yawning measurement method to detect driver drowsiness. Technical Papers.

Hasch, J., Topak, E., Schnabel, R., Zwick, T., Weigel, R., & Waldschmidt, C. (2012). Millimeter-wave technology for automotive radar sensors in the 77 GHz frequency band. IEEE Transactions on Microwave Theory and Techniques, 60(3), 845-860.

Harms, I. M., Bingen, L., & Steffens, J. (2020). Addressing the awareness gap: A combined survey and vehicle registration analysis to assess car owners’ usage of ADAS in fleets. Transportation Research Part A: Policy and Practice, 134, 65–77. doi:10.1016/j.tra.2020.01.018

Harms, I. M., & Dekker, G. (2017). ADAS: from owner to user; Insights in the conditions for a breakthrough of Advanced Driver Assistance Systems. Utrecht, The Netherlands: Connecting Mobility. Retrieved from https://www.verkeerskunde.nl/Uploads/2017/11/ADAS-from-owner-to-user-lowres.pdf

Heinrich, C. (2012). Automotive HMI international standards. Advances in Human Aspects of Road and Rail Transportation (pp. 605–614). CRC Press. doi:10.1201/b12320

Hoedemaeker, M., & Brookhuis, K. A. (1998). Behavioural adaptation to driving with an adaptive cruise control (ACC). Transportation Research Part F: Traffic Psychology and Behaviour, 1(2), 95–106. Retrieved from https://www.scopus.com/inward/record.url?eid=2-s2.0-0012882589&partnerID=40&md5=b4c0a220dd9ed2c57a4f7a67d8106240

Hillel, A. B., Lerner, R., Levi, D., & Raz, G. (2014). Recent progress in road and lane detection: a survey. Machine vision and applications, 25(3), 727-745.

HLDI (2018). Compendium of HLDI collision avoidance research. Bulletin I Vol.35, No.34.

Hu, S., & Zheng, G. (2009). Driver drowsiness detection with eyelid related parameters by Support Vector Machine. Expert Systems with Applications, 36(4), 7651-7658.

ISO/SAE, 21434 - Road vehicles — Cybersecurity engineering (under development).

ISO. (2005). Road vehicles — Ergonomic aspects of in-vehicle presentation for transport information and control systems Warning systems (No. ISO TR 16352:2005(E)). Geneva, Switzerland: ISO.

ISO (2010). Road vehicles — Symbols for controls, indicators and tell-tales (ISO 2575:2010(E)). Geneva, Switzerland: ISO.

ISO. (2011). Road vehicles — Ergonomic aspects of transport information and control systems — Specifications for in-vehicle auditory presentation (No. ISO Standard 15006:2011(en)). Geneva, Switzerland: ISO.

ISO. (2012). Road vehicles — Ergonomic aspects of transport information and control systems - Introduction to integrating safety critical and time critical warning signals (No. ISO/TR 12204:2012). Geneva, Switzerland: ISO – International Organization of Standards.

ISO. (2017a). Road vehicles - Ergonomic aspects of the in-vehicle presentation of transport information and control systems - Dialogue management principles and compliance procedures (No. ISO 15005:2017, IDT). Geneva, Switzerland: ISO.

ISO. (2017b). Road vehicles — Ergonomic aspects of transport information and control systems - Specifications and test procedures for in-vehicle visual presentation (No. ISO Standard 15008:2017(en)). Geneva, Switzerland: ISO.

ISO, (2018). ISO 15622: Intelligent transport systems — Adaptive cruise control systems — Performance requirements and test procedures.

Jeong, H., & Green, P. (2013). *SAE and ISO Standards for Warnings and Other Driver Interface Elements: A Summary* (No. UMTRI-2013-16). Ann Arbor, MI: The University of Michigan Transportation Research Institute (UMTRI).

Jin, L., Niu, Q., Hou, H., Xian, H., Wang, Y., & Shi, D. (2012). Driver cognitive distraction detection using driving performance measures. Discrete Dynamics in Nature and Society, 2012.

Khan, J. (2016, February). Using ADAS sensors in implementation of novel automotive features for increased safety and guidance. In 2016 3rd International Conference on Signal Processing and Integrated Networks (SPIN) (pp. 753-758). IEEE.

Kidd, D. G., Cicchino, J. B., Reagan, I. J., & Kerfoot, L. B. (2017). Driver trust in five driver assistance technologies following real-world use in four production vehicles. Traffic Injury Prevention, 1–7. doi:10.1080/15389588.2017.1297532

Kidd, D. G., & Reagan, I. J. (2019). Attributes of Crash Prevention Systems that Encourage Drivers to Leave Them Turned on. (S. N., Ed.)Advances in Intelligent Systems and Computing, 786, 523–533. doi:10.1007/978-3-319-93885-1_47

Kirchner, A., & Heinrich, T. (1998, October). Model based detection of road boundaries with a laser scanner. In Proceedings of IEEE Int. Symp. on Intelligent Vehicles (pp. 93-98).

Klem, E., & Gorter, M. (2016). Road markings and ADAS: Exploring the performance of Lane Assist. Transport & Planning. Amersfoort, the Netherlands: Royal HaskoningDHV.

Korteling, J. E. (1994). Effects of Aging, Skill Modification, and Demand Alternation on Multiple Task Performance. Human Factors, 36(1), 27–43.

Krajewski, J., Sommer, D., Trutschel, U., Edwards, D., & Golz, M. (2009). Steering wheel behavior based estimation of fatigue.

Kutila, M., Jokela, M., Markkula, G., & Rué, M. R. (2007). Driver distraction detection with a camera vision system. In 2007 IEEE International Conference on Image Processing (Vol. 6, pp. VI-201). IEEE.

Lai, F., & Carsten, O. (2010). What benefit does Intelligent Speed Adaptation deliver?-A close examination of its effect on vehicle speeds. Accident Analysis and Prevention.

Larsson, A. F. L., Kircher, K., & Andersson Hultgren, J. (2014). Learning from experience: Familiarity with ACC and responding to a cut-in situation in automated driving. Transportation Research Part F: Traffic Psychology and Behaviour, 27(PB), 229–237. doi:10.1016/j.trf.2014.05.008

Lenskiy, A. A., & Lee, J. S. (2012). Driver's eye blinking detection using novel color and texture segmentation algorithms. International journal of control, automation and systems, 10(2), 317-327.

Liang, Y., Reyes, M. L., & Lee, J. D. (2007). Real-time detection of driver cognitive distraction using support vector machines. IEEE transactions on intelligent transportation systems, 8(2), 340-350.

Lin, C. T., Lin, H. Z., Chiu, T. W., Chao, C. F., Chen, Y. C., Liang, S. F., & Ko, L. W. (2008). Distraction-related EEG dynamics in virtual reality driving simulation. In 2008 IEEE International Symposium on Circuits and Systems (pp. 1088-1091). IEEE.

Lin, Y., Wu, C., & Eskandarian, A. (2018). Integrating Odometry and Inter-vehicular Communication for Adaptive Cruise Control with Target Detection Loss. 2018 IEEE Intelligent Vehicles Symposium (IV). doi:10.1109/ivs.2018.8500544

Liu, H., Wei, H., Zuo, T., Li, Z., & Yang, Y. J. (2017). Fine-tuning ADAS algorithm parameters for optimizing traffic safety and mobility in connected vehicle environment. Transportation research part C: emerging technologies, 76, 132-149.

Long, S., & Dhillon, B. S. (Eds.). (2015). Proceedings of the 15th International Conference on Man–Machine–Environment System Engineering (Vol. 356). Springer.

Lu, Happee, Cabrall, M. Kyriakidis and J. d. Winter, “Human factors of transitions in automated driving: A general framework and literature survey,” Transportation Research Part, 2016.

Malla, A. M., Davidson, P. R., Bones, P. J., Green, R., & Jones, R. D. (2010). Automated video-based measurement of eye closure for detecting behavioral microsleep. In 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology (pp. 6741-6744). IEEE.

Malta, L., Ljung Aust, M., Faber, F., Metz, B., Saint Pierre, G., Benmimoun, M., & Schï¿½fer, R. (2012). Final results: Impacts on traffic safety (No. Deliverable D6.4). EuroFOT.

Mattsson, K. (2007). In-vehicle prediction of truck driver sleepiness: lane position variables (diva-portal.org).

Mattsson, D. (2012). ADAS: A simulation study comparing two safety improving Advanced Driver Assistance Systems (diva-portal.org).

Mbouna, R. O., Kong, S. G., & Chun, M. G. (2013). Visual analysis of eye state and head pose for driver alertness monitoring. IEEE transactions on intelligent transportation systems, 14(3), 1462-1469.

McCall, J. C., & Trivedi, M. M. (2006). Video-based lane estimation and tracking for driver assistance: survey, system, and evaluation. IEEE transactions on intelligent transportation systems, 7(1), 20-37.

McCarthy, Harnett and Caster (2014). A Summary of Cybersecurity Best Practices. National Highway Traffic Safety Administration, Washington, DC.

Morsink, P., Boender. J., Smienk, A., Selhorst, A., Spaetgens, J., Smeets, R., van Loon, A. (submitted in November 2019). Smart Vehicles On Future Proof Roads: Moving Towards No-regret Measures and Standardisation. Amersfoort, The Netherlands.

Morsink, P., Vissers, J., Claesen, R. (2017). Advanced Driver Assistance (ADAS) & driver training and testing. Position Paper. Amersfoort, The Netherlands.

Naujoks, F., Purucker, C., Neukum, A., Wolter, S., & Steiger, R. (2015). Controllability of partially automated driving functions–does it matter whether drivers are allowed to take their hands off the steering wheel?. Transportation research part F: traffic psychology and behaviour, 35, 185-198.

National Highway Traffic Safety Administration, 2016. Cybersecurity best practices for modern vehicles. NHTSA, Washington, DC.

NHTSA. (2016). Visual-Manual NHTSA Driver Distraction Guidelines for Portable and Aftermarket Devices. Federal Register, 81(233), 87656–87683.

Paine, M., Paine, D., Griffiths, M., & Germanos, G. (2007, March). In-vehicle intelligent speed advisory systems. In Proceedings of the 20th International Conference on the Enhanced Safety of Vehicles.

Pereira, M., Beggiato, M., & Petzoldt, T. (2015). Use of adaptive cruise control functions on motorways and urban roads: Changes over time in an on-road study. Applied Ergonomics, 50, 105–112. doi: 10.1016/j.apergo.2015.03.002

Polychronopoulos, A., Amditis, A., Floudas, N., & Lind, H. (2004). Integrated object and road border tracking using 77 GHz automotive radars. IEE Proceedings-Radar, Sonar and Navigation, 151(6), 375-381.

Prins, P., Voskuil, K., Van der Linde, M., & Morsink, P. (2019). Monitoring Masterclass ADAS: Experiences and stand-out events of participants. [written in Dutch] Amersfoort, the Netherlands: Royal HaskoningDHV.

Pritchett, S., Zilberg, E., Xu, Z. M., Karrar, M., Burton, D., & Lal, S. (2011). Comparing accuracy of two algorithms for detecting driver drowsiness—Single source (EEG) and hybrid (EEG and body

movement). In 7th International Conference on Broadband Communications and Biomedical Applications (pp. 179-184). IEEE.
Raphael, E., Kiefer, R., Reisman, P., & Hayon, G. (2011). Development of a camera-based forward collision alert system. SAE International Journal of Passenger Cars-Mechanical Systems, 4(2011-01-0579), 467-478.
Reagan, I. J., Cicchino, J. B., Kerfoot, L. B., & Weast, R. A. (2018). Crash avoidance and driver assistance technologies–Are they used? Transportation research part F: traffic psychology and behaviour, 52, 176-190.
Regan, M. A., Lee, J. D., & Young, K. L. (2008). Driver Distraction: Theory, Effects, and Mitigation. Boca Raton, Florida: CRC Press.
RESPONSE_3. (2009). Code of Practice for the Design and Evaluation of ADAS (No. Version number V5.0). RESPONSE 3 project, subproject of the integrated project PReVENT.
Rook, A. M., & Hogema, J. H. (2005). Effects of Intelligent Speed Adaptation HMI Design on Driving Behavior and Acceptance. Transportation Research Record, (1937), 79–86.
Rudin-Brown, C. & Jamson, S., (ed.). (2013). Behavioural Adaptation and Road SafetyTheory, Evidence and Action. CRC Press.
SAE International (2014). Adaptive Cruise Control (ACC) Operating Characteristics and User Interface (No. J2399). Warrendale, PA, USA: Society of Automotive Engineers.
SAE International (2015). Active Safety Systems Terms & Definitions (No. J3063). Warrendale, PA, USA: Society of Automotive Engineers.
SAE International (2016). Cybersecurity Guidebook for Cyber-Physical Vehicle Systems (No. J3061). Warrendale, PA, USA: Society of Automotive Engineers.
SAE International. (2018). Surface Vehicle Recommended Practice. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (No. J3016) Warrendale, PA, USA: Society of Automotive Engineers.
Saini, V., & Saini, R. (2014). Driver drowsiness detection system and tec hniques: a review. International Journal of Computer Science and Information Technologies, 5(3), 4245-4249.
Sandberg, D., Akerstedt, T., Anund, A., Kecklund, G., & Wahde, M. (2010). Detecting driver sleepiness using optimized nonlinear combinations of sleepiness indicators. IEEE Transactions on Intelligent Transportation Systems, 12(1), 97-108.
Sayed, R. A., Eskandarian, A., & Mortazavi, A. (2012). Drowsy and fatigued driver warning, counter measures, and assistance. Handbook of Intelligent Vehicles, 2, 977-990.
Schwarz, C., Gaspar, J., Miller, T. & Yousefian, R. (2019). The detection of drowsiness using a driver monitoring system. Traffic Injury Prevention 20 (sup1), S157-S161. Shalev-Shwartz, S., Shammah, S., & Shashua, A. (2018). Vision zero: can roadway accidents be eliminated without compromising traffic throughput.
Sanchez, D., Garcia, E., Saez, M., Benmimoun, M., Pï ¿½tz, A., Aust, M. L., Gustafsson, D., et al. (2012). Final results: User acceptance and user-related aspects (Deliverable D6.3). EuroFOT.
Sixsmith, J., & Sixsmith, A. (1993). Older people, driving and new technology. Applied Ergonomics, 24(1), 40–43. doi:10.1016/0003-6870(93)90159-7
Soares, S., Monteiro, T., Lobo, A., Couto, A., Cunha, L. & Ferreira, S. (2020). Analyzing Driver Drowsiness: From Causes to Effects. Sustainability 12(5): 1971.
Strand, N., Nilsson, J., Karlsson, I. C. M., & Nilsson, L. (2014). Semi-automated versus highly automated driving in critical situations caused by automation failures. Transportation Research Part F: Traffic Psychology and Behaviour, 27(PB), 218–228. doi: 10.1016/j.trf.2014.04.005
SWOV (2015). SWOV Factsheet: Intelligent Speed Assistance (ISA). Leidschendam, The Netherlands.
SWOV (2019). Intelligent transport and advanced driver assistance systems (ITS and ADAS). SWOV Fact sheet, April 2019. The Hague.
SWOV, (2019) “Factsheet Intelligent transport and advanced driver assistance systems (ITS and ADAS),” SWOV, The Hague.

Tan, H., Zhao, F., Hao, H., Liu, Z., Amer, A. A., & Babiker, H. (2020). Automatic emergency braking (AEB) system impact on fatality and injury reduction in China. International journal of environmental research and public health, 17(3), 917.

TeamAlert (2020) Jongeren en ADAS [Young drivers and ADAS]. Retrieved from: https://teamalert.nl/media/26951/jongeren-en-adas-2020.pdf. Utrecht, The Netherlands.

Teoh, Eric R. (2019) What's in a name? Drivers' perceptions of the use of five SAE Level 2 driving automation systems. Insurance Institute for Highway Safety (IIHS), USA.

Thakur, R. (2016). Scanning LIDAR in Advanced Driver Assistance Systems and Beyond: Building a road map for next-generation LIDAR technology. IEEE Consumer Electronics Magazine, 5(3), 48-54.

Thorn, E., Kimmel, S. C., Chaka, M., & Hamilton, B. A. (2018). A framework for automated driving system testable cases and scenarios (No. DOT HS 812 623). United States. Department of Transportation. National Highway Traffic Safety Administration.

TU Automotive. (2015). Levelling up to driverless cars [Online]. Available: http://img03.en25.com/Web/FCBusinessIntelligenceLtd/%7B10b01428-b6d8-477a-9bf149c4edb33e05%7D_2693_10MAR15_Content.pdf [Jun. 12, 2015].

UNECE (2010). Design Principles for Advanced Driver Assistance Systems: Keeping Drivers In-the-Loop. International Harmonized Research Activities (IHRA) Working Group on ITS. Informal Document No.GRE-64-07. United Nations, Economic Commission for Europe.

UNECE (2017). Consolidated Resolution on the Construction of Vehicles - Design principles for Control Systems of Advanced Driver Assistance System (ADAS).

UNECE (2019A). Agreed proposal based on ECE/TRANS/WP.29/GRVA/2019/5.

UNECE (2019B). UN Regulation on Advanced Emergency Braking Systems for cars to significantly reduce crashes. http://www.unece.org/?id=51189.

Unger, T., & Liers, H., (2019). Prediction of the expected accident scenario of future Level 2 and Level 3 cars on German motorways. Conference Proceedings International Research Council on the Biomechanics of Injury, IRCOBI, 47–57.

Unger, T., & Dresden, A. S. (2018). Qualitative assessment of Intelligent Speed Adaptation (ISA) systems Digital unterschrieben. October.

Van der Linde, M. (2020). Binnen de lijntjes kleuren met Lane Keeping Systemen: Het verkennen van de grenzen van het Operational Design Domain van Lane Keeping Systemen in bochten. Universiteit Hasselt & Royal HaskoningDHV.

Van der Steen, A. (2019). Beleidondersteunend Advies ADAS & (schade) reparatie: Hoe sensorisch gaat de autobranche om met veiligheidssystemen? HAN Automotive Research & V-Tron on behalf of Rijkswaterstaat.

Victor, T. W., Tivesten, E., Gustavsson, P., Johansson, J., Sangberg, F., & Ljung Aust, M. (2018). Automation expectation mismatch: incorrect prediction despite eyes on threat and hands on wheel. Human factors, 60(8), 1095-1116.

Victor, T. (2011). Distraction and inattention countermeasure technologies. Ergonomics in Design, 19(4), 20–22. doi:10.1177/1064804611422874

Viti, F., Hoogendoorn, S. P., Alkim, T. P., & Bootsma, G. (2008). Driving behavior interaction with ACC: Results from a Field Operational Test in the Netherlands. IEEE Intelligent Vehicles Symposium, Proceedings (pp. 745–750).

VMS | Insight & BOVAG, Het effect van ADAS op schadeherstel, onderhoud en reparatie, 2019.

https://www.volvocars.com/en-eg/support/manuals/s80/2016-early/driver-support/adaptive-cruise-control/adaptive-cruise-control---fault-tracing-and-action

Wang, W., Zhao, D., Han, W., & Xi, J. (2018). A learning-based approach for lane departure warning systems with a personalized driver model. IEEE Transactions on Vehicular Technology, 67(10), 9145-9157.

Ward, N. J., Humphreys, M., & Fairclough, S. (1996). A field study of behavioural adaptation with and autonomous intelligent cruise control system. International conference on traffic and transport psychology (ICTTP).

Weast, R.A., Jenness, J.W., & De Leonardis, D. (2020) Salesperson knowledge of teen-specific vehicle safety features. Insurance Institute for Highway Safety (IIHS).

Wilschut, E. S., Caljouw, C. J., & Valk, P. J. L. (2009). An evaluation of approaches that can prevent sleepiness at the wheel. (No. TNO-DV 2009 C328). Soesterberg: TNO DSS.

Winter, J. C. F. de, Gorter, C. M., Schakel, W. J., & Arem, B. van. (2017). Pleasure in using adaptive cruise control: A questionnaire study in The Netherlands. Traffic Injury Prevention, 18(2), 216–224. doi:10.1080/15389588.2016.1220001

Wu, Y., & Boyle, L. N. (2015). Drivers' engagement level in Adaptive Cruise Control while distracted or impaired. Transportation Research Part F: Traffic Psychology and Behaviour, 33, 7–15. doi:10.1016/j.trf.2015.05.005

Xiong, H., Boyle, L. N., Moeckli, J., Dow, B. R., & Brown, T. L. (2012). Use patterns among early adopters of adaptive cruise control. Human Factors, 54(5), 722–733. doi:10.1177/0018720811434512

Young, M. S., & Stanton, N. A. (2001). SIZE MATTERS: THE ROLE 0F ATTENTIONAL CAPACITY IN EXPLAINING THE EFFECTS OF MENTAL UNDERLOAD ON PERFORMANCE. IN: ENGINEERING PSYCHOLOGY AND COGNITIVE ERGONOMICS. AEROSPACE AND TRANSPORTATION SYSTEMS. In Third International Conference on Engineering Psychology and Cognitive Ergonomics. Aerospace and Transportation SystemsCollege of Aeronautics, Cranfield University.

Zomotor, Z., & Franke, U. (1997, November). Sensor fusion for improved vision based lane recognition and object tracking with range-finders. In Proceedings of Conference on Intelligent Transportation Systems (pp. 595-600). IEEE.

https://www.bikewalknc.org/2018/02/autonomous-driving-and-collision-avoidance-technology/

http://www.howsafeisyourcar.com.au/aeb/

Royal HaskoningDHV HAN_UNIVERSITY OF APPLIED SCIENCES TNO innovation for life

Appendix I: Online user awareness survey

Dear Sir/Madam,

Welcome to this 10-minute survey about Advanced Driver Assistance Systems (ADAS).

Advanced Driver Assistance Systems (ADAS) support the driver in performing their primary driving task. They can inform or warn the driver, partially take over the driving task from the driver, and / or intervene in critical situations. For example, the Blind Spot Detection System increases the drivers' situational awareness by warning them about vehicles/ people detected in their blind spot. As a result, drivers avoid maneuvers that could result in accidents with the vehicles/people in their blind spot.

The expected potential of ADAS in contributing to road safety is great. In May 2019, the European Parliament agreed that several safety systems must be present on all existing models from 2024. To utilise the full potential of ADAS, drivers' knowledge and awareness about the systems should increase.

Fédération Internationale de l'Automobile (FIA) has set up a research project, which focuses on drivers' awareness on ADAS, amongst other ADAS related aspects. This questionnaire is part of this research project and contains several questions on the following ADAS. These systems have been chosen because they must be present on all existing models from 2024.

- Intelligent Speed Assistance (ISA)
- Adaptive Cruise Control (ACC)
- Emergency Stop Signal (ESS)
- Advanced Emergency Braking (AEB)
- Lane Keeping System (LKS)
- Driver Monitoring (DM) for distraction recognition/drowsiness detection

The aim is to gain insight in the extent to which drivers are informed about these systems' function, capacities and limitations.

Your answers will only be saved after completion of the questionnaire. The collected data will be used for the purpose of this survey only. This survey is completely anonymous.

Thank you for your participation.

Best regards,
Fédération Internationale de l'Automobile

Questions:

1. Do you drive a car equipped with one or more of the following Advanced Driver Assistance Systems (ADAS)? Select the systems that are available in your car (you can choose more than one option).
    - Adaptive Cruise Control (ACC)
    - Intelligent Speed Assistance (ISA)
    - Emergency Stop Signal (ESS)
    - Lane Keeping System (LKS)
    - Driver Monitoring (DM) for distraction recognition/ drowsiness detection
    - Advanced Emergency Braking (AEB)
    - None of the above
    - I do not know

(if “None of the above” end of the questionnaire)

Adaptive Cruise Control automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead. **Intelligent Speed Assistance** ensures that vehicle speed does not exceed a safe or legally enforced speed. **Emergency Stop Signal** send signals to the following vehicle in case the ESS equipped vehicle brakes hard. **Lane Keeping System** gently steers the vehicle into the lane if it begins to drift out of it. **Driver Monitoring** systems monitor driver attentiveness and alerts the driver in case distraction or fatigue are detected. **Advanced Emergency Braking** automatically detects a potential forward collision and warns the driver or decelerates the vehicle.

---

2. How many kilometres did you drive in the last 12 months?
    - Less than 5.000 km
    - 5.000-10.000 km
    - 10.000-20.000 km
    - 20.000-50.000 km
    - More than 50.000 km
    - I do not know

3. What is the year of production of your vehicle?
    - 2019-2020
    - 2016-2018
    - 2010-2015
    - earlier than 2010
    - I do not know

5. Please fill in the brand and model of your car (example: Volvo V40, VW Golf)

6. You drive a:

- company car
- private leased car
- new privately-owned car
- second-hand privately-owned car
- shared car (e.g. rental car)
- other

7. What is your age?

- 18-24 years old
- 25-44 years old
- 45-64 years old
- 65 or older

8. What is your gender?

- Male
- Female

- Other/prefer not to say

The following questions regard the six (6) ADAS that have been introduced in the beginning of this questionnaire:

- Intelligent Speed Assistance (ISA)
- Adaptive Cruise Control (ACC)
- Emergency Stop Signal (ESS)
- Advanced Emergency Braking (AEB)
- Lane Keeping System (LKS)
- Driver Monitoring (DM) for distraction recognition; drowsiness detection

9. To which extent are you familiar with the following ADAS? (you can choose more than one option)

	I am not familiar with this system	I understand how to use and interact with this system	I am aware of the situations under which the system **can** function	I am aware of the situations where the system **cannot** function	I am aware of the technical specifications of the system (used sensors, measured variables, etc).	I can explain how the system works to others
Intelligent Speed Assistance						
Adaptive Cruise Control						
Emergency stop signal						
Advanced Emergency Braking						
Lane Keeping System						
Driver monitoring (distraction recognition; drowsiness detection)						

10. For which reasons did you choose to include ADAS in your car? (you can choose more than one answer)

	It was not an option, the ADAS were already part of the car package	It was a part of the safety package I wanted	To increase driving comfort	To help me drive safer	To avoid traffic fines	To help me drive more sustainable	I was interested in the new technology	It was offered as an extra to close the deal	Other
Intelligent Speed Assistance									
Adaptive Cruise Control									
Emergency stop signal									
Advanced Emergency Braking									
Lane Keeping System									

Driver monitoring (distraction recognition; drowsiness detection)									

11. How often do you make use of the available ADAS in your car? Please indicate how frequently you use the systems.

	Not applicable	Almost never	Several times a month	Several times a week	(Almost) every time I drive
Intelligent Speed Assistance					
Adaptive Cruise Control					
Lane Keeping System					

12. How did you learn about the ADAS' functionality, use and limitations? (you can choose more than one option)

	Not applicable (I do not use/own the system)	From the car seller	From the car mechanic	by reading the car manual document	by reading the car's brochure	by conducting my own research (e.g. YouTube videos, internet search)	during the test drive at the car dealer centre	by using them while driving (trial and error)	by following a special ADAS training	Other
Intelligent Speed Assistance										
Adaptive Cruise Control										
Emergency stop signal										
Advanced Emergency Braking										
Lane Keeping System										
Driver monitoring (distraction recognition; drowsiness detection)										

13. To which extent are you satisfied with the performance of the ADAS your car is equipped with? (1=very dissatisfied, 5=very satisfied).

	Not applicable	1-very dissatisfied	2	3	4	5-Very satisfied
Intelligent Speed Assistance						
Adaptive Cruise Control						
Emergency stop signal						

Advanced Emergency Braking						
Lane Keeping System						
Driver monitoring (distraction recognition; drowsiness detection)						

14. To which extent does your current experience match your expectations about the performance of **the following ADAS?**

	Not applicable	It performs better than expected	It performs as expected	It performs worse than expected	It performs different than expected
Intelligent Speed Assistance					
Adaptive Cruise Control					
Emergency stop signal					
Advanced Emergency Braking					
Lane Keeping System					
Driver monitoring (distraction recognition; drowsiness detection)					

15. Please indicate the extent to which you agree or disagree with the statements about **Adaptive Cruise Control (ACC)** (1=fully disagree, 5=fully agree)

	Not applicable	1-fully disagree	2	3	4	5-fully agree
I trust that ACC works well.						
The ACC makes me feel safer.						
The ACC is annoying.						
The ACC is useful.						
The ACC makes me feel more comfortable.						

16. Please indicate the extent to which you agree or disagree with the statements about **Lane Keeping System (LKS)** (1=fully disagree, 5=fully agree)

	Not applicable	1-fully disagree	2	3	4	5-fully agree
I trust that LKS works well.						
The LKS makes me feel safer.						
The LKS is annoying.						
The LKS is useful.						
The LKS makes me feel more comfortable.						

17. Please indicate the extent to which you agree or disagree with the statements about **Advanced Emergency Braking (AEB)** (1=fully disagree, 5=fully agree)

	Not applicable	1-fully disagree	2	3	4	5-fully agree
I trust that AEB works well.						
The AEB makes me feel safer.						
The AEB is annoying.						
The AEB is useful.						
The AEB makes me feel more comfortable.						

18. Please indicate the extent to which you agree or disagree with the statements about **Emergency Stop Signal (ESS)** (1=fully disagree, 5=fully agree)

	1-fully disagree	2	3	4	5-fully agree
I trust that ESS works well.					
The ESS makes me feel safer.					
The ESS is annoying.					
The ESS is useful.					
The ESS makes me feel more comfortable.					

19. Please indicate the extent to which you agree or disagree with the statements about **Driver Monitoring (DM)** for **distraction recognition/ drowsiness detection** (1=fully disagree, 5=fully agree)

	1-fully disagree	2	3	4	5-fully agree
I trust that DM works well.					
The DM makes me feel safer.					
The DM is annoying.					
The DM is useful.					
The DM makes me feel more comfortable.					

20. Please indicate the extent to which you agree or disagree with the statements about **Intelligent Speed Assistance (ISA)** (1=fully disagree, 5=fully agree)

	1-fully disagree	2	3	4	5-fully agree
I trust that ISA works well.					
The ISA makes me feel safer.					
The ISA is annoying.					
The ISA is useful.					
The ISA makes me feel more comfortable.					

21. Please indicate if these statements about **Adaptive Cruise Control (ACC)** are true or false (select only one answer per row).

	True	False	I am not sure
It is able to successfully brake the car in any situation as long as the system has detected a vehicle ahead.			
It may increase the speed when the vehicle in front of you moves out of the detection zone.			
Because it uses radar technology, the ACC works good in foggy weather.			
It brakes when the vehicle in front stops and accelerates when the vehicle in front starts driving again.			

22. Please indicate if these statements about **Intelligent Speed Assistance (ISA)** are true or false (select only one answer per row).

	True	False	I am not sure
ISA compares the vehicle speed with the speed limit and/or the speed set by the driver			

ISA may detect a speed sign from a road that is parallel to the road you are driving on			
Depending on the version, ISA can prevent you from going faster than the speed limit			

23. Please indicate if these statements about **Emergency Stop Signal (ESS)** are true or false (select only one answer per row).

	True	False	I am not sure
When you have to brake really hard, the ESS will rapidly flash the brake lights and/or turn on the hazard lights			
The system will send a message to emergency services, so that they can find you easily after a crash happened			
The system works regardless of whether the road is wet or dry			

24. Please indicate if these statements about **Advanced Emergency Brake (AEB)** are true or false (select only one answer per row).

	True	False	I am not sure
AEB can detect a potential collision with moving and stationary objects			
AEB can perform an emergency brake to prevent collisions from the front, side and back of the car			
AEB sensors are unaffected by dirt or ice			
With AEB turned on a driver can leave the breaking to the car			

25. Please indicate if these statements about **Lane Keeping System (LKS)** are true or false (select only one answer per row).

	True	False	I am not sure
The LKS does not steer when you activate your indicator signals			
It requires that the driver constantly monitors the system's performance			
In curves, the system may abruptly switch to the standby mode			
Because LKS uses infrared sensors, it can see the lane markings when water or dirt is on top of the lane markings			

26. Please indicate if these statements about **Driver Monitoring (DM)** for distraction recognition / drowsiness detection are true or false (select only one answer per row).

	True	False	I am not sure
The system uses several sensors like cameras and eye-trackers or monitors my driving to detect signs of driver distraction and fatigue			

Depending on the version in your car, the system can apply the brakes when you ignore the warnings			
When you wear sunglasses, the system can not detect your eyes			

This is the end of this questionnaire. Thank you very much for your participation!
You can now exit this page.

Appendix II: Qualitative analysis of four car User Manuals

	Volkswagen Golf (2019)	**Hyundai Kona** (2018)
	Speed range	
Activation speed	65 km/h	64 km/h
Deactivation speed	65 km/h	56 km/h
Max. functional speed	Not mentioned	177 km/h
	Intended area of use	
Road category	Highway & 'well paved' provincial roads	Not mentioned
Road profile	Not mentioned	Not mentioned
(Ambient) conditions that need to be met	It is indirectly mentioned that the system needs a good visibility on the lane markings.	Both lane markings need to be detected and the vehicle must drive in the middle of it in order to activate the system.
	Influencing factors	
(Ambient) conditions that negatively impacts the functioning of the LKS	Without specifying in more detail: bad road surface, road structures or objects can be falsly recognized as a lane edge marking. In bad weather or road conditions or road works, the system might deactivate. This also is the case when the driver has a sporty driving style.	Without specifying in more detail: bad weather, bad road surface, sharp curves, when the turn signal is activated, sudden braking, a very wide or narrow lane, when multiple markings excist on the road surface (eg. near road works), when only 1 lane marking is detected, a too small curve radius, a steep descend or climb, sudden steering inputs, warn or dirty lane markings, signs on the road surface, sudden changes in ambient lighting conditions, light reflections on wet road surfaces, bright lights, too short following distances.
Functioning in combination with other ADAS	Not mentioned	Not mentioned
	Warnings	
General warnings	• *"Lane Assist supports the driver with maintaining the vehicles position within the driving lane."* • The system cannot overcome the laws of physics and will only operate within the system limits. • Inattentiveness or incorrect usage of the system may lead to accidents. • The system cannot replace an inattentive driver. • The driver is always responsible for maintaining a safe position within the driving lane. • In case of a dirty, covered or damaged camera, the operation of the system might be negatively influenced.	• The LKS system is not a replacement for safe driving, but only a comfort enhancing functionality. • The driver is responsible for maintaining situational awareness and driving the vehicle at all times. • The driver should not rely on the LKS system. • The LKS can deactivate or not function properly depending on road conditions and ambient factors. • If the lane markings are not correctly detected, the LKS might function less reliably. • The system must be turned off when the driver has to change direction frequently.
Curve specific warnings	Not mentioned	The system might deactivate when: • Driving on a curvy road • The radius of the curve is too small • The vehicle drives through a sharp curve
	Operation when LKS is inside its ODD	
	A camera behind the windscreen detects the lane markings. When the vehicle approaches a lane marking too closely, the system warns the driver and steers the vehicle away from the marking. The	When the system detects the vehicle straying from its lane, it alerts the driver with a visual and audible warning, while applying a slight countersteering torque, to try to prevent the vehicle from moving out of its lane.

	systems' steering input can be overruled by the driver at any time. When the driver does not steer the vehicle for a longer time, the system warns the driver with visual and auditory warnings until the driver is actively steering the vehicle again.	When the driver does not steer the vehicle for a longer time, the system warns the driver with visual and auditory warnings until the driver is actively steering the vehicle again. When the driver keeps ignoring the warning messages, the system deactivates itself completely.

*Legend: **Good**, **Moderate** or **Poorly** described information.*

	Toyota Corolla (2019)	**Tesla Model 3** (2019)
	Speed range	
Activation speed	50 km/h	59 km/h (Lane Assist) 30 km/h (Autosteer)
Deactivation speed	Not mentioned	Not mentioned
Max. functional speed	Not mentioned.	150 km/h (Lane Assist) 150 km/h (Autosteer)
	Intended area of use	
Road category	Highway	Highway and 'express roads'
Road profile	Lane width 3-4 meter	Not mentioned
(Ambient) conditions that need to be met	A white or yellow line must be detected. The system cannot be activated while driving in a sharp curve. The turn signal must not be activated while attempting to activate the system.	A white or yellow line must be detected. The turn signal must not be activated while attempting to activate the system.
	Influencing factors	
(Ambient) conditions that negatively impacts the functioning of the LKS	• The system only responds to a lane edge if it detects a lane marking. A road with markings on only 1 lane edge will only let the system steer the vehicle on that side of the lane, not the other side. • The vehicle accelerates or decellerates with a certain amount or more. The system might not function when: • The road is slippery • Poorly visible markings because of rain, snow, fog, dirt, et cetera. • When a spare wheel or snow chains are mounted. • When the tyres are worn or have a low pressure. • When using different tyre sizes than advised by the manufacturer. • When driving on roads other than highways. • When the vehicle is being towed. • The lane width is too narrow or too wide. • The distance towards the vehicle in front is too short • There is a (strong) lateral wind.	The performance of Autopilot components can be influenced by many factors. These factors include (but are not limited to): • Bad visibility (heavy rain, snow, fog, et cetera) • Bright light sources (headlights of oncoming traffic, sun light, et cetera.) • Damage or obstacles • Interference by object(s) that are mounted on the vehicle (eg. a bike rack) • Interference by applying too much paint, self-adhesive objects (eg. stickers, rubbercoating, et cetera) • Narrow or curvy roads • Interference by other disruptive equipment • Extreme temperatures
Functioning in combination with other ADAS	The system is connected to the ACC. The system only functions in conjunction with an activated VSC[8] and TC[9].	Autosteer uses Traffic Aware Cruise Control to keep the vehicle in its lane when driving at a constant set speed.
	Warnings	

[8] *VSC: Vehicle Stability Control (also known as ESP or ESC)*
[9] *TC: Traction Control*

General warnings	• The driver is responsible for maintaining situational awareness and operating the vehicle at all times. • The driver should not rely on the system. • The system can deactivate itself or work improperly depending on road conditions and ambient factors. • When the lane markings are not properly detected, the system might not function as intended.	• Autosteer is a BETA-function. • Do not use Autosteer in the city, near road works or in areas with cyclists or pedestrians. • Autosteer is a system where you use your hands to operate it. • When Autosteer is unable to detect lane markings, the driving lane is determined based on the trajectory of the vehilce in front of you.
Curve specific warnings	The system might not function properly when: • Driving in a sharp curve • Driving on a curvy road	See above.
	Operation when LKS is inside its ODD	
	When the system determines that the vehicle might depart from its lane or course, the system provides assistance as necessary by operating the steering wheel in small amounts for a short period of time to keep the vehicle in its lane.	The system warns when the vehicle seems to run off road, by providing haptic feedback to the driver through the steering wheel, in case the lane marking is approaching too closely without activated turn indicators.

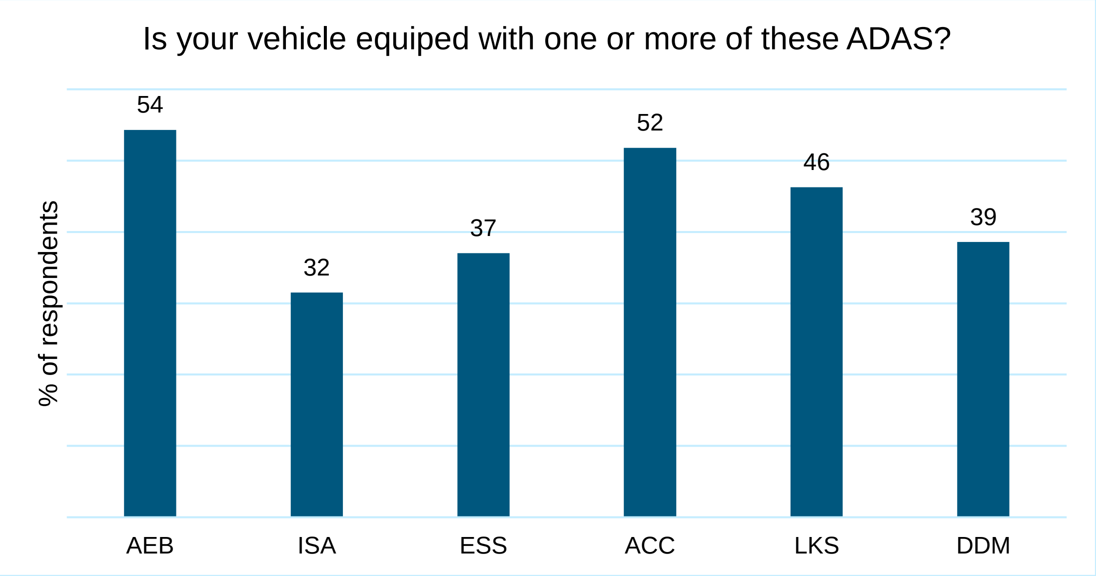
*Legend: **Good**, **Moderate** or **Poorly** described information.*

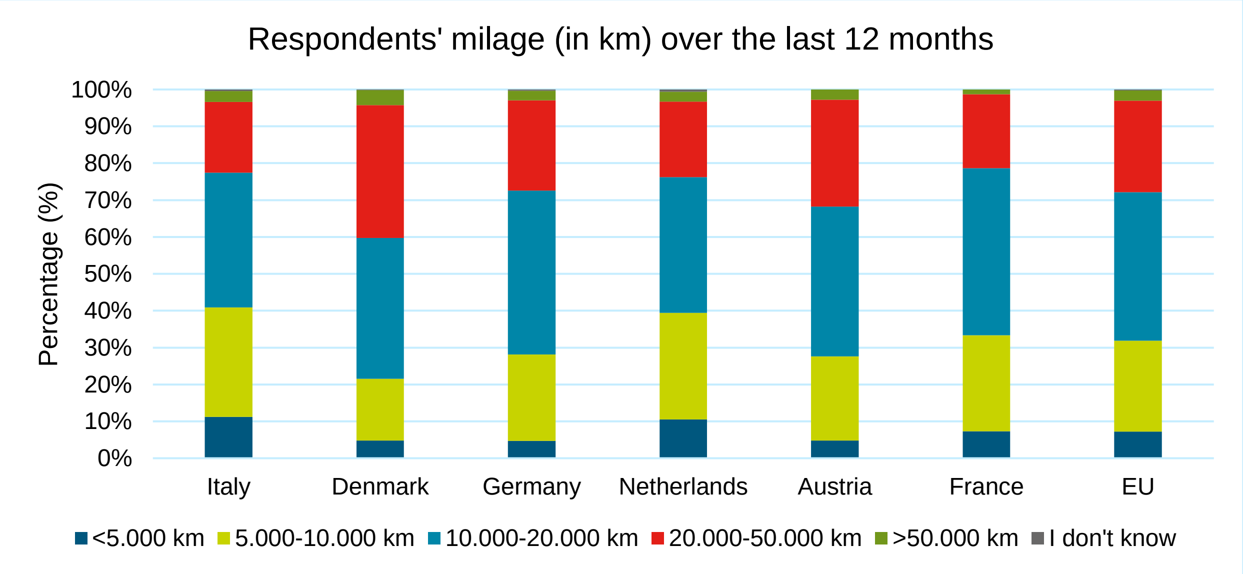
Appendix III: Survey results

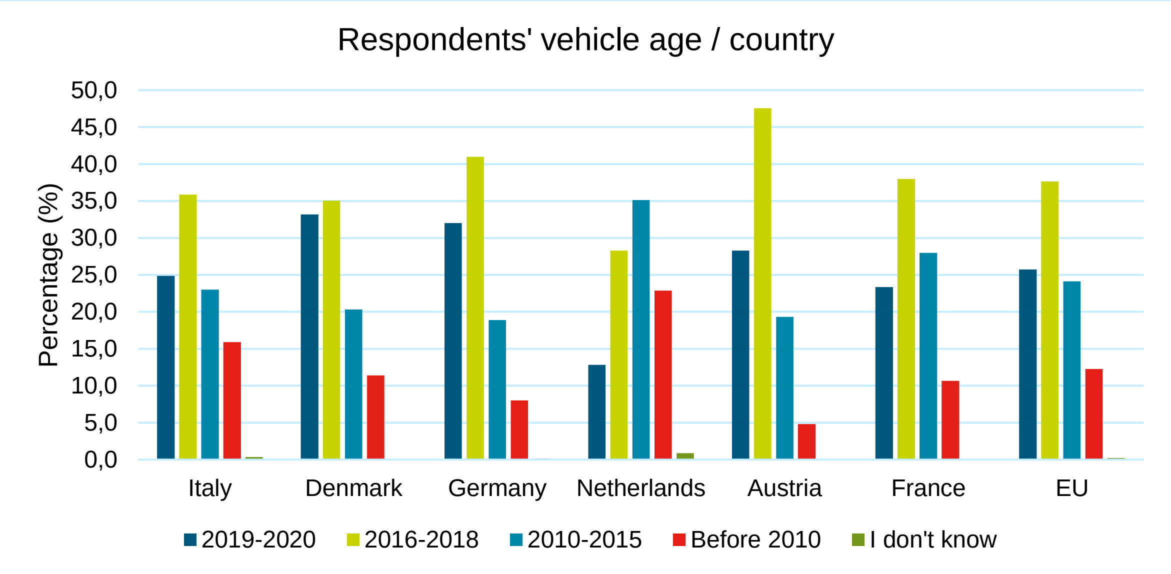
Additional graphs to support the findings in paragraph 5.1.

	Germany	France	Italy	The Netherlands	Denmark	Austria
# respondents	2.096	191	3.020	2.368	1.397	180

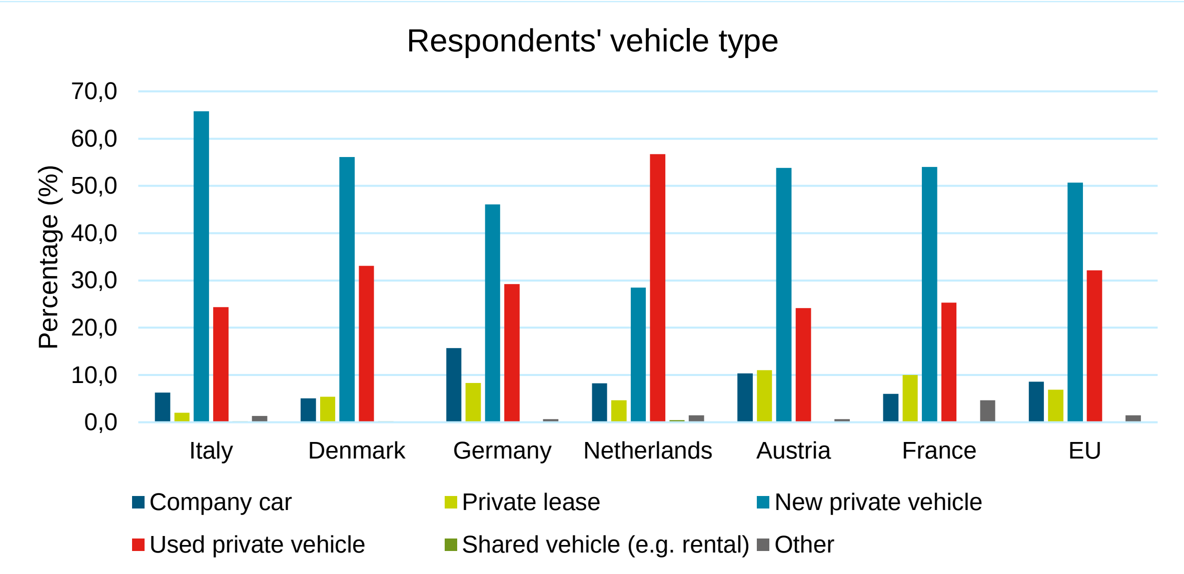
Block 1



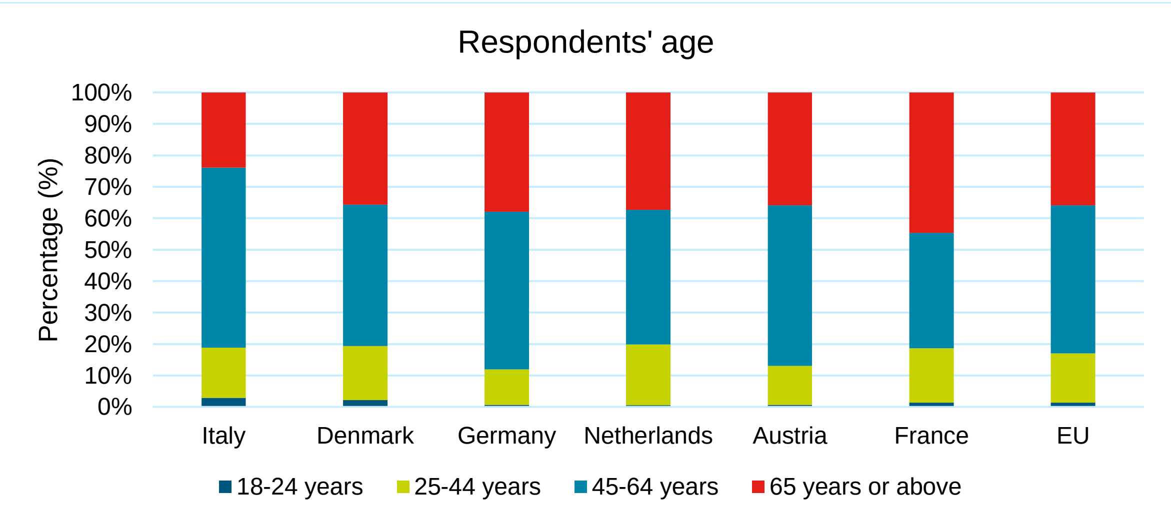




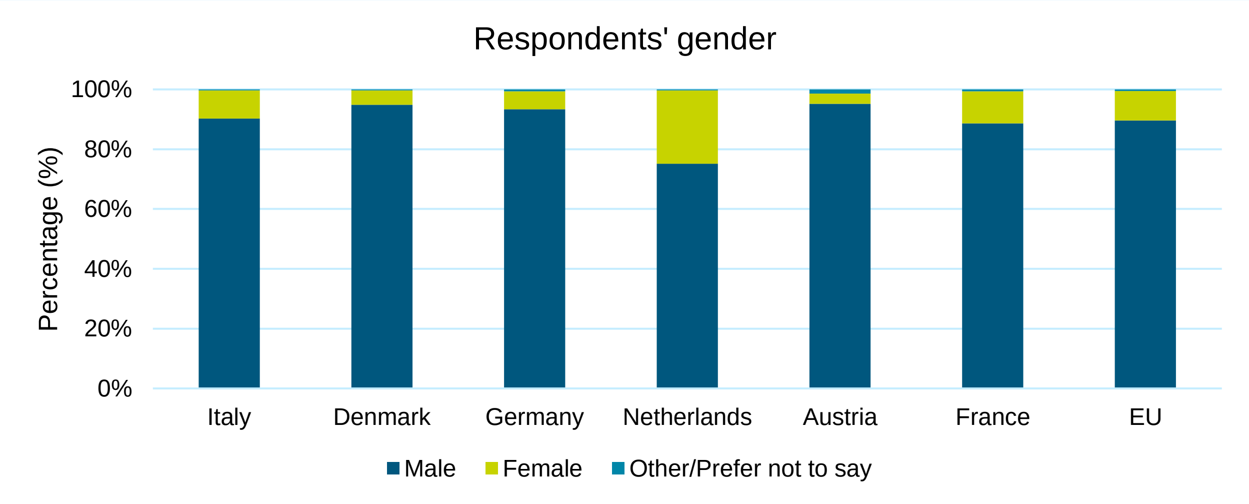
Respondents' vehicle age / country
Percentage (%)
50,0
45,0
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
Italy
Denmark
Germany
Netherlands
Austria
France
EU
2019-2020
2016-2018
2010-2015
Before 2010
I don't know

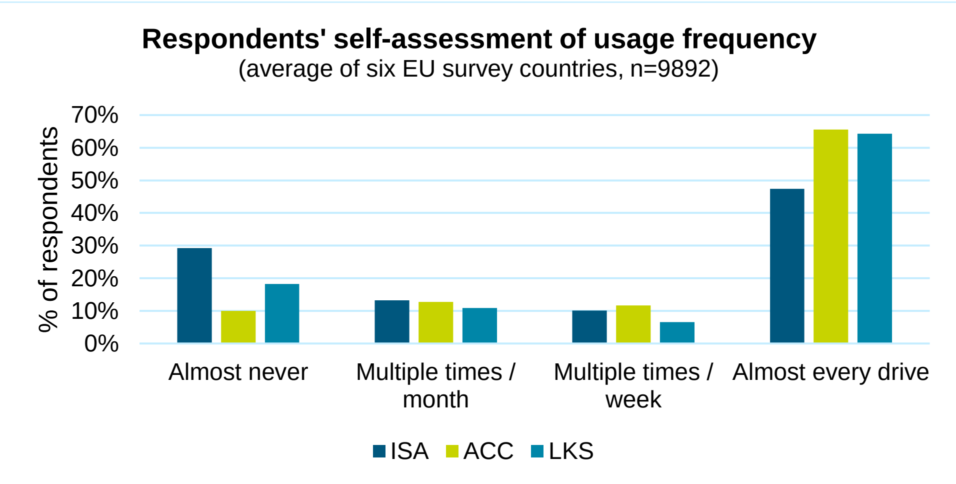


Respondents' vehicle type
Percentage (%)
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
Italy
Denmark
Germany
Netherlands
Austria
France
EU
Company car
Private lease
New private vehicle
Used private vehicle
Shared vehicle (e.g. rental)
Other

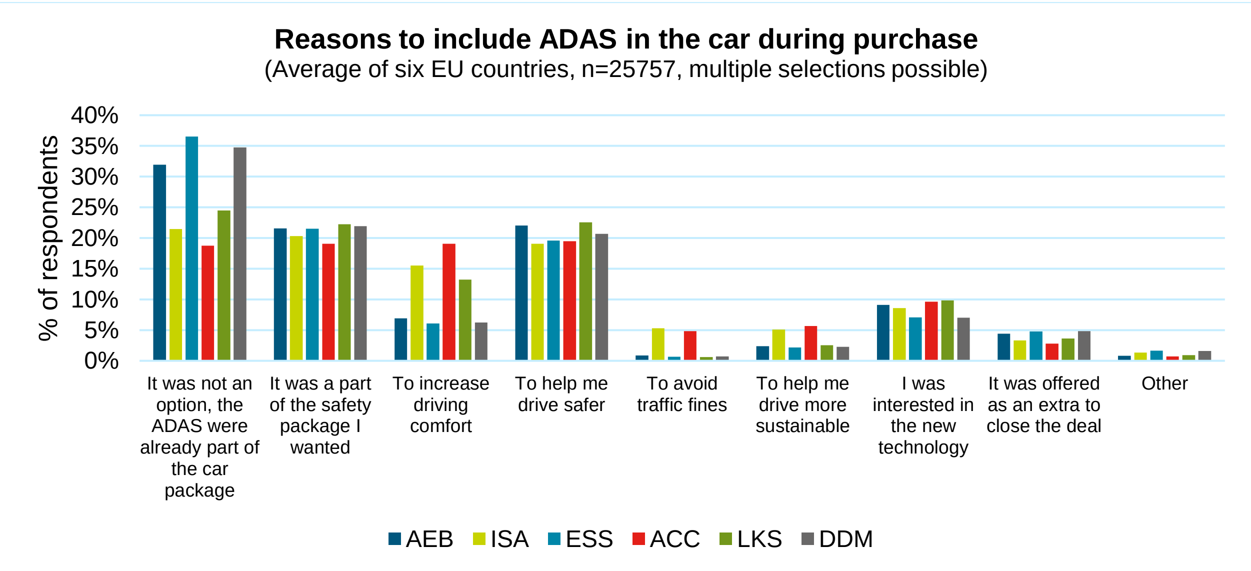


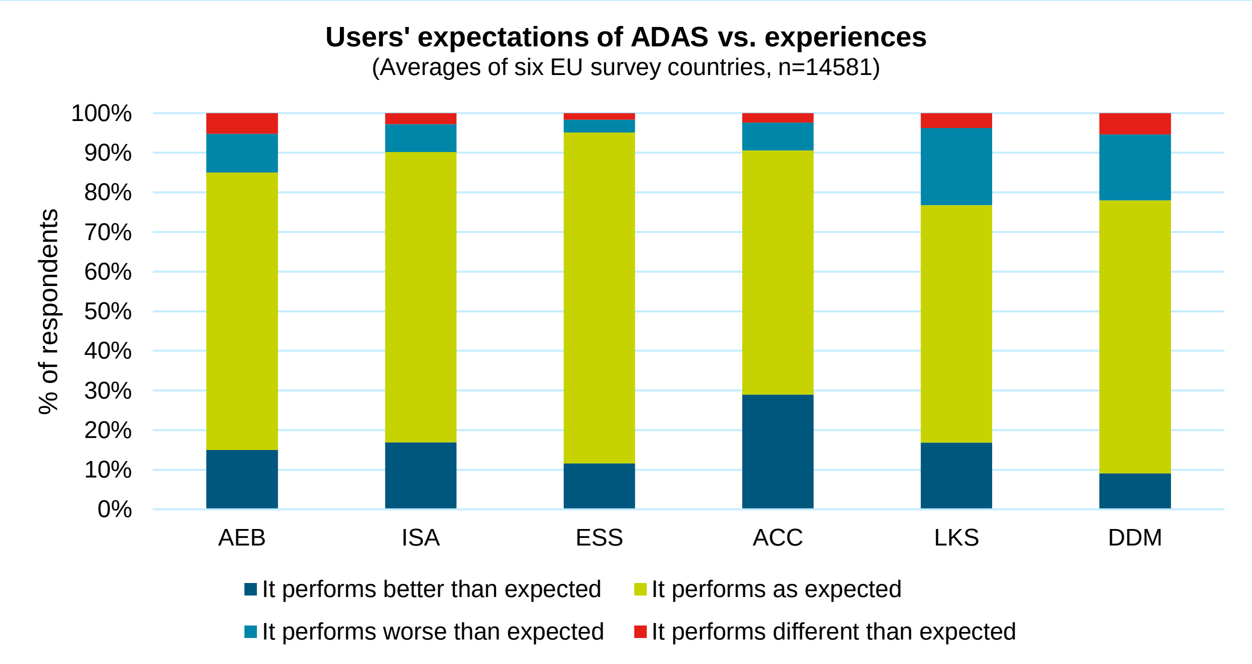
Respondents' age
Percentage (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Italy
Denmark
Germany
Netherlands
Austria
France
EU
18-24 years
25-44 years
45-64 years
65 years or above


Respondents' gender
100%
80%
60%
40%
20%
0%
Percentage (%)
Italy
Denmark
Germany
Netherlands
Austria
France
EU
Male
Female
Other/Prefer not to say

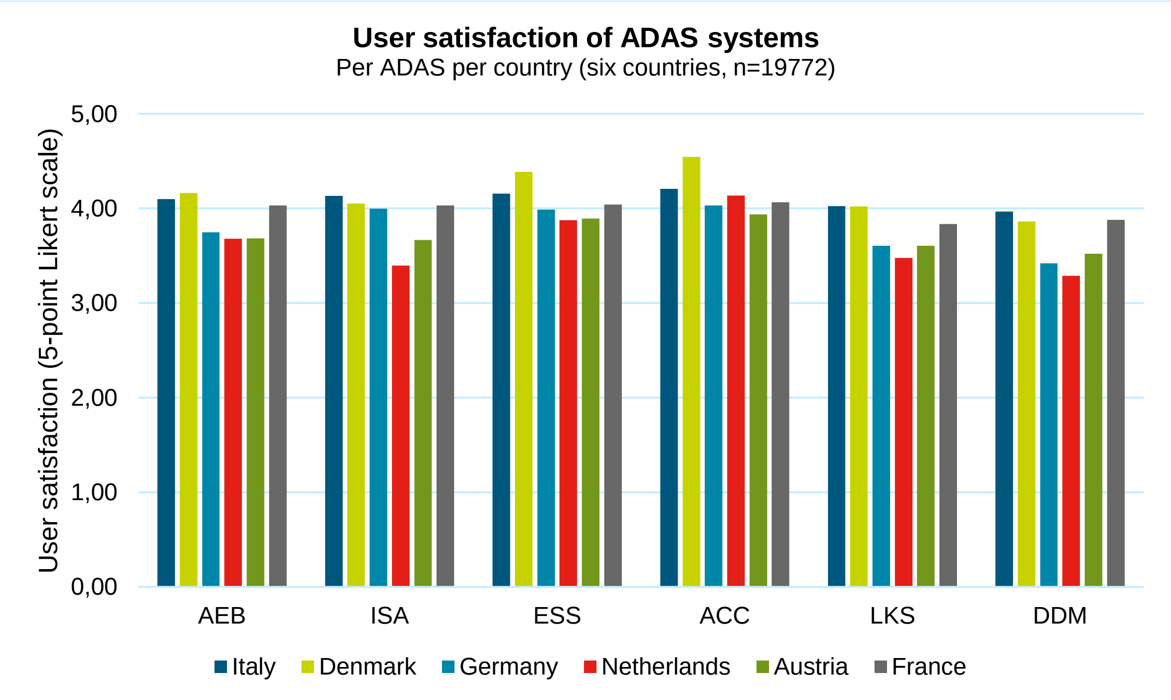

Respondents' self-assessment of usage frequency
(average of six EU survey countries, n=9892)
70%
60%
50%
40%
30%
20%
10%
0%
% of respondents
Almost never
Multiple times / month
Multiple times / week
Almost every drive
ISA
ACC
LKS

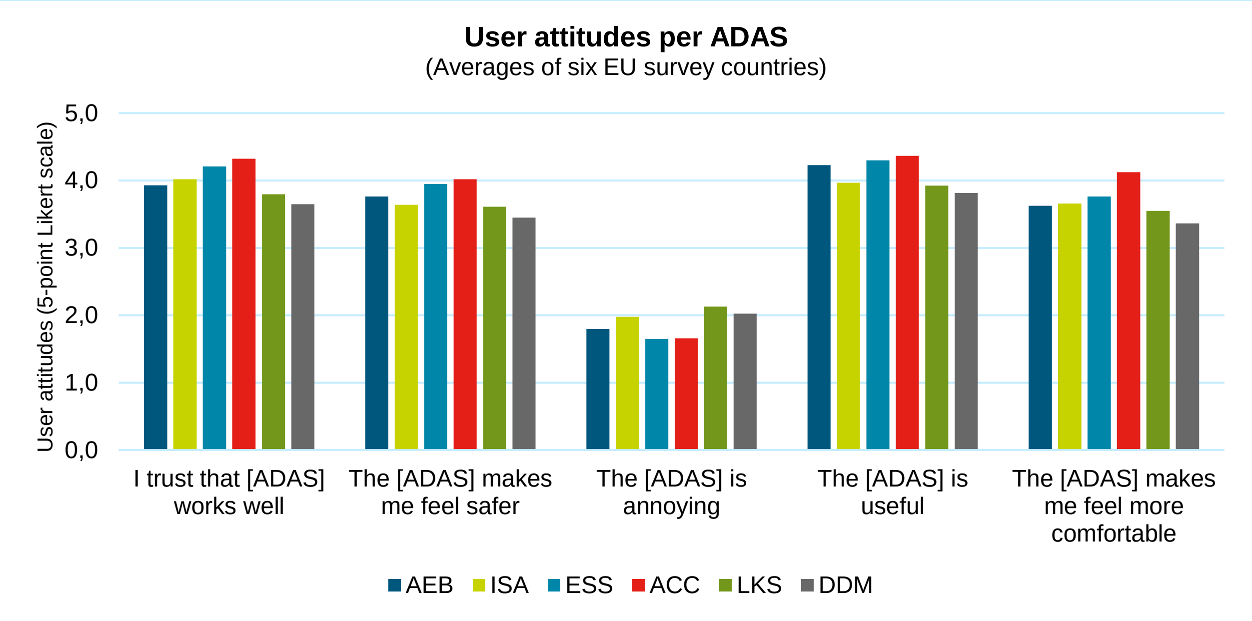
Block 2


Reasons to include ADAS in the car during purchase
(Average of six EU countries, n=25757, multiple selections possible)
40%
35%
30%
25%
20%
15%
10%
5%
0%
% of respondents
It was not an option, the ADAS were already part of the car package
It was a part of the safety package I wanted
To increase driving comfort
To help me drive safer
To avoid traffic fines
To help me drive more sustainable
I was interested in the new technology
It was offered as an extra to close the deal
Other
AEB
ISA
ESS
ACC
LKS
DDM


Users' expectations of ADAS vs. experiences
(Averages of six EU survey countries, n=14581)
% of respondents
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AEB
ISA
ESS
ACC
LKS
DDM
It performs better than expected
It performs as expected
It performs worse than expected
It performs different than expected

Block 3


User satisfaction of ADAS systems
Per ADAS per country (six countries, n=19772)
User satisfaction (5-point Likert scale)
5,00
4,00
3,00
2,00
1,00
0,00
AEB
ISA
ESS
ACC
LKS
DDM
Italy
Denmark
Germany
Netherlands
Austria
France



Correlations

			I trust that AEB works well.	The AEB makes me feel safer.	The AEB is annoying.	The AEB is useful.	The AEB makes me feel more comfortable.	AEB number of correct answers
Spearman's rho	I trust that AEB works well.	Correlation Coefficient	1,000	,835**	,448**	,788**	,784**	,183**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000
		N	5585	5585	5585	5585	5585	5585
	The AEB makes me feel safer.	Correlation Coefficient	,835**	1,000	,482**	,814**	,879**	,172**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000
		N	5585	5585	5585	5585	5585	5585
	The AEB is annoying.	Correlation Coefficient	,448**	,482**	1,000	,451**	,495**	,108**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000
		N	5585	5585	5585	5585	5585	5585
	The AEB is useful.	Correlation Coefficient	,788**	,814**	,451**	1,000	,821**	,191**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000
		N	5585	5585	5585	5585	5585	5585
	The AEB makes me feel more comfortable.	Correlation Coefficient	,784**	,879**	,495**	,821**	1,000	,151**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000
		N	5585	5585	5585	5585	5585	5585
	AEB number of correct answers	Correlation Coefficient	,183**	,172**	,108**	,191**	,151**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.
		N	5585	5585	5585	5585	5585	7498

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

			I trust that ISA works well.	The ISA makes me feel safer.	The ISA is annoying.	The ISA is useful.	The ISA makes me feel more comfortable.	ISA number of correct answers
Spearman's rho	I trust that ISA works well.	Correlation Coefficient	1,000	,921**	,711**	,910**	,907**	,265**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000
		N	5320	5320	5320	5320	5320	5320
	The ISA makes me feel safer.	Correlation Coefficient	,921**	1,000	,738**	,923**	,958**	,250**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000
		N	5320	5320	5320	5320	5320	5320
	The ISA is annoying.	Correlation Coefficient	,711**	,738**	1,000	,723**	,743**	,232**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000
		N	5320	5320	5320	5320	5320	5320
	The ISA is useful.	Correlation Coefficient	,910**	,923**	,723**	1,000	,932**	,262**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000
		N	5320	5320	5320	5320	5320	5320
	The ISA makes me feel more comfortable.	Correlation Coefficient	,907**	,958**	,743**	,932**	1,000	,254**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000
		N	5320	5320	5320	5320	5320	5320
	ISA number of correct answers	Correlation Coefficient	,265**	,250**	,232**	,262**	,254**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.
		N	5320	5320	5320	5320	5320	7498

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

			I trust that ESS works well	The ESS makes me feel safer.	The ESS is annoying.	The ESS is useful.	The ESS makes me feel more comfortable.	ESS number of correct answers
Spearman's rho	I trust that ESS works well	Correlation Coefficient	1,000	,901**	,679**	,892**	,876**	,348**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000
		N	5400	5400	5400	5400	5400	5400
	The ESS makes me feel safer.	Correlation Coefficient	,901**	1,000	,707**	,900**	,945**	,302**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000
		N	5400	5400	5400	5400	5400	5400
	The ESS is annoying.	Correlation Coefficient	,679**	,707**	1,000	,679**	,712**	,241**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000
		N	5400	5400	5400	5400	5400	5400
	The ESS is useful.	Correlation Coefficient	,892**	,900**	,679**	1,000	,892**	,347**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000
		N	5400	5400	5400	5400	5400	5400
	The ESS makes me feel more comfortable.	Correlation Coefficient	,876**	,945**	,712**	,892**	1,000	,300**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000
		N	5400	5400	5400	5400	5400	5400
	ESS number of correct answers	Correlation Coefficient	,348**	,302**	,241**	,347**	,300**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.
		N	5400	5400	5400	5400	5400	7498

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

			I trust that ACC works well.	The ACC makes me feel safer.	The ACC is annoying.	The ACC is useful	The ACC makes me feel more comfortable.	ACC number of correct answers
Spearman's rho	I trust that ACC works well.	Correlation Coefficient	1,000	,872**	,519**	,861**	,861**	,307**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000
		N	5564	5564	5564	5564	5564	5564
	The ACC makes me feel safer.	Correlation Coefficient	,872**	1,000	,535**	,873**	,921**	,309**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000
		N	5564	5564	5564	5564	5564	5564
	The ACC is annoying.	Correlation Coefficient	,519**	,535**	1,000	,518**	,533**	,216**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000
		N	5564	5564	5564	5564	5564	5564
	The ACC is useful	Correlation Coefficient	,861**	,873**	,518**	1,000	,899**	,328**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000
		N	5564	5564	5564	5564	5564	5564
	The ACC makes me feel more comfortable.	Correlation Coefficient	,861**	,921**	,533**	,899**	1,000	,325**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000
		N	5564	5564	5564	5564	5564	5564
	ACC number of correct answers	Correlation Coefficient	,307**	,309**	,216**	,328**	,325**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.
		N	5564	5564	5564	5564	5564	7498

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

			I trust that LKS works well.	The LKS makes me feel safer.	The LKS is annoying.	The LKS is useful.	The LKS makes me feel more comfortable	LKS number of correct answers
Spearman's rho	I trust that LKS works well.	Correlation Coefficient	1,000	,904**	,573**	,877**	,883**	,330**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000
		N	5476	5476	5476	5476	5476	5476
	The LKS makes me feel safer.	Correlation Coefficient	,904**	1,000	,572**	,913**	,951**	,350**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000
		N	5476	5476	5476	5476	5476	5476
	The LKS is annoying.	Correlation Coefficient	,573**	,572**	1,000	,551**	,568**	,347**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000
		N	5476	5476	5476	5476	5476	5476
	The LKS is useful.	Correlation Coefficient	,877**	,913**	,551**	1,000	,913**	,359**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000
		N	5476	5476	5476	5476	5476	5476
	The LKS makes me feel more comfortable	Correlation Coefficient	,883**	,951**	,568**	,913**	1,000	,357**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000
		N	5476	5476	5476	5476	5476	5476
	LKS number of correct answers	Correlation Coefficient	,330**	,350**	,347**	,359**	,357**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.
		N	5476	5476	5476	5476	5476	7498

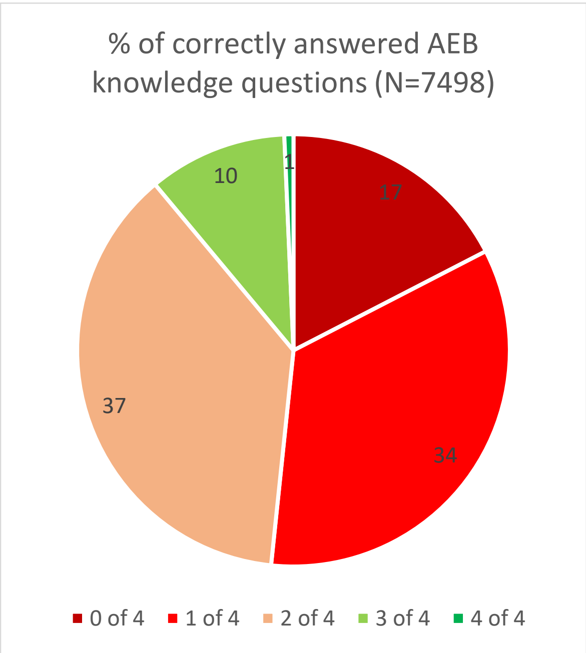
**. Correlation is significant at the 0.01 level (2-tailed).

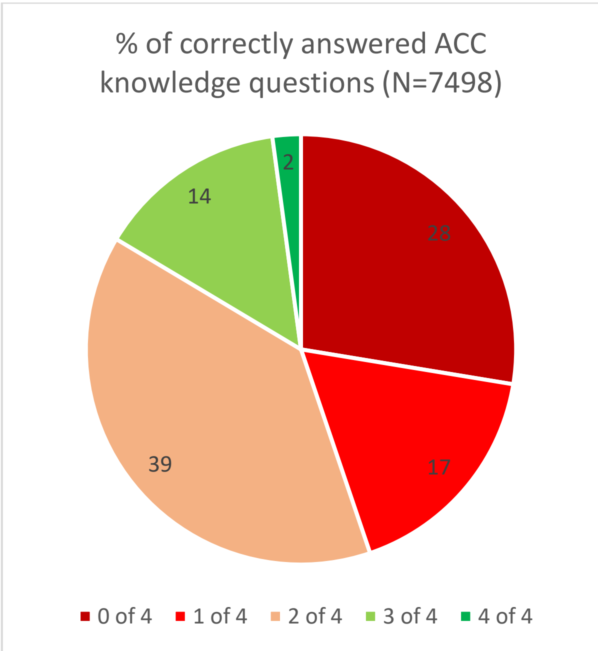
Correlations

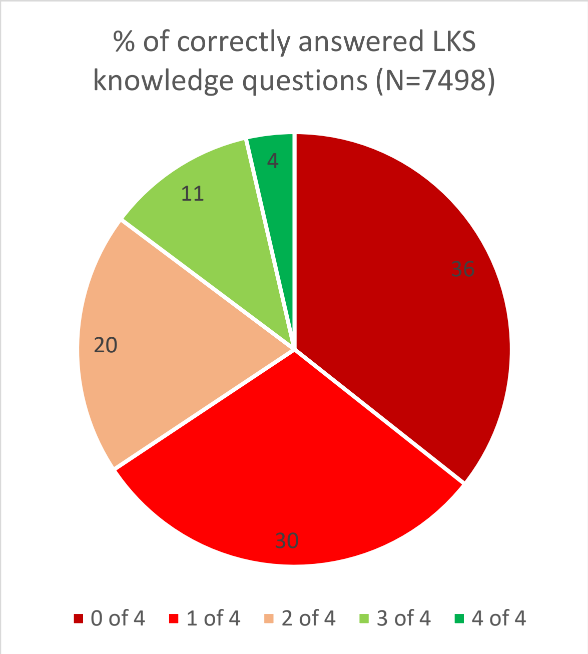
			I trust that DM works well.	The DM makes me feel safer.	The DM is annoying.	The DM is useful.	The DM makes me feel more comfortable.	DM number of correct answers
Spearman's rho	I trust that DM works well.	Correlation Coefficient	1,000	,913**	,665**	,873**	,901**	,291**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000
		N	5372	5372	5372	5372	5372	5372
	The DM makes me feel safer.	Correlation Coefficient	,913**	1,000	,675**	,909**	,958**	,289**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000
		N	5372	5372	5372	5372	5372	5372
	The DM is annoying.	Correlation Coefficient	,665**	,675**	1,000	,645**	,682**	,222**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000
		N	5372	5372	5372	5372	5372	5372
	The DM is useful.	Correlation Coefficient	,873**	,909**	,645**	1,000	,908**	,284**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000
		N	5372	5372	5372	5372	5372	5372
	The DM makes me feel more comfortable.	Correlation Coefficient	,901**	,958**	,682**	,908**	1,000	,288**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000
		N	5372	5372	5372	5372	5372	5372
	DM number of correct answers	Correlation Coefficient	,291**	,289**	,222**	,284**	,288**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.
		N	5372	5372	5372	5372	5372	7498

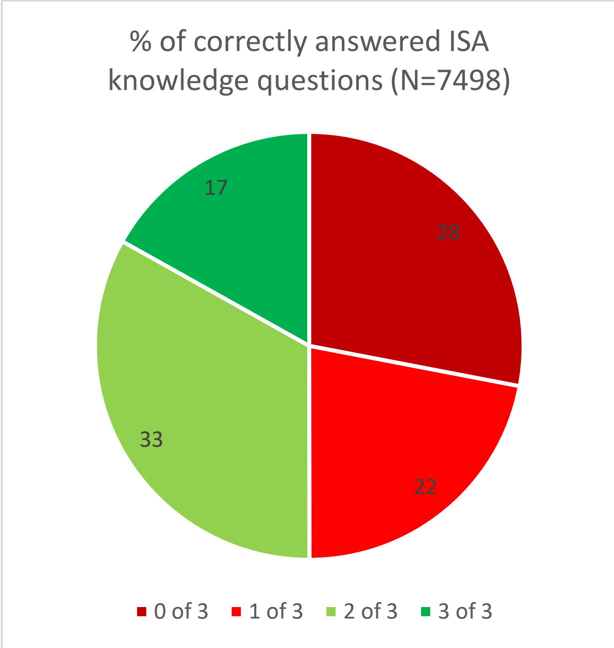
**. Correlation is significant at the 0.01 level (2-tailed).

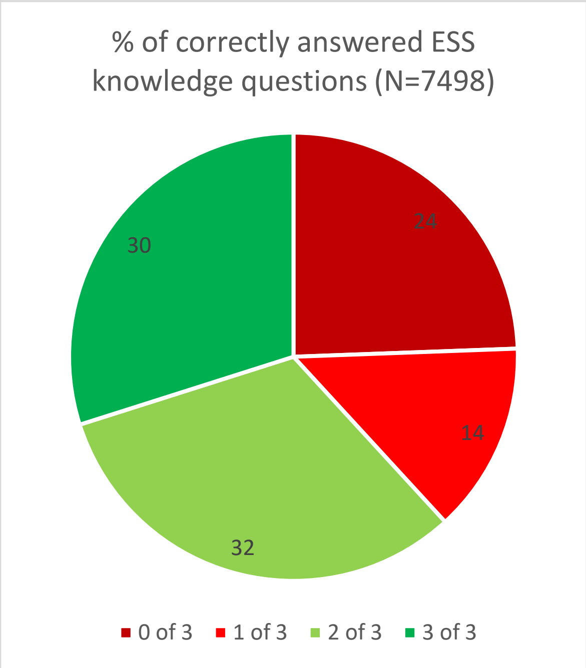
Block 4

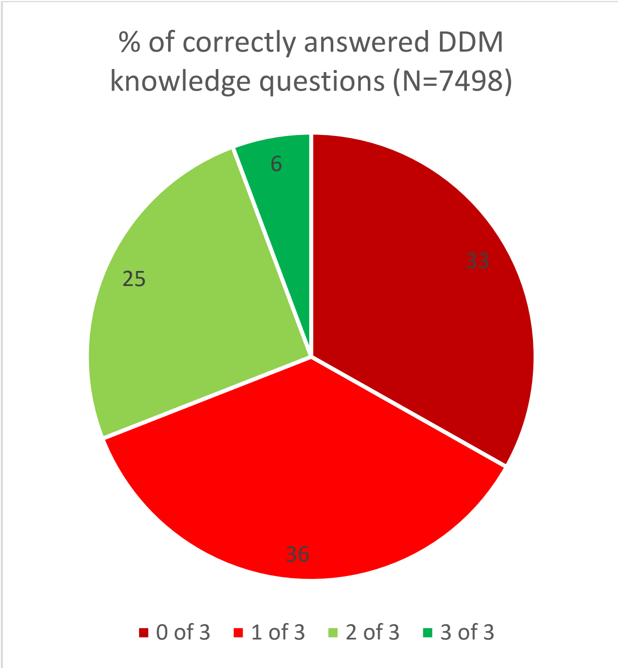





% of correctly answered LKS knowledge questions (N=7498)
36
30
20
11
4
0 of 4
1 of 4
2 of 4
3 of 4
4 of 4


% of correctly answered ISA knowledge questions (N=7498)
28
22
33
17
0 of 3
1 of 3
2 of 3
3 of 3


% of correctly answered ESS knowledge questions (N=7498)
24
14
32
30
0 of 3
1 of 3
2 of 3
3 of 3


% of correctly answered DDM knowledge questions (N=7498)
33
36
25
6
0 of 3
1 of 3
2 of 3
3 of 3

Appendix IV: Online car shopping assignment

Car brand	Country	URL	Date visited
Volkswagen	UK + NL	https://www.volkswagen.co.uk/ https://www.volkswagen.nl	3^{rd} – 10^{th} of June, 2020
Renault	UK	https://www.renault.co.uk/	3^{rd} – 10^{th} of June, 2020
Peugeot	UK	https://www.peugeot.co.uk/	3^{rd} – 10^{th} of June, 2020
Ford	UK + NL	https://www.ford.co.uk/ https://www.ford.nl	3^{rd} – 10^{th} of June, 2020
Mercedes-Benz	UK	https://www.mercedes-benz.co.uk/	3^{rd} – 10^{th} of June, 2020
Toyota	UK + NL	https://www.toyota.co.uk/ https://www.toyota.nl	3^{rd} – 10^{th} of June, 2020
Volvo	UK + NL	https://www.volvocars.com/uk https://www.volvocars.com/nl	3^{rd} – 10^{th} of June, 2020

Appendix V: Detailed outcomes of Round Table Meeting

- Outcomes of the mentimeter survey

Question 1: Should we strive for unified terminology or should we try to reflect the functionality of the exact system in the ADAS names? Which organisation should take a lead in deciding ADAS names?
The answers vary between participants, some experts support that unified terminology is the way to go, whereas others prefer to use names which reflect the functionality of the system. Experts highlighted the need of unified technology as unified names for ADAS will allow users to change to different vehicles, e.g. hire cars. The reasons behind reflecting the functionality of systems with ADAS names were related to the fact that this allows to precisely explain the system and allow forthe right expectations from the systems' level of support.

Another group of experts stated that there is no need to choose among these two, since a combination of these is possible: Why not strive for a unified terminology that reflects the functionality of the system?

Another suggestion is to strive for a combined approach: come up with unified terminology, which can be used voluntary, and, in the future, give manufacturers the right to use their own terminology, while referringto the unified terminology and describing the add on to the minimum functionality.

Finally, another view is that it may be too early to force names to be selected for ADAS and that over time, when systems become widely used, names will naturally become similar (as already happened in the case of ACC).

Regarding the organisations that can take a lead in deciding about the unified terminology, the mostly commonly named organisation was Euro NCAP. The Euro NCAP representative shared the organisation's attitude to the ADAS names selection: "As long as the system's name is not misleading and the explanation of the system uses general function names like AEB, ACC, LSS (Lane Support Systems covering LKS and LDW), the name is sufficient. What should be clear to consumers is whether an ADAS is Safety-based, like AEB or Comfort-based, like ACC". Next to Euro NCAP, the names of the ADAS can be also obtained from the ISO standards or UN-ECE vehicle regulations or OEMs.

Question 2: What are the situations where an ADAS does not contribute to safety or even has adverse safety effects?
The most unsafe situations are related to the misleading warnings of thesystems. Misleading warnings can cause driver's distraction or mental overload of drivers due to the amount of incoming information.

Furthermore, according to the experts, unsafe situations are also caused by users'overtrust in the system. More specifically, when the user misunderstands the function and performance of the ADAS system, they tend to overtrust the system. Overtrust can result in engaging in non-driving related tasks and become complacent. Another potential danger resulting from overtrust is risk-compensation, meaning that users tend to drive riskier, assumingwassume that system will protect them.

Another example of not safe use of ADAS is related to the undetected malfunction of the system or system errors. For example, the case of false negative detections, when the system has not warned the driver about a potential/oncoming hazard. The same applies inthe opposite case of a false positive, when an ADAS is activated and warns/asks the driver to act, although there is no potential hazard.

Moreover, an important reason for reduced safety by ADAS is thefact that some ADAS are not meant to increase safety, but they are aimed to increase driving comfort instead. If drivers are clearly aware about the type of the system and the system's capabilities, comfort aimed ADAS do not reduce a safety. However, sometimes drivers are not fully familiar of this distinction and as a result, do not use the systems accordingly.

Finally, unsafe use of the systems also originates because of drivers' confusion about the systems' status: Is the system activated or not?

Question 3: Which other reasons for deactivating of ADAS have you met?
One of the reasons for deactivating the ADAS is confusing system's behaviour, or in other words when drivers do not understand how the system works. The actions of ADAS are not corresponding to the drivers understanding of the situations. Sometimes systems may even act unpredictable. Additionally, it may be not clear for drivers what will be the experience of driving with ADAS until they have tried it (some drivers do not want to risk and never try ADAS).

Another reason for deactivation of the systems is the mismatch between the driver's driving habbits and the system's behaviour. In some cases, the system's feedback or reactions repeatedly do not meet driver expectations. Also, some users experience difficulties with incorporation of the system's behaviour into proactive driving (systems are reactive). Additionally, ADAS may be inflexible, they do not adapt to the driver's preferences.

Other mentioned reasons for deactivation of the systems are:

- annoyance of warnings;
- undertrust for the system;
- the fear to handle over the control/ steering;
- deactivation due to the unsafe system behaviour as phantom braking, driving too fast in really bad weather, swerving, park assist bad influence on the wheels.

- Outcomes of the open discussion session

Next to the closed-questions section, the round table included an open discussion section. The open discussion provided various insights, the most important of which are presented in this paragraph.

Experts highlighted a need to prioritise the information on the dashboard, now there is excessive and not a precise information. Currently the EU asks for a lot of warnings, this approach can confuse the drivers very much. To reduce the workload some form of info prioritisation is needed. Many systems only give information about the failure of the sensor. However, they do not inform the driver that the system overall has failed to function or that ADAS has been deactivated. Additionally, some ADAS rely on each other, e.g. AEB deactivating when Tire Pressure Monitoring signals low pressure in one tyre, but this may be unclear for the driver. The warning system should explicitly report that the ADAS was deactivated and what was the reason for the system deactivation.

Functionality of ADAS affect usage and acceptance. For instance, ACC: huge difference of situations where system can be used between system equipped with the camera-only and the system equipped with camera plus radar sensors. If the system's functionality is poor, a good HMI cannot save it. Besides looking on the ADAS systems itself, it is also important to remember that ADAS in vehicles are a very important part of an environmental system but after all only one of them. There is infrastructure, education, enforcement and others. If these others are not taken care of there will always be misfunction and with this confusion and even frustration of the consumer.

For example, the functionality is highly affected by the infrastructure development level. The infrastructure is not optimized for the systems. For example, the traffic signs differ between countries. A unified system of signs has to come (their maintenance also strongly differs among countries). No catalogue exists where the traffic signs of all 27 EU country members can be found. So indeed, we should not look at HMI alone but at the whole system. An added benefit ofcourse will be that uniform road design and road furniture (e.g. signs) across EU countries will also enhance the self-explaining[10] characteristics of the road for the non-assisted drivers.

It takes a while after the introduction of a new system for people to stabilize, to get used to them. E.g., ISA: it takes over a year even. For most of the drivers the first experience they have with ADAS is the moment they get their lease car. During the test drive of a car they don't get to know the systems. In a Volvo example from the Netherlands, in 6/10 drivers the ADAS were turned off during the test drive. It is very important to know how to initiate the systems and interact with them. In the training of ProDrive they let people see on the road what the consequences can be of not taking the system warnings into account.

The difficulty with adaptation to ADAS can be a big point of attention for a novel drivers and elderly drivers, as for them the long transition period may be even more tough to handle than for an experience driver. For example, since 2016 all ADAS can be tested in driver exams. However, driver instructors say that they increase the workload a lot and they increase the stress level of the drivers during the exam (example: speed alert integrated in navigation that keeps on beeping false alarms). So, currently the integration of ADAS in the exams is very limited.

During the discussion was raised a point of the not enough competences of the people involved in the process of ADAS creating, selling and using. Some experts mentioned that rental cars personal, dealers and even designers are not familiar with the functionality and the systems' limitations. However, immediately appear another opinion that the designers do lots of experiments and tests in different environments to check the systems. Also, a point was discussed that the limitations of the systems are explained in the car manual, but nobody reads this. However, directive 2007/46/EC (valid till 31.08.2020) and Regulation (EU) 2018/858 which is mandatory by 1st of September give clear legislative requirement to manufactures concerning owner´s manual and what to do if there is a risk for drivers.

- Outcomes of the analysis of the expert's feedback on the minutes of meeting

The insights gained during the round table meeting created the need for further discussion on some topics. Therefore, follow-up discussions with the round table meeting's experts took place (mainly via e-mail), aiming at the clarification of some statements.

"We need to work towards a warning strategy". The provision of lots of signals in different ways (audio, visual, haptic) can lead to great confusion of the driver.
Experts were asked to share their views on the ways to prioritise warning signals. Different approaches were proposed.

The first approach highlights the importance to clearly show the driver what systems are engaged. This should be preferrably done through the Head Up Display. In this case, one audible message should be provided, always with an explanation on what the warning is about. The signals should be then given in the following order:

1. Visual
2. Audible

[10] https://ec.europa.eu/transport/road_safety/specialist/knowledge/road/designing_for_road_function/self_explaining_roads_en

3. Haptic

The second approach regards the warning strategy for beginner drivers. Considering that beginner drivers can handle a minimum amount of information, warnings signals must only be given when necessary and must be meaningful. Signals should be given in the following order:

1. Signalling danger
2. Signalling violation of traffic rules
3. Comfort signals

According to the third approach, some ADAS signals have more priority than other ADAS signals (e.g. AEB signals are more important than ISA signals). Based on this approach, the signals of the studied systems are ranked in terms of importance as following:

1. AEB
2. ACC
3. LKS
4. DM
5. ISA
6. ESS

Next to the three approaches, there is another point of view that it is impossible to prioritize the signals. The warning strategy should be an adaptive strategy that considers the criticality and urgency of the situation.

Policy recommendations for increasing awareness of ADAS users.
Should drivers know how to use the systems before they drive an ADAS equipped car? Most of the round table meeting experts gave a negative reaction to this question.

One of the reasons to disagree with this view is the fact that all ADAS have a reliable back-up system that should intervene in case of emergency. Furthermore, the provision of additional trainings may form a barrier for the adoption of ADAS, while ADAS in the end-run increase safety and it is a priority to promote use of these systems. From another point of view, learning is a process and requires sufficient time. The adaptation to the ADAS system occurs during the daily use of the system.

However, all experts highlighted that voluntary training should be provided to drivers. Regarding the types of ADAS driving trainings, these types were suggested: one-on-one trainings on the public roads (not on a track); broad awareness campaigns and ADAS test drives. The trainings should be provided by importers or lease companies. The training should be given by skilled, certified trainers from training & driving academies. The trainings on specific ADAS used in the exact vehicles can be given by the car sellers. Additionally, it was proposed to involve insurance companies.

Regarding the content of trainings, the following aspects should be indispensable parts of them:

- Explanation of the benefits and limits of the system, safety potential and demonstration of all in-car available systems.
- Demonstration of the ways to engage a comfort ADAS, where to use it and where not to use it.

What ways are there in order to communicate functionality and limitations information to the wide group of buyers that does not read the manual?
Who should be in a lead to ensure that the ADAS functionality is known to the driver? Experts claimed that the responsibility for this lies at vehicle handover: car dealers, leasing and renting companies. One of the ways to ensure that car dealers provide enough information can be that importers make this a mandatory item for their dealers and measure this as a KPI (Key Performance Indicator) bonus. The development of

an ADAS certificate for the byers is also mentioned as a possible effective way to ensure that the buyers are aware of the systems' capabilities and limitations.

Furthermore, users usually do not read manuals. ADAS manufactures should take this into account and develop warning systems that are self-explanatory. One of the approaches could be to make the vehicle itself clearly indicate when a system is available for use and restrict use (geofencing) when the circumstances are not ideal.

The need to look at the system as a whole highlights the importance of working towards uniform infrastructure (at least across Europe) to enable the safe and efficient use of ADAS.
Which organisation can take the lead in working towards unified infrastructure? Currently there is no organisation that can cover all ADAS aspects (driver-vehicle-infrastructure) alone. According to the experts of the round table, the European Commission and Euro NCAP should look at the vehicle side. EuroRAP recently started working on rating roads. Additional support can come from UNECE WP1 and WP29, OICA, FIA.

According to this expert group, road markings and road traffic signs should be the first road elements to be unified. Finally, highways and rural roads should be the first priority, while urban environments can follow in the long term.

Appendix VI: User awareness studies used as basis for awareness online survey

Harms & Dekker (2017). This study by Connecting Mobility combined an online survey with 1,355 business drivers. The study was carried out amongst members of VZR, a Dutch interest group for business drivers.

The study focused on sixteen ADAS that may aid smart mobility. These involved Navigation (without traffic feed), Live Navigation (with traffic feed), Cruise Control, Adaptive Cruise Control (ACC), Speed Limiter, Intelligent Speed Assistance (ISA), Lane Departure Warning, Lane Keeping Aid, Lane Change Merge Aid, Park Assist Pilot, Emergency Brake, Distance Alert, Traffic Sign Recognition, Intersection Assistant, Cross Traffic Alert and Traffic Jam Assistant.

The survey of this study covers questions about the type of the roads where ADAS are mainly used; the frequency of the use of different ADAS and the reasons for purchasing vehicles equipped with ADAS.

A part of the questionnaire looked at the awareness of ADAS users about the functionality of the systems, for which participants had to match ADAS definitions and ADAS symbols with ADAS names, in order to obtain a human perspective on the various ADAS. Hence, participants were shown a description of only one of the sixteen ADAS in this study and were prompted to come up with a name that would match the system's functionality (irrespective of the ADAS with which participant's car is equipped).

To check the familiarity with the systems, participants were shown the symbols of six ADAS and were asked about the functionality they expected from these systems. The symbols used were derived from symbols used by car manufacturers and mycardoeswhat.org.

The study obtained the following results:

- The lack of awareness of ownership of ADAS currently appears to be the largest bottleneck for the breakthrough of ADAS usage. Participants who were aware of owning a specific ADAS also displayed a tendency to use this ADAS. The main reasons to not use cruise control was willingness to be in control both of the driving on motorways and in the city.
- ADAS being part of the default option and ADAS added for comfort are the key factors for explaining why one's car is equipped with ADAS.
- Only 24% of the business drivers received instructions regarding their ADAS at the car dealer. Roughly half of the business drivers (47%) has learned about their ADAS functionality by trial-and-error while driving. This showed to be the most common way of learning about the functionality. However, considering that participants were able to provide multiple answers, it is possible that on top off learning by trial-and-error, participants also used other sources of information.
- The fact that drivers' interpretations of ADAS names deviate from the functionality intended by the automotive industry underlines that the lack of uniformity in ADAS' names and functionality is indeed a shortcoming. Consensus or guidelines on ADAS names, symbols, their functionality, and ease of access to this information, will likely improve consumers' understanding of the ADAS with which their car is equipped and what functionality they can expect from those systems.
- Although the majority of the interpretations of symbols was correct, the remaining answers show that the smallest details of the symbols may cause unintended consequences towards the way the symbol was interpreted. An example of this is the symbol for Traffic Sign Recognition. This symbol contains a 50km/h sign. As a result, 54% of the answers were related to speed, for example Speed Recognition or Intelligent Speed Assistance.
- When interpreting ADAS' functionality, business drivers have difficulties distinguishing between ADAS solely capable of informing or warning the driver and those also capable of intervening in the

driving task. The results show that symbols may be suitable to indicate this distinction. When looking into the symbols used for Lane Departure Warning (which informs) versus Lane Keeping Aid (which intervenes), it seems that most participants are capable of correctly interpreting this difference.

- Not for all ADAS their availability in the car could be derived from the vehicle specifications. An example of an ADAS that could not be obtained is Intelligent Speed Assistance (ISA).
- Business drivers in the current study either drove their lease car, their privately-owned car or a company car. The retail value of 79% of the cars involved lies between €20,000 and €50,000 – with an average retail value of €39,400 – and 84% of the cars were manufactured between 2012 and 2016. The cars involved in the study are both relatively new as well as expensive.
- Both Cruise Control and Navigation yield the largest difference between vehicle specifications stating the car is unequipped versus the drivers stating that it is, in fact, equipped.

The L3 pilot includes experimental road tests carried out with instrumented vehicles in real traffic conditions on a predefined test route. During the pilots data was collected through questionnaires, which were completed by participants testing the ADAS on the test site. The questionnaires used during the pilot studies covered information about sociodemographic information of participants, vehicle purchasing decisions, driving history, in-vehicle system usage and trip choice; participants' impression of the ADAS performance, including acceptance, safety and comfort, among others; willingness to pay for the particular ADAS.

The results of the pilot are not yet publicly available. It is expected that that the data will become available in September 2020.

Boelhouwer et al. (2020): This study from the University of Twente *("How are car buyers and car sellers currently informed about ADAS? An investigation among drivers and car sellers in the Netherlands")* covers questions on the general interest in innovative technologies, the way of receiving information about the system during the purchase, and the level and satisfaction of the information that customers have received; additional questions about sources of information that customers use to learn about functionality and limitations of systems.

The results of the study are presented below:

- The majority of the respondents consisted of men around 60 years old with an MBO degree that have general interest in innovative technologies (for the phones also) (40,7%) and in automotive technologies (43,6%). Most of the respondents own a vehicle with the year of production 2018 (20,9%), 2017 (22,2%) or cars elder than 2010 (11,1%).
- Most of the respondents received their vehicles personally from the auto seller (89,2%), almost all vehicles equipped with the lane changing systems (98,18%) and an automated parking (80,65%), lane keeping (75,88%), adaptive cruise control (77,42%). Following that, 76,5% of respondents use CC and 72,7% use ACC.
- Lane Keeping was used by 61,2% of the participants and Automated Lane Changing by 61,5%
- With regard to the purchase of the vehicles with ADAS functions, 24,4% of the drivers have not received information about the systems' functionalities during the purchase. Further, 6,7% mentioned that they declined information themselves; the main reason for declining explanations was previous experience with the systems.
- Participants indicate that they were particularly satisfied with the clarity of the seller, the time taken for them, service and the car / systems themselves. People are particularly dissatisfied with the lack of information or incompleteness of the information. Some also indicate that the information is too much or too fast.
- Looking at the way of receiving information, 51,2% of the drivers get information only from the seller, while 18,7% receive it both from seller's explanations and driver manual/brochure. The quality of received information was extensive for 56,1% on the functions, 55,5% on the operations, 39,8% on the limitations and 41% on technical operation.
- Concerning the understanding of the system, 82,3% of the respondents stated that they know which automated systems their car is equipped with, 75,3% understand the functions of the automated systems, 75,1% understand how to operate the automated systems, 68,5% know the possibilities and limitations of the system and 63,2% understand what equipment the systems contain and how they work.
- After the purchase majority of respondents receive information from the driver manual (69,9%), 30,43% search on the webpage. Participants who look up information on websites primarily use google.com, the car manufacturer's website, and video websites such as youtube.com. Only 8,8% of the participants decided to try the system themselves.