TRUSTONOMY

Building Acceptance and Trust in Autonomous Mobility

Deliverable D6.8

Policy Recommendations to Facilitate the Adoption of CAD Vehicles in Europe

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1 Introduction

1.1 Trustonomy project overview

Trustonomy (*trust+autonomy*) is a project connecting stakeholders from different automotive industry, research and transport areas. The consortium is composed by sixteen organizations from nine countries in North, Central and Southern Europe. The goal of Trustonomy is to raise the safety, trust and acceptance of automated vehicles by investigating, testing and assessing different relevant technologies and approaches in a variety of autonomous driving scenarios. The project assumes experts and ordinary citizens involvement. *Trustonomy* compares in terms of performance, ethics and acceptability different technologies and approaches in different scenarios for automatic driving and requests to take control (*RtI – Request to Intervene*). It refers to a various types of users (age, gender, experience), means of transport (cars, trucks, buses) as well as automation levels (L3-L5) and driving conditions [1][2].

The project represents a central-human approach as the human factor remains essential for the safety and performance, due to necessary driver-vehicle interaction while ADS reaches its boundaries and because of the co-existence of autonomous and non-autonomous vehicles.

1.2 Trustonomy frameworks

The project investigates the domains of: Driver State Monitoring (DSM), Human-Machine Interfaces (HMI), driver training, risk assessment, early warning, trajectory planning, Driver Intervention Performance Assessment (DIPA), driver's trust, and acceptance. The main objectives are:

- develop a methodological framework for the operational assessment of different Driver State Monitoring systems,
- develop a methodological framework for operational assessment of various HMI designs
- develop an automated-decision-support framework, covering liability concerns and risk assessment,
- develop novel driver training curricula for human drivers of Automated Driving System (ADS),
- define a Driver Intervention Performance Assessment framework,
- measure performance, trust and acceptance (simulations and field trials) of human driver of ADS.

The schema in Figure 1 showcases the Trustonomy Frameworks.

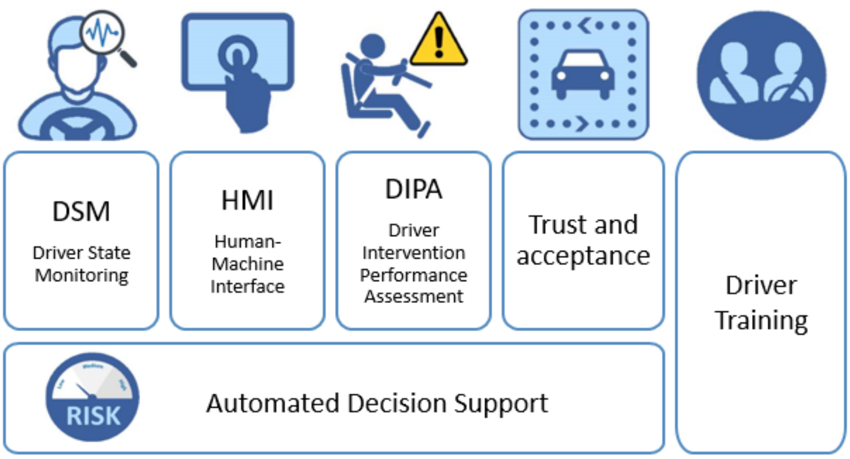

Figure 1 Trustonomy frameworks concept.

1.3 Document structure

This document is structured as follows:

Section 1 contains the introduction to the document with description of the Trustonomy goals and mission, frameworks and methodology. Furthermore, it provides an overview of the deliverable and its structure.

Section 2, Section 3 and Section 4 provides an overview of the challenges identified by the consortium in the field of existing regulations. Then, the Trustonomy approach and key lessons learned are presented, followed by key recommendations driven from the consortium experience.

Trustonomy does not neglect the essential role of human factors. Human drivers were at the core of the project during all phases, starting from the definition of requirements and specifications up to the final validation and extraction of lessons learned. Therefore, the deliverable focuses on the pillars that are highly associated with human-vehicle interaction, road safety and increasing trust in automation.

Section 2 refers to the Driver Training Framework, Section 3 is focused on human-machine interfaces, and Section 4 provides insights from the perspective of Driver State Monitoring.

Section 5 concludes this deliverable, wrapping up the achievements and recommendations.

2 Driver training and social awareness

2.1 Challenges

The use of a car requires a human to obtain a licence. The process of training and examination of drivers should be properly organized and conducted to ensure that there are drivers on the road, who not only were able to pass the exam, but also know how to use their cars safely.

The subject of driver training at the European Union level is regulated by Directive 2006/126/EC of the European Parliament and of the Council of 20 December 2006 on driving licences [3]. It describes in a general way the principles of issuing driving licences, requirements for drivers, categories of driving licences, knowledge and skills which should be demonstrated by candidates for drivers during theoretical and practical tests, indicates minimum standards for persons conducting practical driving tests.

The directive sets minimum requirements for training, giving EU member states the opportunity to regulate in detail the pre-examination training process: theoretical and practical, and the rules for driver training centres. The examination standard introduced by the Directive allows managing the requirements for drivers by subjecting them to a mandatory theoretical and practical examination on the basis of the requirements described in the directive, including precise rules for conducting the theoretical and practical tests and requirements for examiners.

Therefore, each Member State determines, on the basis of its own regulations, how to train candidate drivers so that they will finally have the knowledge required by the EU for the exam. The **Directive does not specify the requirements for drivers to have knowledge of safety systems**. The ABS, ASR and ESC systems are discussed during the standard driver training course. Information on other systems is largely a matter of instructor involvement. The same applies to the use of a vehicle equipped with parking sensors, a rear reversing camera, mirrors that automatically lower when reversing, and a hill support system during the examination. In some countries it is possible to use these devices (Estonia, Norway) in some countries, e.g. in Poland, this is a vague issue. The cars in which candidates take the exam may not be equipped with these systems. Participants can use them if they use private cars on the exam, but ultimately it is the examiner who makes a final decision which systems the examined person can use. In the UK, the exam drive is carried out using navigation. This country, similarly to Germany and Finland, presents a pro-automation approach, meaning that the candidate is expected to make effective use of driving aids e.g. adaptive cruise control and lane warning systems.

On the other hand, there are countries, e.g. Poland, Switzerland (e.g. Friborg district), in which legislators are more cautious. Pursuant to the Regulation of 28 June 2019 on examining applicants for driving licenses, training, examining and obtaining qualifications by examiners as well as templates of documents used in these matters during the driving test [4], it is not forbidden to use parking sensors, rear reversing camera, mirrors automatically lowering when reversing, hill start assist system (if this system does not activate after applying or applying the parking brake). This means that the above technologies can be used during the exam. For other systems (e.g. Active Cruise Control, Blind Spot Sensor, and Lane Keeping Assist - both active and passive), they can be fitted to vehicles but cannot be used during the test.

Provisioning road safety, the examiner should be able to assess the safe use of individual driving support systems by the candidate for driver. Consequently, there is an ongoing discussion on enabling the admission of vehicles equipped with assistance systems for use during the practical part of the examination. However, this is associated with a broader problem mainly related to the **lack of unification** in the way of operation and activation of individual systems by various vehicle manufacturers.

As **each country has its own training system**, there are significant differences regarding training prior the examination. In some countries it is possible to prepare for the practical exam without the participation of a driving instructor (Sweden, Finland), in others such training is mandatory, in addition, a minimum number of training hours is defined (Poland, Bulgaria, Portugal).

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The current driver training-related Directive **does not address the implementation of ICT-based solutions**. Due to their low implementation costs and impact made on a trainee, these tools could play a complementary role in the training process and could support the real-life training, as well as provide an alternative to traditional educational platforms. On the other hand, Directive 2003/59/EC on qualification and requirements for professional driver training, describes the possibilities of using driving simulators in the process of training professional drivers [5]. However, it does not mention the requirements related to the use of VR or e-learning. Driving schools in individual countries offer training using these methods according to their own guidelines.

Last, but not least, as none of the regulations stress out the **need to occasionally refine driver's knowledge and skills** (for non-impaired drivers), it is highly possible that not only novice drivers will pose a danger on the road. Changing a vehicle to a newer one (meaning equipped with automation features) is not associated with the necessity to undergo supplemental training. Usually, it is a matter of buyer to learn new systems or identify changes in their operation. The drivers should then read a manual (if buying a used car) and/or listen to instructions given by a dealer (if buying a new car).

2.2 Trustonomy course of research - Key lessons learned

The Trustonomy project addresses its solutions to drivers of automated vehicles. It should be noted that in the context of automation, novice drivers should be defined not only as driving license applicants, but also as those who have the opportunity to test a given technology for the first time in their lives. It is worth noting that the rapid technological development means that two apparently identically equipped models of the same manufacturer may have different assisting properties – different sets of messages, buttons, dynamic characteristics. For this reason, Trustonomy treats all drivers who encounter a given solution for the first time as inexperienced, requiring additional training.

The dynamic development of systems, as well as their number, cause a situation that users either have no knowledge about them and do not use them, or use them, learning from mistakes. Vehicle users, in large part, declare that they do not read manuals. On the other hand, the manual describing "driver assistance" i.e. in the Volvo XC 90 model has 150, and the entire manual has 745 pages, which means that most users will never read the instructions, although they should. According to the conducted research 53% of respondents learn how to use automation features by actually driving a vehicle, therefore posing a big threat on the road. Currently, the manual is the only source of reliable knowledge that allows the user to learn and understand the operation of the systems. It is worth verifying the quality of the information contained in the manual in terms of the extent to which reading the instructions guarantees the correct use of the systems.

Apart from defining the necessary knowledge required to optimize human-machine interaction, ensure efficient driving and appropriate use of automated features implemented in vehicles, Trustonomy took a chance to incorporate ICT-based training course and tested its effectiveness in comparison to traditional forms – reading a manual and practical training.

The SimYouLearning Platform is a web password-secured application designed to teach drivers the safe and responsible cooperation with automation. The platform was developed specifically for the project and represents a new quality of online training. It functions as an advanced e-learning platform, which results from an expert-based analysis (see Deliverable D3.1 [6]). The consortium developed several trainings for 5 different brands, 3 types of vehicles and different target groups (Figure 2). Depending on the possibilities of a given test location, the e-learning was performed either alone or in combination with other forms of the course, i.e. lecture and practical classes with a professional trainer/instructor.

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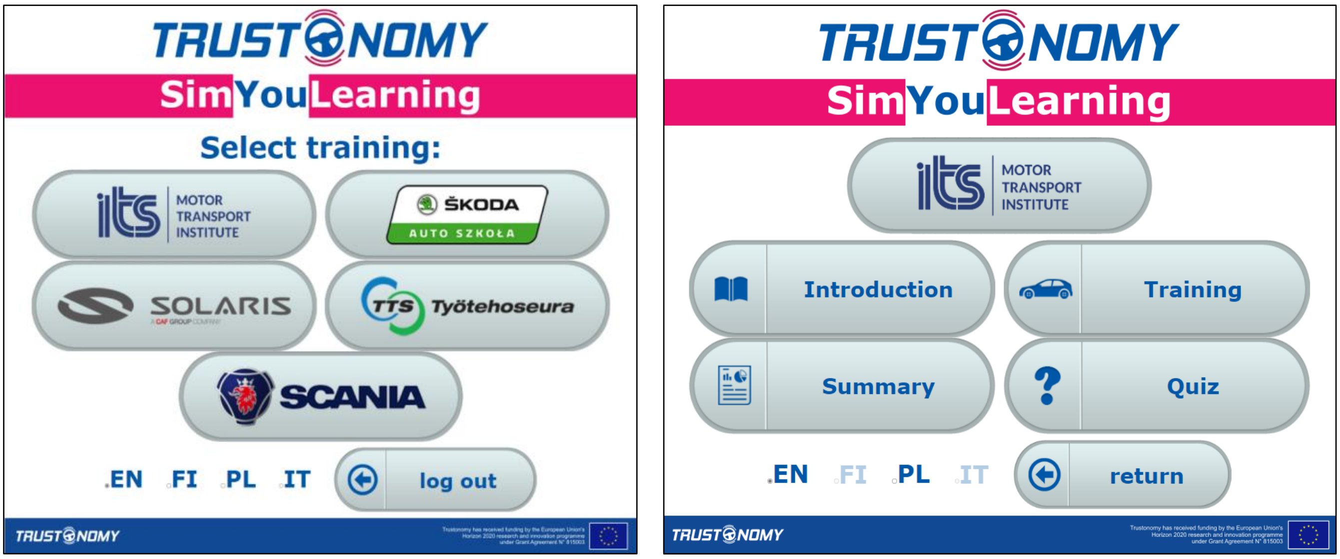

(a) (b)

Figure 2 SimYouLearning platform: (a) training selection page, (b) module selection page.

The content and materials implemented in the platform meet the criteria and detailed map of competences extracted within the project. The innovative form gives the opportunity to transfer theoretical and semi-practical knowledge, and also to assess the progress. The final prototype has four sub-modules [7]:

- the **"Introduction"** module is designed to familiarize drivers with automation - build a context, discuss changes that are introduced in new vehicles, etc. Then, in the same module, the trainee learns information specific to a given driving automation system, i.e. what messages are displayed, in what situations they can appear, what content they convey and what actions should be taken after seeing them. Also in this module, the driver learns that automation systems will never replace humans and, despite their advanced technology, can make mistakes.
- **"Training"** gives the opportunity to test the knowledge gained in the theoretical module in conditions similar to real ones. "Training" is an advanced semi-simulation that allows to build a driver-vehicle interaction, showing the actions in a real cabin. For this purpose, for each of the four courses, a recording was made presenting the operation principles of the automation system, with particular emphasis on messages that appear and actions necessary to be taken to preserve safety. The scope of the video materials was adapted to the individual automation solutions. The above requirements made it possible to enrich the recording with an interactive layer, allowing for interaction. Thanks to semi-simulation, the participant controls the vehicle to some extent, but is asked to perform specific actions. In this way, the driver has a practical learning experience as in a real vehicle (actuators and icons location, view from the perspective of the driver behind a wheel), and in fact can perform training session on any device connected to the Internet (e.g. PC, tablet).

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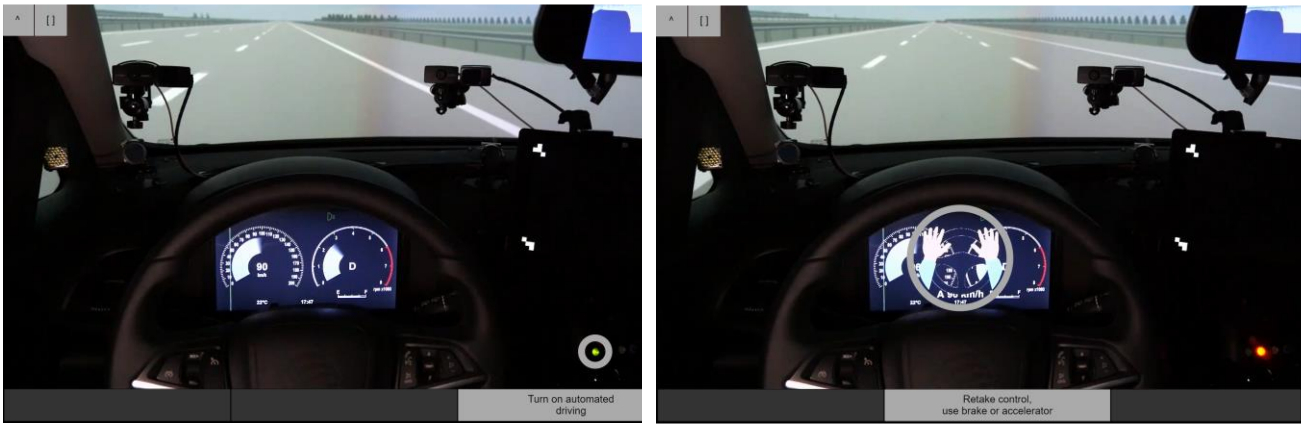

Figure 3 Screenshots from ITS-dedicated training part (scenarios: turning on automation, RtI).

- "Summary" is implemented in the form of a presentation. It aims to repeat the most important information from the entire training, consolidate knowledge and draw the trainee's attention to the most important aspects of the course.
- "Quiz" section is designed to evaluate the participant's individual progress. It contains a few short questions that relate directly to the content conveyed during the training, mainly messages and limitations. After submitting all the answers, the student has the opportunity to check the obtained result, but the correct answers are not visible. This is to encourage the trainee to read the material again and find an answer.

According to the obtained results, SimYouLearning was found to be a good replacement for manual-reading. The use of e-learning allowed to obtain better reaction times and reduce the number of errors, considered especially the first and second interaction. Later on, the participant usually got acquainted with the functioning of the system (through his own interaction), so that the differences in the results were not so significant. It should be noted that the instruction designed for the project contained only the most important information. The knowledge was condensed and presented on one A4 page, so the participants did not have to look for relevant information through dozens of pages. Therefore, the e-learning efficiency compared to reading the manual could be considered underestimated and the results using actual volume instructions would be worse.

The e-learning allowed to prepare drivers to properly behave in unexpected situations, that are either hard to explain in the manual or difficult to imitate (or dangerous) in the practical course. The use of simulation allows to test the operation of the system in conditions of limited visibility or in emergency situations. Trustonomy tested 3 trainings in the context of a Request to Intervene and in fog. As expected, the participants of the practical course achieved the best take-over times, followed by the e-learning group and the manual one. This result is due to more interactions with the system during the practical and semi-practical sessions.

The results obtained in the fog scenario revealed a high usability of the ICT-based training. In a situation where the given conditions are difficult to obtain, simulation (or in the case of Trustonomy, extended e-learning) makes it possible to combine theoretical knowledge with the expected response. Studies have shown that drivers who received semi-practical training performed better during the fog (low-visibility which affects system performance) scenario. Their reactions were more adequate than those of the other participants.

The proposed e-learning course allows for easy updates and the relatively low cost of producing many different versions. It should be noted that with the rapidly evolving technology, the systems implemented in vehicles may change several times within one generation. The changes may concern the driving characteristics, message location, message type and pictogram. Bearing in mind road safety, providing drivers with access to up-to-date knowledge (corresponding to the vehicle operated) is one of the main factors with the potential to reduce accident rates.

On the other hand, online trainings are easily accessible, meaning their completion does not require advanced equipment, only a computer or smartphone. The course can be held at any time to suit the schedule of the day and

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obligations. An additional advantage of this type of training is the possibility of periodic repetition without additional financial effort (as long as the login details remain unchanged).

2.3 Key recommendations - guidelines

At the moment, the training process has not kept pace, not only with the technological development of vehicles but, above all, future drivers are not gaining the necessary knowledge about mandatory vehicle equipment. The curriculum should include new technologies that influence driving, the most important being navigation devices, adaptive cruise control (ACC), lane departure warning and lane keep assist systems, etc. Proper use of these systems significantly improves road safety, while lack of training in their use can lead to dangerous situations or to abandonment of their application. What is also important, periodic trainings should be introduced mainly associated with vehicle change. For this reason Trustonomy consortium suggests to make use of online simulation-based training courses. They ensure satisfactory results of the driver-system cooperation efficiency, by precisely defining the operating principles, requirements and limitations of the system, and above all thanks to the possibility of gaining new skills in a safe and realistic environment. On the other hand, the solution is accessible and easy to use (intuitive). No advanced technology is needed to complete the course, the driver can do the training at any time and place.

At the same time, the consortium suggests that the EU should pay attention to the need to standardize the principles of operation of assistive systems, and introduce the necessity to provide ICT-based training materials to buyers (including older vehicles so that buyers from the secondary market can familiarize themselves with the materials for their vehicle).

It is also necessary to enforce the course and complete the knowledge test after the training. In this regard, the consortium proposes to introduce a requirement to undergo supplemental training if one changes vehicle's level of automation or to switch to a different automated vehicle. The lack of unification in the operation of systems and HMIs (see section 3) means that the driver, when changing the car, may not be able to safely operate similar systems of a different brand. Only a good knowledge of the automation features and their limitations can reduce the number of accidents on the roads. Aviation market experts came to a similar conclusion many years ago, where process automation and correct message understanding play a key role, and pilots are regularly trained.

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3 HMI design guidelines

3.1 Challenges

A human-machine interface (HMI) is a fundamental component of a device that enables and handles human-machine interactions. It could comprise an **input** (e.g. buttons, knobs, control systems) or **output device** (e.g. displays, speakers) or a device that provides **both** to the user (e.g. touchscreen). The term HMI or user interface encompasses "all components of an interactive system (software or hardware), that provide information and controls for the user to accomplish specific tasks with the interactive system" as defined by ISO 9241-110 [8].

In the automotive industry, there is a rapidly increasing research interest dedicated to the development of autonomous vehicles. Thus, designing advanced HMI technologies that enable smooth interaction between the driver and the vehicle could prove to be vital. For a long time, automotive HMI design was mainly determined by technology-related factors. Safety awareness-raising however, forced different approaches in order to address human factors and road safety challenges. The limited amounts of information that can be handled by the driver and road safety issues have forced moving from technology-centred and feature-driven approaches to human-centred design approaches. This change necessitated different concepts of the automotive HMI design, focusing on the cognitive ergonomic criteria used as design principles and assessment factors, as well as different approach to the design process, assuring user involvement [9]. The huge push towards automated driving functionality which appeared in the last few years, brought yet more challenges for the automotive HMI design [10].

The EU General Safety Regulations [11], that have come into force in 2022 introduces a range of mandatory advanced driver assistant systems to improve road safety and establishes the legal framework for the approval of automated and fully driverless vehicles in the EU. The new safety measures are said to help better protect passengers, pedestrians and cyclists across the EU. The directive introduces new types of systems necessary to obtain approval, while focusing on the technical requirements for the operation of individual systems. The regulation, however, does **not address the problem of unifying warnings** appearing during the use of systems, focusing mostly on the accuracy and error rate of such systems. Currently all manufacturers are allowed to use their own set of warnings. This means that a change of vehicle may result in a misunderstanding of the signal (warning). **Manufacturers are free to choose the pictograms of icons used to inform the driver about the danger**, i.e. about the need to take control. Most of them use only visual messages, while ignoring the advantages of combined visual-audio and visual-haptic modalities. The icons used are of different shapes, sizes and locations. Therefore, when changing the vehicle, the driver may not know where to look for information about the system status, which therefore causes a high risk of an accident.

Although the ISO Technical Report from 2005 [12] covering the experimental experiences about the efficiency and acceptance of different modalities and combinations of warnings, provides recommendations on visual, auditory and tactile warnings, the UN Regulation No. 157 [13] introduced haptic signals in the automated vehicles. The law adopted by the World Forum for Harmonization of Vehicle Regulations refers mainly to the content and timing, stating that the following information shall be indicated to the driver:

a) the system status,
b) any failure affecting the operation of the system with at least an optical signal unless the system is deactivated (off mode),
c) transition demand by at least an optical and in addition an acoustic and/or haptic warning signal. At the latest 4s after the initiation of the transition demand, the transition demand shall: (i) contain a constant or intermittent haptic warning unless the vehicle is at standstill; and (ii) be escalated and remain escalated until the transition demand ends.
d) Minimum risk manoeuvre by at least an optical signal and in addition to an acoustic and/or a haptic warning signal,
e) Emergency manoeuvre by an optical signal.

The Regulation describes optical signals as the ones that shall be adequate in size and contrast and acoustic signals that shall be loud and clear. Lawmakers do **not provide any specific information on the signal itself**. The regulation does not address the issue of the key factor of road safety, which is the human factor, meaning in this context the ability to correctly understand the message transmitted by the HMI. **None of the regulations currently in force introduces the need to first test the signals in terms of triggering the expected driver reactions**.

3.2 Trustonomy course of research - Key lessons learned

The vision of Trustonomy regarding HMIs is to design and develop an HMI assessment framework, able to assess different HMIs. An appropriate and comprehensible HMI should assist in a successful and smooth transition of driving control, maximizing user trust and acceptance. The framework aimed for studying the effects of different HMI designs, including visual, auditory, haptic, timing and content factors, on driver intervention performance across all related levels of automation (L3-L4), as well as on keeping the human driver aware of the ADS state and reliability".

The HMI assessment framework ambition was to develop a set of approaches and software tools capable of acquiring subjective and objective measurements to assess driver performance, in the context of physical and cognitive load, and ADS state awareness. This holistic approach is accomplished by two separate modules that work independently, but in conjunction to provide a complete assessment of driver – HMI interactions.

More specifically, the first module undertakes a time-based approach to assess driver performance, distraction, and physical and cognitive load when interacting with different HMI designs. These include haptic, auditory warning systems or a combination of visual and auditory/visual HMI systems. These HMI designs would provide information to the drivers in the form of warning messages, during urgent driving conditions and when a Take – Over Request is demanded. Also, these HMI devices should always display and update the vehicle's automation status. The ability to regain control of the autonomous vehicle at any time should be studied and the driver should give feedback to the system if he/she is ready to take over. The user's experience and assessment score of the efficiency of the take-over procedure and level of awareness should be taken into consideration using dedicated questionnaires.

The second module aims to create an ergonomics software tool for the assessment of different HMI designs. The main ambition was to evaluate ergonomic indices in a virtual setup, using digital twins of the HMI design, the driver anthropometry and recorded motion of the user interactions. This evaluation is performed based on available HMI guidelines, and biomechanics, for estimation of the driver's musculoskeletal system's fatigue. In this regard, a virtual model that combines the proposed HMI design and a representative human musculoskeletal model in the driver's position were implemented in a neuromusculoskeletal modelling and simulation environment.

As the importance of ergonomics was raised a couple of times by different normalization bodies, issuing specific standards, e.g. ISO 9241-110 [8]. This factor affects not only the comfort of the driver, but also his reaction times.

ISO 15008:2017 [14] specifies minimum requirements for the image quality and legibility of displays containing dynamic (changeable) visual information presented to the driver of a passenger car by on-board transport information and control systems used while the vehicle is in motion. These requirements are intended to be independent of display technologies. The document is applicable mainly to perceptual, and some basic cognitive, components of the visual information, including character legibility and colour recognition. It is not applicable to other factors affecting performance and comfort, such as coding, format and dialogue characteristics.

ISO/TS 16951:2020 [15] provides formal procedures and methods for determining the priority of on-board messages presented to drivers of road vehicles by transport information and control systems (TICS) and other systems. It is applicable to the whole range of in-vehicle messages, including traveller information, navigation, travel and traffic advisories, "yellow pages" information, warnings, systems status, emergency calling system information, and electronic toll/fee collection, as well as to messages from the telephone.

ISO 2575 [16] provides information about color-coding of either correct operation or malfunctioning of the related devices.

Regarding audio warnings, ISO 15006:2011 [17] establishes ergonomic specifications for the presentation of auditory information related to transport information and control systems (TICS) through speech or sounds. It applies

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primarily to the use of auditory displays to the driver when the vehicle is in motion, but it may also be applied when the vehicle is stationary. It presents a set of requirements and recommendations for in-vehicle auditory signals from TICS, and provides characteristics and functional factors for maximizing auditory signal intelligibility and utility while helping prevent auditory or mental overload.

All the above-mentioned standards refer to the technical requirements for signals (e.g. colour, quality, loudness), but none of them refer directly to signal intelligibility. There are methods for determining comprehension, incl. Comprehension Test (ISO 9186 [18]) that could be used by manufacturers to evaluate the effectiveness of the proposed HMIs. Trustonomy made use of the test, by adapting it and incorporating in the testing methodology.

In the time-based approach, the effectiveness of individual HMI solutions was measured using both objective and subjective measures. The methodology is mainly based on comparing the response parameters for individual HMIs, complemented by additional subjective support measures based on the concept of the degree of message comprehension, perceived utility and the level of task load declared by the participants of the study. Trustonomy has succeeded in developing a methodology for assessing HMIs that is independent from the platform type (i.e. vehicle) burden and modalities, but uses sophisticated equipment to measure driver and vehicle related data. The methodology takes into account the distraction of the participant by engaging in an additional task (not related to driving). Therefore, it can be successfully used for research on HMI implemented in vehicles with various degrees of automation, i.e. wherever the need to take control may occur.

The subjective evaluation module can be partially used independently, i.e. without testing on a real solution, in order to optimize the development of HMI design, early detection of errors (e.g. illegibility of icons, difficulty in understanding the message) and introducing temporary corrective actions. Therefore, the methodology is suitable to assist the process of designing HMIs for use in automated vehicles. The results of the analysis show the characteristics of the pictograms with the greatest potential to evoke the correct driver reaction.

During the pilot studies, the methodology was applied to evaluate several different HMIs:

- 4 in ITS (P1): audio-visual, visual, visual-haptic, personalized audio, 3 different icon pictograms, two icon locations (dashboard, HUD),
- 2 in Solaris (P1): both audio-visual with different icons,
- 2 in UGE (P2): visual with dashboard location and HUD display, same icons.

In all cases, the methodology proved successful in determining the effectiveness of the HMI solutions, their impact on driver response and cognition.

When analysing reaction times obtained in the ITS laboratory it turned out that fastest mean reaction time and also the lowest standard deviation were obtained by participants who were warned via audio modality. Those drivers took control 0,17 s faster than average. Surprisingly, personalized audio group (drivers were setting warning signal before driving) reacted a lot slower than expected – 0,1807 s slower than the average value and 0,3522 s slower than if warned by a pre-set signal accompanied with hands-on-wheel icon displayed on the full instrument cluster. The obtained results revealed that <u>audible modality as a single method is potentially not as effective as visual+sound combination, even if the driver is allowed to choose the warning intensity.</u>

Participants were also asked to choose the best location of RtI-informing icon. The largest number of drivers believe that displaying the icons on the entire screen of the instrument cluster is the best way to give a visual warning of the need to take control (46%). About a third of the participants pointed to the windscreen display (HUD), while the small icon on the instrument cluster was rated the lowest.

When it comes to the preference of use, respondents rated HUD-based HMI design to be the one they would like to use best (Figure 4). The results show also that the solution has potentially the same number of supporters as opponents (only 13% of people did not choose the extreme answer). The audio interface (pre-set warning signal & ”hands-on wheel” icon displayed on the full instrument cluster) received the most "average" votes (56%). In the case of the haptic interface (vibration of the driver seat & ”hands-on wheel” icon displayed on full instrument cluster), there was no significant difference in the number of votes per tier.

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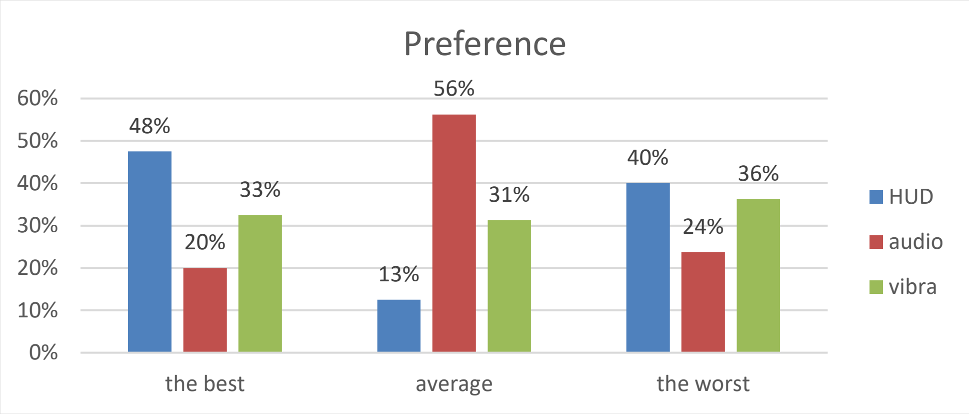

Figure 4 User expected preference in using HMIs.

Selected comments from participants:

- *"I feel the vibration of the chair the most";*
- *"In the first one* (HUD)*, I would change the icons because of the colours. The orange one on the windshield can blend in with the surroundings, the road, the colour of the soil, so I would prefer to have it on my dashboard. It can be, and even should be, big, like the other one here* (full screen)*. I would put the one with hands on the front glass. It would be more visible there. Short sounds in the car are not valuable because they may not be noticed, for example due to the noise outside the open window or the playfulness of children in the car or music from the radio. Vibrations? It depends on the degree of sensitivity/reactivity of the driver (some are "thick skinned") or the thickness of the outerwear, e.g., in winter.";*
- *"I'm afraid that I may not hear the signal when the radio is on";*
- *"Vibration would be best if connected with a HUD display and with sound";*
- *"when distracted vibrations allow for quick reaction".*

3.3 Key recommendations - guidelines

Taking into account the above results and the results of conducted surveys, the best HMI according to respondents consists of:

- intense colour (orange or red) hand wheel icons displayed on the HUD,
- a sufficiently intense vibration of the driver's seat (but not too much so as not to scare him).

Therefore, the Trustonomy consortium recommends putting more emphasis on introducing tactile warnings, especially in the context of automated vehicles, in which drivers may not have full situational awareness and there might be a need to quickly shift attention. We foresee seat vibration as an effective communication channel, because it is very rarely used as a warning signal in vehicles and there is a possibility to build a new habit: seat vibration -> intervention required. We also recommend conducting more research on this modality in order to set requirements for the most-efficient seat vibrations that can be associated with warning.

Regarding visual signals, Trustonomy suggests sticking to the ISO 2575 coding [16], as it has been already sufficiently incorporated and drivers may clearly understand system status by correct colour-coding. We also suggest putting more emphasis on regulating the location of the icons, especially the icons warning about the need to take control. It is suggested that such warnings be easily visible and large, e.g. on a full instrument cluster or on the HUD. Additionally, attention should be drawn to the necessity to introduce testing of new icons using standardized tools as a compulsory factor, considering that the result of such analysis might be a valuable input for vehicle approval.

Moreover, besides issues raised above, the consortium appeal to the EU to give special consideration to the implementation of regulations regarding icon location, size, shape, type of audio signal or vibration. The

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standardization of warning signals in automated vehicles has a great potential to reduce the accident rate, because expectancy plays a big role in warning recognition. All drivers have certain expectations, which are based on their exposure to practices in traffic engineering, and influence their behaviour. Conversely, if a system or an interface does not work according to the believe in the way it is configured, the result can be annoyance, errors, prolonged time required for planning further actions. Good HMI designs should therefore make intuitive sense to the driver, be easily learned and recognized, and above all, correspond to the prior experience.

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4 DSM testing in simulated environment

4.1 Challenges

In order to prevent dangerous situations on the road and build enough trust in automated vehicles the driver's availability to intervene has to be evaluated, through continuous Driver State Monitoring (DSM). The DSM collects observable information about the human driver in order to assess the driver's capability to perform the driving task in a safe manner. With the development of Highly Automated Driving, these systems gain more relevance due to the need for understanding and adjusting to the driver conditions. The need to monitor occupant status has been recognized by regulatory and standardization bodies, as reflected in relevant documents and regulations. The EU General Safety Regulations [11], which have recently come into force, make it mandatory for all new vehicle types to impose safety features to assist the driver, including attention warning in case of driver drowsiness or distraction. These features will be mandatory for all new vehicles starting in 2024. Another example is EuroNCAP, which in its assessment protocols places a great emphasis on driver state monitoring [19].

Driver state monitoring systems can measure different modalities, but the most commonly they constitute a camera-based systems that estimate driver focus and psycho-physical state based on several factors related to gaze vector, eye movements and blinking (much like humans do). This is very informative, as there are known methods (e.g., PERCLOS, blinking rate) to use visual data to detect distraction or drowsiness. However, camera-based systems must process what they see, and the most efficient methods of vision processing involve machine learning techniques. This is both strength and a weakness. On the one hand, the machine/deep learning approach provided excellent results in pictures segmentation and classification of the features. On the other hand, Deep Neural Network (DNN) require vast and various data sets to be sufficiently sensitive to environmental conditions modifying input (such as light, which can change dynamically during driving) and subject-specific features (such as ethnicities, anthropometry, or obscuring objects such as sunglasses or surgical masks). DNNs can be trained to cope with these challenges. Unfortunately, what is nowadays called "AI" is not very good in automatic generalization yet – for example, if a deep learning-based system is supposed to handle different ethnicities, it must be trained to recognize patterns specific to each of them.

Very similar problems arise when we consider validation or testing of driver state monitoring systems. A DSM introduced to detect the drowsiness of a Caucasian male will not necessarily be able to do the same for an Asian woman. The same goes for coping with environmental conditions – training or testing data must include ambient light, shadows, and occlusions. For example, the upcoming version 10.0.1 of EuroNCAP Safety Assist protocol "Safe Driving" (January 2023)[19] defines quite precisely a range of different variants of factors to be included in the dossier from the OEM describing a detailed technical assessment of DSM system. This range contains, among others different types of drivers (including factors like age, sex, stature, skin complexion and eyelid aperture), occlusions (lighting, eyewear, facial hair, hand on the wheel, facial occlusion, eyelash makeup), as well as different driver behaviors (eating, talking, laughing, singing, smoking, sneezing, etc.). All of this, combined with a set of driver states to be recognized constitutes a huge set of different permutations to be considered in the process of testing DSM systems. Therefore, considering a broad spectrum of conditions requires horrendously sized data sets, especially if one plans to reach the robustness level required by automotive standards. That means many thousands of hours of driving and data recording, followed by time-costly data labeling. Due to the cost and stringent time constraints, many automotive projects challenge organizing extensive studies with volunteers. Although test campaigns collect more valuable data representing a more comprehensive range of cases, DSM performance may vary when vehicle users deviate from the test group.

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4.2 Trustonomy course of research - Key lessons learned

One of the objectives of the Trustonomy project was to develop a DSM assessment framework (DSMAF) to evaluate the performance and consistency of DSM systems at their State-Of-The-Art. It was decided to focus on camera-based systems, as the most popular. The framework was tested using 2 examples of DSM systems:

- Video-based DSM, developed using AI image processing techniques, to track driver's hands, head pose and distraction when using objects, such as smartphones, while driving,
- Video-based Android application to detect eye and mouth to track drowsiness levels.

One of the issues identified during the creation of the framework methodology concerned the collection of an adequate amount of data. Development and testing of DSM systems require proper, well-annotated ground truth data, covering a vast range of driver behaviors. To achieve a high level of accuracy, keeping the level of false positives (false alarms) as low as possible, it is extremally important to include edge case scenarios – non-typical, rare situations challenging DSM algorithms. The problem with such scenarios is, that they are rare, and – most often – related to dangerous situations. Recording such scenarios requires arranging complicated tests. It requires a lot of effort, especially concerning the fact, that DSM should cover different groups of drivers, of different ages, different ethnicity, etc. When considering other factors, like obstructing objects like glasses or face masks, different lighting conditions, DSM camera location and parameters, a number of permutations become irrational. This is an excellent proving ground for a computer simulation technique.

Computer simulation enables researchers and engineers to observe the natural world digitally. They can better understand the functioning of complex phenomena and thus draw better conclusions and eventually build better products. The simple reason behind it is that when they have a "piece of reality" in a digital form, they can do virtually a lot of testing that is typically very expensive. Computers and virtual reality have limitless patience and no limits on errors. Behind the graphical representation (visualization) of a computer-simulated object, there are typically complex numerical formulas describing its physical or biological properties. Creating a simulation model of an object and finding optimal formulas for it often takes years of research, analytics, laboratory testing, and then ongoing improvements and fine-tuning. And the result is a "piece" of our world in a digital form or, as nowadays named: a digital twin. And finally, a simulation model is a scene representing a real-life phenomenon with the digital twins as actors interacting with each other following the rules of physics.

While simulations approximate reality, they will always give the same output for the same set of initial conditions, which are fully controllable. The simulation scenario is designed, while real-life data are random, uncontrollable events. No one can tell when (and if) a meaningful event will be recorded, when (and if) it will repeat, and how well it can be understood based on the records. There is no such problem with simulations, which, combined with the automated ground-truthing and labeling of the data, makes virtual models so attractive.

To be used as valid research and engineering tool, every simulation must achieve an adequate level of fidelity. This issue is related to various aspects, such as photo-realistic rendering, and physics-based simulation of DSM sensors. One of the key aspects is related to simulated driver behavior in the test scenario. The movement of different parts of the driver's body plays a crucial role in DSM algorithms. Tracing of eyelids and mouth movements is typically one of the key aspects of drowsiness recognition. Detailed head and hands poses are used to classify distraction. Recognition of pupil and iris movements on the contrasting sclera is extremely important to estimate gaze direction which is important in virtually all aspects of driver monitoring. At the same time DSM accuracy may be highly influenced by overall movements, including facial expressions. Therefore, obtaining reliable driver behavior data is one of the crucial aspects on the way to achieving a satisfactory level of simulation fidelity. And one of the best ways of achieving the most realistic driver behavior scenarios is to capture the motion of real drivers. Although the most reliable data can be obtained by recording drivers in real vehicles moving in real road conditions, considering safety issues this is extremally difficult in case of distraction, not mentioning drowsiness situations. One of the best solutions, which was applied in the Trustonomy project, is to use a vehicle simulator. By creating a proper simulation scenario, desired behaviors can be forced, without the safety concerns of the real vehicle.

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The AS1200-6 passenger car simulator (Figure 5), which was used in the Trustonomy project is a high-fidelity device designed for examining the impact of various types of dysfunctions (e.g. fatigue) on the ability to perform the driving activity. The simulator may be utilized to practice driving skills in difficult road conditions, and due to advanced measurement capabilities, it is suitable for conducting infrastructure research, creating driving models and reconstructing road accidents, leading to a significant impact on safety. Extensive simulator software allows projection of several road objects simultaneously and imitation of driving on hundreds of kilometers of virtual roads, in various atmospheric and road conditions, such as rain, wind, snow, reduced grip surface, fog, night or day, in any combinations.

Figure 5 AS1200-6 passenger car simulator.

To record parameters describing driver's behavior SmartEye internal monitoring system was used. It consists of 3 near-infrared (NIR) cameras and 2 NIR light sources, all mounted in the simulator cabin, in the dashboard area. Signals from these cameras are processed by a computing unit and transferred to an external computer. Based on image recognition, the system can extract various information describing the driver's movement, in particular:

- driver's head pose (3 DOF position, 3DOF rotation),
- gaze direction,
- eyelids positions.

Driver movements were also recorded using separate video cameras, which enabled the extraction of additional data by using image recognition and tracking techniques (Figure 6).

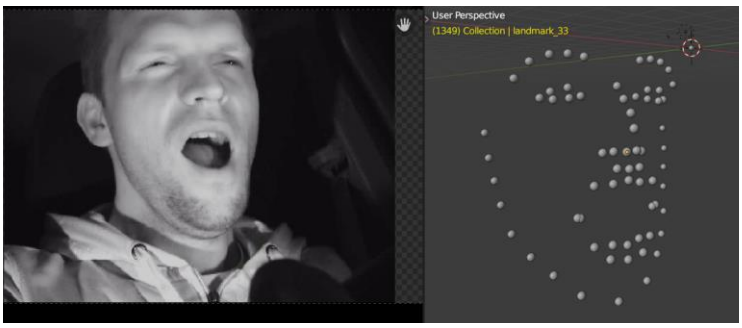

Figure 6. Source image and 3D landmark layout as a result of motion capture algorithms

To create simulated DSM training data, custom software based on the Unreal Engine [20] was used. It is a simulation software developed to facilitate the development of DSM systems by providing simulated testing data. Simulated scenarios are based on data recorded during trials on a vehicle simulator, providing realistic driver behavior. This behavior is converted to an animation sequence of the simulated human model. Software is highly configurable, allowing to tailor the simulation to individual requirements, by modifying the following aspects:

- Different driver/occupant models;

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- Occluding objects such as glasses or face mask;
- Different vehicle interior models;
- Different lighting conditions;
- Custom DSM camera models, to match simulated sensor, working in visible light (RGB) or near-infrared (NIR);
- Custom NIR illuminators;
- Parameterized camera position.

Since it harnesses all the advantages of computer modeling for DSM development, the idea behind the software is relatively straightforward – it simulates selected behavioral patterns related to driver's distraction and drowsiness in a realistic way. Then, it alters the simulation setup related to aspects such as driver model, or sensor location to create large datasets of differently looking drivers in a different psycho-physical state. Finally, it uses sensor models (visual and NIR cameras) to capture data for state assessment algorithms. Simulation can also provide automated data labeling and ground-truth information about important factors, such as gaze vectors, eye/pupil dilation, or PERCLOS, making all synthetic datasets use-ready for AI training or system validation. In the end, it supports the development process by reducing the need for real-life data, thus helping to bring the product to the market faster, more robust, and at a lower cost.

Figure 7 Trustonomy results: image from DSM camera (left) and simulation result (right).

One of the results of works on the DSM assessment framework within the Trustonomy project was a demonstration that simulation can be successfully used to test different DSM systems. The real scene was successfully recreated in the simulated environment (Figure 7). Driver behavior in the test scenario was recorded during research in the vehicle simulator and transferred to the simulation environment. Simulated data were successfully passed through the DSM algorithm and imported into the DSM assessment framework (Figure 8), allowing the evaluation of DSM accuracy.

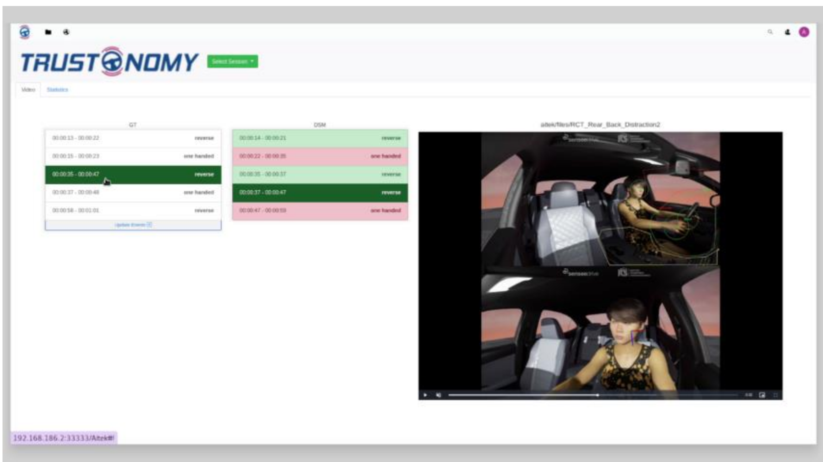

Figure 8. DSM Assessment Framework using input data from simulation

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It is important to highlight that computer simulation can be used to test DSM systems trained on real images. The DSMs tested during the project, based on CNN to detect driver distractions, can be used also to process virtual images. Such virtual images, coming from the synthetic driving session, can be loaded on DSMAF, can be processed and analysed to detect driver distraction and therefore used to assess different processing algorithms.

Thanks to the synthetic scenario generator, it is possible to automatically generate well-labelled ground truth (GT) data associated with each driving session. The DSMAF strongly relay on labelled GT to assess the performance of the DSM under test. Unfortunately to collect such data is a time-consuming activity that requires external software or a huge manual effort in post-processing. Furthermore, thanks to the synthetic scenario generator, a plethora of different driving sessions can be simulated to have a large amount of data for robust DSMs evaluation and assessment.

4.3 Key recommendations - guidelines

Using computer simulation in DSM testing may be highly beneficial, as demonstrated in the Trustonomy project. Simulation makes it easy to generate input data for each DSM system with different sensor parameters and locations in the vehicle cabin containing exactly the same driver in the same conditions with the same behavior. This means, the accuracy of each system can be assessed using recordings from the same situation, which would be impossible when recording data in a real vehicle or even a car simulator. What's more, simulation can be easily modified to change aspects such as lightning conditions, occluding objects (e.g. eyewear, facial hair, hand on the wheel, eyelash makeup), type of driver (e.g. age, sex, stature, skin complexion). All this can be done in combination with different driver behaviors, such as eating, talking, laughing, singing, smoking, sneezing, using a cell phone or even falling asleep. This results in the development of a huge database of different variants. Since these variants represent exactly the same conditions for each DSM to be tested, it is possible to perform a detailed comparison of a large variety of different aspects. To ensure a high level of scenario fidelity, driver behavior represented in the simulation should be based on real data recorded with real drivers. Using a vehicle simulator for this task makes it possible to arrange even dangerous situations in a completely controlled way.

According to the authors, using computer simulation for DSM testing is a good way of improving automotive safety and it should be considered to initiate activities to treat it as a valid testing methodology.

5 Conclusions

Trust is fundamental to many everyday activities, and is especially critical when two situational factors are salient [10]: where there is uncertainty (risk) and also incomplete product information (information asymmetry) [21]. Trust has been identified as a key factor influencing reliance on automation, and in particular in determining the willingness of a human operator to rely on automation in situations of uncertainty [22].

A general definition of trust was proposed by Mayer, Davis, and Schoorman (1995) [23]: *"the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (p. 712).* Using this definition, the "party" within the context of the Trustonomy framework could refer to either the HMI with which the user directly interacts or the "hidden" aspect relating to the trust put in the system designers. In Trustonomy therefore, we define trust as being not only relevant to the HMI, but to all ADS components, as well as to the perceived designers.

The challenge is to design ADS which are trusted appropriately: drivers have to trust it enough to glean all the promised benefits of, for example, traffic efficiency. On the other hand, over-reliance on automation is also not desirable and may lead to situations whereby drivers cognitively distance themselves so far from the driving task that they encounter difficulties in the transition periods.

All activities undertaken in the Trustonomy project contributes to building trust and acceptance in the adoption of CAD. Based on the research, several good practices and recommendations have been formulated in order to facilitate the implementation of automated vehicles on European roads. In general, drivers have a high level of trust in AVs (Kircher, Larsson, Hultgren, 2013 [24]), but the trust is fragile and tends to decrease after drivers experience automation failures (Blanco et al., 2015 [25]).

The vision of the Trustonomy project was to provide different solutions that show a great potential for improving trust in automation, either by helping to eliminate potential design failures at the early stage of component development (assessment frameworks), by addressing impediments to technological progress (emergency trajectory planning, intervention assessment) or by raising social awareness on the topic of automation (novel training curriculum, trust and acceptance). The consortium would like to therefore highlight the importance of taking into consideration recommendations presented in this deliverable, asking superior bodies to introduce new regulations addressing the above-mentioned suggestions. We believe that their implementation will have a positive impact on the improvement of safety on European roads, and will also facilitate the process of transition from non-automated vehicles to autonomous mobility

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Glossary

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADS	Automated Driving System
AI	Artificial Intelligence
ASR	Acceleration Slip Regulation
CAD	Connected Automated Driving
DIPA	Driver Intervention Performance Assessment framework
DNN	Deep Neural Network
DoA	Description of the Action
DOF	Degree of Freedom
DSM	Driver State Monitoring
DSMAF	Driver State Monitoring Assessment Framework
ESC	Electronic Stability Control
EU	European Union
GT	Ground Truth
HMI	Human-Machine Interfaces
HUD	Head Up Display
ICT	Information and Communication Technology
ISO	International Organization for Standardization
NIR	Near-Infrared
PERCLOS	Percentage Eye Closure
RtI	Request to Intervene
TICS	Transport Information and Control Systems
UN	United Nations
VR	Virtual Reality

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