BRAVE

BRidging gaps for the adoption of Automated VEhicles

No 723021

D7.3 Publication of BRAVE Guidelines

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Abstract

Throughout the course of the BRAVE project, numerous results and recommendations have been issued, to contribute to the development of the acceptance of automated vehicles. Those guidelines have been issued in various forms, in public deliverables, news, conferences and various dissemination actions. This deliverable summarizes the main contributions and guidelines, in connection with the project objectives.

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Executive summary

The main objective in BRAVE is to improve safety and market adoption of automated vehicles, by considering the needs and requirements of the users, other road users concerned (drivers and vulnerable road users) and relevant stakeholders (i.e. policy makers, standardisation bodies, certifiers, insurance companies, driving schools), assuring safe integration of key enabling technology advancements. The project activities are organized around 5 main objectives:

- Conduct a multidisciplinary study of the requirements and expectations of drivers and other stakeholders regarding the use of automated vehicles (social, economic, safety and ethical considerations).
- Develop innovative Human Machine Interface-paradigms based on the conclusions of the multidisciplinary study in order to bridge the gap between users and automation technologies.
- Enhance current Advanced Driving Assistance Systems by the inclusion of new predictive algorithms to increase the accuracy of vehicles and vulnerable road users' paths prediction to reduce the reaction time in emergency manoeuvres.
- Guarantee system robustness and reliability under any possible scenario and condition.
- Evolve validation protocols and propose advancements on the regulation or consumerist assessment.

During the course of the project, major results have been achieved. The outcomes of BRAVE activities have led to progresses for the scientific and industrial know-how. To date, the main outcomes have been published and fully detailed in various deliverables, publications and communications dedicated to the scientific and industrial community. The main outputs of the project include a literature review (on the acceptance and road safety, ethical, legal, social and economic implications of automated vehicles), a population and an stakeholder / expert survey on acceptance, technical developments (HMIs, drivers monitoring tools, pedestrian and vehicles tracks prediction, etc.), various testing (simulators, circuits, open roads) and users' feedbacks. The guidelines are also based on the reaction from the "Mirror Group" members - the advisory board of the project - to the developments of BRAVE.

This report gathers in a single place the main outcomes of the project presenting how the actions create a whole process which leads the consortium to the formulation of guidelines. Those guidelines are BRAVE's "Dos and Don'ts" to favour the acceptance and market adoption of automated vehicles.

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Abbreviations

AV:	Automated Vehicle
CAC:	Conditionally Automated Cars
CPLNA:	Car-to-Pedestrian Longitudinal to Nearside Adult crossing
DMS:	Driver Monitoring System
FHWA:	Federal Highway Administration
HMI:	Human-Machine Interface
MWL:	Mental workload
NHTSA:	National Highway Traffic Safety Administration
OEM:	Original Equipment Manufacturer
PES:	Personal Ethics Settings
PTW:	Powered Two-Wheelers
SA:	Situational Awareness
TOC:	Transfer of control
VRU	Vulnerable Road User

1 Introduction

The main objective in BRAVE is to improve safety and market adoption of automated vehicles (AVs), by considering the needs and requirements of the users, other road users concerned (drivers and vulnerable road users) and relevant stakeholders (i.e. policy makers, standardisation bodies, certifiers, insurance companies, driving schools), assuring safe integration of key enabling technology advancements. The project activities are organized around 5 main objectives:

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This report gathers in a single place the main outcomes of the project, for each Work Package, and presenting how the actions create a whole process which leads the consortium to the formulation of guidelines. Those guidelines are BRAVE "Dos and Don'ts" to favour the acceptance and market adoption of automated vehicles.

2 Multidisciplinary study

2.1 Objectives

The "Multidisciplinary study and specification of the road users and stakeholders' requirements" was addressed in WP2 of BRAVE, as a first layer to the project development. It focuses on the understanding of automated vehicles' acceptance from the perspective of current research literature as well as from the perspective of drivers, other road users (including vulnerable road users) and relevant stakeholders in general. A wide adoption of automated vehicles will have effects for all road users and therefore their needs, requirements, expectations, and concerns shall be met to ensure a safe future adoption of automated vehicles. A multidisciplinary research approach has thus been applied to identify the needs, requirements, expectations, and concerns of organized stakeholders and the general public in EU Member States. The research has tackled the various implications of the adoption of automated vehicles that refer to ethical, legal, and social aspects as well as to road safety and economic issues.

2.2 Main results achieved

Three main documents have been produced:

- An exhaustive **literature review**, which summarizes the scientific knowledge regarding the ethical, legal, social, road safety and economic implications of the advent of automated vehicles as expressed in the current literature. It also includes the findings of the exploration of gender issues in the acceptance of automated vehicles.
  The full content is available in the project Deliverable 2.1 (D2.1: Report on literature review[1]).
- The key **findings of an expert online survey**, with responses from relevant stakeholders, reflect the requirements of automated vehicles from the institutional level. Statements from different stakeholder groups are juxtaposed and compared.
  The full content is available in the project Deliverable 2.2 (D2.2: Report on the findings of the expert online survey[2]).
- The **findings of a population survey**, conducted among the general population, have also been issued. This is one of the key actions to include a user-centric perspective in the project, to the direct benefit of the other activities of BRAVE. The analysis of the population survey results unveils the needs, expectations and concerns on the individual level among drivers and other road users with a special focus on vulnerable road users. It focuses on social and cultural factors that shape individual attitudes and behavioural intentions towards the technology of automated vehicles. Gender issues are covered too.
  The full content is available in the project Deliverable 2.3 (D2.3: Report on the findings of the population online survey[3]).

2.3 Recommendations / Guidelines

There is no universal, valid definition to acceptance nor a single approach, but a broad range of theoretical constructs, so that it still is not certain which theoretical model fits best with the objectives of BRAVE. Studies of public opinion on acceptance and attitudes on automated driving indicate that concerns related to system failure seem to be present in the public and need to be taken into account. In its characteristic as a cross-

[1] http://www.brave-project.eu/wp-content/uploads/2018/02/D2.1-Literature-Review-V1.0-FINAL.pdf
[2] http://www.brave-project.eu/wp-content/uploads/2020/05/D2.2-Report-on-the-findings-of-the-expert-online-survey.pdf
[3] http://www.brave-project.eu/wp-content/uploads/2020/05/D2.3-Report-on-the-findings-of-the-population-survey.pdf

sectional study, the BRAVE population survey can be used as a starting point for a future regular monitoring of the attitudes of the population of EU member states towards highly automated or autonomous driving.

The guidelines presented in this section are based on three main sources of information: literature review, experts and stakeholders survey, and public online survey.

Acceptance / Trust

The literature review shows that the general level of trust in automated or autonomous driving is limited, within the reviewed studies the majority of participants were concerned that self-driving vehicles cannot drive as well as human drivers. Worries regarding system failure can also be related to trust problems. The comfort that passengers of highly / fully automated vehicles expect or what secondary task they engage in might depend on their tendency to trust machines.

The findings on the general a priori acceptance of conditionally automated cars (CACs) indicate a rather positive attitude of the respondents in the BRAVE population survey. With a relative majority, the respondents expect CACs to increase road safety as well as to be useful, easy to use and easy to communicate with. Nevertheless, a certain scepticism of the respondents can be detected e.g. when assessing the own intention to use such a car or the future interaction of the road users with CACs on the roads. The index of general acceptance of CACs reveals differing acceptance between the respondents' countries of residence, a lower general acceptance of CACs for females compared to males as well as for respondents aged 55 and older compared to their younger counterparts. The general trust in CACs is also rated as rather positive by the road users surveyed. Almost half of the respondents express that CACs will be dependable, will act reliably and that they will overall trust in CACs. The level of general trust in CACs differs between the gender of the respondents, their age, their country of residence and their main transportation mode.

The three concerns most strongly stressed in the population survey are those relating to the reliable functionality of the CAC including the possibility of system failures, hacker attacks or the take-over situation of a CAC. The unresolved question of liability in the case of a crash and the technical ability to detect the behaviour of other road users are emphasised as further possible areas of concern. Pedestrians and car drivers are often more strongly concerned than cyclists and powered two-wheeler-(PTW)-riders. In addition, females expressed concerns more strongly than males. Another issue accompanying the introduction of the CACs is its communication with other road users via external human-machine interfaces (HMI). Regarding the indication whether a CAC is in automated mode, a large majority of the respondents pleads for such a signal. The respondents also see the need for the CAC to indicate at a pedestrian crossing that it has recognised the pedestrian and gives right of way. The three most preferred options of this indication are a flashing light signal, a prolonged deceleration phase or a continuous light signal.

With regard to the different road user groups, the analysis of the population survey shows that the road user group specific acceptance of pedestrians, cyclists and riders of powered two-wheelers (PTW) – the VRUs – is lower than that of car drivers. The strongest predictors for road user group specific acceptance are personal innovativeness and general trust in CACs and thus point to the considerable importance of a predisposing attitude in the formation of acceptance. Out of eleven listed benefits, the four most expected benefits of CACs relate to safer driving behaviour: sufficient distances to other road users, better emergency braking reaction times, stricter adherence to traffic rules and more predictable driving. Two-wheelers, whether on bicycles or motorcycles, more than pedestrians and car drivers expect the introduction of CACs to have an increased positive impact on themselves as road users.

Gender issues

The results of the literature review and the population survey also clearly illustrate that males and females have distinct perceptions, expectations and concerns towards automated / autonomous vehicles. Men generally have more positive expectations regarding automated driving and also seem to be slightly more willing to purchase such systems than females and have other ideas regarding how to spend their time within self-driving vehicles. The attitude of females towards automated / autonomous vehicles is rather reserved. Compared to males, they assess their level of interest in these types of technical innovations lower, and they express more doubts about the safety of self-driving systems and a higher tendency to mistrust in such systems driving.

Findings from the population survey largely confirm results from the extant research literature on gender specific attitudes towards automated vehicle technology. In the populations survey, males reported higher acceptance of CACs as well as stronger trust. Also, in the road user specific perspective, females were more sceptic than males towards the possible interactions with CACs. This gender specific pattern also continues in questions regarding expected benefits and concerns about CACs. There, males emphasised expected benefits of CACs more strongly than their female counterparts and expressed greater concerns than men in almost all items surveyed. Interestingly, differences between males and females are less pronounced in findings of the population survey when it comes the ethical considerations. Still, different opinions on ethical issues, on possible external HMI for the communication with other road users or on legal aspects appear.

Legal aspects, data privacy and liability

Many aspects and topics related to automated vehicles are not yet regulated by law. Other implications can be related to worries about data privacy and liability. Concerns or questions include: Who is liable in an accident caused by the automated vehicle? Who has the right to access the data gathered? The uncertainty about the regulation of these issues was found to be a concern to European citizens also confirmed with findings in the population survey.

Moreover, the population survey additionally gives insights into opinions of the respondents on legal issues that come across with the introduction of CACs. The respondents tend to see the liability in case of a crash with the CAC in automated mode going to the person behind the steering wheel, then subsequently the manufacturer. A majority of the respondents to the population survey would allow the car owner and the police to access the stored data. Only about one out of ten respondents would not grant access to the data stored in the CAC to anybody. Differences between the respondents' countries of residence become apparent and indicate possible difficulties for transnational solutions. The issues of liability – who is liable in case of a crash – and privacy – who has access to the data collected by the automated car – should be regulated comprehensibly and transparent for the ordinary consumer in order to make the market launch of automated cars a success.

Road safety

The review of studies in Deliverable D2.1 concerning human-machine-interaction (HMI), transfer of control (TOC), mental workload (MWL), situational awareness (SA) and trust indicates that cars on SAE level 2 and level 3 of automation are shadowed by several issues that are problematic from a road safety perspective. Studies show that humans are not well suited for supervision tasks and therefore easily lose track of the situation at hand and intervene less well compared to being in control at all times. The road safety literature suggests a problematic pattern of issues. These concerns or issues will need to be considered if potential increases in road safety from AVs are to be realised. There is a potential for improved road safety, as long as driver behavioural adaptation – such as drivers engaging in non-related driving tasks – can be mitigated.

Regarding road safety, findings from the population survey also suggest that CACs still are not accepted from other road users and must prove their fit to the current traffic system. Two out of five road users state from their specific perspective as pedestrian, cyclist, rider of a powered two-wheeler, or driver of a conventional car, that CACs will cause problems for the other road users. Though, almost half of the respondents expect safer roads.

View of stakeholders

Organised stakeholders may, either directly or indirectly, play a role in enabling that automated vehicle technology is widely adopted in a safe and effective manner. It is thus important to include their perspective. There are different expectations on automated transport logistics between different stakeholders and different views regarding the timing of widespread implementation and adoption of automated vehicles.

The online stakeholder survey shows a strong expectation among stakeholders that vehicles with lower SAE levels will remain in traffic for 15 to 20 years and that automated vehicles will adhere to traffic rules. However, there is concern that when a SAE level 3 system is present and may be in charge of monitoring the traffic, it will be difficult to react quickly enough for humans in case of emergency. Also, stakeholders are concerned that for the foreseeable future there will be areas where automated vehicles SAE level 3 technology and driver-controlled vehicles share the same traffic area. Legal aspects are raised as needed by stakeholders and include international regulations, liability and insurance laws, as well as access to the data generated by automated vehicles and the protection of data.

Ethical implications and societal acceptance

There has been a discussion about the ethical implications of autonomous driving for some years now, mainly about ethical issues in unavoidable accident situations where at least one road user gets harmed. The literature review only allows limited conclusions, so it cannot be decided what would be the most appropriate ethical approaches for the programming of autonomous cars – there is no consensus on this in the literature – and whether there should be the possibility of individual Personal Ethics Settings (PES) for the users of automated cars. The few empirical studies on how the public thinks about the ethics settings of autonomous cars also show no clear result. There seems to be an acceptance that a car should be programmed in such a way that, in the event of a crash, as little human harm as possible occurs, but it is not clear whether many people would be willing to purchase or use a car, which sacrifices the car occupant to save someone else's life. In the future autonomous cars must make decisions that touch on ethical issues and these ethical issues have not yet been sufficiently and transparently discussed in the public. Such a discussion would be important because rules have to be drawn up here, which have to balance between the two socially important ethical principles of self-determination and safety. And the way automated / autonomous vehicles are ethically programmed will also determine their societal acceptance.

In the assessment of the ethical principles guiding the programming of the CAC, in the population survey an inconsistency becomes observable: a vast majority of the respondents agree with an (utilitarian) approach which states that in the event of a crash the automated car should behave to minimize the overall number of fatalities. At the same time, most respondents prefer to sit in a car that protects the passengers against all other road users. Further, findings reveal the preference of the respondents that the programming for crash events should be pre-set in a manner defined by regulation,,and mandatory for all CACs. Against the background of significant differences between the respondents' countries, the findings regarding the ethical considerations overall suggest that it will be challenging to find internationally uniform and universal guidelines for the behaviour of CACs in the case of an unavoidable crash.

Social and economic impacts

Regarding the social and economic impacts, many studies predict that on the one hand the deployment of automated cars will have the potential to reduce crashes, increase fuel efficiency, reduce parking demand, improve road capacity, ease congestion, and increase mobility for non-drivers. On the other hand, there could be negative externalities such as increased congestion and environmental degradation and negative effects on employment. The great uncertainty regarding if and how people will change their travel behaviour makes it hard to draw any clear conclusions regarding the social and economic impacts of automated vehicles. Thus, it is important to further investigate the possible behavioural changes that might come from the implementation of autonomous vehicles, since they will play an important role for the societal acceptance of automated vehicles.

3 Driver-Vehicle interaction

3.1 Objectives

Based on the results from the multidisciplinary study, HMI guidelines and an exemplary cockpit implementation have been developed, turning users' requirements into innovative interaction and monitoring concepts for driver vehicle interaction, in order to bridge the gap between users and automation technologies, while assuring safe vehicles handling with reduced driver attention. Those tasks where performed within the framework of BRAVE Driver-Vehicle interaction tasks.

A user-centred methodology has been applied to achieve a highly acceptable automation experience, which fosters system transparency and thus supports the user in creating a valid mental model. The interaction concept embraces take overs and makes them routine tasks, while still allowing the drivers to get involved in non-driving related tasks during automated periods. This is possible based on the driver monitoring system that differentiates among availability states, which in turn allows for HMI adaptation to increase acceptance. Different levels of visualization have been used, from paper drawings to renderings to VR visualisations and physical mock-ups connected to driving simulators. The generated concepts can then be turned into demonstrators and be evaluated.

3.2 Main results achieved

The tasks performed in relation with Driver-Vehicle interactions have concentrated on:

- The production of a **methodology for the development process** of vehicle-driver interaction and driver monitoring concepts, specifying the requirements in terms of use cases, scenarios, and success criteria.
  The full content is available in the project Deliverable 3.1 (D3.1: Development methodology report[4]).
- The iterative development of **concepts for vehicle-driver-interaction**.
  The full content is available in the project Deliverable 3.2 (D3.2: Vehicle-Driver Interaction Concept Report[5]).
- The iterative development of **concepts for driver monitoring**.
  The full content is available in the project Deliverable 3.3 (D3.3: Driver Monitoring Concept Report[6]).
- The release of **functional prototypes**, which can be evaluated during the final demonstration
  The full content is available in the project Deliverable 3.4 (D3.4: Vehicle Interaction and Driver Monitoring: Functional prototypes[7]).

3.3 Recommendations / Guidelines

A successful HMI concept for automated vehicles needs to be safe, as unobtrusive and satisfactory as possible, and intuitive to use. The main purpose of the HMI development process is to create a concept that supports drivers according to their current level of distraction and fosters high levels of acceptance and trust towards the automation. This requires advanced driving monitoring algorithms. To develop and evaluate the HMI concepts, a user centred approach must be applied. During the early phases, a great number of possible solutions can be compiled during expert and focus groups workshops. The most promising concepts may then be iteratively tested in user studies regarding safety and acceptance, which includes measures of usability and

[4] http://www.brave-project.eu/wp-content/uploads/2018/02/deliverable_wp3_1.1.pdf
[5] http://www.brave-project.eu/wp-content/uploads/2020/05/D3.2-Vehicle-Driver-Interaction-Concept-Report.pdf
[6] http://www.brave-project.eu/wp-content/uploads/2020/05/D3.3-Driver-Monitoring-Concept-Report.pdf
[7] http://www.brave-project.eu/wp-content/uploads/2020/11/BRAVE-D3.4.pdf

trust. The most successful and technically feasible concepts can finally be tested in a driving simulator or a mock-up vehicle.

The final purpose of the work performed in the BRAVE project in regard to Vehicle-Driver interaction was meant to facilitate the adoption of Level 3 vehicle automation by providing OEMs with guidelines that are general enough to allow for maintaining or integrating own developments and brand-specific elements. Nevertheless, the project consortium has created demonstrators to showcase the developments to different groups of stakeholders. A focus of the work was on designing an interaction concept that would foster trust in the automation and that would help to keep the driver in-the-loop. The latter is highly relevant, since in SAE Level 3 vehicle automation, the driver is needed as a fallback solution in case the conditions of the automations are not met (anymore), or if there is a failure in the automation system.

BRAVE HMI guidelines consist of a list of short, generic heuristics that have a broad applicability, and also a more detailed description of the BRAVE HMI concept, which represents one possible instantiation of the generic heuristics, based on the BRAVE design space. The general heuristics are:

- If the system is in control, drivers do not want to be disturbed.
- System transparency on what the vehicle does, and why, can enhance trust.
- The amount of information provided (e.g. the car's intentions) should be adjustable (e.g. depending on the driver trust and experience with the system).
- To inform the driver about the vehicle and the environment mainly visual feedback should be used.
- Auditory and haptic feedback should only be used in case a driver reaction is necessary.

The BRAVE Driver Monitoring System (DMS) has been developed with a view to providing accurate measures about the driver state, behaviour, and degree of distraction or drowsiness while acting as a supervising driver in a self-driving car. The DMS provides the means for monitoring the driver's degree of attention so that the transition from automatic to manual driving so it can be done in a robust manner.

Of the drowsiness-detection measures evaluated in our study, the measure referred to as PERCLOS was found to be the most reliable and valid determination of a driver's alertness level. PERCLOS is the percentage of eyelid closure over the pupil over time and reflects slow eyelid closures rather than blinks. The American governmental agencies FHWA and NHTSA consider PERCLOS to be among the most promising known real-time measures of alertness for drowsiness-detection systems. BRAVE's thorough evaluation of alternatives confirms this. On the other hand, for visual distraction, gaze direction is divided into regions of interest into which the driver's gaze would fall. These regions are defined beforehand and contain regions such as road ahead, mirrors, or on-board screens.

For the HMI concept developed in the BRAVE project, the system provides four levels of attention according to the driver's attention focus and possible level of drowsiness. Depending on the level of attention, a different type/level of warning alarm would be necessary. Alarm generation is an essential part of the vehicle-driver interaction concept.

4 Monitoring concepts for vehicle-environment interaction

4.1 Objectives

To turn users' requirements (outlined in the multidisciplinary study) into innovative monitoring concepts for vehicle environment interaction, it is necessary to enhance current Advanced Driving Assistance Systems (ADAS) through the inclusion of predictive capabilities for better and faster ADAS reactions in nominal and emergency situations under Autonomous Driving Mode. Specifically, this activity includes:

- Enhancing ADAS through a robust system for predictive intelligent, efficient, and safe interaction between vehicles, manually driven and automated, by providing support to human and automated drivers with a special focus on VRUs protection.
- Developing a robust VRU predictive model based on body language, motion, and contextual information.

4.2 Main results achieved

The activities related to the development of monitoring concepts for vehicle-environment interaction have led to the production of the following elements:

- Construction of a **methodology for Vehicles and VRUs prediction of intentions**, defining the variables and procedures used for learning the prediction of intentions of vehicles and VRUs, as well as for the testing and assessment phases
  The full content is available in the project Deliverable 4.1 (D4.1: Methodology for vehicles and VRUs prediction of intentions[8]).
- Creation of an exhaustive **Vehicles and VRUs database**, containing thousands of examples describing vehicles and VRUs actions in real life traffic. This database was the basis for developing the prediction systems
  The full content is available in the project Deliverable 4.2 (D4.2: Vehicles and VRUs Database[9]).
- The definition of a **model for the prediction of vehicles intentions**, and a second **model for the prediction of VRUs intentions**.
  The full content is available in the project Deliverable 4.3 (D4.3: Model for the prediction of vehicles intentions[10]) and Deliverable 4.4 (D4.4: Model for the prediction of VRUs intentions[11]).
- The development of a full **Vehicle-VRU Interaction Concept**
  The full content is available in the project Deliverable 4.5 (D4.5: Vehicle-VRU interaction concept report[12]).
- The **assessment of the effectiveness of Vehicles and VRUs prediction of intentions** for the two prediction systems developed (vehicles and VRUs).
  The full content is available in the project Deliverable 4.6 (D4.6: Assessment of the effectiveness of Vehicles and VRUs prediction of intentions[13]).

[8] http://www.brave-project.eu/wp-content/uploads/2018/02/BRAVE-DL4.1WP4-v1.0.pdf
[9] http://www.brave-project.eu/wp-content/uploads/2019/11/D4.2-Vehicles-and-VRUs-Database.pdf
[10] http://www.brave-project.eu/wp-content/uploads/2020/05/D4.3-Model-for-the-prediction-of-vehicles-intentions.pdf
[11] http://www.brave-project.eu/wp-content/uploads/2020/05/D4.4-Model-for-the-prediction-of-VRUs-intentions.pdf
[12] http://www.brave-project.eu/wp-content/uploads/2020/07/D4.5-Vehicle-VRU-Interaction-Concept-Report.pdf
[13] http://www.brave-project.eu/wp-content/uploads/2020/11/BRAVE-D4.6-v1.0.pdf

4.3 Recommendations / Guidelines

One of the most innovative parts of the BRAVE project is to endow vehicles with the capability to communicate with other vehicles that are not equipped with electronic communication devices. This involves the understanding and prediction of manoeuvres of other vehicles. A number of techniques have already been implemented to locate other vehicles on the road, detect their movements, and assess their trajectory. BRAVE builds upon them to estimate the next position of each vehicle and road user sharing the road with the ego-vehicle

Prediction of vehicles' intentions and trajectories

Current advances in autonomous vehicles and active safety systems have demonstrated autonomy and safety in a wide set of driving scenarios. SAE levels 3 and 4 have been achieved in some predefined areas under certain restrictions. In order to improve the level of safety and autonomy, self-driving cars need to be endowed with the capacity of anticipating potential hazards, which involves a deeper understanding of the complex driving behaviours corresponding to VRUs and other human-driven vehicles, including inter-vehicle interactions. Furthermore, a precise understanding of the current and future vehicle positions and intentions is needed to increase the effectiveness of AEB systems or Collision Avoidance Systems (CAS).

Consequently, BRAVE has developed advanced methods for providing accurate predictions of driver intentions and vehicle trajectories. This task is complex, given that it requires a deep understanding of the contextual situations, not only based on kinematic data. For such purpose, the dataset built in BRAVE project has been used to develop the algorithms proposed to carry out this task. Complementary to the prediction of intentions, a trajectory prediction system has also been developed.

Prediction of VRUs intentions

One of the major challenges concerning the interaction between autonomous vehicles and VRUs is to detect risky situations and react accordingly in order to avoid or mitigate collisions. Thus, an autonomous vehicle has to be capable of understanding the behaviour and intentions of VRUs as well as estimating their future motion. The problem is often treated as tracking a dynamic object by considering the changes in position, velocity, and orientation, and extrapolating the observed dynamics. However, this approach is subject to error for large look-ahead times due to the highly dynamic and nonlinear nature of VRUs motion and the diversity and unpredictability of their behaviour. Predicting the trajectory and short-term destination of VRUs is closely related to predicting their intentions.

As a consequence of this, BRAVE has developed advanced methods for providing accurate predictions of Vulnerable Road Users (VRUs) intentions and trajectories. The prediction of pedestrians' intentions has been developed in two incremental steps. In the first step, only body pose features have been considered to provide predictions in a time horizon of 1s. In a second step, a context-based approach has been developed and tested in order to extend the ability to anticipate critical situations. Such approach is based on a combination of CNN and Recurrent Neural Network (RNN), yielding very accurate results in predictive tasks.

Vehicle-VRU Interaction Concept

Automated Vehicles (AVs) need to signalize their planned manoeuvres clearly to VRU in the vicinity. BRAVE considers even direct interaction between vehicle and VRU as a requirement of Automated Vehicles. Based on literature reviews and a road user workshop it was found that participating road users consider it important to include external HMI into automated vehicles, to feel safer in traffic. Participants predominantly proposed visual cues, such as LED strips, followed by auditory cues for warnings. The exemplary BRAVE Vehicle to VRU interaction concept contains a visual cue for showing the automation mode (windshield), a frontal brake light (grill), a visualization for reflecting VRU recognition, a trajectory projection for backing out of a parking lot, and auditory warnings.

5 Experiments and testing activities

5.1 Objectives

The experiments carried out in BRAVE are building on the results from the multidisciplinary study, developments regarding driver-vehicle interaction and monitoring concepts for vehicle-environment interaction. But it also feeds back the results to them in an iterative approach, consisting of three stages. BRAVE have used an agile, iterative and incremental user-centric approach starting with existing on market systems in stage 1 providing input to user requirements (multidisciplinary study). BRAVE then continued with virtual prototyping in stage 2, first with sketch HMI concepts and then more advanced prototypes in a driving simulator and oculus rift simulated environment. In stage 3, the experiments have been carried out in real vehicles starting with advanced testing of prototypes. A final demonstration will be organized on real roads (February 2021). Since BRAVE has a focus on user requirements, the tests have incorporated not only drivers but have also focused on users outside the vehicle such as VRUs. The concepts and virtual prototypes developed in BRAVE have been tested by the use of partners testing facilities and high-tech equipment to build repeatable and measurable tests in a relevant environment.

5.2 Main results achieved

Experiments and testing activities conducted within BRAVE WP5 have produced valuable information to the benefit of the other activities of the project. Specifically:

- A test methodology has been produced at the beginning of the project, together with **use cases specifications**, study design and measures to be used in testing.
  The full content is available in the project Deliverable 5.1 (D5.1: Test methodology and use case specification [14]).
- **HMI recommendations based on virtual prototyping** have been issued (which HMI's to proceed with based on user and stakeholder requirements). A similar activity has produced **HMI recommendations based on on-road testing**.
  The full content is available in the project Deliverable 5.2 (D5.2: Results and HMI recommendations based on virtual prototyping [15]) and Deliverable 5.3 (D5.3 Results and HMI recommendations based on on-road testing [16]).
- **Recommendations on test targets and protocols** are also available, with the evaluations from all prototypes and stages, as well as a synthesis and conclusion of recommendations for evaluation and new requirements proposed to Euro NCAP and normalization and regulation working groups for methodology, protocols and equipment.
  The full content will be available in the project Deliverable 5.5 – due February 2021 (D5.5 Conclusions & recommendations on test targets and protocols).

5.3 Recommendations / Guidelines

The test sequence in BRAVE follows the V-ISO model and consists of the following steps:

- Tests of already available market systems and vehicles;
- Concept and technology development;
- Test in a simulated environment;

[14] http://www.brave-project.eu/wp-content/uploads/2018/02/D5.1-Test-methodology-and-use-case-specification_v1.0.pdf
[15] http://www.brave-project.eu/wp-content/uploads/2020/05/D5.2-Results-and-HMI.pdf
[16] http://www.brave-project.eu/wp-content/uploads/2020/10/D5.3-Results-based-on-on-road-testing.pdf

- Test in test track;
- Test in real traffic.

Virtual prototype evaluation

The “Virtual prototype evaluation” tests are conducted using human-in-the-loop driving simulators of varying fidelity, from intermediate fidelity simulators (sketch type simulators) to high fidelity full motion moving base driving simulators. The overall goal of the tests was to evaluate a variety of HMI concepts in a safe and repeatable virtual environment. The focus of the simulator tests were mainly from the point of view of the driver of a level 3 vehicle, although it considers the views of stakeholders and other road users as the HMI concepts are derived in a iterative human centred design process were these actors input have been considered.

Those activities lead to HMI recommendations to be considered during HMI design, which are the following:

- Support the driver to co-monitor the driving environment with the automated driving system in urban areas were VRU are present.
- The HMI can be used to enhance the trust in the system if it keeps the driver informed about whether, it is safe or not to attend other non-driving related tasks.
- Timely information in the HMI regarding situations where the system boundaries are exceeded has the potential to reduce automation surprises and prompt efficient take-over response from the driver.
- An adaptive HMI, preferably to both situation and driver state, could be beneficial to driver’s acceptance of the ADS.
- A DMS coupled to a categorization of risk level of other road users (especially VRUs) could support the driver to maintain in the loop, while at the same time causing less disturbance.

6 Evolutions on testing and pre-validation protocols

6.1 Objectives

One of the objectives of BRAVE is to propose evolutions on testing and pre-validation protocols and equipment (pedestrian and VRU targets), proposing advancements on the regulation and Euro NCAP assessments.

A number of use cases and configurations have been evaluated and tested with a BRAVE prototype vehicle. In addition, HMI and Driver monitoring with BRAVE concepts and tests in driving simulator have been considered. These experiences provide a basis for recommendations on enhancement of AV regulations and ratings (in Euro NCAP).

6.2 Main results achieved

The activities related to the evolution of tests and validation protocols are derived from the experimentations and testing (as shown in section 5 of this report). The main outcomes regarding this topic, part of BRAVE WP6, are the following:

- Proposals for the **evolution of existing regulations**, with explanations taken from the project activities, have been issued, and discussions engaged with the **WP29 GRRF ADAS & AD** working group.
  The full content is available in the project Deliverable 6.1 (D6.1 Regulation protocols evolution and requirements proposal [17]).
- A similar action has been conducted to provide arguments towards the **evolution of Euro NCAP protocols**.
  The full content is available in the project Deliverable 6.4 (D6.4: Euro NCAP protocols evolution or requirements proposal [18]).

6.3 Recommendations / Guidelines

To have a relevant evaluation of a car's capability to perceive, understand, predict and manage a pedestrian movement, BRAVE proposes modifications of the Euro NCAP test protocol, as well as new tests more focused on pedestrian intentions and prediction. It is recommended that a pedestrian target with more precise and defined head movements, with eyes and face, is used for Euro NCAP and homologation tests.

Furthermore, for the driver, the state of the body and the head movements need to be more precisely monitored than in today's tests, to be able to evaluate the car capability to perceive, understand, predict and manage the driver's state and intentions.

Dialogues with parties involved in regulatory and rating development working groups have been initiated. A proposal for four new tests have been identified as possible candidates for this discussion:

- Hidden pedestrian crossing with new pedestrian head articulated target;
- Vehicle crossing false-positive;
- Smooth driving proposal to better evaluate higher anticipation-lower braking decelerations;
- Pedestrian crossing after head movement and seeing vehicle external HMI (green signal).

[17] http://www.brave-project.eu/wp-content/uploads/2020/10/D6.1-Regulation-protocols-evolution-and-requirements-proposal.pdf
[18] http://www.brave-project.eu/wp-content/uploads/2020/11/D6.4-Euro-NCAP-protocols-evolution-or-requirements-proposal-V2.0-FINAL.pdf

It should also be noted that the BRAVE tests showed good results for BRAVE prototype vehicle:

- Capacities to correctly anticipate vehicle cut-in & hidden crossing pedestrian scenarios;
- No impact, lower braking decelerations (smooth driving);
- Results compared to the most recent AD level 3 OEM's development vehicles.

To have a relevant evaluation of a car's capability to perceive, understand, predict and manage a pedestrian movement, BRAVE proposes modifications of the Euro NCAP test protocol, as well as new tests more focused on pedestrian intentions and prediction. It is recommended that a pedestrian target with more precise and defined head movements, with eyes and face, is used for Euro NCAP and homologation tests.

Furthermore, for the driver, the state of the body and the head movements need to be more precisely monitored than in today's tests, to be able to evaluate the car capability to perceive, understand, predict and manage the driver's state and intentions.

Focus on recommendations to Euro NCAP

Adoption of a new pedestrian dummy by ENCAP is proposed. Not only will it give a more realistic human representation, but it would also benefit the arrival of more anticipation-oriented scenarios. One of those scenarios combines both longitudinal and crossing setups. Advanced detection meaning advanced reaction is the key rule.

Furthermore, it is proposed that consideration is given to are provided on the way test vehicles are assessed in current ENCAP protocols extend to the criterion on smoothness of driving. It will be exposed why this criterion is set to play an important part of Assisted Driving vehicles, before drawing a general conclusion on all the proposals.

In order to help progress in the development of new assessment methods for AD vehicles, the propositions given throughout BRAVE framework highlight the importance of a global evolution in testing. Evolution shouldn't only concern the equipment used – where improved dummies turn out to play a key role – but also the assessment protocols via their scenarios and grading method.

Four recommendations are to be retained:

- Firstly, the use of a fully articulated pedestrian dummy. Through the latter the representativity of a human pedestrian is improved and deeper testing scenarios could be set up in the future, especially using robotized platforms. Such an evolution could enhance the real-life relevance of future assessments.
- Secondly, the pedestrian CPLNA scenario should be the first milestone of advanced anticipation scenarios. It is based on face recognition to anticipate the pedestrian's behaviour to best react in a smooth way – assuring both pedestrians and drivers thanks to a prolonged window for reaction. This matter can pave the way for anticipation assessments.
- Thirdly, the ENCAP inspired obstructed pedestrian crossing represents an interesting evolution of what is already being used nowadays.
- Finally, it can be assumed that adoption of automated vehicles would increase if they could offer smooth and comfortable ride to their occupants, whilst dealing autonomously with exterior disruptions. Suggestions could be made for taking into account the concept of smooth driving within the assessment would allow to highlight the best performing vehicle.
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Focus on recommendations to VMAD regulation WG

BRAVE will address level 3 VMAD (Validation Methods to for Automated Driving) regulation Working Groups (in GRVA regulation body).This VMAD WG is leading the build-up of AD level 3 futures regulations, in city, roads and no standardization WG (like ISO WGs) has to be addressed. The choice of WG is further motivated by the fact that the WH for AEBS regulation is ending its work on the AEBS regulation, without including hidden pedestrian and anticipation functionalities tests and requirements.

The following four proposals will be presented by UTAC regulation experts end of 2020 (VMAD has yet not started discussing scenarios and tests for urban level 3 AD):

- New AD test proposal: Hidden pedestrian crossing with new pedestrian head articulated target. This test will be very useful to challenge OEM's to anticipate when pedestrian head is visible. This test is new, mixing two Euro NCAP scenarios CPNC-50 and CBNA-O-50 (Euro NCAP, 2018).
- New AD test proposal: Vehicle crossing false-positive. This test will be very useful to evaluate useful anticipation and useless anticipation. This test is new, but in line with AEBS 12th WG proposals (scenario 7, proposed by Japan).
- Smooth driving proposal to better evaluate higher anticipation-lower braking decelerations. Smooth driving is today mentioned in regulation work and requirements, but without method nor evaluation. BRAVE proposes to add "smooth driving" to level 3 regulation requirements and tests, to challenge OEM's to a less brutal and more smooth driving items in the automated driving evaluation.
- New AD test proposal: Pedestrian crossing after head movement and seeing vehicle external HMI (green signal).

7 Guidelines from BRAVE Mirror Group

7.1 Objectives

Transversally to the whole project, BRAVE partners have organised a structured dialogue with a number of European and international stakeholders, in order to maximise the outreach of the project. BRAVE long-term plan aims at raising awareness on project's objectives, building the project identity, brand and profile, and the activities aimed at disseminating the project results to maximise its impact. To this aim, BRAVE has established a two-way communication with key stakeholders (public and private).

An advisory board, named "Mirror Group" has been created at the beginning of the project, inviting 28 experts and stakeholders (automotive industry, end-users, drivers associations, sociological institutes, regulators and policy makers), also twinning with international initiatives through the participating international partners in the US and Australia, among others.

7.2 Main results achieved

Regular meetings have been organized with the Mirror Group. This was part of the communication and dissemination activities composing WP7 of the project. Those meetings have engaged discussions with its members (key stakeholders and experts) and provide the project partners with **recommendations and guidance** along the project to align activities to the needs and expectation of key stakeholders.

It has contributed to the reinforcement of connexions between stakeholders, thus contributing to the emergence of further initiatives regarding the acceptability of Automated Vehicles in Europe.

The full content of the discussions will be available in the project Deliverable 7.5 – Due November 2020 (D7.5: Minutes of meetings with Mirror Groups).

7.3 Recommendations / Guidelines from the Mirror Group

Along the project lifetime, Mirror Group members have provided views and guidance to the project. The main elements to be retained are the following:

Multidisciplinary study

- Regarding ADAS, it is often difficult for road users to understand clearly what they are dealing with, and to know the differences between the various levels of automation. Making video clips could help, ahead of the population survey, to make people understand the differences.
- The levels of automation are not universal. It is best to talk about a specific system, instead of a level of automation.
- Results from conducted surveys are changing a lot depending on the level of knowledge of people. This level of knowledge must be addressed both before and after the test activities to see the evolution of behaviour.

Driver-Vehicle interaction

- The project really needs to focus on the SAE level 3 if dealing with driver monitoring concepts.
- It is highly important to ensure that the project clearly talks about SAE level 3 in its communication and dissemination actions about the project. It must not talk about SAE level 4 (confusion is often made). BRAVE should not draw any conclusion on one level and then apply the same conclusion on a different SAE level.

Monitoring concepts for vehicle-environment interaction

- There are very similar issues experienced for automated ships, including communication with small crafts.
- Regarding the interactions between vehicles and cyclists, the following use-cases should be considered:
  - Cyclist avoiding pothole
  - Cyclist losing straight line of travel because of unexpected circumstance
  - Cyclist changing lanes without warning (cutting in)
  - Cyclist running against a red light in an intersection.

Experiments and testing activities

- To validate the results of the studies and test sessions if the users are not aware of the SAE level and/or have no previous experience in SAE level 2 cars, pre-experience is crucial. It must be monitored in the studies. Insight can be provided in cars to ease the understanding.
- It is important to ensure the alignment between tests and real-life, and to use the test results carefully when they are applied to real-life situations (there is a possible risk of a change in the users' behaviours)
- Automation can be surprising to the drivers or passengers. To ensure a good automation transparency, the decision-making process of a car to road users can be shown as follow:
  - External HMIs must be developed, to inform the road users that the car is in automated mode.
  - BRAVE partners have focused the actions on the prediction of intention, and no major improvements are provided regarding communication features (apart from the GRAIL system)

Evolutions on testing and pre-validation protocols

- Considering the regulation protocols: It seems that the maturity in the field is not good enough. The activities included in BRAVE might be too early, which will lower the impact of the project inputs. However, it is an important point to raise to regulation working groups.
- Activities that are most important to the industry are the links and interaction with Euro NCAP, UNECE etc. It is crucial to propose a validation protocol, including a methodology to compare the quality of different systems (not only validating basic requirements). Common criteria must be set for all systems (is the system working properly or not), and specific features should be provided to test the driver monitoring (from a similar point of view to the work done with pedestrian dummies for instance).

8 Conclusions

Major results have been achieved in the framework of BRAVE. The outcomes of the project activities have led to progresses for the scientific and industrial knowhow, with inputs on the following topics:

- Literature review and surveys on automated vehicles acceptance.
- Vehicle-driver interaction concepts
- Vehicle-VRUs and Vehicle-vehicle interaction concepts
- Evolution of validation protocols and regulation

To date, those guidelines have been published and fully detailed in various deliverables, publications and communication dedicated to the scientific and industrial community. They have also been transferred along the project to stakeholders through the Mirror Group and the project partners' networks.

The project results and guidelines detailed in this deliverable will be presented to a wide specialized audience during the final event of the project, with the objective to ensure a large uptake of the project outcomes.