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PhD thesis

Driver's behavioural adaptation to the use of Advanced Cruise Control (ACC) and Blind Spot Information System (BLIS).

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Abstract

Advanced Driver Assistance Systems (ADAS), such as Adaptive Cruise Control and Blind Spot Information System (BLIS) have the potential to increase driving comfort and to make journeys safer. However, previous studies conducted on ADAS, warned about the possibility for drivers to incur into negative behavioural adaptations to the systems. Unfortunately, the research performed on the topic often led to contrasting outcomes and, therefore, up to now, it is not possible to deliver unanimous results. In order to contribute to the progress of research, in this study, it is presented the combination of three methods to assess negative behavioural adaptations to ACC and BLIS. In chronological sequence, focus groups discussions, a naturalistic Field Operational Test (nFOT) and a driving simulator study were carried out with users of ACC and focus groups discussions were performed with users of BLIS. The results show that the users of ACC and BLIS are globally satisfied about the systems, despite some recognized functional limitations. Regarding ACC, some concern derived from the ACC users' reaction to a safety critical situation with the system activated and for the incomplete mental model relative to the system (low awareness of the critical situations that might occur with the system activated). On the other hand, concerning BLIS, the lane change does not seem to be modified by the introduction of the system but further research should be addressed to study behavioural adaptations in the long-term period.

Keywords: road safety, Intelligent Transport Systems, human factors, human-machine cooperation, mental representation.

Resumo

Os Sistemas Avançados de Apoio à Condução (ADAS - Advanced Driver Assistance Systems), nomeadamente o Controlo de Velocidade Adaptativo (ACC – Adaptive Cruise Control) e o Sensor de Ângulo Morto (BLIS – Blind Spot Information System) propiciam ao condutor condições potenciais de maior conforto e segurança. Porém, alguns estudos prévios realizados sobre os ADAS demonstraram que a utilização destes sistemas pode conduzir a adaptações comportamentais com efeitos negativos. Por outro lado, a investigação realizada e publicada apresenta resultados contrastantes e, portanto, até hoje, não é possível obter conclusões unânimes. Com o presente estudo de investigação, pretende-se analisar a adaptação comportamental dos condutores ao ACC e BLIS. No caso da utilização do ACC, foram consideradas três metodologias complementares: entrevistas de grupo, um estudo de campo (nFOT - naturalistic Field Operational Test) e um estudo em ambiente virtual, com recurso ao simulador de condução DriS. Para os utilizadores do BLIS, dadas as especificidades deste sistema, foram realizadas apenas entrevistas de grupo. Os resultados mostram que os utilizadores do ACC e do BLIS estão, globalmente, satisfeitos com os sistemas embora tenham noção das limitações. No que respeita ao ACC, é de destacar que os utilizadores têm um conhecimento insuficiente das limitações do sistema, particularmente em situações críticas, e uma representação incompleta do modelo mental relativo à utilização deste sistema. No que concerne ao BLIS, as mudanças de via não parecem ser influenciadas pela introdução do sistema mas é necessário realizar estudos adicionais de forma a averiguar modificações comportamentais no longo prazo provocadas pelo uso generalizado e sistemático deste sistema avançado de apoio à condução.

Keywords: segurança rodoviária, Sistemas Inteligentes de Transportes, fatores humanos, cooperação homem-máquina, representação mental.

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LIST OF ACRONYMS

ACC - Adaptive Cruise Control

ADAS - Advanced Driver Assistance Systems

AIDE - Adaptive Integrated Driver-vehicle Interface

BLIS - Blind Spot Information System

CAS - Collision Avoidance Systems

DBQ - Driving Behaviour Questionnaire

FCW - Forward Collision Warning

FOT - Field Operational Test

HW – Space Headway

IVIS - In-Vehicle Information Systems

ISA - Intelligent Speed Adaptation

ITS - Intelligent Transportation Systems

LCA - Lane Change Assistant

LDW - Lane Departure Warning

LOC - Locus Of Control

NDS - Naturalistic Driving Study

nFOT - naturalistic Field Operational Test

OECD - Organization for Economic Co-operation and Development

SBZA - Side Blind Zone Alert

SS - Sensation Seeking

TET - Time Exposed Time-to-Collision

TETH - Time Exposed Time Headway

TIT - Time Integrated Time-to-collision

TITH - Time Integrated Time Headway

TH - Time Headway

T-LOC - Traffic Locus Of Control

TTC - Time To Collision

INTRODUCTION

Introduction

The present study has been elaborated within the frame of the European project ADAPTATION. From a scientific perspective, the project aimed at investigating drivers' behavioural adaptation and its underlying processes over the time in response to Advanced Driver Assistance Systems (ADAS) use.

Advanced Driver Assistance Systems (ADAS) are devices that support the drivers during the primary driving task (activities undertaken by the driver to maintain the longitudinal and lateral vehicle control within the traffic environment). Among the ADAS available in the market, for the purpose of this research work, the Adaptive Cruise Control (ACC) and the Blind Spot Information System (BLIS) were selected. The ACC is a system that maintains the speed and the headway adaptively to a forward vehicle. On the other hand, the BLIS is a device that detects and warns the driver about the presence of another vehicle in the blind spots (areas located on the left and right side of the vehicle and which are not visible by the drivers through the side mirrors).

Both ACC and BLIS have the potential to make the driving task more comfortable and safer. However, previous studies conducted on ADAS warned about the possibility for drivers to incur into negative behavioural adaptations to the systems, defined as those behaviours, originated by the introduction of changes to the road-vehicle-user system and that could have negative effects on road safety. Concerning the behavioural adaptations to the systems investigated, the following results can be summarized:

- In regards to ACC, the studies conducted on behavioural adaptation to the system led to contrasting results regarding speed, headway, lane keeping and reaction to critical events and, therefore, no unanimous results can be drawn;

- In regards to BLIS, there is lack of studies that concentrate their attention on behavioural adaptation to the system and, therefore, more research should be performed on the matter.

Besides, a relevant aspect is that the research performed on ACC and BLIS mainly involved participants who never drove with the assistance of the systems before taking part in the experiments. Then, there is scarcity of studies including users of ACC and BLIS, justifying the need for further research on the topic that include users of the systems as participants.

Based on the research needs, the detailed objectives of the study are fourfold:

1. To ascertain in which driving contexts (road typology, weather conditions and road traffic situations) the ACC and BLIS users utilize the systems;
2. To discover if users of ACC and BLIS experienced any critical situations (caused by functional limitations of the systems) while driving with the systems activated;
3. To spot any behavioural adaptation to the systems, produced by the continuous usage of ACC and BLIS;
4. To understand the changes in the design of ACC and BLIS that would make them more suitable for the users.

Besides, merely for the Adaptive Cruise Control, this study explores the relevance of the driver's mental model of the system and of the trust in the ACC for a proper usage of the device. It also proposes a comparison between ACC users and regular drivers (people who never used the ACC before the study) relative to the utilization of the system. In order to fulfill the objectives of the study, focus groups discussions, a naturalistic Field Operational Test (nFOT) and a driving simulator study were carried out with users of ACC and focus groups discussions were performed with users of BLIS.

The present work is organised in four parts: at the beginning, the theoretical framework is defined, introducing the relevant concepts for the research (ACC, BLIS, behavioural adaptations, mental model and trust), the research questions and the research hypotheses. Then, the methodology is presented, dedicating a specific section for each method adopted in the study (focus groups discussions, naturalistic

Field Operational Test and driving simulator study). The third part reports the results, devoting a section for each part of the study (focus groups discussions, naturalistic Field Operational Test and driving simulator study). Besides, in the third part, the discussion, the verification of the hypothesis and the limitations of the study are also covered. Eventually, the final considerations close the document, summarizing the results achieved by the research performed and outlining some implications of the study for futher development of the systems.

PART 1: THEORETICAL FRAMEWORK

1. Intelligent Transportation Systems (ITS) and Advanced Driver Assistance Systems

Broadly, ITS is the acronym for ‘Intelligent Transportation Systems’ or ‘Intelligent Transport Systems’ and includes “several combinations of communication, computer and control technology developed and applied in the domain of transport to improve system performance, transport safety, efficiency, productivity and level of service, environmental impacts, energy consumption, and mobility” (Sitavancova & Hajek, 2009).

The implementation of ITS is extended to all modes of transport (road, rail, air, pipeline, maritime, etc.) and it is not only restricted to the movement of passengers but it includes also freight transportation. For this study, however, the attention will be limited to the applications aiming to improve safety for road passenger movement. In this context, ITS can be defined as the “road based, vehicle based, vehicle to road based or vehicle to vehicle based technologies supporting the driver and/or the management of traffic in a transport system” (Linder et al., 2007). Narrowing down to the devices installed inside the vehicle, a major distinction can be made between two sorts of systems: In-Vehicle Information Systems (IVIS) and Advanced Driver Assistance Systems (ADAS).

IVIS are systems that provide the driver with information or communications related to the trip (e.g. traffic, weather, route guidance) or to not-driving related activities (e.g. listening to radio, reading mails, conversing with phone) and, in this category it is included equipment like navigation system, the radio and the mobile phone. Some of those devices (e.g. the navigation system) if properly used, might guarantee that driver’s workload and stress can be reduced in critical driving conditions (Brusque, 2007).

Concerning ADAS, the acronym relates to assistance systems supporting the drivers in the primary driving task (activities undertaken by the driver to maintain the longitudinal and lateral vehicle control within the traffic environment); these devices, conversely to IVIS, actively stabilize or manoeuvre the car but without taking over the task completely, leaving the responsibility always to the driver (PREVENT, 2006).

Despite the straightforward definition outlined above, a clear and official division between IVIS and ADAS has not been yet stated and this is evident when we refer to systems such as Blind Spot Information System (BLIS), studied in this thesis, or Lane Departure Warning (LDW) because those devices are generally described as ADAS even if no direct intervention on the driving task is involved. However, their direct influence on the primary driving task is so clear that they cannot be considered as IVIS.

Initially, ADAS emerged as optional features in luxury cars in United States, Europe and Japan but they are now becoming an integral part of modern road vehicles and the number of such systems is forecasted to be increasing in an exponential manner in the future. For this research work, ADAS will be divided into two categories, according to the typology of control that they supply:

- **Lateral control**: systems supporting the driver in keeping the correct lateral behaviour such as Lane Change Assistant (LCA), Lane Departure Warning (LDW), Blind Spot Information System (BLIS), etc.;
- **Longitudinal control**: devices supporting the driver in maintaining the correct longitudinal behaviour including Adaptive Cruise Control (ACC), Forward Collision Warning (FCW), Intelligent Speed Adaptation (ISA), Pedestrian Protection System, etc.

As it was previously mentioned, throughout this document, we will not stick to the traditional definition of ADAS but, in the category, we will include as well systems like BLIS that don’t have any practical intervention on the primary driving task, even if they highly influence it. Since the study is focused on ACC and BLIS, below, the devices under analysis will be introduced.

1.1. Adaptive Cruise Control

Adaptive Cruise Control (ACC), known also as Advanced/Autonomous/Intelligent Cruise Control, is a comfort and convenience system and it is an extension of conventional cruise control. The system became, at first, accessible in Japan and, later, in the USA and Europe (Dickie, 2010), mainly on high-class vehicles. However, the market penetration of the ACC is constantly increasing and, in the next future, the ACC will be also available on vehicles of lower grade (Young, 2012).

The ACC has, as declared objective, the partial automation of the vehicle's longitudinal control and the alleviation of driver's workload in a convenient manner (ISO, 2010): the system, controlling the engine, the powertrain and, potentially, the brakes, maintains the speed adaptively to a forward vehicle, according to settings pre-defined by the users. During the usage of ACC, the driver can set desired speed and time headway, using the buttons placed on the steering wheel and the system reacts based on the following logic: if the system does not detect any vehicle in front, the ego vehicle's speed is maintained equal to the setting specified by the driver. On the other hand, when the system detects a vehicle in the trajectory ahead, the speed will be adjusted so that it can be maintained the value of time headway imposed by the driver. In this second working modality, the system's priority is allocated to the time headway setting and the speed changes accordingly. The functional principle of Adaptive Cruise Control is based on a finite state machine framework (Fig. 1). The system can be deactivated or put on standby by the driver at any time in order to allow him/her to take back the control of the vehicle. The deactivation is obtained manually (pressing the on/off button) whereas the standby mode can be achieved applying the brake pedal or through a long depression of the accelerator and clutch pedal. On the other hand, the temporary pressing of the accelerator pedal does not place the system in standby or either deactivates it.

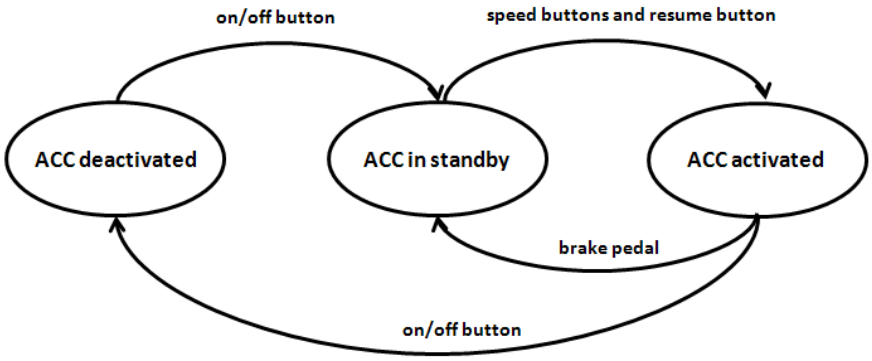

Figure 1 Finite state machine working principle for ACC

The controls, located on the steering wheel enable the driver to switch on/off the system, to change the speed and the headway (Fig. 2). According to the settings defined by the user, the graphic interface reports the actual selected speed and the current headway to the vehicle in front (Fig. 3). The system emits a warning when it is not able to handle strong decelerations of the vehicle in front: in this situation, the driver must regain control of the longitudinal vehicle dynamic. Some limitations of the system are clearly recognized (Volvo Car Corporation, 2009):

- Due to the limited field of vision of the radar sensor, the system might detect a vehicle later than expected or not detect it at all;
- In some situations, the radar sensor cannot detect vehicles at close quarters;
- Small vehicles (e.g. motorcycles) or vehicles not driving in the center of the lane might not be detected by the radar sensor;
- In curvy roads, the radar sensor might detect the wrong vehicle or lose the vehicle previously detected;
- The radar sensor cannot timely react when the vehicle in front is hardly braking or when the speed difference between the equipped vehicle and the target vehicle is too large;
- The system does not react to slow moving or stationary objects.

Figure 2 Example of ACC controls on the steering wheel (BMW)

Figure 3 Example of ACC display (BMW)

Compared to the first versions of ACC with limited braking authority, recently, a ‘Stop-and-Go’ feature was introduced to ACC (Young, 2012). Through this function, the ACC can bring the car to a complete standstill and, subsequently, accelerating it when the lead vehicle moves again (this feature was especially designed thinking about the use of ACC in traffic queues). In order to do this, the “Stop and go” ACC, among other things, has to be capable of detecting other road users or stationary objects at a much closer range than the common ACC (SWOV, 2010).

1.2. Blind Spot Information System

Blind Spot Information System (BLIS) is a device that, using cameras installed on the side view mirrors (Fig. 4), detects the presence of another car/motorcycle moving in the same direction of the equipped vehicle in the left and right ‘blind spot’ (areas located on the left and right side of the vehicle that are approximately 9.5 m long and 3 m width, as reported in Fig. 5). The blind spots are extremely important for road safety because the vehicles entering in those zones are not visible to the driver through the exclusive usage of side view mirrors. In this context, the usage of BLIS might be beneficial considering that lane change crashes account for 4%-10% of overall crashes (Wang & Knipling, 1994) and that, in those situations, most drivers did not try an avoidance manoeuvre (Lee et al., 2004), suggesting that they were, probably, not aware of the presence of another vehicle or crash hazard when carrying out the lane change.

Figure 4 Camera and warning of the Blind Spot Information System (BLIS)

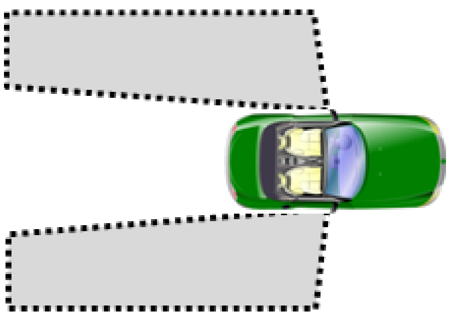

Figure 5 Blind spot areas on left and right side areas

When the camera detects a vehicle in the left/right blind spot area, the warning of the relative side is issued through a blinking yellow light (Fig. 4), in order to advise the driver that it is not safe to perform the lane change. The BLIS was first introduced around 2005 in Volvo cars and an analogous system became gradually available also in Ford and Mazda vehicles. Later, other automobile manufacturers (e.g. BMW) developed a different system that included as well a vibration on the steering wheel in case the driver had activated the left/right indicator to approach a lane change. The system is automatically activated when the driver ignites the vehicle but it can be deactivated and, later reactivated by the pressure on a button located in the center console. Similarly to the ACC, the BLIS presents some working limitations (Volvo Car Corporation, 2009):

- It cannot react to vehicles approaching at speeds 70 km/h higher than the one of the equipped vehicle;
- The system does not work when the equipped vehicle is travelling at speeds lower than 10 km/h;
- The system does not react to mopeds or bicycles and to vehicles standing still.
- The system does not work in sharp curves and when the equipped vehicle is backing up;
- The BLIS camera is impaired by adverse driving conditions such as heavy snowfalls and dense fog;
- Due to direct light on the mirror or light reflected from a wet surface, the warning might illuminate even when no vehicle is detected.

As reported in the owner manual, the system does not eliminate the need for the driver to visually confirm the conditions around the vehicle and the need for the driver to turn his/her head to safely perform the lane change. As introduced before, unlike ACC, BLIS does not directly intervene in the primary driving task but, simply indicates the presence of a vehicle in the blind spot areas by a warning light that blinks on the respective left/right A pillar of the equipped car.

1.3. Summary

Neither of ACC and BLIS has been marketed as safety systems but, rather, as "Comfort and driving pleasure" technologies in order to emphasize that the driver is, nevertheless, the ultimate responsible for the driving activity. However, through these devices, a crucial modification has been introduced: the relationship between humans and machines has evolved from a simple human-machine interaction, in which the user fully controls the system, onto a more complex and dynamic context, in which the machine processes information and the user assumes a supervisory role (Hoc, 2000). Then, although ADAS might reduce human errors and accidents, there is also the possibility that drivers might react to these systems in unexpected ways that can compromise safety. Up to now, the research available on the benefits/drawbacks in using these devices is still lacking and, too often, the effects that those systems might have on road safety are measured through proof-of-concept studies that are not sufficient for a global evaluation; indeed, not only the driving performances (braking, steering, etc.) will be modified but, also, other aspects of the driving task will be affected so that it should be assumed that trade-offs of mobility for safety are possible (Smiley, 2000): one critical example of those trade-offs is the occurrence of drivers' negative behavioural adaptation to those systems, as it will be explained in the next section.

2. Behavioural adaptations

Adaptation, in biology, can be defined as the process of change by which an organism or species become better suited to its environment and, therefore, able to survive to the rising pressures and opportunities (Encyclopaedia Britannica, 2013). In social evolutionism, a similar approach has been adopted, with cultural innovations seen as the objects of environmental selection and the means through which social groups may be able to adapt to their physical and social environment. Then, from these definitions, it is clear that adaptation should be regarded as a manifestation of intelligent behaviour.

In the context of road safety, when we drive, we constantly face changing conditions to which we must adapt; this can occur at different levels, in response to the driving task, in response to the roadway environment or in response to changes in the vehicle (Smiley, 2000). In describing the human-machine interaction, the Organization for Economic Co-operation and Development (OECD) defined 'behavioural adaptation' as "those behaviours which might occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change. [...] They create a continuum of effects ranging from positive increase in safety to a decrease in safety" (OECD, 1990). These changes could appear within the activity of the equipped drivers or within their interaction with other road users and they evolve from the complex interplay of different factors (Saad, 2006):

a) Characteristics of the assistance system such as the level of automation, the system's performance and the design of the human-machine interface, etc.;

b) Variability of the driving situation depending on the conditions of the road infrastructure, the traffic conditions, the travel purpose, the trip duration and the social and cultural background;
c) Individual driver peculiarities like experience with the system, general driving experience, age, gender, etc.

Extremely tied with those three factors is the process of learning with whom the driver takes possession of the purpose, working principles and expected performance of the ADAS he/she interacts with; this will direct affect the usage which the driver makes of the system. Notably, we speak about the temporal factors affecting behavioural adaptation and two main phases are, namely, considered (Cacciabue & Saad, 2008):

- Learning and appropriation phase: during this period, the driver discovers the system, learns how it operates and identifies its limits. This learning process is assumed to be crucial for the driver's mental representation of the system, the confidence he/she has in it and its optimal use;
- Integration phase: the driver, through experience using the system in different road situations, reorganises his/her activity by integrating the system in the management of the overall driving task.

The deep analysis of the 'learning and appropriation' phase was one of the research objectives of the European project AIDE (Adaptive Integrated Driver-vehicle Interface) because, depending on its progress and duration, it is expected a different evolution over time of the drivers' behaviour. Then, during the development of the 'learning and appropriation' phase, the driver acquires elements that are essential for the construction of the mental model relative to the system. Based on this mental model, the user decides (consciously or unconsciously) when to drive manually and when to activate the system (Boer & Hoedemaeker, 1998) and, also, how much to trust the system (Rajaonah et al., 2006). Those decisions might have repercussions on the occurrence of negative behavioural adaptations to the system and will be analysed later in this thesis.

So far, research on behavioural adaptation focused on different systems such as airbags and antilock brakes (Sagberg et al., 1997), Lane Departure Warning (Rudin-Brown & Noy, 2002), warning and tutoring messages (De Waard & Brookhuis, 1997), fatigue warning systems (Vincent et al., 1998) and several others. With regard to ACC, it is reported below a short summary of the main research conducted on behavioural adaptation to the system.

2.1. Behavioural adaptations to ACC

In one of the first study (Stanton et al., 1997), twelve participants were asked to drive in a simulated environment three times, once manually (without the ACC) and twice with the assistance of ACC. The task consisted in following the lead vehicle at a comfortable distance, to attend a secondary task whenever possible and to react to an unexpected acceleration of the system without colliding with the vehicle ahead. The findings showed that one-third of the sample failed to regain control of the vehicle and crashed into the car in front. In addition, comparing the practice with ACC and the practice driving manually, the authors did not find any significant differences related to speed and headway from the lead vehicle. Finally, driving with the system was associated to a reduction of driver's workload: participants engaged more in a secondary task when driving with the ACC, compared to the situation of manual driving.

In a later paper (Hoedemaeker & Brookhuis, 1998), twenty-eight subjects drove in a simulated highway route four times, once manually (without ACC) and three times with ACC. During the three trials with ACC, the drivers could select the desired speed while the headway was fixed respectively to 1 s, 1.5 s and to a time headway preferred by each driver. Similarly to the previous article, in some occasions, drivers were requested to brake and avoid the vehicle ahead. The results showed that, while driving with the ACC activated, participants displayed a tendency to pay less attention to the vehicle's lateral position and to stop closer to the vehicle ahead when hard braking was required. The last finding confirmed what was already shown in the previous study (Stanton et al., 1997): drivers' reaction was delayed in an emergency situation when the system was activated. In addition, comparing the rides with the ACC activated and the ride driving manually, another effect of the usage of ACC was reported: drivers travelled faster during the rides with ACC compared to the manual driving. On the other hand, the setting of the headway was not adjustable by the drivers during the trials and, therefore, no comparison can be made about the variable between driving with ACC and manually. The conclusions on workload were coherent with Stanton et al. (1997).

In a subsequent closed track study (Rudin-Brown & Parker, 2004) eighteen experienced drivers drove a test vehicle while following a lead vehicle in three conditions: without ACC (maintaining an average headway of 2 s), with ACC (maintaining an headway of 1.4 s) and once more with ACC (maintaining an headway of 2.4 s). Again, as in the previous two studies, the participants were requested to react to an hazard while driving with and without the system. The results supported the findings of Stanton et al. (1997): again, drivers took longer to brake in a safety-relevant detection task and performed better in a secondary task while driving with the ACC. Furthermore, in accordance with Hoedemaeker and Brookhuis (1998), lane-keeping performance deteriorated when using the ACC, compared to the manual driving condition. Unlike the previous studies, during this research, it was not assessed the effect of ACC usage on travelling speed and headway.

Later, a meta-analytical approach was used to draw some conclusions about the effects induced by the usage of ACC on the travelling speed and the time headway (Dragutinovic et al., 2005). The study reported that, concerning the impact of the ACC usage on the travelling speed, both positive and negative effects were reported. Regarding the headway, not all the analyzed papers adopted the same type of measurement and, in some cases, the headway was even experimentally predefined. Overall, the research concluded that it is not possible to provide unanimous results about the effects induced by the usage of ACC on speed and headway, because these effects seem to be dependent on the type of ACC used.

During more recent research (Vollrath et al., 2011), twenty-two participants drove in different scenarios (highway and motorway) in a driving simulator, under three different conditions (assisted by ACC, by Cruise Control and manually without any system). Different driving scenarios were examined, including a secondary task condition and critical situations (e.g. narrow curve or fog bank). Again, in accordance with previous studies, the drivers' reactions to the critical situations were slower when using the ACC, compared to driving without the system. On the other hand, positive effects of the system were also derived: while driving with the ACC, the participants perceived a lower workload level and decreased their maximum speed as well. However, no results were drawn on the headway to the vehicle in front maintained with and without the system.

Then, considering the research carried out up to now, the results obtained focused mainly on 4 driving performance variables:

- Speed: the outcomes are, often, contradictory because, in some studies (e.g. Hoedemaeker & Brookhuis, 1998), the speed resulted higher driving with ACC compared to driving without the system whereas, in other papers (e.g. Stanton et al., 1997), the speed did not change;
- Headway: for this variable, Stanton et al. (1997) found comparable values while driving with and without ACC whereas, in a later meta-analysis (Dragutinovic et al., 2005), it was stated that not all the analysed papers adopted the same type of measurement and, in some cases, the headway was even experimentally predefined;
- Lane-keeping: the lateral position of the vehicle appeared to deteriorate while using ACC (Hoedemaeker & Brookhuis, 1998; Rudin-Brown & Parker, 2004);
- Reaction to safety critical event: several studies (Hoedemaeker & Brookhuis, 1998; Rudin-Brown & Parker, 2004; Stanton et al., 1997; Vollrath et al., 2011) found a later reaction to critical events while driving with ACC compared to driving without the system.

Besides the driving performance, considering the subjective assessment of driver's mental workload, the studies conducted showed, generally, lower levels compared to the ones registered without the system (Hoedemaeker & Brookhuis, 1998; Stanton & Young, 2005; Rudin-Brown & Parker, 2004; Stanton et. al., 1997; Vollrath et al., 2011).

Overall, due to the diverse findings available, it is very difficult to obtain clear results about the positive or negative effects that ACC could bring to the driving task. Besides, the studies previously described have been conducted with individuals who never drove with the ACC before participating in the experiment. On the other hand, more recently, some researchers investigated the effects that ACC could have on drivers' behaviour, involving actual users of the system. A selection of those studies is reported below.

In the USA, a survey was carried out with ACC users with the aim of collecting information on users' general perceptions, patterns of use and understanding of the system, and its limitations (Dickie & Boyle, 2009). From the results of the survey, three clusters of ACC users were distinguished: the 'unaware', 'unsure' and 'aware'. Some concern arose for the drivers in the 'unaware' and 'unsure' clusters, due to the combination of the improper mental model relative to the system (low awareness of system's limitations) and the high level of trust. During the driving with the ACC activated, those drivers might change their behaviour, relying on the system even in situations that the ACC cannot handle. As a result, the drivers might not be able to react in case the ACC fails, given that their mental model relative to the system is not accurate.

In a later study, focus group sessions were held with ACC users in Sweden in order to understand the usage, the driving behaviour and the risks associated with the ACC utilisation (Strand et al., 2011). From this study, the users appeared satisfied about the system but also stated that they had already experienced some critical situations with the ACC (e.g. in curvy roads and roundabouts, or during overtaking manoeuvres). Overall, the researchers concluded that, for many participants, the functioning principle of the ACC was still based on a rudimentary mental model relative to the system.

Again in Sweden, a questionnaire survey was performed to understand drivers' specific experiences and patterns of use with the ACC (Larsson, 2012). The results showed that, overall, the drivers understood the limitations of the system and this awareness was related to the system's ownership: the longer the drivers had the system, the more they were aware of its limitations. However, the author also underlined that more effort is required to help drivers in developing an appropriate mental model relative to the ACC: the implementation of appropriate in-vehicle interfaces would be a proper move in this direction, in order to deliver to the driver the information about the general working principle of the system (especially, for the earliest utilizations) and about the behaviour of the system in specific situations.

Finally, a driving simulator study was performed in the USA in order to better understand the behaviour of ACC users when driving with the system (Xiong et al., 2012). Through the data collected (subjective and performance measurements), drivers were divided in three groups: conservative, moderately risky and risky. The risky drivers showed high trust in the system and used it more in the simulator compared to the other groups. In addition, they had an improper mental model relative to the ACC because they expected the system to work even in situations where it could not (e.g. with stationary vehicles). The partial mental model relative to the system could lead the drivers in the risky group to incur in negative behavioural adaptations (usage of the system is inappropriate situations) and, possibly, to fail overriding the system in case of a functional limitation.

Overall, the studies conducted so far revealed that the users of ACC are not completely aware of the limitations of the system (that is, their mental model relative to the system is not complete yet) and, therefore, there is the risk that they incur in behavioural adaptation (e.g. use the system in driving situations where it should not be adopted) and, as a consequence, that critical situations arise (e.g. the drivers might react late or not react if the system doesn't detect a still vehicle, a motorcycle or vehicles at close quarters).

2.2. Behavioural adaptations to BLIS

For what concerns BLIS, conversely to ACC, less research has been performed mainly because the system was only recently put into the market and because, being less intrusive than ACC, it was supposed to have fewer effects on the driving activity. In a study conducted by Kiefer and Hankey (2007), a system similar to BLIS, called Side Blind Zone Alert (SBZA) was tested and the findings concentrated on the modifications of drivers' lane change behaviour as a consequence of the usage of the device. Notably, it was found that some positive effects to the driving task could be brought by SBZA:

- SBZA increased the number of glance rates to the mirrors, associated with most common behaviours for left and right lane changes (i.e., left side mirror glance for left lane changes and inside mirror glance for right lane changes);
- SBZA did not influence the lane change frequency and did not bring the driver to assume a more aggressive lane change behaviour;
- SBZA provided information about the blind spot zones that would be usually missed by drivers prior to an intentional lane change.

Overall, from this short-term study, the SBZA appeared to be highly beneficial for the lane change task but nothing can be said about effects that the system might have on the real users of the system, as already stated for ACC.

In another study (Svenson et al., 2007), it was investigated the behaviour of drivers while changing lane with the assistance of a system called Lane Change Collision Avoidance Systems (CAS). In particular, the scope of the research was to determine if the use of a warning system analogous to the BLIS could provide sufficient warning to drivers. The study was conducted in simulated environment and compared five types of lane change CAS. The results showed that some benefits were observed for each system under analysis.

Globally, there is still little information regarding the usage of BLIS (or similar devices) and, especially, concerning possible behaviour adaptations to the system. However, it is relevant to investigate those aspects considering that, probably, BLIS will become a standard feature for modern vehicles.

2.3. Summary

Then, as a whole, for both ACC and BLIS, it is necessary to broaden the present knowledge about the possible behavioural adaptations to the devices with special care to the actual users of the system. In addition, it is important to find the factors that might cause the behavioural adaptations to the system. Among those, for this study, the drivers' mental model relative to the system and the trust in the system will be investigated considering that, from previous research on ACC, they were shown to be relevant for a proper usage of the system.

3. Mental model and trust

A mental model (or mental representation) is a dynamic representation or simulation of the world (Craik, 1943). In the more specific interaction with a system, a mental model can be described "as the mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (Rouse & Morris, 1986). From this definition, it is clear that the mental model relative to the system directly influences the interaction and the cooperation between the user and the system and, therefore, it is critical to the performance and to the operations with that system (Stanton & Young, 2000a). As a consequence, an incorrect mental model relative to a system might cause an improper usage of the device or a misunderstanding of the actions undertaken by the same (or, as well, of the information provided by it).

With regard to the specific use of ACC, the 'mental model' concept is especially important taking into account the system's limitations, mentioned earlier in this section. If the driver's mental model relative to the system is incomplete, the driver might not be aware of some limitations of ACC and, as a consequence, risky circumstances might originate (Stanton & Young, 2000b). For example, let's imagine the situation of a still vehicle on the path of the car equipped with ACC: in this case, the system cannot detect the still vehicle (due to a functional limitation) and, therefore, it cannot brake to avoid it. If the driver's mental model relative to the system does not include this limitation, the driver might not be able to promptly brake and avoid the still vehicle. As well, if the driver's mental model relative to the system doesn't take into account the limited braking capacity of the ACC, the user might think that the system is able to work in every driving condition (including the hard braking situations) and, he/she might not react if an emergency braking is required.

The drivers' mental model relative to ACC has been already assessed in previous research (Beggiato & Krems, 2013; Kazi et al., 2007). Kazi et al. (2007) continuously measured the driver's conceptual model (mental model) of ACC during 10 days and they found that in this short period of time, drivers consolidated an incorrect mental model relative to the system. Such mental model differed from the designers' mental model relative to the system and induced the drivers to confuse the ACC with the Anti-Crash system. On the other hand, Beggiato and Krems (2013), in a multi-trials study, investigated how different preliminary information about ACC (correct, incomplete and incorrect information) can influence the driver's mental model relative to the system. The results demonstrated that the driver's mental model relative to ACC changed according to the provided preliminary information about the working principle of the system. However, along with practice, the driver's mental representation of ACC converged towards the correct mental model, due also to the fact that drivers experienced some critical situations with the system (cut-in situations, queues, failure to recognize motorbikes). Overall, it seems that the evolution of driver's mental model depends on the usage of the system made by the driver. In particular, when critical situations occur, the mental model changes accordingly.

As reported by other studies (Boer & Hoedemaeker, 1998; Inagaki and Itoh, 2013; Rudin-Brown & Parker, 2004), the concept of mental model is strictly linked to the trust in the system. In general, trust can be defined as an attitude resulting from knowledge, beliefs, emotions and other elements, which generates positive or negative expectations concerning the reactions of a system and the interaction with it (Cahour & Forzy, 2009). If the driver has a misconception about the working principle, the capacities or the limitations of a system, its trust in the system won't be adequate and, therefore, inappropriate usage might derive (Dzindolet et al., 2003; Lee & See, 2004; Parasuraman & Riley, 1997; Stanton & Young, 2000a).

With respect to the impact of trust on the usage of ACC, previous research has been already performed. In a study conducted in Sweden, it was shown that an excessive trust in the system might create expectations about the possibility of the system to brake autonomously in a scenario with a stationary queue (Nilsson, 1995). In a later paper, a higher trust in the ACC was considered as the cause for a more frequent use of the system and for lower time headway to the vehicle in front in the critical circumstance of a cut-in situation (Rajaonah et al., 2006). Finally, Beggiato and Krems (2013) and Kazi et al. (2007) examined the evolution over time of the trust in ACC. In the former, drivers who tried different variants of the system (reliable, incomplete and incorrect) differed for the level of trust placed in the system before experiencing it and, as well, after using it over time. In the latter, drivers who experienced partly and completely unreliable versions of ACC placed an inappropriate level of trust in the system. However, their trust did not increase over time whereas the trust in the system rose during the 10-day experiment for the reliable group. Contrarily to Kazi et al. (2007), in Beggiato and Krems (2013), the drivers in the incorrect group did not rely excessively on the system and changed over time the trust in the ACC. Globally, those results show that the trust in the ACC has an impact on the usage of the system and, also that the usage of ACC influences the trust in the system.

Hence, although only little part of the research conducted on mental model relative to ACC and on trust in the system has been presented here, it is clear how those constructs have a relevant impact on the proper and safe usage of ACC. Based on the literature review, the following information could be collected:

- The drivers' mental model relative to ACC and the drivers' trust in the system can change over time, depending on the situations experienced by the drivers;
- In some cases, drivers were shown to have an exaggerated trust in the system and an inappropriate mental model relative to the system;
- The excessive trust and the improper mental model relative to the system might favour the creation of expectations relative to the usage of the system and those expectations might not match with the real working principle of ACC (with the consequent negative effects on road safety).

Taking into consideration the knowledge gathered so far but neglecting the influence of the personal traits (sensation seeking, locus of control, driving behaviour, sex and gender), the relationship among trust, mental model and ACC usage can be represented as in Fig. 6. There, two moments can be distinguished, being the first usage of the system considered as the breaking situation.

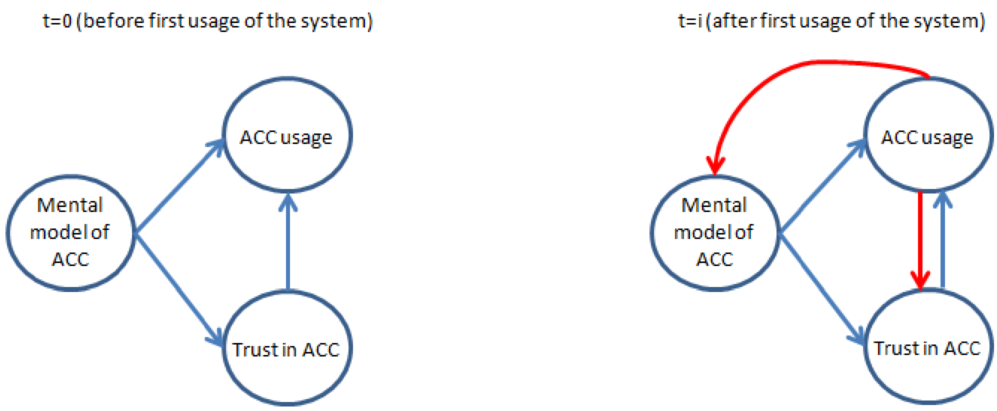

Figure 6 Relationship among mental model, trust and ACC usage

Before the first usage of ACC (Fig. 6, on the left), the driver would have already built a mental model relative to the system based on the information acquired (owner's manual, presentation of the car dealer, inputs from friends, etc.). The defined mental model would influence the trust that he/she puts in the system and, as well, the usage that the driver makes of the system at the first time of utilization (the latter would be also swayed by the trust in the system itself). However, after the first usage (Fig. 6, on the right), the mental model relative to the system and the trust in ACC would be continuously updated based on the information acquired during the utilization of the system. Besides, the ACC usage would, in turn, change based on the reorganized driver's mental model relative to the system and driver's trust in ACC. However, the evolution of the process would highly depend on the situations experienced by human beings while driving with the system activated: if a driver has never gone through a critical situation with the system, his mental model might not be accurate (because it might miss the behaviour of the system in the critical situation) and, therefore, an excessive trust might be placed on the system with the consequent dangerous consequences (the driver might adopt the system even in situations where its usage is discouraged).

4. Research questions

Summarizing the literature review supplied in this document for the Adaptive Cruise Control, the following information can be extracted:

- The studies conducted on behavioural adaptation to ACC led to contrasting results regarding speed, headway, lane keeping and reaction to critical events and, therefore, no unanimous results can be drawn;
- The research performed mainly involved participants who never drove with the assistance of ACC before taking part in the experiment. Then, there is still lack of studies including users of the system and, especially, there is the need to focus on the type of usage made by actual users;
- The research performed on ACC was, mainly, based on subjective assessments (e.g. questionnaires, focus groups interviews) or driving simulator studies and, therefore, there is the rising need for on-road real driving studies;
- The research on the topic has been mainly carried out in the USA and Northern Europe. However, driver's behaviour and performance differ across cultures, and South European drivers show more inclination to speeding behaviour and aggressive driving compared to North European drivers (Özkan, 2006). Then, similar research should be performed also in the Southern Europe;
- Previous research demonstrated that the drivers' mental model relative to ACC and the trust in the system have an effect on the usage of the ACC but, up to now, it has not been demonstrated a clear relationship between those two constructs and the behavioural adaptation to the system.

On the other hand, concerning the Blind Spot Information System, below, it is reported a recap of the main results:

- There is lack of studies that concentrate their attention on behavioural adaptation to the BLIS and, therefore, more research should be performed on the matter;
- Actual users of BLIS have not been yet involved in studies that aim to understand better the usage of the system and, then, research including users of the system should be conducted;
- There is no information related to users' opinions about the system and, therefore, it is not clear if the system benefits for the final users.

The summaries reported above allowed to extract the research questions that are formulated below, in two different sections, each one dedicated to a specific system.

Concerning ACC, the following research questions are expressed:

1. In which driving contexts do ACC users utilize the system, with regard to road typology, weather conditions and road traffic situations (based on subjective and objective data)?
2. Did the drivers experience any critical situations with the ACC activated, due to the functional limitations of the system (based on subjective and objective data)?
3. Which travelling speed and which time headway do ACC users set when they use the system (based on subjective and objective data)?
4. Does the ACC cause any negative behavioural adaptation with regard to speed and time headway (based on subjective and objective data)?
5. Are the drivers aware of the critical situations that they might experience when the ACC is activated and do they know how to react to those events (based on subjective and objective data)?
6. How do the driver's mental model relative to the ACC and the trust in the ACC change when the drivers experience a critical situation with the system activated (based on subjective data)?
7. Do the driver's mental model relative to the ACC and the trust in the ACC have an effect on drivers' capacity to react to a critical situation with the system activated (based on subjective and objective data)?

8. What changes in the design of ACC would make it more suitable for drivers and, therefore, more adapt to enhance the road traffic safety (based on subjective data)?

On the other hand, for what concerns BLIS, the following research questions are formulated:

1. In which driving contexts do the drivers use BLIS, with regard to road typology, weather conditions and road traffic situations (based on subjective data)?
2. Did the drivers experience any critical situations with the BLIS activated, due to the functional limitations of the system (based on subjective data)?
3. Does the BLIS cause any negative behavioural adaptation, with respect to the lane change task (based on subjective data)?
4. What changes in the design of BLIS would make it more suitable for drivers and, therefore, more adapt to enhance the road traffic safety (based on subjective data)?

5. Research hypotheses

The research questions elaborated in the previous part emerged from the detailed literature review and from the accurate study of the working principles controlling the functioning of Advanced Cruise Control (ACC) and Blind Spot Information System (BLIS). Based on the collection of the existing knowledge on the topic and on the research questions proposed, the hypotheses can be drawn for each system.

With regard to the ACC, the main hypothesis is established on the conclusions of a previous study (Mehlenbacher et al., 2002), showing that the vast majority of drivers do not read the owner's manual. Given this premise, ACC users might not be adequately aware of the working principle of the system and, as a consequence, they might not be able to appropriately use the ACC. Based on this assumption, the detailed hypotheses are reported below.

Assumption_1_ACC – The ACC users might consider the ACC very useful to increase the comfort of the driving performance and might not be aware that the usage of ACC in some driving contexts (urban environment, high density traffic conditions) can be dangerous, due to the functional limitations of the system.
Hypothesis_1_ACC – The users of ACC will utilize the system not only in the appropriate driving contexts (major/larger roads, low density traffic situations) but, also frequently in situations in which the system should not be used (urban environment, high density traffic conditions).

Assumption_2_ACC – The ACC users might not have a complete picture of the working principle of the system, especially during the first period of usage. Besides, due to the trust placed in the system, the ACC users might show a different behaviour compared to regular divers (individuals who never drove with the system before).

Hypothesis_2_ACC – The users of ACC are not completely aware of the critical situations that might occur during the usage of the system. In particular, when faced with one of those critical situations (still vehicle in the right lane), the ACC users will stop closer to the vehicle ahead than in the situation of driving manually. Compared to regular drivers (people who never used the ACC before the study), the users of the system will stop closer to the vehicle ahead during the critical situation, while driving with Adaptive Cruise Control.

Assumption_3_ACC – During the usage of ACC, due to the partial automation of the driving task, the users of the system might not pay attention to the speed limits and to the observance of safe headways. Besides, ACC users might excessively trust the system and set higher speeds and smaller time headway compared to driving manually. Finally, due to the confidence acquired with the system, the users of ACC might adopt different speeds and time headways compared to the regular drivers (who never used the ACC before the study).

Hypothesis_3a_ACC – ACC users will opt for speeds higher than the speed limits while driving with the system activated. Besides, they will increase the speed when driving with ACC as opposed to driving manually. Compared to regular drivers, the users of the system will opt for higher speeds while driving with Adaptive Cruise Control.

Hypothesis_3b_ACC – ACC users will adopt headways shorter than 2 seconds (safety critical value) while driving with the system activated. Besides, they will decrease the time headway from the vehicle in front when driving with ACC as opposed to driving without the system. Compared to regular drivers, the users of the system will opt for smaller time headways, while driving with Adaptive Cruise Control.

Assumption_4_ACC – Due to the low awareness of system's working principle, the users' mental model relative to ACC might be not accurate and their trust in the system might be too high.

Hypothesis_4a_ACC – The drivers' mental model relative to the system will have an effect on drivers' ability to react to a critical situation. If the drivers' mental model relative to the system is not accurate, the driver's performance, during a critical situation with the system activated, will be affected. Besides, after experiencing a critical situation with ACC, the drivers' mental model relative to the system will change and become more accurate.

Hypothesis_4b_ACC – The trust in the system will have an effect on drivers' ability to react to a critical situation. The more drivers trust the system, the worse will be the driver's performance during a critical situation with the system activated. Besides, after experiencing a critical situation with ACC, the trust in the system will change and a lower trust in the system will be shown.

Concerning BLIS, the main hypothesis is founded on the lower level of automation introduced by the system in the driving task, compared to Adaptive Cruise Control. This lower level of automation will partly change the behaviour of the users but it won't originate a relevant number of critical situations. Based on this assumption, the detailed hypotheses are reported below.

Assumption_1_BLIS – The BLIS users might consider the system very useful to assist the driver in the performance of a lane change and, therefore, they might employ the BLIS in any driving conditions (regarding road environment, traffic conditions and weather conditions).

Hypothesis_1_BLIS – The users of BLIS will utilize the system in any road environment, in any traffic conditions and in any weather conditions. However, they will switch off the system in some occasions, due to the annoyance caused by the blinking lights (that warns the driver about the presence of a vehicle in the left/right blind spot) on the left/right A pillars of the vehicle.

Assumption_2_BLIS – Despite the low level of automation introduced by BLIS in the driving task, the drivers might change their driving behaviour based on the assistance provided by the system.

Hypothesis_2_BLIS – The users of BLIS will show behavioural adaptations to the system during the usage of BLIS in the driving task. Notably, in some occasions, they will trust the system and not look anymore at the side mirrors before performing a lane change.

Assumption_3_BLIS – Due to the low level of automation introduced by BLIS in the driving task, the limitations of the system might be few and easily perceivable by the users.

Hypothesis_3_BLIS – The users of BLIS will be aware of the limitations of the system.

The investigation on ACC will be based on both subjective and objective data whereas the one focusing on BLIS will be founded exclusively on subjective data. This difference is motivated by limitations of time and limitations of the experimental means. Concerning the limitations of time, unfortunately, it won't be possible to analyse the data collected during the naturalistic Field Operational Test both for the ACC and BLIS. Therefore, the attention will be placed only on Adaptive Cruise Control (that, based on the literature review, revealed more interesting points of analysis). Regarding the limitations of the experimental means, the vehicle used to simulate the driving task (in the driving simulator at the Faculty of Engineering of Porto) is equipped with left and right mirrors but the side mirrors cannot display to the participants the traffic moving behind the vehicle (and, therefore, the simulation of the Blind Spot Information System won't be possible)

PART 2: METHODOLOGY

1. Overview of the methodology

The inquiry strategy has been designed so that it can answer the research questions stated above and, therefore, satisfy the predefined aim of this study. In order to reach all the objectives of the research, three methodological moments have been considered:

1. Focus groups interviews to collect opinions about the systems under analysis from the perspective of the users of ACC and BLIS. As such, the focus groups interviews were employed within the study to design and prepare the following experiments;
2. Naturalistic Field Operational Test (nFOT) to confirm the data collected during the focus groups discussions, using an on-road real driving experiment (and, therefore, from an objective point of view). Besides that, the nFOT was also an input for the further experimental design;
3. Driving simulator study to verify the behaviour of the users when faced with a critical situation occurring with the system activated. As such, the driving simulator study completed the nFOT, testing the behaviour of drivers in conditions that cannot be recreated in natural settings.

During each methodological moment, it has been decided to administer questionnaires to the participants in order to have access to more information (this is especially true for the nFOT and for the driving simulator study because no subjective information about the participants is available).

The reason justifying the planning of research experiments with different natures is related to the fact that neither of them could, as a stand-alone method, answer the entire set of research questions; indeed, it is quite common the usage of multiple methods to improve the effectiveness of the findings of a study because the weaknesses in one method can be balanced by the strengths in another (Wilson, 1995). For instance, in the case of the present project, despite the nFOT and the driving simulator study are the core part of the research activity, those methods cannot retrieve any subjective information from the driver, making it necessary to utilize a different method for that task (in this study, focus groups interviews and questionnaires will be considered). In addition, the decision to conduct both the nFOT and the driving simulator study is motivated by need to test the driver's behaviour in critical conditions that, hopefully, cannot occur during real driving in a naturalistic setting. For this scope, driving simulator studies are especially practical because the driver is not put at any risks (except the ones concerned with the simulation sickness which can be experienced during the simulated trial).

The focus group interview is a well-established research technique "designed to obtain perceptions on a defined area of interest in a permissive, nonthreatening environment" (Krueger & Casey, 2009, pag. 2). The detailed objectives of focus groups interviews are the following:

- Look for the range of ideas or feelings that people have about something (for example, an object or a system);
- Understand differences in perspectives between groups of people according to the experience with the object/system;
- Uncover factors that influence opinions, behavior or motivation;
- Allow ideas emerging from the groups.

During the focus groups, the participants (usually, in a number between 5 and 10 individuals but also with size ranging from as few as 4 to as many as 12) are invited to get together in order to discuss about a specific topic under the supervision of a moderator and an assistant. The former should encourage and lead the conversation whereas the latter should take notes about some relevant aspects of the focus group sessions. During the focus groups, a questioning route is prepared and followed by the moderator during the discussion. A good questioning route should present some specific traits:

- Begin with a question that is easy for everyone in the group to answer;
- Be sequenced so that the conversation naturally flows from one question to another;
- Start with general questions and narrow to more specific and important questions;
- Wisely use the available time.

Focus group interviews were, initially, adopted during the 1920s, to assist the development of questionnaires and, later, as a market research method to ascertain the desires and needs of the public; with an analogous purpose, they are still used now (Newman, 2005). Typically, focus group interviews have 5 features that are the ingredients of the technique: “(1) people, who (2) possess certain characteristics, (3) provide qualitative data, (4) in a focused discussion, (5) to help understand the topic of interest” (Krueger and Casey, 2009, pag. 6). The main advantage related to this technique is that it allows interviewing small groups of individuals simultaneously, guaranteeing to the participants to feel more comfortable in speaking openly on what often are sensitive subjects (Newman, 2005).

The Naturalistic Field Operational Test (nFOT) method originated from the combination of Naturalistic Driving Study (NDS) and Field Operational Test (FOT) and includes studies realized in natural driving conditions which aim to evaluate the relation between the overall system driver-vehicle-environment and the driving behaviour, the accident risk and the efficiency of the countermeasure taken. As such, the nFOT are especially addressed to research the factors that can explain the occurrence of an accident or to evaluate a new technology (Victor et al., 2010). Coherently with the general scopes of the nFOT, in the case of the present study, the method is employed to evaluate the usage of Adaptive Cruise Control in a real setting. During the performance of the nFOT, participants drive their own vehicle or one assigned to them for the whole time period of the experiment. Besides, participants do not receive manipulative instructions with respect to how they should drive and neither how should they use the system under analysis and, also, no investigator is present during the test. The nFOT previews the in-vehicle installation of sensors and video cameras to record vehicle manoeuvres, driver behaviour and external conditions in the drivers' real-world environment. Similarly to the other observational methods, the nFOT is characterized by high degree of face validity (since the system is observed in a natural state) and very low experimental control (the experimenters don't change the system under study) so that causality cannot be inferred (Drury, 1995). However, the showed behaviour meets much more the typical driving behaviour than laboratory studies do and, therefore, reliable statements can be made. If there are no concerns with respect to the functionality of the system and there is no potential danger for participants and other road users, naturalistic Field Operational Test (nFOT) are a good opportunity to investigate the effect of ADAS in the field and to finally generalise the results (Dotzauer et al., 2012).

The driving simulator study involves the usage of simulated scenarios to test the drivers' behaviour. For the scope, different solutions can be used (Dotzauer et al., 2012):

- Simple PC's including one or more monitors and a minimal mock-up of a vehicle that reproduces driver seat, steering wheel and pedals (Fig 7);
- Fixed-based driving simulators including a mock-up of a vehicle but without any simulation of acceleration and deceleration movements (Fig 8);
- Dynamic simulators including a vehicle with simulated acceleration and deceleration movements (Fig 9).

Figure 7 Example of pc-based driving simulator (Transport Canada, Canada)

Figure 8 Example of fixed-based driving simulator (Faculty of Engineering of Porto, Portugal)

Figure 9 Example of dynamic driving simulator (DLR, Germany)

Depending on the type of driving simulator adopted (pc-based, fixed-base or dynamic), several parts should be integrated together. Even in the simplest case, the following elements should be included:

- Mock up of vehicle with controls (steering wheel, accelerator, brake, seat);
- Force feedback on the steering wheel (generally, provided by a electric motor) to simulate the force produced by the contact between the tyres and the road;
- Displays (the number can vary based on the specifications) that show the simulated environment;
- Sound system with speakers reproducing the sound of the simulated vehicle (and, possibly, the sound of other vehicels);
- Simulation software (the degree of sophistication can differ according to the expected results).

Driving simulator studies have the advantage to administer experiments in a controlled and standardised environment and, doing so, they reproduce identical conditions for all the participants. In addition, being the environment virtual and not real, driving simulator studies don’t raise any risky situation for the people taking part in the study (Caird & Horrey, 2011). Driving simulators are relevant tools to assess the risks and benefits of in-vehicle technologies (Fisher et al., 2011) and represent a good alternative to field studies: compared to the latter, the main advantages of driving simulators research concern the lower costs, the higher experimental control, the easier procedures for data collection and the higher safety for the participants (Bella, 2008).

2. Focus groups interviews

Considering that focus groups interviews can be used to bring together people in an effort to better understand how specific systems work or interact (Hendrick & Kleiner, 2001), the method was employed to collect drivers' opinions about the ACC and BLIS. The same technique was already adopted in the past to get a deeper understanding of participants' opinion about in-vehicle systems and, to a larger extent, road safety. For example, Young and Reagan (2007) performed focus groups interviews to investigate the patterns of use for speed alerting and cruise control. The same method was used by Pereira et al. (2010) to look into why, when, where and how people interact with in-vehicle technologies. Strand et al. (2011) conducted focus groups interviews to examine user experiences and road safety implications about the usage of the ACC. Finally, Shams et al. (2011) adopted the same method to collect taxi drivers' views on risky driving behaviours in order to propose countermeasures for the improvement of road safety in Iran.

Notably, the detailed objectives of the focus groups interviews in this study are reported below:

1. Identify in which driving contexts (e.g. road typology, weather conditions and road traffic situations) the drivers activate and use the systems;
2. Determine the drivers' patterns of use for the devices (e.g. the operation of the system, the frequency of activation and the ability to face critical situations);
3. Find out which issues the drivers experienced while using the systems (for instance, failures of the device, problems in interacting with the system, etc.);
4. Get information about the features that drivers would include or eliminate in the current systems to improve them.

Initially, it was planned to include in the study, overall, between 18 and 24 participants, divided in 3 groups according to their experience with the ACC and BLIS (low, medium and high) to keep into account the effect of this variable on the usage of the system and, therefore, to build a multiple-category design for the focus groups. Unfortunately, despite the various efforts made (distribution of leaflets, direct contact with car makers, etc.), due to the reduced number of systems' users in Portugal, the initial expectations had to be modified and the experience with the systems was not included among the variables. Besides, the original plan aimed at keeping the percentage of men and women in the sample as closest as possible to 50%. However, the prevalence of men driving vehicles equipped with ADAS in Portugal did not allow to have a well distributed sample between genders. Finally, the sample was defined based on a 'convenience sampling' method (Bryman, 2008) and the participants were contacted and selected through the assistance of a Volvo dealer 'in loco'. Besides, the requirements for the sample were restricted to the following ones:

1 Participants should be experienced drivers (more than 150,000 km driven after getting the driver's licence);
2 Participants should have a minimum experience with the ACC and the BLIS (more than 50 km driven with the systems activated).

The selection process was completed with 13 Portuguese drivers, aged 33–61 years old (mean = 44.3; SD = 8.0), involved in two focus groups sessions: six drivers joined the first session and seven participants took part in the second one. Given that males are greatly overrepresented in the reference population of ADAS users, it was hard to include women in the research. The final sample was made up of 12 males and 1 female. The participants did not receive any monetary incentive to participate in the study. The complete information about participants' experience in driving with the ACC and BLIS is reported in Table 1 and Table 2.

Table 1 Number of participants (percentage) for each ACC experience category

Less than 50 km	*51–200 km*	*201–500 km*	*501–1,000 km*	*1,001–3,000 km*	*More than 3,000 km*
0 (0%)	2 (15.4%)	2 (15.4%)	1 (7.7%)	3 (23.1%)	5 (38.4%)

Table 2 Number of participants (percentage) for each BLIS experience category

Less than 50 km	*51–200 km*	*201–500 km*	*501–1,000 km*	*1,001–3,000 km*	*More than 3,000 km*
0 (0%)	1 (7.7%)	0 (0%)	2 (15.4%)	3 (23.1%)	7 (53.8%)

The preparation of the focus group interviews followed the suggestions reported in Krueger and Casey (2009). The study took place in Braga, in the northern part of Portugal, between September and November 2011. Each focus group session lasted about two hours and it was divided in two parts: the first one focused on the Adaptive Cruise Control and the latter was dedicated to the Blind Spot Information System (BLIS).

The focus groups were performed by a research team including a moderator, an assistant moderator and a note taker, whose main tasks are outlined in Table 3. The moderator had the primary role of leading the discussion, ensuring that all the participants contributed to expand the topic under analysis. The assistant moderator helped the moderator in the administrative tasks (distributing consent forms and questionnaires, operating the video recorder, etc.) and the note taker was responsible for sketching participants' position and noting down the most salient moments during the discussion. Concerning the practical aspects, during the performance of the focus groups interviews, it is necessary to make available a comfortable room designated uniquely to that purpose and able to convey relaxed and friendly feelings to the participants (Newman, 2005).

Table 3 Main tasks of moderator, assistant moderator and note taker

Moderator	Assistant moderator	Note taker
Welcome participants	Welcome participants	Welcome participants
Introduce study and research team to the participants	Arrange material for ACC presentation	Sketch participants' position
Lead the discussion	Keep the time during discussion	Take notes about salient moments

About 1 week before the session, a letter of invitation was sent by email to the participants to remind them of the date, time and location designated for the focus groups. The letter enclosed a document, in which the drivers were asked to list any critical situations experienced with the ACC and the BLIS while driving, due to an unexpected reaction of the systems. The purpose of such document was to facilitate the discussion on this topic during the focus groups.

On the day appointed for the session, once everyone arrived, the moderator asked the participants to seat around the table according to the assigned disposition (previously defined by the note taker through a named paper tag set on the table). After introducing the members of the research team, the moderator described the purpose of the study and the modality of the session: special attention was devoted to explain to the participants that the objective of the focus group was not to reach a consensus but to have the widest range of opinions from all the participants. Besides, the moderator clarified the doubts/concerns that participants might have about different issues (aim of the study, procedure of the interviews, etc.).

When the introduction was completed, the participants signed a consent form and filled in a questionnaire requiring personal information (name, age, yearly mileage, etc.) and including general questions about the ACC and the BLIS (total time of usage, frequency of usage, etc.). The questionnaire, translated in English (from the original Portuguese version) is reported in Appendix I. Overall, the purpose of the questionnaires was to get some personal information about the participants (demographic information and facts about the usage of the systems) that, by design, would not have been collected during the focus groups discussions.

Once the questionnaire was filled, the session related to the ACC started and the research team played a short video on the Adaptive Cruise Control in order to remind the participants of the basic functionality of the system and to make sure they were informed about which device was under discussion.

The part of the session dedicated to the ACC began with the drivers filling in another questionnaire about the patterns of use for the system (numbers of kilometres driven with the ACC activated, setting of headway and speed, etc.). This questionnaire is presented in Appendix II (like the previous one, the reported English version was translated from the original Portuguese version).

Afterwards, the moderator led the discussion according to a questioning itinerary prepared in advance by the research team and including all open-ended questions. The questioning route was designed expressly to get articulated data, information resulting from the discussion, in direct response to the questions presented (Massey, 2011). The questioning route was broken into five parts: Introductory questions, Transition questions, Key questions 1, Key question 2 and Closing questions. The questions revolved around four topics: users' satisfaction with the ACC, critical situations and problems occurred with the system, usage of the ACC, and suggestions for further development of the system (Table 4). In the questioning route, some questions were marked to indicate that they could be skipped in case the time for the discussion was running out. In order to deepen the study, the participants were free, at any time, to raise other topics of discussion.

Table 4 Questioning route for the ACC session

Questions	Topic	Question category
1. Before using ACC, what were your expectations from the system?	Satisfaction	Introductory question
2. With respect to the previous question, were your expectations satisfied?	Satisfaction	Transition question
3. Which critical situations did you experience while driving with ACC?	Critical situation / problems	Key question 1
4. Besides the critical situations, what were the problems you encountered with ACC?	Critical situation / problems	Key question 1
5. What do you usually do when driving with ACC activated?	Usage	Key question 2
6. Do you think that, since you started using ACC, your driving behaviour has changed?	Usage	Key question 2
7. Do you have any suggestions to improve the actual version of ACC?	Suggestions	Closing question

The part of the focus group session dedicated to BLIS started with the research team showing a short video about the system in order to remind to the participants the main functionality of the system. Then, the drivers filled in a questionnaire concerning the patterns of use for the system (usage of the BLIS in the different types of road, weather, luminosity and traffic conditions). This questionnaire is presented in Appendix III (like the previous ones, the reported English version was translated from the original Portuguese version). Then, as already happened for the ACC, the discussion began and developed according to a questioning route prepared in advance by the research team and revolving around four topics: users' satisfaction of BLIS, critical situations occurred with the system, usage of BLIS and suggestions for the future implementation of the system (Table 5).

Table 5 Questioning route for the BLIS session

Questions	Topic	Question category
1. How were your expectations about BLIS satisfied?	Satisfaction	Introductory question
2. Can you discuss with the other participants the critical situations you experienced while driving with BLIS?	Problems / critical situation	Transition question
3. When you are driving, is the BLIS always activated or is there any specific situation in which you deactivate it?	Usage	Key question 1
4. When you want to change lane with BLIS activated, how do you behave with respect to the warning signal (light)?	Usage	Key question 1
5. Is there any situation in which you don't look at the warning signal (or you don't keep it into account)?	Usage	Key question 1
6. Are there any suggestions to improve the actual system or other functions that you would like to implement?	Suggestions	Closing question

Each focus group session was video and audio-recorded with a camera in order to assist the subsequent transcription that will be described in the section of the results.

3. Naturalistic Field Operational Test (nFOT)

As reported above, the focus groups interviews are a very interesting method for getting participants' opinions and perceptions about a specific system. However, their main disadvantage is related to the fact that the information collected is extremely subjective and, therefore, no objective data can be gathered. In order to fill this gap, it was decided to perform a naturalistic Field Operational Test (nFOT) that, through the installation of sensors and cameras, can record the driver and the road environment in real driving conditions. The detailed objectives of the nFOT are reported below:

1. Determine, through real observation, in which driving contexts (e.g., road typology, weather conditions and road traffic situations) the drivers activate and use the systems;
2. Identify, through real observation, the drivers' patterns of use for the devices (e.g. for the ACC, define which are the selected speed and headway);
3. Find out, through real observation, which possible critical situations or issues occurr during the interaction between the driver and the systems (e.g., critical situations originated by functional limitations of the system);
4. Spot, through real observation, utilizations of the system that might be prejudicial for road safety.

Initially, it was planned to conduct the nFOT to address research questions related to both systems, the ACC and the BLIS. However, as it will be shown in the section of the results, the usage of BLIS did not seem to represent a particular danger for the occurrence of behavioural adaptations. Therefore, also taking into account time constraints imposed by the preparation of the experiment and by the analysis of the data, the nFOT was dedicated exclusively to the study of driver's behaviour while interacting with the ACC.

In addition to the objectives mentioned above, the nFOT also aimed to quantitatively assess the drivers' mental model relative to ACC, through a questionnaire, already adopted in a previous study on ACC (Beggiato & Krems, 2013). The questionnaire was applied at this stage in order to have a comprehension of the users' understanding of the working principle of the ACC. Such evaluation could not be conducted through the focus groups discussions because the center element of that method is the group and not the individual. Based on those assumptions, a questionnaire applied during the nFOT seemed the most appropriate tool for assessing the mental model relative to the system.

The nFOT was performed between June and September 2012 with a total duration of 2 months (taking into account a short interruption) and, for the scope, a Volvo S80 was borrowed from a national dealer and instrumented with a specific platform developed in the frame of the FP7 European project INTERACTION. The acquisition platform included the following elements:

1. 4 cameras that allowed the recording of the driver, the left side of the vehicle, the instrument panel and the road ahead (images from Fig. 10 to Fig. 13);
2. 3 microswitch sensors to measure the depression of the pedals (accelerator, brake and clutch);
3. 1 GPS/GPRS module to localize the vehicle and record the speed;
4. 1 computer that permitted to run a software that received the signals coming from the sensors and the videos coming from the cameras. In addition, the computer temporarily stored all the information collected;
5. 1 battery necessary to charge the computer (this expedient was adopted to avoid that the functioning of the computer could consume energy coming from the main battery of the vehicle);
6. 1 event manager to record the events coming from the sensors. The event manager also included a triaxial accelerometer to record the accelerations on the 3 axis (x, y and z).

The overall box, installed in the trunk of the vehicle and containing the main elements of the platform (GPS/GPRS module, computer, battery and event manager) is shown in Fig. 14 (the GPS/GPRS module is not visible because hidden behind the battery). On the other hand, the scheme representing the elements forming the platform and their connections is reported in Fig. 15.

Figure 10 Camera recording the driver

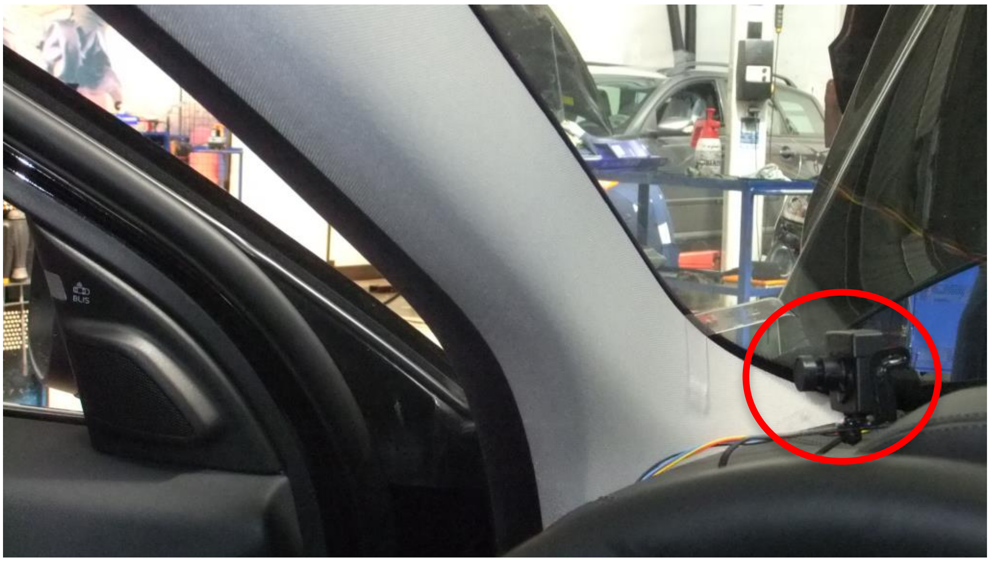

Figure 11 Camera recording the left side of the vehicle

Figure 12 Camera recording the instrument panel

Figure 13 Camera recording the road ahead

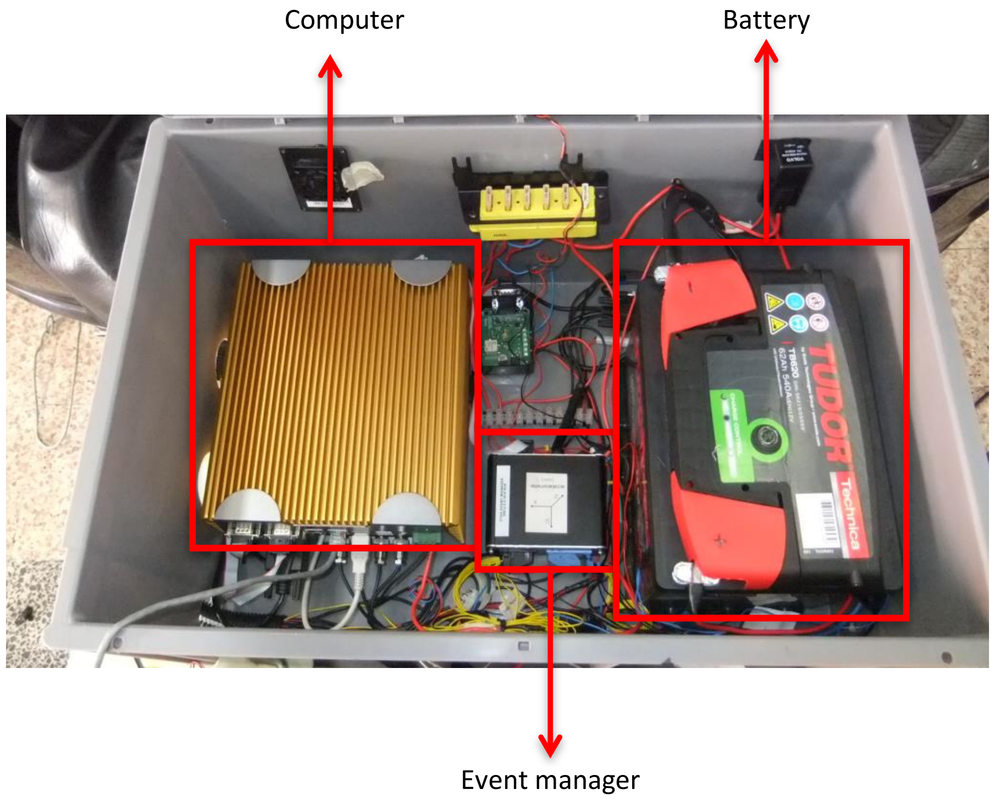

Figure 14 Box including the main elements of the platform

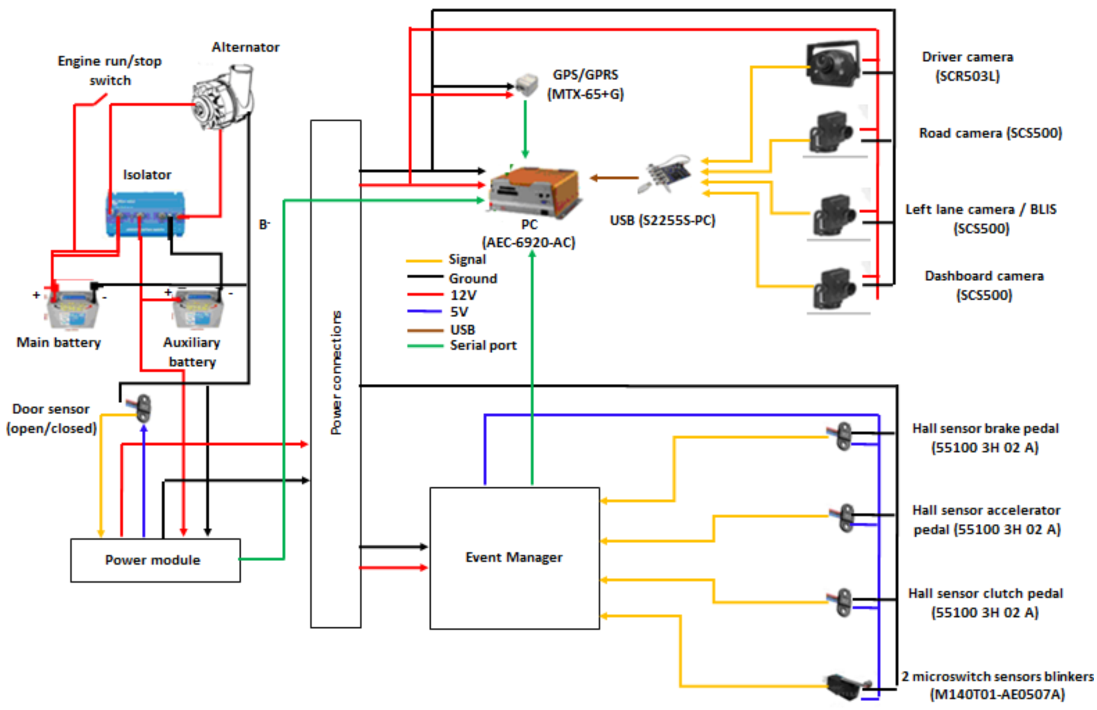

Figure 15 Scheme representing the components of the platform

An example of the images resulting from the video recordings is reported in Fig. 16. Beginning from the top left corner and proceeding clockwise the following videos are displayed: driver, left side of the vehicle, road ahead and instrument panel.

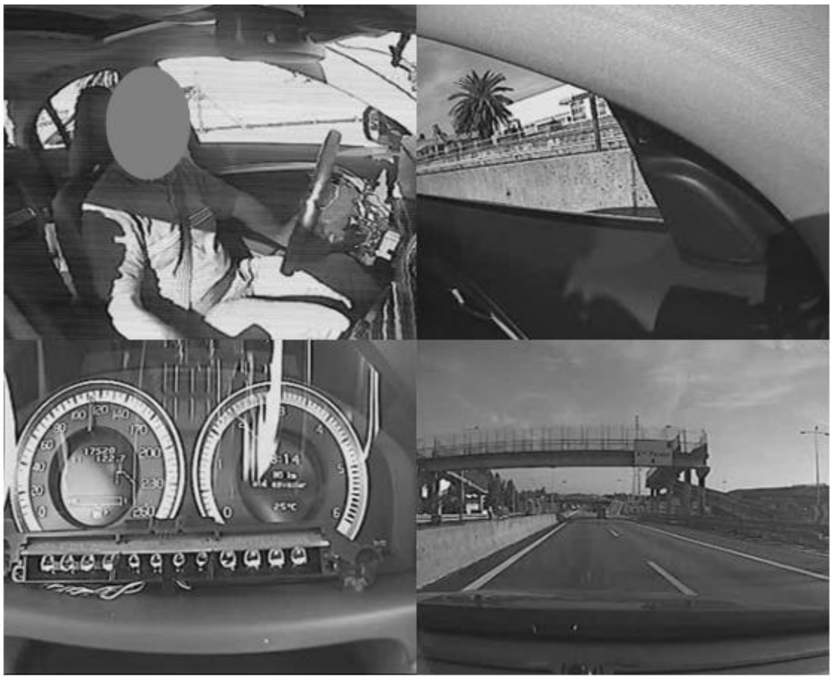

Figure 16 Example of images collected from the cameras during the nFOT

The requirements defined for the selection of the participants are reported below:

1 Participants should be experienced drivers (more than 150,000 km driven after getting the driver's licence);
2 Participants should have already used the ACC before taking part in the study.

Overall, 9 participants took part in the experiment, 8 males and 1 female (as for the focus groups discussions, it was difficult to find female users of ACC). The participants' age ranged from 37 to 65 years old (mean=49.11; SD=9.05) and their driving experience, ranged from a minimum of 19 to a maximum of 43 years (mean=30.22; SD=8.18). All the participants had driven in their life more than 150,000 km and, therefore, can be considered expert drivers (according, as well, with the criteria set for the focus groups discussions). The yearly mileage was higher than 20,000 km for all the participants, except one who drove between 5,001 and 10,000 km. The participants were all users of ACC and the mileage driven with the system is reported in Table 6. The demographic information (age, gender, driving experience, yearly mileage) and the data about the usage of ACC (months of usage, total distance travelled with the system, usage of the system in different contexts) were retrieved from a later study conducted in simulated environment (that will be described in the next section).

Table 6 Number of participants (percentage) for each ACC experience category

Less than 50 km	51-200 km	201-500 km	501-1,000 km	1,001-3,000 km	More than 3,000 km
$1\ (11.\overline{1}\%)$	0 (0%)	$1\ (11.\overline{1}\%)$	$2\ (22.\overline{2}\%)$	$3\ (33.\overline{3}\%)$	$2\ (22.\overline{2}\%)$

Originally, the plan for the nFOT previewed an overall recording period of 1 month for each participant, divided in 2 parts:

- One week driving with the ACC deactivated (baseline);
- Three weeks driving with the system activated.

Unfortunately, due to organizational reasons (originated by the fact that the vehicle was accessible exclusively for two months), it was not possible to guarantee one month driving for each participant. Therefore, the baseline period was deleted from the study and the driving period for each participant was shortened. Besides, due to the different availability of each participant, the drivers did not use the car for the same amount of time. Eventually, the participants picked up the instrumented vehicle at the dealer and drove it for a certain period depending on the availability of the vehicle and of the participant (the driving period for each participant ranged from few days up to 2 weeks).

Within six months after the end of the test, the participants sent back (by post or email) the mental model questionnaire that they were previously asked to fill in. The questionnaire (Beggiato & Krems, 2013) was founded on 30 items and aimed to quantitatively assess the mental model relative to Adaptive Cruise Control. The questionnaire was translated from English to Portuguese by three researchers and, then, back-translated in order to check the consistency in meaning between the two versions of the questionnaire.

4. Driving simulator study

The nFOT, through the recording of information during real driving, allowed to collect objective data about the usage of the system made by the participants. However, due to the low experimental control typical of naturalistic driving studies, during the nFOT, it was not possible to assess the behaviour of drivers when faced with critical situations originated by the functional limitations of the system. Besides, since it was not possible to create a baseline dataset (driving without the system), during the nFOT, it was not possible to compare the behaviour of users during the driving with the ACC activated with the behaviour during the driving without the system. Then, in order to fill those research gaps left by the nFOT, a driving simulator study was designed and realized between November 2012 and February 2013. As for the nFOT, also this study focused exclusively on the Adaptive Cruise Control. In fact, through the driving simulator at the Faculty of Engineering of Porto (where the study was performed), it was not possible to simulate the traffic behind the ego vehicle (vehicle where the participant is sitting) in the side and center mirrors. Therefore, the driving simulator study did not take into account the Blind Spot Information System.

The detailed objectives of the driving simulator study were the following:

- Assess the behaviour of drivers when faced with a critical situation occurring with the system activated;
- Compare the speed and time headway maintained by the drivers with and without the system activated.

For both objectives, an additional scope of the study was the comparison between ACC users and regular drivers. As reported in the Theoretical Framework, so far, the studies on ACC were mainly conducted with drivers who never used the system before taking part in the experiment. Considering that, this study aimed at assessing if it exists any differences between the behaviour of ACC users and regular drivers during the usage of the ACC, to give some foundations for further research on the topic.

The initial target of the driving simulator study was to have 30 participants, divided in 2 groups (ACC users and regular drivers). Unfortunately, 4 possible participants experienced simulation sickness during the first trial and, therefore, were excluded from the sample. In total, 26 drivers were considered for the research: 13 participants were ACC users and the remaining 13 were regular drivers who had never driven with the system before.

The first group was set up with the assistance of a Volvo dealer located in Portugal, as already done for the previous focus groups interviews and nFOT. This solution was chosen after trying alternatives (distribution of leaflet to take part in the study, contacts with car makers' representative) that did not prove to be fruitful. The scarce success in the first attempt derived from the fact that, unfortunately, the number of ACC users is still limited (Xiong et al., 2012), and this circumstance complicated the selection procedure. The essential requirements demanded were the following:

1) Participants should have driven more than 100,000 km since getting the driving license;
2) Participants should have driven more than 5,000 km in the last year;
3) Participants should have normal or corrected vision.

As expected, the sample of ACC users was mainly composed by middle aged (mean = 45.2 years; SD = 9.9 years) men (13 males out of 13 participants), having long driving experience (mean = 26.7 years; SD = 9.9 years), driving luxury vehicles and travelling many km per year by car. As such, comparing with other studies previously conducted (Strand et al., 2011; Xiong et al., 2012), the sample can be considered representative of the overall population of ACC user.

On the other hand, the second group (regular drivers) was constituted by staff of the ‘Faculty of Engineering at the University of Porto’ (FEUP), recruited following a multi-stage modality. As first preconditions for the selection, the drivers were asked to possess a valid driving licence and to have never used the ACC before. In addition, the candidate participants were demanded to hold specific features to form a paired match sample with the ACC users. Such a procedure was adopted in order to avoid the unsystematic variation that is peculiar of an independent design (different participants taking part in the experiment in 2 different groups) and to control for the possible differences between the two groups. For the creation of the matched sample, the drivers were asked to fill in the following questionnaires:

- Personal questionnaire, including demographic variables (gender, age and driving experience);
- Manchester Driving Behaviour Questionnaire (DBQ) developed by Lawton et al. (1997);
- Multidimensional Traffic Locus of control (T-LOC) scale developed by Özkan and Lajunen (2005);
- Sensation seeking (SS) scale, designed by Arnett (1994).

The Manchester Driver Behaviour Questionnaire has its origins in the error theory of Reason (Reason, 1987). It has been employed to measure aberrant driving behaviours and to predict self-reported road traffic accidents. The original DBQ was developed by Reason et al. (1990) and consisted of 50 items, describing two distinct driving behaviours (errors and violations). Since then, the Driver Behaviour Questionnaire (DBQ) has been used in a variety of driver safety research areas, in different countries (Freeman et al., 2008). In this study, the extended 27-item DBQ (Lawton et al., 1997) was administered, composed by 4 scales (‘Aggressive violations’, ‘Ordinary violations’, ‘Errors’ and ‘Lapses’). Respondents were asked to indicate how often they committed each of the violations and errors reported in the questionnaire, while driving. The responses were recorded on a six-point Likert scale. For the scope of this research, the DBQ was used to ensure that the 2 groups of drivers (ACC users and regular drivers) did not differ with respect to the driving style and the tendency to produce aberrant driving behaviours.

The personality trait of locus of control (LOC) was introduced by Rotter (1966) to explain individual differences in responses to external events and it was measured through the Rotter’s I-E scale (1966). The LOC is a construct that describes if an individual generally perceives the events to be under his/her own control (internal locus of control) or under the control of outside forces (external locus of control). Persons with an internal locus of control believe that their life circumstances and behavioural outcomes are the result of their own efforts, talent and behaviours. Persons with an external locus of control are more likely to believe that fate or the actions of others dictate their circumstances (Sticher, 2005). Montag and Comrey (1987) developed 2 dedicated scales to measure the locus of control related to driving (Driving Internality and Driving Externality). Later, Özkan and Lajunen (2005) claimed that the original structure based on internality and externality was too simple and, therefore, developed a new scale that was used in this study. The scale is based on 17 items and measures four aspects: ‘Other Drivers’ (i.e. causes of accidents attributed to other drivers), ‘Self’ (i.e. causes of accidents attributed to oneself), ‘Vehicle and Environment’ (i.e. causes of accidents attributed to external factors), and ‘Fate’ (i.e. causes of accidents attributed to fate or bad luck). Respondents were asked to indicate on a five-point scale how possible it was that the 17 items had caused or would cause an accident when they think about their own driving style. For the sake of this study, the T-LOC was adopted to ensure that the 2 groups of drivers (ACC users and regular drivers) did not present significant differences regarding risky or unsafe driving behaviors.

Finally, Sensation Seeking is defined as the the need for “varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experience’’ (Zuckerman, 1994, p. 27). In a review conducted by Jonah (1997), it was highlighted the correlation between the personality trait of sensation seeking and risky driving (Jonah, 1997). For the scope of this study, it was administered the questionnaire developed by Arnett (1994) that includes 40 items and is based on two scales (‘Novelty’ and ‘Intensity’).

For each item, the participants chose which definition applied best for them on a four-point scale. The SS scale of Arnett was used in place of of the one developed by Zuckermann because the latter included items that are dated ('hippies', 'jet set', 'queer', etc.) and items related to alcohol use, drug use and sexual behavior (that might be perceived as uncomfortable by the participants). For this research, the questionnaire was used to ensure that the 2 groups of drivers (ACC users and regular drivers) were homogfeneous with regards to risky behaviour during driving.

The DBQ, the T-LOC and the SS questionnaires were translated from English to Portuguese and, later, back-translated (from Portuguese to English) by 3 researchers in order to ensure the correspondence of meaning between the original questionnaire and the translated version. Overall, between the two groups (ACC users and regular drivers), there were not statistically significant differences regarding gender, age, driving experience and score on the DBQ, T-LOC and SS (Table 7). The overall sample was composed by 24 males and 2 females, had average age of 44.5 years (SD = 8.5) and average driving experience of 25.3 years (SD = 9.0). In addition, all the participants had 10/10 or corrected to normal vision.

Table 7 Results of the matched sample procedure

Variable		ACC drivers		not ACC drivers		Between-groups comparison	Statistical significance 2-tailed
		Average	SD	Average	SD		
Gender		/	/	/	/	Fisher test	p = 0.480
Age		45.231	9.901	43.846	7.174	t(24) = -0.408	p = 0.687
Driving experience		26.692	9.919	23.846	8.153	Kolmogorov-Smirnov	p = 0.260
DBQ	Aggressive Violations	0.795	0.553	0.949	0.381	Kolmogorov-Smirnov	p = 0.305
	Ordinary Violations	1.510	0.506	1.692	0.553	t(24) = 0.878	p = 0.389
	Errors	0.865	0.373	0.798	0.268	t(24) = -0.528	p = 0.602
	Lapses	1.212	0.406	1.038	0.316	t(24) = -1.212	p = 0.237
T-LOC	Other drivers	3.731	0.744	3.833	0.461	t(20.044) = 0.422	p = 0.677
	Self	2.885	0.759	3.013	0.405	t(18.328) = 0.537	p = 0.597
	Vehicle and environment	2.872	0.566	3.000	0.446	t(24) = 0.642	p = 0.527
	Fate	2.051	0.458	2.269	0.357	t(24) = 1.352	p = 0.189
SS	Total	52.538	9.492	52.692	7.488	t(24) = 0.0459	p = 0.964
	Novelty	25.154	4.705	24.923	4.957	t(24) = -0.122	p = 0.904
	Intensity	27.385	5.331	27.769	3.655	Kolmogorov-Smirnov	p = 0.751

The study was performed in the medium fidelity driving simulator of the Faculty of Engineering of the University of Porto, in Portugal (Fig. 8). Driving simulators represent a good alternative to field studies to investigate various aspects of traffic research, including the usage of in-vehicle systems.

The simulator employed for the study was fixed-based type, composed by a real vehicle (Volvo 440 Turbo), a projector hung to the ceiling above the car, one screen set in front of the vehicle to display the simulated road environment and a multi-point sound system to produce the expected audio feedback. Like a normal vehicle, the Volvo 440 Turbo is supplied with the steering wheel, the pedals (accelerator, brake and clutch), the gear stick (the vehicle can be used with manual or automatic transmission), the indicators and an ad-hoc instrument panel where all the relevant information (speed, rotations per minute and gear selected) is shown. In a room near the one containing the driving simulator, several computers were located to control the driving environment, the instrument panel, the audio and the video recording (Fig. 17).

Figure 17 Control room with the relative computers

For this specific experiment, the simulator was equipped with additional elements:

- A graphical interface in the instrument panel (behind the steering wheel) to report information related to the ACC functioning (speed and time headway set by the driver and distance to the vehicle in front) as reported in Fig. 18;

- A steering wheel with integrated ACC controls to activate/deactivate the system and to set the desired speed and time headways (Fig. 19).
- A graphical display with a touch panel sensor on the centre console to allow interaction with the driver during the simulated driving experiment (Fig. 20).

Figure 18 Instrument panel showing information about the ACC functioning

Figure 19 ACC controls on the steering wheel

Figure 20 Graphical display on the centre console

The simulated Adaptive Cruise Control allowed for the selection of the desired speed and headway to the vehicle in front through the controls on the steering wheel (Fig. 19). The speed could be changed pressing the buttons "+" or "–" and, the respective increase/decrease was done by 5 km/h. The desired speed could also be acquired from the actual vehicle speed when activating or reactivating the ACC system. Concerning the time headway, the system allowed to set the desired headway between 1 and 2.5 seconds with each increment/decrement being approximately 0.5 seconds. The instrument panel of the vehicle (Fig. 18) allowed the drivers to check the current headway and the selected desired headway and speed. This graphic element presented information about the ACC state (On/Off) in the left section. In the right section, it showed the desired speed set by the driver (on the upper zone) and the selected desired headway (at the bottom). When a front vehicle was detected, the central section provided graphical information about the actual headway, using a variable set of rows with intuitive colors. Finally, the graphical display on the centre console was used by the drivers to answer a phone call, placed during the simulated route. However, this part of the experiment won't be treated in this thesis.

During the sessions, four cameras were placed in an adequate position to record the simulated road, the feet of the participants, the driver and the position of drivers' hands on the steering wheel. The images resulting from the recordings are shown in Fig. 21.

Figure 21   Images recorded during the driving simulator study

Regarding the procedure for the experiment, once completed the selection process, the participants were invited for the first trial on the simulator. When the person arrived at the facilities, he/she was briefed about the objective of the experiment: a general description of the overall research project was given without going into detail about the real scope of the study. The participants were instructed to drive safely as they would normally do with their car, despite being in a simulated environment, to stay on the right lane whenever it was possible and to use the ACC as frequent as possible (during the trial with ACC). In addition, only before the trial with ACC, the participants were invited to read a description of the ACC implemented in the simulator: such description included the general working principle of the system, the controls to be used for setting the speed and the headway and, finally, the main limitations of the system. Overall, the description was a short summary of the explanation reported in the Volvo S80 owner's manual.

After the introductory part, the participants filled in the consent form and, only before the trial with ACC, they completed also a mental model questionnaire (Beggiato & Krems, 2013) and a trust questionnaire (Jian et al., 2000). As the previous questionnaires, the mental model and the trust questionnaires were also translated from English to Portuguese and, later, back-translated from Portuguese to English by 3 researchers. After the practicalities and the questionnaire filling, drivers went to the driving simulator and had different levels of practice ('Practice 1' or 'Practice 2') according to the condition (driving with ACC or driving manually) to which they were assigned (Table 8 and Table 9). The order of the rides (driving with ACC and driving manually) was balanced among the twenty-six participants to avoid learning effects.

Table 8 'Practice 1' before the ride with ACC

Order	Duration	Motivation	ACC state
1	5 minutes	Experience the driving simulator	ACC off
2	10 minutes	Experience the ACC and the hand free device	ACC on

Table 9 'Practice 2' before the ride manually

Order	Duration	Motivation	ACC state
1	7 minutes	Experience the driving simulator	ACC off
2	5 minutes	Experience the hands-free device	ACC off

Overall, two randomized groups were formed and each one included both ACC users and non- users (Table 10 and Fig. 22). In the route performed with the ACC, despite being instructed to use the system as much as possible, the drivers were free to deactivate it through a button located on the steering wheel close to the interface for the speed and the headway (Fig. 19). In addition, the system was automatically deactivated when the drivers pressed the brake pedal. Similarly to the real behaviour of the system, the ACC was programmed for not working when the vehicle in front was a still vehicle or a motorcycle.

Table 10 Randomized groups

Randomized group	Number of ACC users	Number of ACC non-users
1	7	6
2	6	7

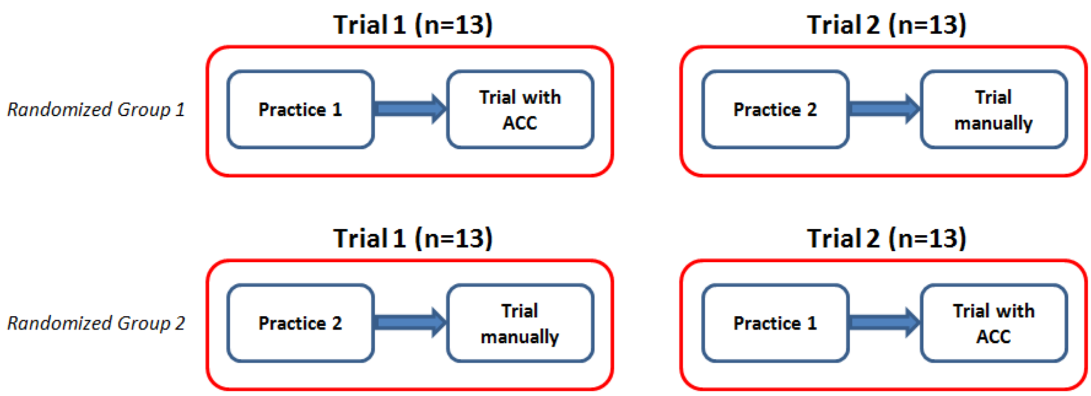

Figure 22 Experimental design for the driving simulator study

Once the route with ACC was completed, the drivers were asked to fill in again the mental model questionnaire and the trust questionnaire. The participants came twice to the location to perform the two driving trials: the average time period between the first and the second trial was 28.5 days, with a minimum of 7 days and a maximum of 62 days.

Considering that ACC is predominantly used in rural roads, highways and motorways (this information is available from the previous focus groups discussions and from Strand et al., 2011), the designed test route was a 46-km stretch of the motorway A25 (Aveiro-Viseu), in Portugal (Fig. 23).

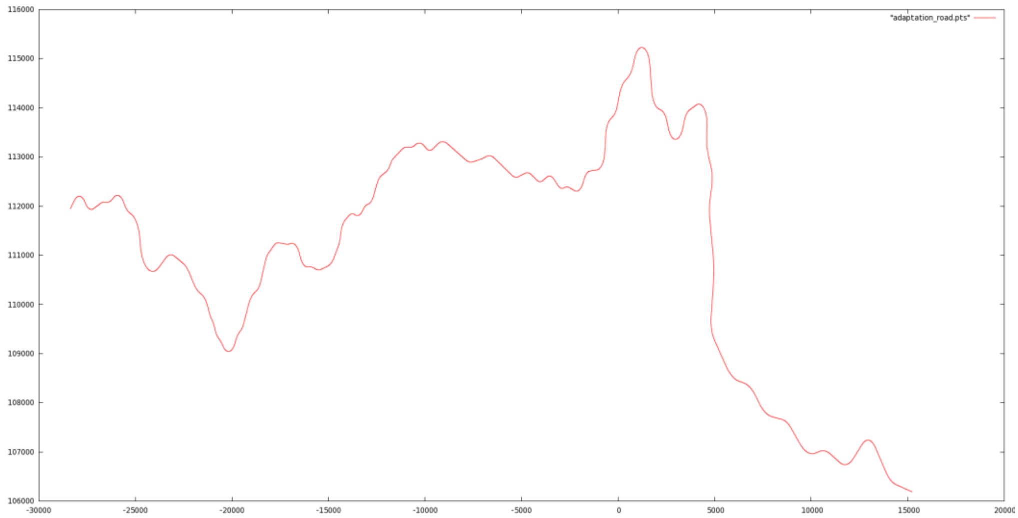

Figure 23 Horizontal alignment of the A25 motorway used for the simulated environment

The simulated route had two lanes for each direction, with radius of curves ranging from 420 m to 2400 m. The choice of the real motorway for the simulated scenario was made in order to guarantee more reality to the experiment. An image taken from the simulated scenario is reported in Fig. 24.

Figure 24 Image of the simulated scenario

The route was divided in 6 sections, in order to have different experimental conditions (Table 11). The traffic conditions were always constant with the exception of Section 3 and Section 6, where there were no vehicles. The speed of the constant traffic was 90 km/h on the right lane and 120 km/h on the left lane. The speed limit shifted from 100 km/h to 120 km/h and the weather conditions changed between cloudy and foggy. The drivers faced 2 critical situations, one in Section 3 (vehicle stopped in the right lane) and one in Section 6 (ACC misdetection of a motorbike) but, in this PhD thesis, only the former will be treated. The critical situations were designed so that attentive and responsive drivers could safely overcome them and, as well, so that any repercussions in the subsequent experimental blocks and/or repetition of the trial could be avoided (Caird & Horrey, 2011). The detailed information and a sketch of each section are reported in Appendix IV.

Table 11 Main characteristics for the sections of the test route

Section	Traffic	Length	Speed limit	Weather	Critical situation
1	Constant traffic	4 km	120 km/h	Cloudy and foggy	No
2	Constant traffic	10 km	120 km/h	Cloudy	No
3	No traffic	4 km	120 km/h	Cloudy and foggy	Vehicle stopped
4	Constant traffic	10 km	120 km/h	Cloudy	No
5	Constant traffic	15 km	100 km/h and 120 km/h	Cloudy and foggy	No
6	No traffic	3 km	120 km/h	Cloudy	Motorbike misdetection

The driving simulator experiment was conducted as a two-way (2x2) repeated measures mixed design study: the experience with ACC (ACC users and regular drivers) was the between-subjects factor and the driving condition (ride along the same route with ACC and manually) was the within- subjects factor. The dependant variables were the measures of the driving performance (minimum Time To Collision and minimum space Headway) during the critical situation, the scores on the mental model questionnaire and on the trust questionnaire, the speed and two different measurements of time headway (Time Exposed Time Headway and Time Integrated Time Headway) that will be introduced later.

PART 3: RESULTS AND DISCUSSION

1. Focus groups interviews

The analysis process was carried on for data originating from two sources:

1. The questionnaires submitted to the participants prior to the beginning of the focus groups discussions;
2. The video recorded focus group discussions and the notes taken during the sessions.

From the analysis of the questionnaires, the research team obtained demographic data (such as gender and age), information about driving experience (total mileage driven and mileage driven with the assistance of the ACC and BLIS) and information about the usage of the ACC and BLIS (driving contexts in which the system is activated). The demographic information was used to describe the sample. The information about driving experience was used to confirm the fulfilment of the selection criteria (given that the selection was performed through the Volvo dealer). Finally, the information about the ACC and BLIS usage was used to identify tendencies with regard to the road context, the traffic level, the weather conditions and the lighting conditions in which the systems are used. In general, given the small sample, no statistical analysis was performed on the data.

Concerning the focus group discussions, a thematic analysis approach was adopted to identify patterns emerging from the data (Braun & Clarke, 2008). Each video recording was watched, separately, by two members of the research team (who attended the focus group sessions) and transcribed verbatim, using the ‘f4’ software. The double review of the video recorded material was useful to avoid the loss of relevant information resulting from the discussion. The output of the transcription process was a document reporting the words pronounced by each participant (including hesitations and expressions). According to the questioning route prepared, during the analysis, the attention was directed towards articulated data.

The transcribed discussions were, at first, carefully read and, with the help of the MAXQDA software, codes were identified along the text (a mix of deductive and inductive coding was adopted during the analysis). Through an iterative procedure, a hierarchical coding system was established with higher level codes containing lower level sub-codes. The higher level codes represent the themes of the focus groups discussions and differ from the topics that guided the discussions due to the iterative procedure adopted.

The focus groups were held, transcribed and analysed (thematic analysis) in Portuguese. However, the striking parts (such as some relevant citations) were translated into English by the research team (moderator, assistant moderator and note taker) in order to be reported in this thesis. In the remaining part of this chapter, the description of the results will be divided in two parts, one regarding the ACC and the other one regarding the BLIS.

1.1. Adaptive Cruise Control

As shown in Fig. 25, three main patterns (themes) emerged from the thematic analysis: ‘Effects on driving task’, ‘Road safety concerns’ and ‘Usage’. The detailed description of each theme is reported in the next sections.

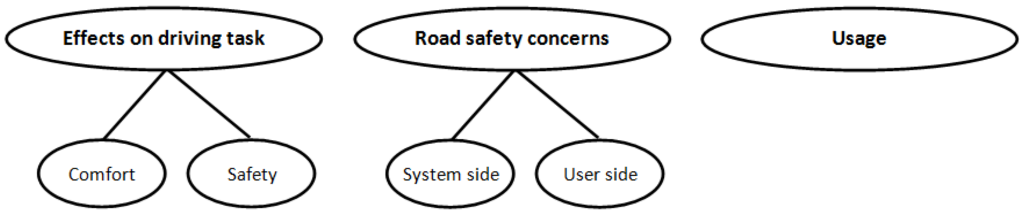

Figure 25 Patterns (themes) retrieved from the thematic analysis for ACC

Effects on driving task - Comfort

Most participants consider driving with the ACC activated very comfortable. The assistance provided by the system allows the drivers to rest and reach the destination in a more relaxed condition. As reported by a participant, there is a manifest distinction between a vehicle equipped with the ACC and one without the system: “When I move from my car to another one which does not have the system (ACC), there is a clear difference since it is very comfortable to drive with this assistance (ACC).” Besides, the participants underlined that the ACC is a good enhancement, compared to the ‘regular’ cruise control because, in addition to the setting of the speed, it is also possible to adjust the headway to the vehicle in front. Only one participant disagreed, affirming that he prefers the cruise control to the ACC because the former is more comfortable and more apt to various driving conditions (compared to the ACC which is only good in highways).

Referring to the ACC with ‘queue assistant’ function (only available for cars provided with automatic gearbox), the participants were extremely satisfied since it is very favourable when the driver is stuck in a queue. Through the ‘queue assistant’ function, the equipped vehicle brakes and accelerates following the vehicle ahead, even at speeds lower than 30 km/h, leaving only the task of steering to the driver. One participant summarised: “The system (ACC with ‘queue assistant’ function) is extremely beneficial when we are driving in a motorway and a situation of queue suddenly occurs. The driver can be completely relaxed, taking care of only the direction of the car, without the need for continuously braking and accelerating.”

Despite the many positive comments, some discontent was also shown. The main reason for discomfort resulted from the abrupt braking actions undertaken by the system when detecting a vehicle travelling at a lower speed. This situation is mostly common in conditions of heavy traffic and it often prompts the drivers to deactivate the system. One participant mentioned “I have the feeling that it (the ACC) is constantly braking. The system gets completely confused with any objects and the feeling of comfort gets wiped out.”

Effects on driving task - Safety

The participants admitted to feel safer when using the ACC compared to driving without the system. One driver stated “In terms of quality, the system is fantastic and this is true as well for what concerns safety.” In particular, the drivers reported improvements such as lower speeds and safer distances to the vehicle in front. About the latter aspect, one participant mentioned “The system (ACC) does not allow us to commit the foolish behaviour of being attached to the vehicle in front.”

Road safety concerns - System side

The participants reported that, in some occasions, the functioning of the system is a reason of concern. For instance, they cited that the continuous braking activity undertaken by the system might appear odd for the drivers travelling behind, especially when there is a large amount of space in front of the equipped vehicle. One participant reported: “Basically, the drivers who are in the vehicles behind probably think: Why is this mad guy braking even if there is nothing in front?”

Another concern mentioned during the discussion was related to the ACC working in road bends. In those circumstances, the system should not be used because it gets confused, as reported by a participant: “In curvy roads, if we are approaching a curve with an object (on the side of the road), the ACC detects it as an obstacle and brakes. On the other hand, if there is a curve on the edge of a precipice, the ACC cannot discern the situation and, as a consequence, the system accelerates the vehicle in the curve.”

Road safety concerns - User side

Rather than from the functioning of the system itself, greater road safety concerns were originated from the drivers’ attitude while driving with the ACC. The participants reported some behavioural adaptations, taking place to a lesser or greater extent depending on drivers but which were mainly caused by a more relaxed attitude during the driving task (as reported in the section about comfort). From the discussion, it emerged that the most evident negative effect of the ACC is that drivers pay less attention to the road. One participant summarised: “In my opinion, the more the cars are equipped with systems assisting us like this one (ACC), the more we are paying less attention to the road.”

The participants admitted that the usage of the ACC leads them to engage more frequently in distracting tasks. Among the activities undertaken, drivers mentioned making a call with their mobile phone, using the smart phone to surf on the internet in queues and reading a book. It appeared that the drivers perceive the system as reliable and divert the attention from the primary driving task to other secondary tasks. This claim is especially true for what concerns the system with ‘queue assistant’ function, as reported by a participant: “Actually, that system (ACC with ‘queue assistant’ function) is very interesting and, since the driver is aware of being stuck in the queue for some time, he can think about the possibility of working and driving at the same time.”

Finally, other behavioural adaptations were the consequence of reported improper usages of the ACC. Some drivers mentioned that they drive the car using the ACC controls (speed and headway settings) only to avoid pressing the accelerator or the brake pedal. One participant stated: “Sometimes, I play with the system and I don’t even touch the pedals, I only push on the controls’ buttons.” Other participants admitted to set short headways to the vehicle in front in order to always have a reference vehicle to follow and avoid the abrupt braking of the ACC. With regard to that, one participant said “The system brakes by itself and gives an uncomfortable feeling to the user. Therefore, people prefer to deactivate the ACC or set headways closer to the vehicle in front.”

Usage

From the questionnaire filled in at the beginning of the focus group session, it was possible to withdraw some information about the circumstances in which the drivers use the ACC. The participants reported to activate the system mainly in motorways (speed limit equal to 120 km/h) and highways (speed limit equal to 100 km/h). As well, the drivers mentioned to use the ACC indifferently during the day and at night, and in any weather conditions (except for the situations of hard rain and fog). With respect to traffic conditions, it was not possible to find a unique tendency but, globally, it seems that drivers find the system more useful in low and stable traffic.

Probably more interesting and useful was the discussion about the deactivation of the system. The main motivation leading the drivers to switch off the system is the feeling of discomfort perceived in some situations, such as the already mentioned abrupt braking or functioning in curve. One participant reported: “Sometimes, the driver deactivates the ACC because driving with the system is perceived as uncomfortable.” Furthermore, some drivers pointed out that they do not use the ACC in long trips because the system reduces the average speed that the driver would like to maintain. Finally, one participant stated not to use the system as he likes to manage his driving without the system interfering.

Besides, participants indicated that the system might be perfectly adapted for the Swedish market but, on the other hand, it is not completely operable in countries such as Portugal due to the different driving styles in the two countries. Notably, one participant said “In a market (car market) like the United States or Sweden, where all drivers respect the speed limit, the system is fantastic. When we consider a market like Spain, Italy or Portugal, this is not appropriate anymore because people don’t respect the speed limits.”

1.2. Blind Spot Information System

From the qualitative analysis of the focus groups sessions, three main themes appeared: “Judgement about the system”, “Drivers’ behaviour with the system” and “Behavioural effects on drivers”. Each main theme was, then, subdivided in various subthemes as reported in Fig. 26.

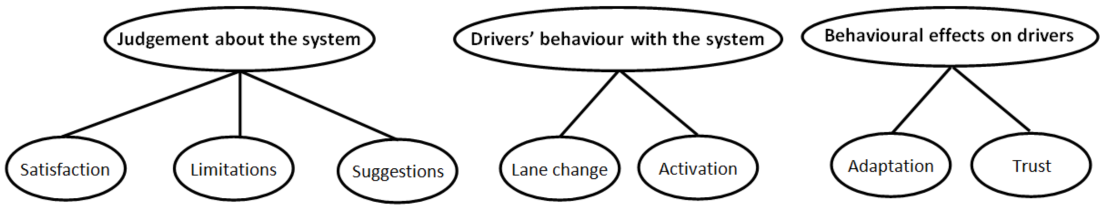

Figure 26 Patterns (themes) retrieved from the thematic analysis for BLIS

Judgement about the system - Satisfaction

Taking into account ‘Satisfaction’, the drivers appear to be very pleased about BLIS since the system went over drivers’ expectations. One participant mentioned: “The system really exceeded my expectations. I was a bit reluctant, knowing other systems, but after using it, I think it is an added value, without any doubts”. Overall, the participants judge the system useful, comfortable and safe. A driver reported: “In all those years, I had many dangerous situations because I did not notice the vehicle in the blind spot. I had already several of those circumstances and I got scared. For me, BLIS is extremely beneficial”.

Judgement about the system - Limitations

Drivers are satisfied about the system even being aware of its limitations. During the discussion, the participants mentioned some shortcomings, among which, the more frequently reported are:

- The system does not work properly with hard rain;
- BLIS gets confused when driving close to a barrier between lanes in motorway;
- The system is late in detecting vehicles approaching fast on the side;
- The camera of the system detects a too small blind spot angle;
- BLIS has often false detections of vehicles.

In particular, the late detection of fast vehicles is considered a relevant limitation in terms of trust towards the system as reported by a participant: “My feeling is that, when I drive at 120 or 130 km/h and a car overtakes me at 140 or 150 km/h, the warning lights up when the car is already passing on my left [...]. I don’t trust the system at 100%”.

Despite the limitations, the participants seem confident about the fact that the system won’t create any critical situations (incidents, accidents, etc.). One driver stated: “I favour more those systems which inform the drivers and don’t interfere in the functioning of the vehicle because they leave to the user the responsibility to intervene. [...] When I used the system, I did not notice any critical situation”.

Judgement about the system - Suggestions

In the end of the discussion, participants proposed some solutions to further improve the system:

- To increase the angle of the camera in order to detect a larger blind spot area;
- To enhance the efficiency of detection in order to reduce the false alarms;
- To arrange a solution to clean the camera when it gets dirty;
- To reduce the dimension of the camera;
- To adopt the system only on the left side of the vehicle;
- To introduce a warning sound associated to the warning light.

With respect to the last suggestion, there was not agreement in the group as the introduction of a warning sound might represent a bother for the driver. One participant stated: “Personally, I don’t like it so much [...]. I get more stressed with the sound than with the light”.

Drivers’ behaviour with the system – Lane change

Regarding the sub-theme ‘Lane change’, it emerged that, in large majority, the sample considers the system as an assistant for taking the decision of changing lane. One participant summarized the lane change behaviour with the system as: “I think that the (lane change) behaviour must be separated in two situations: when the warning lights up and when it does not. When the warning light is on, my behaviour is to delay the overtaking, waiting for the light to turn off. On the other hand, when there is no warning light, I confirm in the mirror [...] and then, I start the overtaking manoeuvre”. In describing the lane change behaviour with BLIS, the participants remarked a positive feature of the system: they don’t need to move their head to get the system’s warning signal. This aspect of the system is related to the location of the warning light that, overall, was considered as the proper one. A driver mentioned: “The warning of the system is located in the ideal position [...]. I think that it is not required to move your eyes from the road in order to perceive if the warning light is on or off”.

Drivers’ behaviour with the system – Activation

With regards to the other sub-theme (‘Activation’), the participants stated that they never switch off the system. Unlike other Advanced Driver Assistance System (such as the Lane Departure Warning), the BLIS is not bothering the driver and therefore, it is always kept activated. The drivers admitted to switch off the system only when the system gets confused. The utility of BLIS was considered especially relevant in reducing the risk of an accident when entering the motorway, in the acceleration lane. One participant reported: “There is a very critical situation in the acceleration lane in the motorways [...]. I never had an accident but when I have it, I already know how it will happen. And, it will be in a car without BLIS [...]. So, I think BLIS is very important”.

Behavioural effects on drivers - Adaptation

The sub-theme ‘Adaptation’ refers, to a larger extent, to the definition of “behavioural adaptations” introduced by the Organization for Economic and Co-operation Development (OECD, 1990). This sub-theme gathered the parts of the discussion related to possible modifications of drivers’ behaviour during the lane change task, as a consequence of the introduction of BLIS. In general, participants stated that the lane change task is not modified by the introduction of BLIS. One participant reported: “I think that it isn’t (the lane change task does not change) because the lane change behaviour always passes from looking at the mirror”. However, other participants mentioned about the possibility to incur in behavioural adaptations in the long-term: “The tendency, at the beginning, is to confirm (with the mirror) [...]. But when you get used to the system, it is almost instinctive. [...] If the warning does not light up, there is a predisposition of trusting the system”. Another participant referred about the possibility to lose attention for what is passing on ahead: “Having the light always blinking and having the fear that there is something which, in reality, is not there, draws the attention to the warning light and leads us to lose the attention for what there is in the front”.

Behavioural effects on drivers - Trust

Concerning the second sub-theme (‘Trust’), generally, people do not seem to completely trust the system when taking the decision to change lane. A participant stated: “I don’t trust the system for what it concerns the decision of changing lane, based on the information that provides [...]. It was reported that, sometimes, there are situations in which the system detects vehicles that do not exist in reality. However, I think there is also the opposite risk that the system fails in detecting a vehicle that is coming". On the other hand, some participants admitted that, in some occasions, they started the lane change without looking at the mirror, based only on the information provided by the system: "The system always met my expectations up to the point that I have the encouragement to start changing lane before looking at the mirror. When BLIS is not detecting anything on the side, people have the tendency to begin turning the steering wheel and, only afterwards, looking at the mirror".

In the next section, the results of the Naturalistic Field Operational Test (nFOT) will be reported.

2. Naturalistic Field Operational Test (nFOT)

The video data were analyzed through the software ELAN, developed by the Max Planck Institute for Psycholinguistics and freely downloadable from the website http://tla.mpi.nl/tools/tla-tools/elan (for more information about the coding tool, please see Wittenburg et al., 2006).

The first objective of the nFOT was the understanding of drivers' patterns of usage of ACC, with special interest in 3 aspects:

1. The settings of ACC (speed and headway) chosen by the participants;
2. The type of roads where the ACC is used;
3. The level of traffic in which users prefer to adopt the system.

In Fig. 27, it is reported the percentage of time for which each participant, while driving with ACC activated, selected a speed higher than the speed limit or a speed lower or equal to the speed limit. Overall, from the graph, it is evident that most of participants (7 out of 9), set, for the majority of time, speeds higher than the speed limit. However, from those results, it is not possible to state if the usage of ACC brings the drivers to increase or reduce their travelling speed and, therefore, no conclusion can be drawn about the drivers' behavioural adaptations to the system (affecting the speed). This aspect of the research will be addressed through the driving simulator study that will investigate the speed adopted by drivers when using the system and while driving without it.

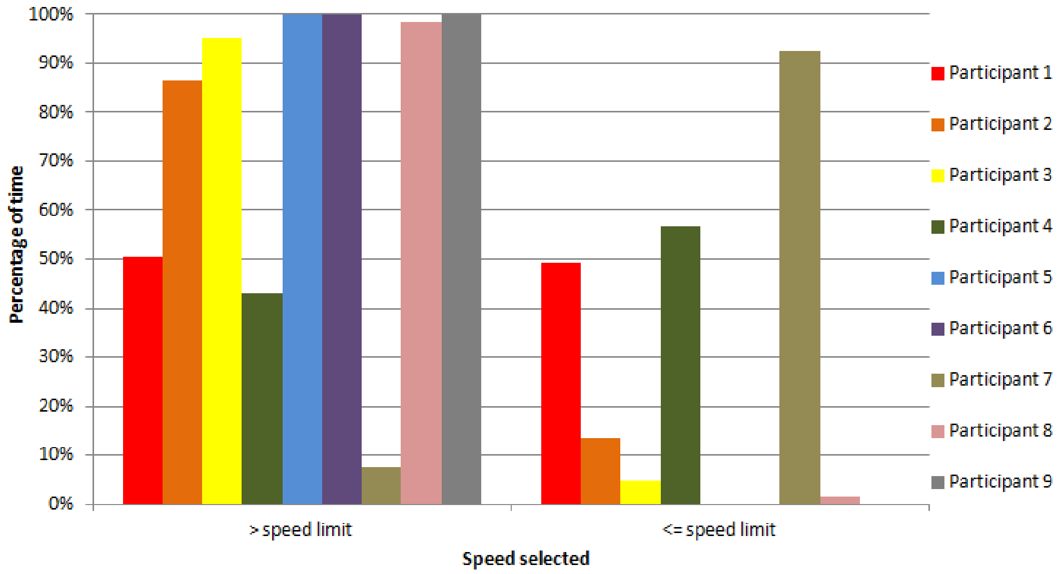

Figure 27 Speed selected by the participants while driving with ACC

On the other hand, in Fig. 28, it is drawn the percentage of time for which each participant, selected a specific headway while driving with the system. The ACC allowed the drivers to choose a distance from the vehicle ahead ranging from 1 to 5 intervals, being 1 interval equal to about 1 second and 5 intervals corresponding to about 2.5 seconds. The results presented in Fig. 28 show that drivers, while using ACC, adopt almost continuously the smallest headway available. This outcome is a confirmation of the findings obtained during the focus groups discussions where the participants admitted to adopt short headways in order to avoid that the ACC could lose track of the vehicle in front and, as a consequence, induce an abrupt braking behaviour of the vehicle (especially, in dynamic traffic conditions). The setting of short headways might represent an example of behavioural adaptation to the system because the driver, due to a particular aspect of the external environment (in this case, the highly dynamic traffic) and on account of the usage of the system, is driven to select a short headway to the vehicle in front. However, as in the case of the speed, there is no information available about the behaviour of the participants when driving without the system. Again, as for the speed, this aspect of the research will be addressed through the driving simulator study where the headway from the vehicle in front while driving with and while driving without the system will be compared.

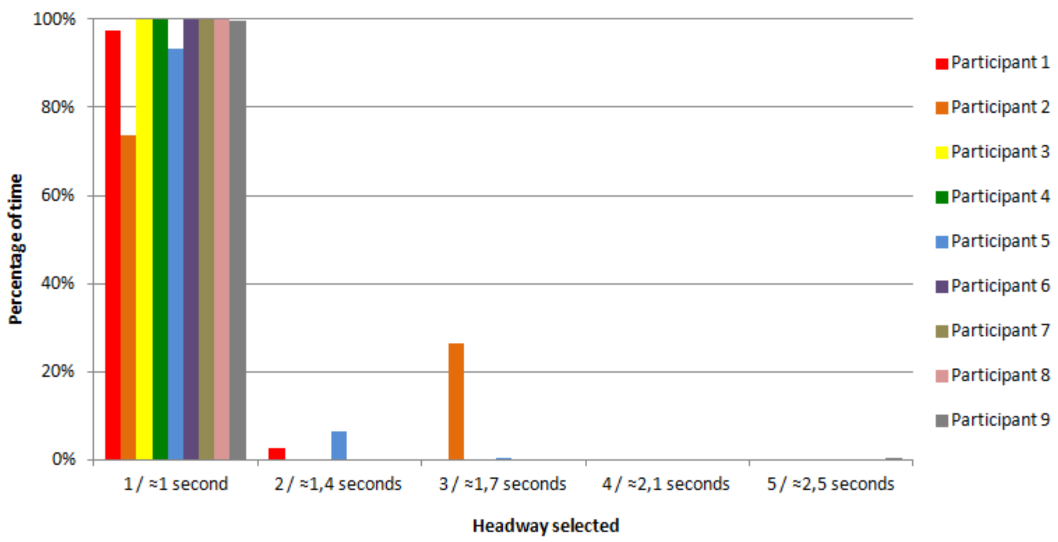

Figure 28   Headway selected by the participants while driving with ACC

Concerning the type of roads where the participants used the system, the results are reported in Fig. 29 (always in percentage of time). For the classification of the roads, 3 categories were considered:

- Motorways: roads, generally located outside the urban areas, with physical separation between the 2 carriageways, with at least two lanes for each direction and speed limit equal to 120 km/h (unless differently specified);
- Main/Rural roads: roads, generally located outside the urban areas, with/without physical separation between the 2 carriageways and speed limit higher than 50 km/h and lower or equal to 110 km/h;
- Urban roads: roads, inside populated areas, with/without physical separation between the 2 carriageways and speed limit equal or lower than 50 km/h.

Overall, it appears clear that drivers adopt the ACC almost exclusively on motorways, probably because, in such environment, the usage of the system is smoother, due to the fact that the way is distinguished by the scarcity of curves. This usage of the system is actually, in accordance with the advice provided in the owner's manual.

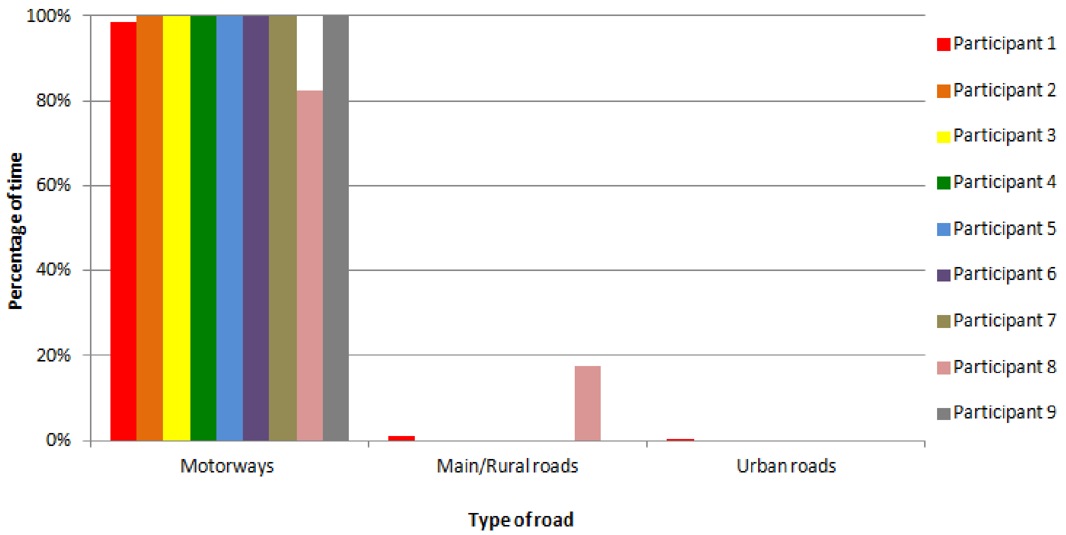

Figure 29 Usage of the ACC by type of roads

Finally, the last chart (Fig. 30) concerns the usage of ACC in the different traffic conditions. For the measurement of the traffic level, the definition of Level of Service (LOS) from the Highway Capacity Manual was used (Highway Capacity Manual, 2010). According to this definition, 6 Level of Service are identified, with the following characteristics:

- Level of Service A: free-flows operation, vehicles are almost completely unimpeded in their ability to manoeuvre within the traffic stream (density ≤ 11 passenger car/mile/lane);
- Level of Service B: reasonably free-flows operation, vehicles manoeuvre within the traffic stream is only slightly restricted (11 ≤ density ≤ 18 passenger car/mile/lane);
- Level of Service C: freedom to manoeuvre within the traffic stream is noticeably restricted (18 ≤ density ≤ 26 passenger car/mile/lane);
- Level of Service D: freedom to manoeuvre within the traffic stream is more noticeably limited and the driver experiences reduced physical and psychological comfort level (26 ≤ density ≤ 35 passenger car/mile/lane);

- Level of Service E: vehicles are closely spaced, leaving little room to manoeuvre within the traffic stream at speed that still exceed 49 mph (35 ≤ density ≤ 45 passenger car/mile/lane);
- Level of Service F: breakdowns in vehicular flow (density > 45 passenger car/mile/lane).

Unfortunately, through the frontal camera, it was not possible to have a perfect classification of the Level of Service. Hence, the traffic conditions were coded in three categories: low traffic (LOS=A or LOS=B), medium traffic (LOS=C or LOS=D) and high traffic (LOS=E or LOS=F).

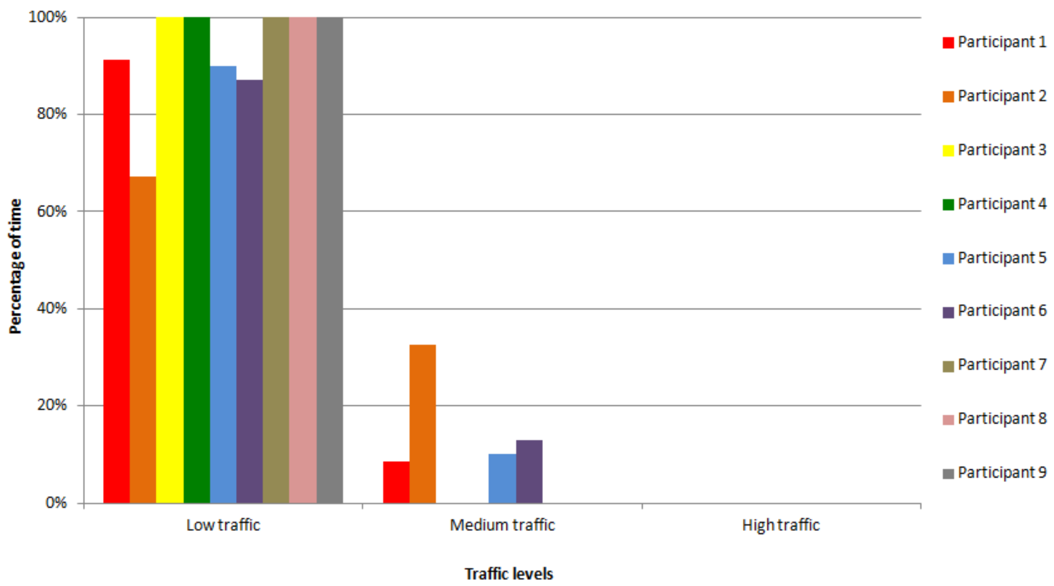

Figure 30 Usage of the ACC by level of traffic

From Fig. 30, it is evident that drivers adopt the ACC almost exclusively in low traffic conditions, as it is advised in the owner's manual. Indeed, in unstable traffic, the behaviour of the system is not completely reliable due to the continuous change in the target vehicle. Only few participants used the ACC in medium traffic conditions and none of them in high traffic conditions.

Further objectives of the nFOT were the detection of critical situations and improper utilizations of the system during the driving with the ACC activated.

Regarding the first scope, three “cut-in” situations were spotted. The “cut-in” occurs when a vehicle (travelling on the left or on the right lane relative to the equipped vehicle) suddenly enters the space between the equipped vehicle and the vehicle in front of it. In such situations, the radar of the ACC cannot detect the “cut-in” vehicle and, therefore, the intervention of the user is required. It is relevant to notice that, in all the three critical situations mentioned, the participants had used the ACC in environments where its utilization is not advised (with demanding traffic or in winding roads). This inappropriate usage of the ACC can be deemed as a considerable factor in the origin of the risky driving situation. Fortunately, in all the mentioned circumstances, the driver was able to react quickly enough to avoid an accident.

With regard to the improper utilizations of the system, none of the behaviours mentioned during the focus groups was found during the procedure of video coding. However, some participant used the ACC in situations in which, according to the instructions reported in the owner’s manual, it should not be, such as in winding roads, at motorway entrances/exits, in demanding traffic or during overtaking in double carriage roads. The usage of the ACC in those situations should be avoided because the radar of the system might easily lose the target vehicle and, therefore, provoke undesired fast accelerations of the equipped vehicle (and the associated necessary intervention of the driver).

Eventually, the last aspect that was investigated during the nFOT is the driver’s mental model relative to the system. As mentioned earlier, a 30-items questionnaire (Beggiato & Krems, 2013) was used to assess quantitatively the driver’s mental model relative to ACC. The questionnaire presented statements about the system and, for each assertion the participants could choose a response between 1 and 6 (1 corresponding to “Completely disagree” and 6 corresponding to “Completely agree”). Some examples of statements included in the questionnaire are “The system works in motorways” or “The system warns when the intervention of the driver is required”. From the questionnaire, some interesting findings can be obtained, with regard to the drivers’ understanding of the ACC working principle.

Regarding the “cut-in” situation previously described, only one participant was aware that the system cannot always detect the vehicle that enters in the gap between the equipped vehicle and the vehicle ahead (Fig. 31).

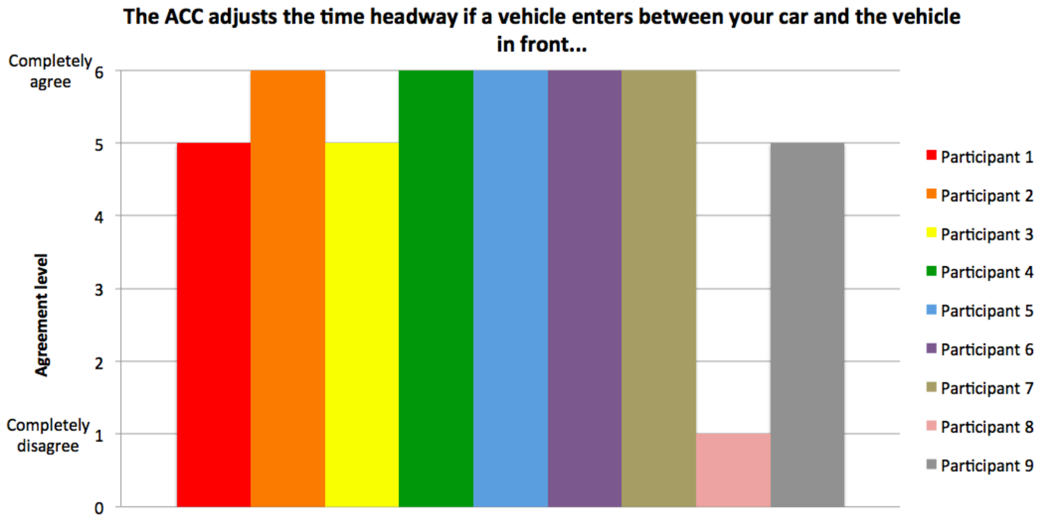

Figure 31 Driver’s mental model relative to the cut-in “situation”

Another aspect examined through the mental model questionnaire is the possibility of ACC to work in any weather conditions. As reported in the owner’s manual, the system might not work properly in poor weather conditions (such as snow or hard rain) due to the possible obstruction of the ACC radar. However, three participants out of six were not aware of such limitation of the ACC, considering that they totally agree that the system can work in any weather condition (Fig. 32)

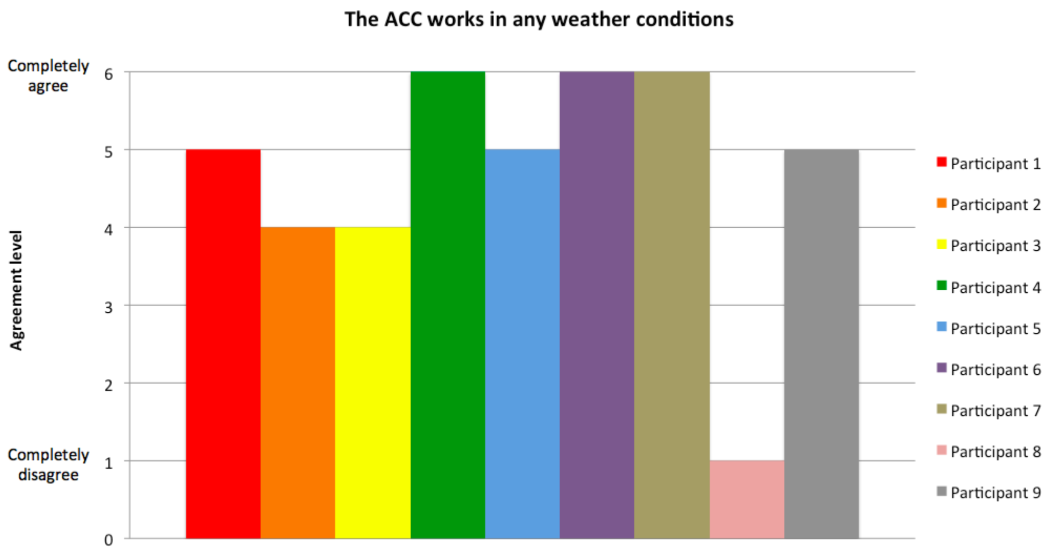

Figure 32 Driver's mental model about the ACC usage in any weather condition

From the 2 statements reported in this section, it seems that the drivers' mental model relative to ACC is not yet complete despite the experience acquired with the system. Then, from a flawed knowledge of the systems' working principle, critical situations might arise but, luckily, none of those situations happened during the nFOT. In order to test the drivers' reaction during a critical situation under safe conditions, the driving simulator experiment was planned and realized.

3. Driving simulator study

The driving simulator study focused on the following variables:

- Mean Speed driving with and without ACC;
- Time Headway driving with and without ACC;
- Time To Collision in the critical situation driving with and without ACC;
- Minimum space Headway in the critical situation driving with and without ACC;
- Drivers' mental model relative to the system;
- Trust in the system.

The speed and the Time Headway were assessed in Section 2 and Section 4. The two sections were selected because, in those stretches of the route, the traffic was constant (Table 11) and there weren't experimental criticalities (that were conceived to evaluate driver's behaviour while driving with ACC activated). On the other hand, the Time To Collision and the minimum space Headway were measured in Section 3 (Table 11), where the drivers were faced with a critical situation (still vehicle in the right lane of the motorway). The drivers' mental model relative to the ACC and the trust in the system were assessed before and after the trial with Adaptive Cruise Control, through a mental model questionnaire (Beggiato & Krems, 2013) and a trust questionnaire (Jian et al., 2000).

The results are presented below and each section is dedicated to a specific variable. The data were analyzed through the software SPSS.

3.1. Speed

The mean speeds of ACC users and regular drivers in both driving conditions (without and with ACC) are reported in Fig. 33. As for the charts regarding the Time Headway, the result has been obtained as an average of the value measured in Section 2 and Section 4.

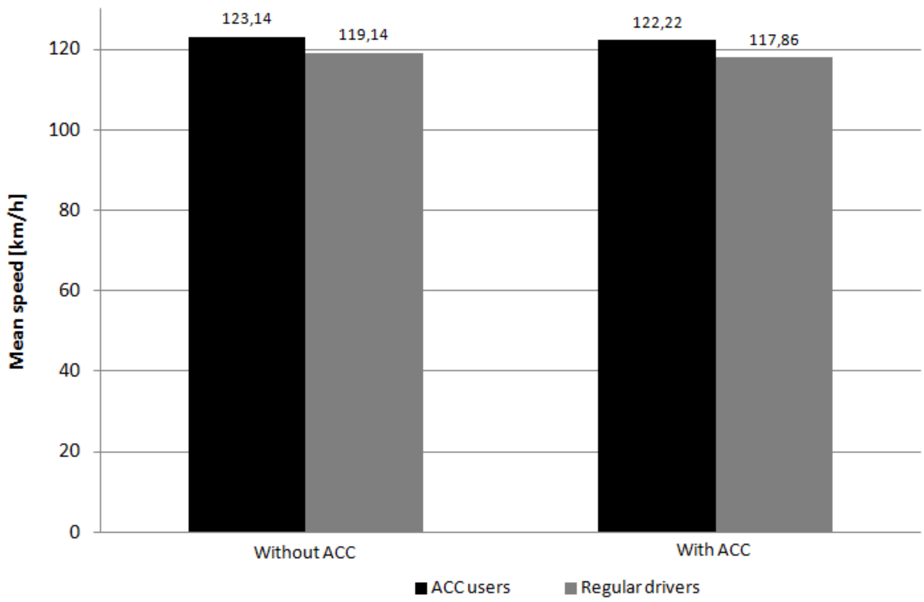

Figure 33 Mean speed for ACC users and regular drivers (without and with ACC)

In relation to the two independent variables examined (experience with ACC and driving condition), the figure shows that:

1. The usage of ACC brought a decrease in mean speed both for ACC users and regular drivers;
2. The ACC users drove faster than regular drivers in both driving conditions.

A two way (2x2) repeated measures mixed design ANOVA was run on the data collected. The results (Table 12) reveal that the manipulation of the independent variables did not have a significant effect on speed and, also, the same conclusions can be drawn for the interaction of the two independent variables.

Table 12 Effects of the variables and their interaction on the mean speed

Variable	Results	Significance
Experience with ACC	F(1,24) = 0,758	p = 0,393
Driving condition	F(1,24) = 0,371	p = 0,548
Experience with ACC * Driving condition	F(1,24) = 0,010	p = 0,923

3.2. Time headway

For the scope of this study, the Time Headway (TH) was defined as the elapsed time between the front of the lead vehicle passing a point on the roadway and the front of the following vehicle passing the same point (Evans, 1991), and calculated with the formula (1).

$$TH = t_i - t_{i-1} \qquad (1)$$

Where:

t_i : time at which the front of the lead vehicle *i* passes the measurement point;

t_{i-1} : time at which the front of the following vehicle *i-1* passes the measurement point.

The Time Headway calculated with the previous formula is well applicable to the case of a punctual measurement but cannot be adopted as a continuous assessment because the oscillations of the TH preclude the possibility to have a meaningful index for road safety, along an entire stretch of road. In order to clarify the reasoning, a fictitious example is given in Table 13.

Table 13 Examples of different Time Headways

Driver ID	Section 1 (10 km long)	Section 2 (10 km long)	Overall TH_{mean}
1	$TH_{mean1} = 0.5$	$TH_{mean2} = 4.5$	$TH_{mean} = 2.5$
2	$TH_{mean1} = 2.5$	$TH_{mean2} = 2.5$	$TH_{mean} = 2.5$

The driver 1 maintained a very short TH_{mean1} compared to the driver 2 in Section 1. Despite this unsafe behaviour for the driver 1 in Section 1, his overall TH_{mean} is equal to the TH_{mean} of the driver 2 (considering that the TH_{mean2} of driver 1 was very long in Section 2). So, analyzing the results in Table 13, the two drivers have equal TH_{mean} but, from the overall point of view of road safety, the driver 1 manifested a more risky behaviour (since he maintained a very short headway in Section 1, lower than the safety critical value recommended by the traffic code in several countries). Taking into account the previous considerations, in order to evaluate the time headway along Section 2 and Section 4, two surrogate measurements of Time Headway were chosen in this study: the Time Exposed Time Headway (TETH) and the Time Integrated Time Headway (TITH). Both measurements were calculated along the same line as the Time Exposed Time-to-Collision (TET) and the Time Integrated Time-to-collision (TIT), described in the article from Minderhoud and Bovy (2001). The Time Exposed Time Headway (TETH) represents the overall temporal exposure to a time headway value lower than the safety critical value, during a specific time interval T (that, in the specific case of this experiment, it is considered as the time spent to drive through Section 2 and Section 4). Computationally, the TETH is the sum of the time periods τ_{sc} in which the participant travels with time headway to the vehicle in front lower than the safety critical value TH^*, as expressed in the formula (2).

$$TETH = \sum_{t=0}^{T} \delta_i(t) \cdot \tau_{sc}$$
$$\delta_i(t) = \begin{cases} 0 & else \\ 1 \ \forall\ 0 \le TH_i(t) \le TH^* \end{cases} \tag{2}$$

Where:

T :	total interval of time considered;
$\delta_i(t)$:	binary parameter;
τ_{sc} :	minimum time period for which the TH is calculated;
TH^* :	safety critical value of the time headway;
$TH_i(t)$:	instant value of the time headway at the time t.

On the other hand, the Time Integrated Time Headway (TITH) is the integral of the difference between TH^* (the safety critical value for the time headway) and $TH_i(t)$ (the current time headway), taking into account exclusively the intervals of time where the Time Headway is lower than the critical safety value. The TITH is calculated through the formula (3).

$$TITH = \int_0^T [TH^* - TH_i(t)]dt$$
$$\forall\ 0 \le TH_i(t) \le TH^* \tag{3}$$

Considering that recommended values for TH vary among countries (Vogel, 2003), two different safety critical values of Time Headway (TH^*) were considered: an upper safety critical value of 2 seconds (recommended during driver training programmes in the USA) and a lower safety critical value of 1 second (evaluated as limit under which fines are imposed in Sweden).

The mean values for the TETH of ACC users and regular drivers in both driving conditions (without and with ACC) are reported in Fig. 34 and Fig. 35, respectively for the safety critical value of 2 seconds and the safety critical value of 1 second.

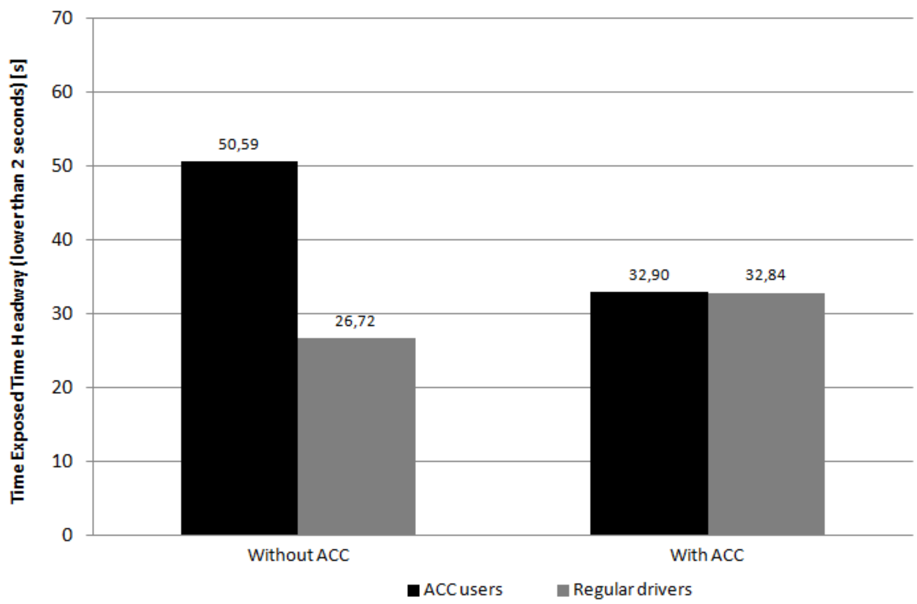

Figure 34 TETH (TH^*= 2 seconds) for ACC users and regular drivers (without and with ACC)

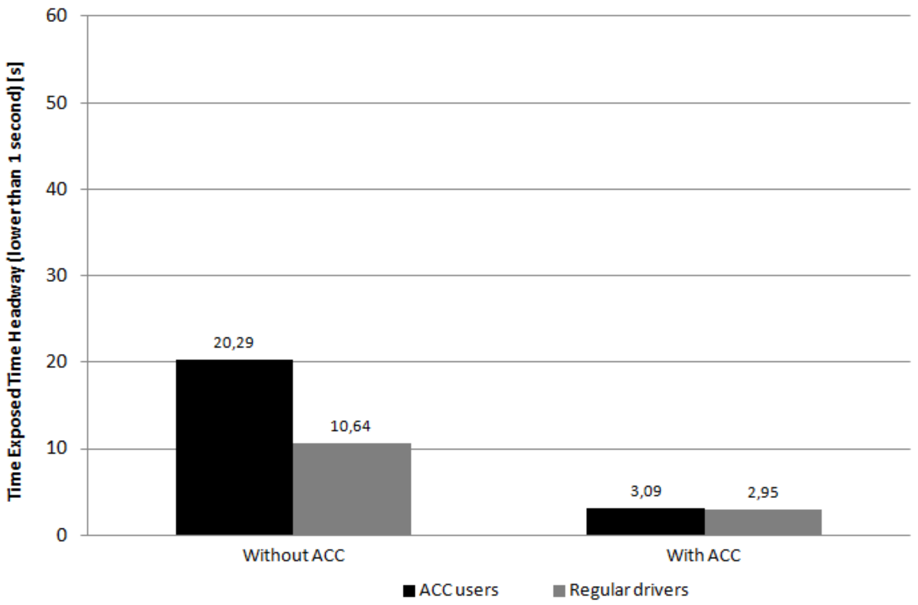

Figure 35 TETH (TH^*= 1 second) for ACC users and regular drivers (without and with ACC)

Concerning the results reported in Fig. 34, the usage of ACC produced a decrease of TETH (TH^*= 2 seconds) for ACC users but not for regular drivers and, therefore, the effect of the driving condition is not significant (Table 14). However, the interaction of the two variables (experience with ACC and driving condition) resulted significant to underline that the usage of ACC brought a reduction of TETH for ACC drivers but an increase of TETH for regular drivers.

Table 14 Effects of the variables and their interaction on the TETH (TH^*= 2 seconds)

Variable	Results	Significance
Experience with ACC	F(1,24) = 1,343	p = 0,258
Driving condition	F(1,24) = 1,659	p = 0,210
Experience with ACC * Driving condition	***F(1,24) = 4,923***	***p = 0,036***

On the other hand, looking at Fig. 35, after the usage of ACC, there is a reduction of TETH (TH^*= 1 second) for both ACC users and regular drivers and a significant effect of the variable driving condition on the TETH, as reported in Table 15. In this case, the interaction of the two variables (experience with ACC and driving condition) does not have a significant effect on the TETH.

Table 15 Effects of the variables and their interaction on the TETH (TH^* = 1 second)

Variable	Results	Significance
Experience with ACC	F(1,24) = 0,528	p = 0,475
Driving condition	***F(1,24) = 21,176***	***p = 0,000***
Experience with ACC * Driving condition	F(1,24) = 2,890	p = 0,102

In regard to the TITH, the average results are drawn in Fig. 36 and Fig. 37, respectively for the safety critical value of 2 seconds and the safety critical value of 1 second.

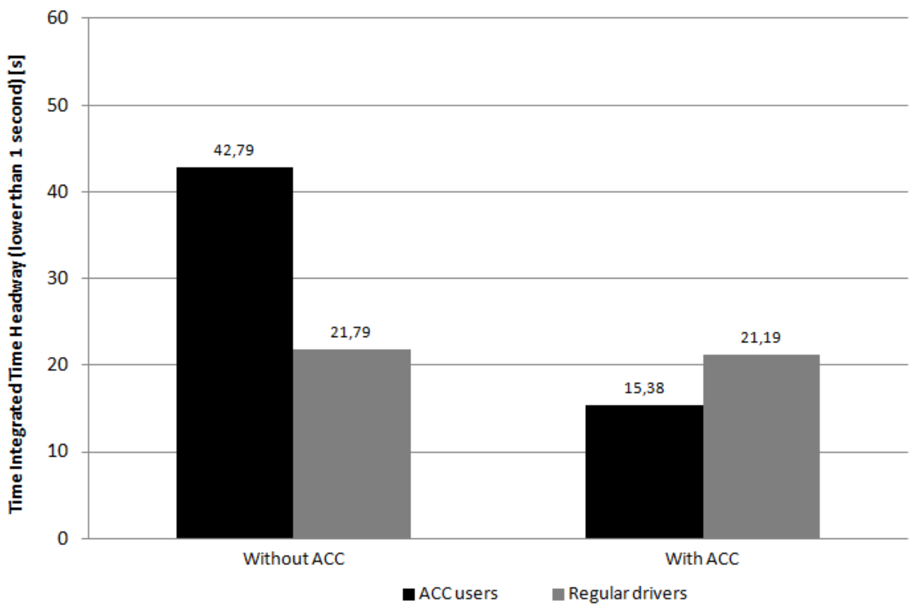

Figure 36 TITH (TH^* = 2 seconds) for ACC users and regular drivers (without and with ACC)

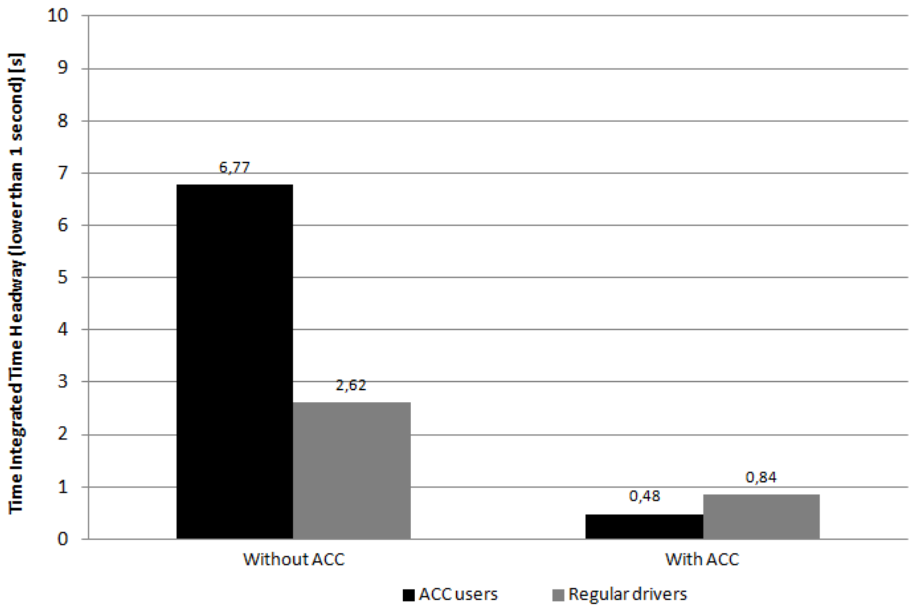

Figure 37 TITH (TH^* = 1 second) for ACC users and regular drivers (without and with ACC)

The results reported in Fig. 36 show that the usage of ACC generated a decrease in the TITH (TH^*= 2 seconds) for both ACC users and regular drivers, being however the second effect less pronounced: the variable driving condition has a significant effect on the TITH to indicate the reduction of TITH as a consequence of ACC usage. Besides, also the interaction between the two variables (experience with ACC and driving condition) has a significant effect on the TITH to denote the fact that, for ACC users, the decrease of TITH is significantly higher compared to the decrease of TITH for regular drivers (Table 16).

Table 16 Effects of the variables and their interaction on the TITH (TH^*= 2 seconds)

Variable	Results	Significance
Experience with ACC	F(1,24) = 0,595	p = 0,448
Driving condition	***F(1,24) = 7,4***	***p = 0,012***
Experience with ACC * Driving condition	***F(1,24) = 7,170***	***p = 0,013***

Finally, the charts of Fig. 37 show again that there is a decrease of TITH following the usage of ACC, being such decrease more evident for ACC users compared to regular drivers. In Table 17, it is reported the significant effect of the variable driving condition and of the interaction between the two variables on the TITH (TH^*= 1 second).

Table 17 Effects of the variables and their interaction on the TITH (TH^*= 1 second)

Variable	Results	Significance
Experience with ACC	F(1,24) = 0,512	p = 0,481
Driving condition	***F(1,24) = 16,997***	***p = 0,000***
Experience with ACC * Driving condition	***F(1,24) = 4,990***	***p = 0,035***

3.3. Time To Collision

The Time To Collision (TTC) assesses the time left before a collision with a lead vehicle, in the travel path, occurs if the speed stays constant (Östlund et al., 2005). This measurement is commonly used to establish the accident risk of an actual traffic situation and, smaller TTC values indicate a higher risk of accidents (Vogel, 2003). The formula for the calculation of TTC is reported below and it is exclusively valid for $\dot{x}_i(t) > \dot{x}_{i-1}$.

$$\frac{x_{i-1}(t) - x_i(t) - l_{i-1}}{\dot{x}_i(t) - \dot{x}_{i-1}(t)} \tag{4}$$

Where:

$x_{i-1}(t)$ frontal position of the lead vehicle at the time t;

$x_i(t)$	frontal position of the following vehicle at the time t;
l_{i-1}	length of the lead vehicle;
$\dot{x}_{i-1}(t)$	speed of the lead vehicle at the time t;
$\dot{x}_i(t)$	speed of the following vehicle at the time t.

For the scope of this research, during the critical situation in Section 3 (still vehicle stopped in the right lane), the minimum Time To Collision (TTC_{min}) was measured. In order to have a computation of the minimum value of TTC, the TTC_{min} was calculated at the time t in which the condition below was satisfied (the formula makes reference to Fig. 38):

$$y_2 + d \cdot \frac{\cos\alpha}{\sin\alpha} > y_1 + l_1 \tag{5}$$

Where:

y_1	lateral distance for lead vehicle (from the edge of the road to the right edge of the vehicle);
l_1	total width of the lead vehicle;
y_2	lateral distance for following vehicle (from the edge of the road to the right edge of the vehicle);
d	distance between the rear of the lead vehicle and the front of the following vehicle angle;
α	angle between the longitudinal axis of the road and the longitudinal axis of the car.

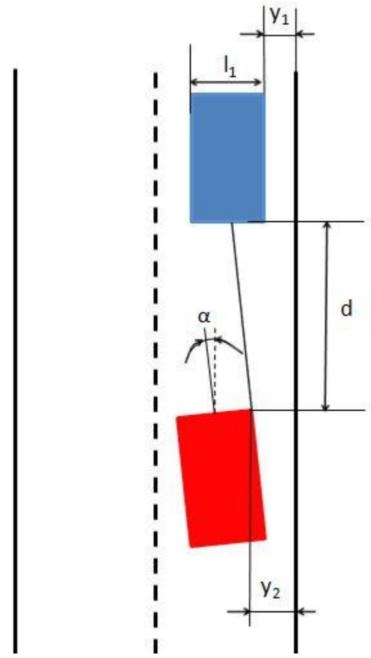

Figure 38 Measurements to be used for defining the condition at which TTC_{min} is calculated

The minimum Time To Collision was measured in both trials (driving with ACC and driving manually) for all the participants to infer the effect of the two variables under analysis (experience with ACC and driving condition) on the TTC_{min}. The average TTC_{min} for ACC users and for regular drivers in both driving conditions (driving manually and driving with ACC) is reported in Fig. 39.

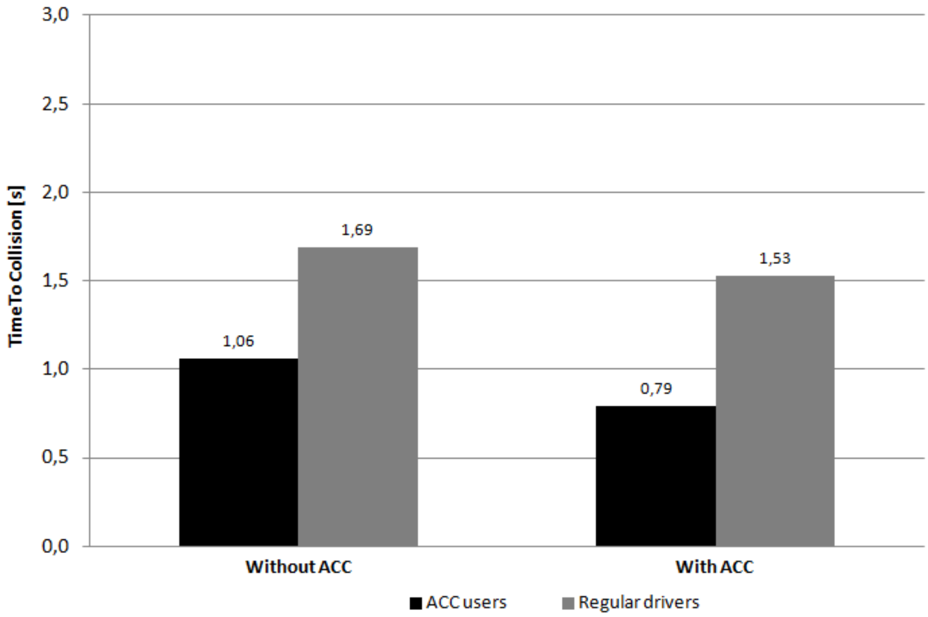

Figure 39 Average TTC_{min} in Section 3 for the 2 groups by driving condition

From Fig. 39, it is evident the difference in TTC_{min} between the two groups of users: overall, ACC users exhibited shorter TTC_{min} compared to regular drivers and so, in average, they had a higher risk to be involved in an accident with the still vehicle in front. The referred outcome is valid both in the manual driving and in the driving with ACC. A further result shows that the TTC_{min} presents a decrease of value when driving with the ACC compared to driving manually for both groups of drivers. In order to evaluate the effect that the ACC experience (between-subjects variable) and the driving condition (within-subjects variable) had on TTC_{min}, a two-way (2x2) repeated measures mixed design ANOVA was performed. The results of the test are reported in Table 18, where it is clear that the only variable producing a significant effect on the TTC_{min} is the 'Experience with ACC' (ACC users showed lower TTC_{min} in both driving conditions, compared to regular drivers). This result proves that ACC users and regular drivers behaved differently in the critical situation, provoked by the vehicle stopped in the right lane. In particular, this difference is more pronounced during the driving with ACC activated compared to the driving manually, even if the interaction between the 2 independent variables did not reach statistical 'significance'.

Table 18 Effects of the variables ACC usage and ACC experience and their interaction on the TTC_{min}

Variable	Results	Significance
Experience with ACC	***F(1,24) = 7.099***	***p = 0.014***
Driving condition	F(1,24) = 0.984	p = 0.331
Experience with ACC * Driving condition	F(1,24) = 0.066	p = 0.799

3.4. Minimum space Headway

In road safety, the headway indicates a distance between vehicles, expressed in time or in space (Ranney, 1999). For the scope of this research, the space headway was defined as the distance between the lead vehicle's rear bumper and the following vehicle's front bumper. Given that, the minimum space Headway HW_{min} was the value of the space headway at the time *t* in which the TTC_{min} was calculated (see previous section). The average HW_{min} for ACC users and for regular drivers in both driving conditions (driving manually and driving with ACC) is reported in Fig. 40.

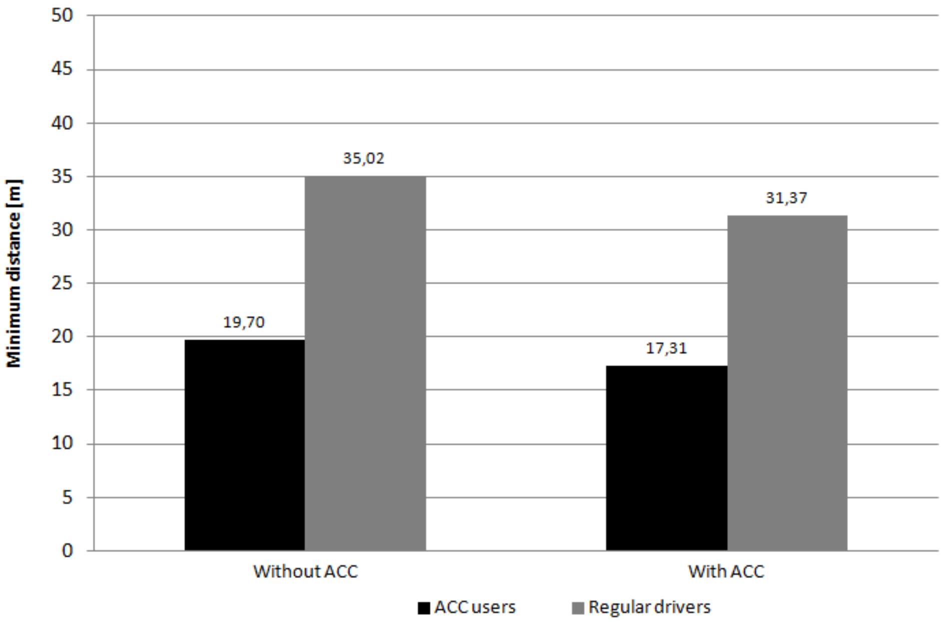

Figure 40 Average HW_{min} in Section 3 for the 2 groups by driving condition

Looking at the figure, analogies can be found with the chart of the TTC_{min}. Again, there is a drop in the measurement (HW_{min}) due to the usage of ACC for both ACC users and regular drivers. However, as opposed to the chart of the TTC_{min}, in this case, the reduction is similar for ACC users and regular drivers (whereas, in the previous section, more accentuate decrease of TTC_{min} was found for ACC users respect to regular drivers). Besides, as already obtained for the TTC_{min}, the ACC users presented smaller HW_{min} compared to the regular drivers in both driving conditions.

A two-way (2x2) repeated measures mixed design ANOVA was performed to determine the impact of the independent variables on the HW_{min} and the results of the test are reported in Table 19.

Table 19 Effects of the variables ACC usage and ACC experience and their interaction on the HW_{min}

Variable	Results	Significance
Experience with ACC	***F(1,24) = 8.333***	***p = 0.008***
Driving condition	F(1,24) = 0.322	p = 0.576
Experience with ACC * Driving condition	F(1,24) = 0.498	p = 0.487

The results of the ANOVA are similar to the ones obtained for the TTC_{min}. Again, the only variable that had a significant effect on the HW_{min} is the between-subjects variable 'Experience with ACC', to point out that ACC users always got closer to the stopped vehicle.

Overall, the analyses performed on TTC_{min} and HW_{min} yielded the following results:

- The 'Experience with ACC' had a significant effect on both TTC_{min} and HW_{min}, with ACC users displaying lower values of TTC_{min} and HW_{min} compared to regular drivers in both driving conditions;

- The usage of ACC originated a decrease of TTC_{min} and HW_{min} for both ACC users and regular drivers but this effect was not statistically significant.

In order to better understand which factors might have originated those results, the driver's mental model relative to the ACC and the trust in the system were investigated. The smaller TTC_{min} and HW_{min} might have been occurred because the ACC drivers expected the system to brake during the critical situation and, therefore, took more time to react. Such a wrong belief would have been originated by a wrong mental model relative to the system which, in turn, produced an excessive trust in the system. In order to deepen the impact of those variables (driver's mental model relative to the system and his/her trust in the system) on the results, additional analyses were performed.

3.5. Mental model

The mental model questionnaire was administered before and after the route with ACC. Before the route, the drivers were asked to read a description of the ACC and to shortly experience the functioning of the system in the simulator. After this brief trial, they filled in the questionnaire for the first time. Then, they drove in the simulated route with the assistance of the system and, after the trial they filled in the questionnaire again. The questionnaire adopted in the experiment was a revised version of the mental model questionnaire designed by Beggiato and Krems (Beggiato & Krems, 2013) and was based on 30 items. Each item included a statement about the working principle of the system and the driver was requested to indicate his agreement in a scale from 1 to 6 (with 1 corresponding to "I completely disagree" and 6 corresponding to "I completely agree"). The statements had a simple structure such as "The ACC works in motorways" or "The ACC warns if the intervention of the driver is required". Among the statements included in the questionnaire, the item 4 ("The ACC reacts to stationary objects") was especially interesting for the analyses reported in this paper for its close link to the critical situation occurred in Section 3 (still vehicle in the right lane).

As a first investigation, the average score for item 4 (assessed before and after the trial with ACC) was calculated and reported in charts for ACC users and regular drivers. The results are drawn in Fig. 41 and show that ACC users disagreed more with the statement compared to regular drivers, especially before but also after driving with ACC. Such an outcome points out that the mental model of ACC users relative to the critical situation was more accurate compared to the one of the regular drivers (considering that the most appropriate answer to the statement would have been a complete disagreement, that is a score close to 1), mainly before driving with the ACC. In that moment, regular drivers' answer was in average high (an average score of 3.38) compared to the correct one (that should have been close to 1), whereas ACC users' answer was more close to the proper one (since they returned an average score of 2.15).

From Fig. 41, it can also be inferred that the score after the driving with ACC decreased for both groups compared to the score before the trial.

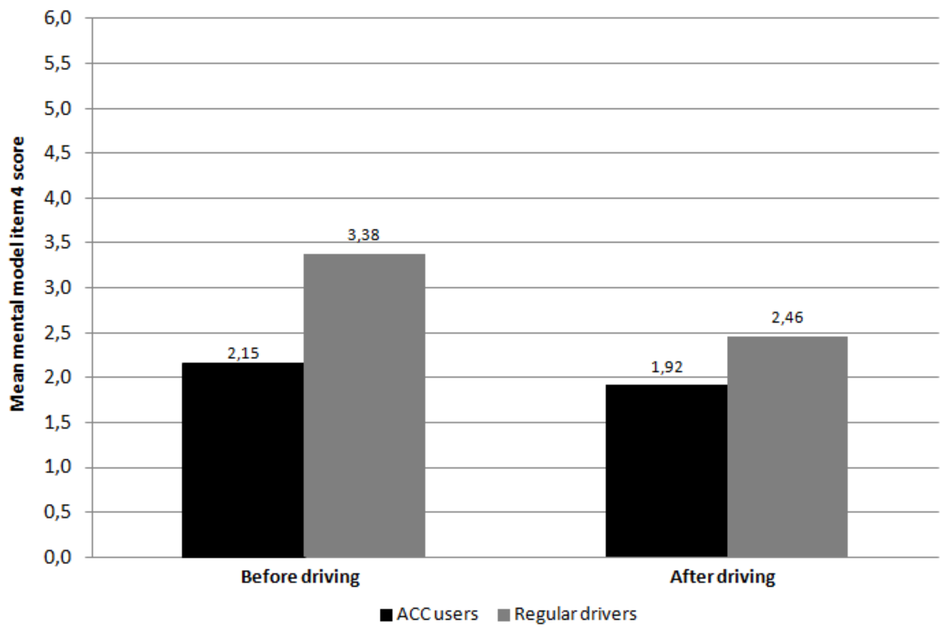

Figure 41 Average score on item 4 of the mental model questionnaire before and after using ACC

A two-way (2x2) repeated measures mixed design ANOVA was performed to determine the impact of the independent variables on the item 4 of the mental model questionnaire (Table 20). The results indicate that, for item 4, there was a significant effect of the ‘Driving condition’ to take into account that, after the route with ACC, the score on the item decreased. This outcome can be explained as a change of opinion about the statement (possibility for the system to react to a stationary vehicle), due to the critical event experienced by the drivers. Besides, the variable ‘Experience wih ACC’ almost reached ‘significance’ to indicate that ACC users had a lower score on the item 4 of the mental model questionnaire, compared to regular drivers, before and after the route with ACC.

Table 20 Effects of the independent variables and their interaction on the item 4 of the mental model questionnaire

Variable	**Results**	**Significance**
Experience with ACC	$F(1,24) = 3.286$	$p = 0.082$
Driving condition	***$F(1,24) = 4.592$***	***$p = 0.042$***
Experience with ACC * Driving condition	$F(1,24) = 1.653$	$p = 0.211$

In summary, the results regarding the mental model questionnaire were not as expected. It was hypothesized that the smaller TTC_{min} and HW_{min} for ACC users were caused by an incomplete mental model relative to the system concerning the critical situation. However, from the results, ACC did not manifest a less accurate mental model relative to the system during the critical situation compared to the regular drivers despite they had shorter TTC_{min} and HW_{min}. Apparently, the mental model relative to the system did not seem to influence directly the TTC_{min} and HW_{min}. In order to better understand the relationship between the item 4 of the mental model questionnaire and the two variables (TTC_{min} and HW_{min}), the Spearman’s correlation coefficient was calculated. The result demonstrates that the item 4 of the mental model questionnaire (measured before the driving with ACC) is not related neither to the TTC_{min} ($r_S = 0.035$, p (one-tailed) = 0.433) neither to the HW_{min} ($r_S = 0.023$, p (one-tailed) = 0.457).

3.6. Trust

The trust in the system was assessed using the questionnaire developed by Jian et al. (Jian et al., 2000), that consists of 12 items. For each item, the respondent was asked to indicate how much he/she agreed/disagreed with a scale ranging between 1 (fully disagree) and 7 (fully agree). Examples of statements included in the questionnaire are “I am confident in the system” or “The system is dependable”. The items 2, 3, 4, 5 and 7 of the questionnaire were reversed because they expressed a negative meaning. Like the mental model questionnaire, the trust questionnaire was administered once before the trial with ACC and once later, after the driving with the system activated. Reliability analysis, based on the Cronbach’s alpha, showed a value of 0.875 before the trial with ACC and a value of 0.858 after the experiment.

In order to have a unique score for the trust, the average score of all the items was taken (in case of items with a negative meaning, the reversed score was taken). The average scores for the trust questionnaire before and after the driving with ACC are reported in Fig. 42 for both ACC users and regular drivers.

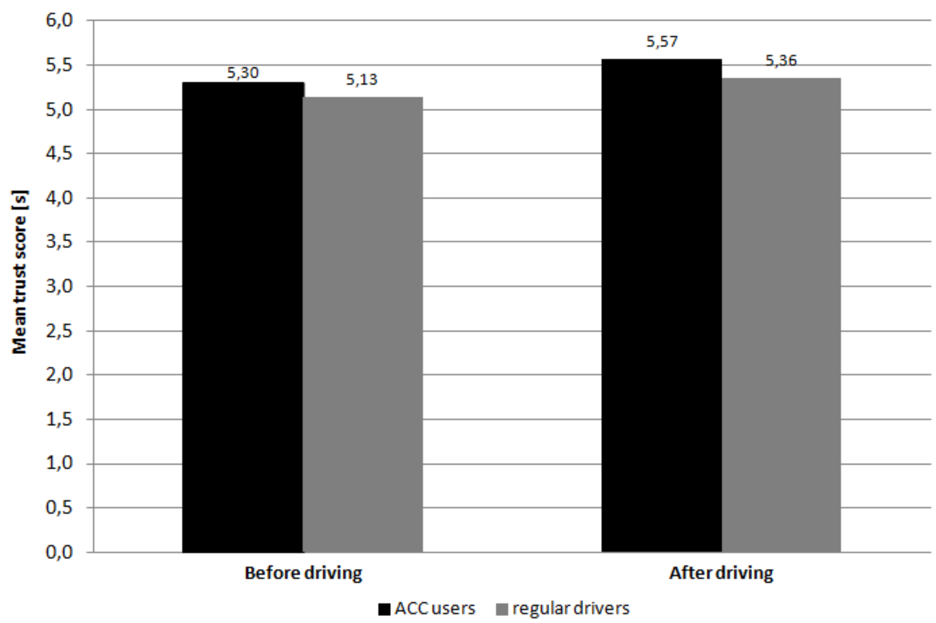

Figure 42 Average score for trust before and after driving with the ACC

From Fig. 42, two main conclusions can be drawn:

- Despite the critical situation occurring in Section 3, the trust score slightly increased for all the participants after the route with ACC compared to the score before the route;
- The ACC users showed a higher trust in the system compared to regular drivers, both before and after the route.

A two-way (2x2) mixed design ANOVA was performed in order to find out the effect of the two variables on the trust score. The calculations are reported in Table 21 and none of the variables and neither the interaction between the variables resulted significant. This outcome suggests that, unlike the mental model, the trust did not significantly changed after the trial with ACC (compared to before) and that ACC users and regular drivers did not differ in regard to the trust placed in the system.

Table 21 Effects of the independent variables and their interaction on the trust score

Variable	Results	Significance
Experience with ACC	F(1,24) = 0,423	p = 0.521
Driving condition	F(1,24) = 2,300	p = 0.142
Experience with ACC * Driving condition	F(1,24) = 0,014	p = 0.906

As for the mental model, a further analysis was performed in order to discover the relationship between the trust in the system (before the route with ACC) and the dependant variables (TTC_{min} and HW_{min}). Using the Spearman's correlation coefficient, a significant negative relationship of medium effect was found between the trust score (assessed before the trial with ACC) and the TTC_{min} (r_S = - 0.376, p (one-tailed) = 0.029) and, a significant negative relationship of large effect between the trust score (assessed before the trial with ACC) and the HW_{min} (r_S = -0.509, p (one-tailed) = 0.004). In light of those results, it is assumed that the more the drivers trusted the system before the ride, the more they got closer to the still vehicle during the Section 3 of the route.

4. Discussion

4.1. Focus groups interviews

The focus groups discussions were performed with a sample of Portuguese ACC and BLIS users in order to better understand how the usage of the systems can have an impact on the driving task and on road safety. The discussion for each system will be conducted separately within this chapter.

Regarding ACC, the results retrieved from the discussions were centred on three themes: the effects of the ACC on the driving task, the impact of the ACC on road safety and the drivers' usage of the ACC.

Regarding the effects of the ACC on the driving task, the participants reported satisfactory comments: overall, they mentioned that, driving with the ACC was more comfortable and safer than driving without the system. This confirms the findings reported in Strand et al. (2011). The drivers admitted that the assistance provided by the ACC let them feel more relaxed during the trip and more rested once they reach their destination. In what regards the safety benefits introduced by the system, drivers reported lower speeds and safer distances to the vehicle in front. Those positive effects clash with previous findings (Hoedemaeker and Brookhuis, 1998). Since no objective data can be retrieved through the focus groups discussions, the driving simulator study has been performed to compare the drivers' behaviour related to speed and headway while driving with and without the ACC.

Discussing the impact of the ACC on road safety, only one driver experienced a critical situation while driving with the system activated. In contrast with the findings of Larsson (2012), few limitations of the system (driving on curvy roads and braking behaviour) were mentioned by the participants. On the other hand, as had already been found by Strand et al. (2011), high concern was shown for the vehicles travelling behind the equipped car: due to the abrupt braking behaviour of the ACC, the drivers in the back might not clearly understand what is happening in the front. Compared with previous research on the topic, a relevant result of this study was that some behavioural adaptations were reported during the discussion. Drivers admitted to engage more in secondary tasks (using the mobile phone, surfing on the web, reading, etc.) when driving with the ACC activated: this result seems to acknowledge that the reduction of workload reported in previous findings (Stanton et al., 1997; Hoedemaeker & Brookhuis, 1998) stimulates the drivers to undertake other activities that are not related to the driving task. Furthermore, some participants revealed improper usages of the ACC, like driving only using the ACC buttons, seeking a vehicle in front and setting short headways while driving with the ACC. In order to confirm/reject that, in real circumstances, drivers manifest some improper usage of ACC, in the following experiment (naturalistic FOT), participants were recorded in naturalistic conditions while driving with the ACC activated.

Concerning the usage of the ACC, the findings of the focus groups discussions are comparable to the ones reported in the study carried out in Sweden (Strand et al., 2011). Participants stated to use the system mainly in high speed supporting roads and with stable or low traffic conditions.

Overall, the results of the focus groups discussions seem to confirm some aspects of previous research conducted on the ACC. However, new findings emerged, with respect to the impact of the ACC on road safety:

1 Drivers did not seem fully aware of the critical situations that might occur when driving with the system activated (despite the considerable experience acquired with the ACC, especially for some participants);
2 The participants revealed some improper usages of the system (playing with the ACC controls, setting short headways);
3 The users admitted to undertake distracting tasks (calling, surfing on internet, etc.) more frequently when driving with the ACC compared to driving without the system.

Concerning the first two findings, the cause might be framed within the concept of mental models. Mental models can be defined as "the mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (Rouse & Morris, 1986). As such, mental models (founded on the knowledge acquired about the working principle of the system) directly influence the interaction between the drivers and the system because they reflect users' judgements about the characteristics of the device: then, if the driver's mental model relative to the ACC is not accurate, the driver might not be completely aware of critical situations occurring with the system or might use the system in inappropriate ways. A correct mental model relative to the ACC is, therefore, extremely relevant for the proper usage of the system: the naturalistic FOT and the driving simulator study were performed in order to shade more light on the evolution of the driver's mental model during the usage of ACC. Besides, the driving simulator study also aimed to study the possible negative effects on the driving performance induced by an improper mental model relative to the ACC.

Regarding the third finding, an explanation might come from the compensatory control model of Hockey (1997). The model distinguishes two control loops used by the humans to monitor any task (including the driving task). The first loop keeps human performance level according to the defined goals. The second loop, instead, monitors the workload involved in achieving the level of performance. According to this theory, when the perceived workload exceeds a specific limit (different for each person), the goals can be adapted, accepting a lower performance. On the other hand, if the workload decreases up to a certain level, the humans will attempt to increase the workload to an optimum level. Given that the ACC automates the longitudinal driving task, drivers are released from the need of pressing the pedals and constantly monitoring the distance to the preceding vehicle. As a consequence, the workload level registers a decrease and, according to the Hockey's compensatory control model, drivers might be tempted to engage in other distracting tasks. Future studies should be oriented towards the deeper identification of the secondary tasks undertaken by drivers while using the ACC and towards the feasible actions to avoid such behaviours.

On the other hand, concerning BLIS, drivers expressed satisfaction about the help provided by the system during the lane change task, despite being aware of its limitations. According to the comments made by the participant, two situations need to be distinguished during the lane change with BLIS, depending on the state of the warning light. If the warning light is on, drivers wait for it to turn off. On the other hand, when the warning is off, drivers verify in the mirror and perform the lane change as they would regularly do in a traditional vehicle. Then, apparently, the introduction of BLIS does not modify drivers' lane change behaviour and, also for this reason (besides, the organizational motivations), the remaining experiments (nFOT and driving simulator study) were exclusively focused on the Adaptive Cruise Control.

It should be noted that some participants referred that, in the long-term, behavioural adaptations to BLIS might occur: in fact, drivers could rely on the system and carry out the lane change without looking at the mirror when the warning doesn't light up. This behaviour would be extremely dangerous since the system is not completely dependable, especially in some situations that are clearly identified (hard rain, fast approaching vehicles, etc.). This aspect of the study represents an interesting point for further research on the topic.

Some limitations must be mentioned about the focus groups discussions performed. First, due to the sampling method adopted and the small number of participants, the sample cannot be considered representative of the overall population of the ACC and BLIS users in Portugal. However, it is important to mention that it was not in the scope of this research to draw a statistical inference about the reference population. In addition, the focus groups interviews, being solely based on users' opinions, do not deliver any objective results about drivers' behaviour while using the ACC and BLIS. It is manifest that subjective assessment might actually differ from the actual behaviour. However, the precious comments supplied by the users are an indubitable help for future research on the topic; in particular, for what concerns ACC, the focus groups discussions represented useful foundations for the preparation of the hypothesis and for the performance of the naturalistic Field Operational Test (nFOT) and the driving simulator study.

4.2. Naturalistic Field Operation Test (nFOT)

The naturalistic Field Operation Test was conducted with a small sample of ACC early-adopters to increase the awareness about the usage of the system in Portugal. In addition, through the questionnaire applied after the nFOT, some aspects of the drivers' mental model relative to ACC were clarified. As mentioned above, the study exclusively focused on the Adaptive Cruise Control and, therefore, only this system will be treated in the discussion. The main findings are hereafter summarized:

1. The participants mostly chose speeds higher than the speed limit when driving with the ACC activated;
2. The participants selected short headways (about 1 second) to the vehicle in front when driving with the system activated;
3. The participants used the system almost exclusively in motorways and in low traffic conditions;
4. In some cases, the participants showed usages that are not in accordance with the instructions reported in the owner's manual (e.g., usage in winding roads or demanding traffic);
5. The users' mental model relative to the system is not complete even after the initial usage of the system.

Regarding the second result, taking into account the opinions collected during the focus groups, it is possible that drivers prefer to set the shortest headway in order to avoid that the radar of the system lose the target vehicle, producing an abrupt braking behaviour of the vehicle. This tailgating behaviour might be due to the fact that the study was conducted in South of Europe, where it is common to observe an aggressive driving style, as mentioned in the result section related to the focus groups discussions.

The last finding is especially interesting because it proves that ACC users, despite the practice acquired with the system, are not yet completely aware of the situations in which the functioning of the system might be limited. However, during the real driving, it was not possible to obtain any confirmation of the findings gathered through the mental model questionnaire because, luckily, critical situations never occurred. Therefore, to know more about the ACC users' ability to react to an imminent critical situation and about behavioural adaptations to the system (comparing the behaviour while driving with and without the system), the driving simulator with users of the system has been performed.

Overall, based on the results of the focus groups discussion and of the nFOT, it is possible to have a clearer indication of how users of ACC adopt the system. However, some doubts still remain especially regarding two aspects:

1. Does the introduction of ACC provoke any behavioural adaptations regarding the speed and the headway chosen by the users?
2. Which impact might be produced on road safety by the omissions in the drivers' mental model relative to ACC?

In particular, further research should address the following aspects:

- Are there any differences between the speeds and headways adopted with and without the system for the users of ACC?
- Are users of ACC able to promptly react to a critical situation that might rise while driving with the system activated?

In order to answer those questions, the driving simulator study has been realized.

The nFOT presents some limitations: first of all, the sample was small, as it already occurred during the focus groups discussion. As well, in view of the fact that users of the system, in Portugal, are mainly businessmen, there was not a balance between men and women in the sample. However, with respect to those limitations, it is important to mention that it was not in the scope of this research to draw a statistical inference about the reference population.

A further limitation of the proposed research is that, during the nFOT, it was not possible to acquire a baseline measurement of participants' behaviour while driving without the ACC activated, due to the limited availability of the experimental vehicle. However, the comparison between the driving task with and without the ACC will be the subject of the study performed in the driving simulator.

4.3. Driving simulator study

The driving simulator study was planned to investigate the research questions that could not be answered by the previous focus groups discussions and nFOT, due to the subjective assessment and the low experimental control. In particular, the study focused on three aspects of the interaction with ACC:

1. Travelling speed and time headway to the vehicle in front;
2. Reaction to a critical situation caused by a functional limitation of the system;
3. Drivers' mental model relative to ACC and drivers' trust in the system.

In order to investigate those aspects, a two-way (2x2) repeated measures mixed design study was performed in the driving simulator of the Faculty of Engineering of the University of Porto. The experience with ACC (ACC users and regular drivers) was the between-subjects factor and the driving condition (ride along the same route with ACC and manually) was the within-subjects factor. The distinctive traits of this work compared to previous studies are mainly two:

1. Up to now, the research performed on ACC mainly involved participants who never drove with the ACC before the experiment. Differently from previous works, this study focused on users of the ACC to better understand their behaviour while driving with the system;
2. Previous research did not stress the differences that exist between ACC users and regular drivers regarding the usage of the system. In order to fill this gap, in the present research, a comparison between ACC users and regular drivers was conducted during the interaction with the system.

This section of the discussion chapter will be divided in three parts, according to the previously mentioned aspects of the interaction with ACC.

Concerning the first aspect analyzed, this research was conducted because, up to now, the studies performed did not yield unanimous results on behavioural adaptation to ACC, related to the travelling speed and the time headway to the vehicle in front.

With respect to the travelling speed, the results showed that the usage of ACC provoked a reduction for both ACC users and regular drivers, compared to the manual driving condition, although this effect did not result statistically significant. This outcome seems to confirm the findings of Stanton et al. (1997), (in contrast with what described by Hoedemaeker and Brookhuis, 1998), revealing that the usage of ACC did not have a negative impact on road safety. In the previous focus groups discussions, the ACC users mentioned that the system manifests an abrupt braking behaviour that starts when the vehicle in front is still far away. This conduct of the ACC might prevent the drivers from increasing the travelling speed when using the system (compared to the manual driving), due to the presence of other vehicles in the traffic. Then, if more vehicles are equipped with ACC in the future, a favourable outcome on road safety might be expected, given that speed is considered one of the basic risk factors in traffic (Wegman et al., 2008).

However, it should be remarked that, in this experiment, the velocity of the simulated traffic on the left lane was constant and equal to 120 km/h, in both routes; this experimental setting might have limited the reduction of speed brought by the usage of ACC and, therefore, further research should be conducted in conditions of free-flow driving. Concerning the time headway, two novel measurements were adopted, the Time Exposed Time Headway (TETH) and the Time Integrated Time Headway (TITH), that allowed a continuous assessment of the time headway in defined stretches of the route. The results show that, with regards to the TETH (TH^* = 2 seconds), there is a reduction, for ACC drivers, due to the usage of the system but the same result is not shown for regular drivers. On the other hand, considering the TETH with TH^* = 1 second, there is a reduction of TETH for both groups, despite being it more evident for ACC users.

Looking at the TITH, for both safety critical values (TH^* = 1 second and TH^* = 2 seconds), the ACC usage generated a positive effect on the observance of safety distances (demonstrated, in this case, by the reduction of TITH) for both groups of drivers. In addition, it was demonstrated that the reduction of TITH is more evident for ACC users, compared to regular drivers (as already reported for the TETH).
Globally, the calculations of the TETH and the TITH indicated that, through the usage of ACC, the drivers maintained safer distances to the vehicle in front and this result is especially evident for the ACC users (respect to the regular drivers). The reduction of TETH and TITH might be a consequence of the disparity between the minimum headway settable with the ACC and the comfortable headway usually preferred by the driver. Indeed, with the ACC simulated (and, also, with the ACC available on actual vehicles), it was not possible to choose headway values smaller than 1 second whereas drivers' comfortable headway is, in many cases, equal or smaller than 1 second (Chen, 1996; Van Winsum & Heino, 1996; Taieb-Maimon & Shinar, 2001). Based on this result, the usage of ACC might be considerably beneficial because it could prevent the drivers from the 'tailgating' practice, as mentioned by a participant during the focus groups discussions previously conducted.

The fact that the reduction of TETH and TITH was greater for ACC users compared to regular drivers might be an effect of the experience gained with the system: the ACC drivers, through the continuous adoption of the system, might have developed optimal strategies of usage with a consequent positive beneficial effect on the preservation of safety distances. As an instance, given that people have difficulties in evaluating the distances in terms of seconds (Taieb-Maimon & Shinar, 2001), the experience with ACC might assist drivers in acquiring the ability to define more precisely the time headway and, as a consequence, to select a safe distance when using the system.

Overall, it seems there is no evidence that the usage of ACC might cause negative behavioural adaptations to the system for what concerns speed and time headway, confirming the results found by Stanton et al. (1997). However, contrary to previous studies on the topic, the present research was conducted not only with standard drivers but also with a group of ACC users, broadening the results achieved to a wider population. In addition, two novel measurements were used to continuously assess the time headway to the vehicle in front. Those measurements could be exploited in further experiments, since they demonstrated a good suitability to the predetermined scope.

Regarding the second aspect analysed, the research was performed in order to assess the driver's reaction to a critical situation originated by a functional limitation of the system. For the first time, users of the ACC were involved in this type of experiment.

With respect to the minimum Time To Collision (TTC_{min}) and to the minimum space Headway (HW_{min}), the ACC users experienced lower TTC_{min} and HW_{min}, compared to regular drivers, during the critical situation while driving with ACC. However, they also reported lower TTC_{min} and HW_{min} during the critical situation while driving manually. Considering that the study was designed as a matched sample research (and, so, the effect of confounding variables have been limited), the results might account for the fact that ACC users developed a lower capacity to promptly react to a critical situation, due to the usage of the system. Then it is presumed that, due to the continuous adoption of ACC during their daily driving, ACC users might have lost their ability to promptly react to a critical event, both during the driving with the system and in the manual driving condition. Unfortunately, this study was not sufficient to support the assumption but further research should be conducted to investigate if the usage of ACC, besides decreasing the capacity to react to a critical event during the usage of the system (Hoedemaeker & Brookhuis, 1998; Rudin-Brown & Parker, 2004; Stanton et al., 1997; Vollrath et al., 2011), might also reduce it during the manual driving, after a continuous usage. If this was the case, the discussed matter would represent a phenomenon very similar to the loss of skill manifested by human operators following the automation of industrial processes (Woods, 1986).

A further result shows that, for both variables and for both users, there was a reduction of TTC_{min} and HW_{min} while passing from driving manually to driving with ACC, although this outcome did not prove to be statistically significant. This reduction of TTC_{min} and HW_{min}, for regular drivers, might indicate a decreased reaction capacity of drivers while driving for the first time with the system activated, confirming the results reported by previous literature (Hoedemaeker & Brookhuis, 1998; Rudin-Brown & Parker, 2004; Stanton et al., 1997; Vollrath et al., 2011). However, it is relevant to notice that this reduction of TTC_{min} and HW_{min} was also reported for ACC users, whose behaviour was expected to be different from the one of regular drivers. If this result was confirmed by further studies, it would represent an important outcome for road safety and quick measures should be taken to avoid that a critical situation originated by a limitation of the system might create the conditions for an accident to occur.

With regards to the third aspect analysed, the study was carried out in order to investigate if the driver's mental model relative to ACC and the trust in the system are appropriate for the critical situation experienced by drivers. Besides, a possible correlation between the two constructs (the driver's mental model relative to ACC and the trust in the system) and the reaction to the critical situation was also explored.

The mental model relative to the ACC in the specific critical situation was assessed through the score on the item 4 of the mental model questionnaire. Surprisingly, the mental model of ACC drivers appeared to be appropriate for the critical situation of the still vehicle, whereas the same did not hold for regular drivers. This result could be explained presuming that ACC drivers, due to the continuous usage of the system, developed a better mental model relative to the system compared to novice users. Therefore, based on this study, it can be confirmed the outcome of Beggiato and Krems (2013), where it was shown that the driver's mental model relative to the system converge towards the correct model along with time.

Contrary to what hypothesized, the results showed that the item 4 of the mental model questionnaire (assessed before the route with ACC) did not relate neither with the TTC_{min}, nor with the HW_{min}, suggesting that the mental model did not directly influence the driving performance with the ACC during the critical situation.

Following the critical situation, the mental model relative to the system was modified for both drivers, becoming more appropriate to the real working principle of the system. In particular, the regular drivers changed more their mental model relative to the system compared to ACC users (even if this effect did not result significant), probably because the mental model of ACC users is already more consolidated (compared to the one of regular drivers) and less subject to fluctuations.

With respect to the trust in the system, ACC users and regular drivers had a similar high score on the questionnaire, both before and after the critical situation. Then, it appears that the system is well trusted by the users, both during the first usage (for regular drivers) and during the later ones (for ACC users). In addition, unlike the mental model, the trust in the system correlated negatively with the TTC_{min} and with the HW_{min}: the more the drivers trusted the system (before the route with ACC) and the more they revealed lower values of TTC_{min} and HW_{min}. This outcome confirms the results found by Rajonah et al. (2006) but it extends them also to users that already have a certain experience with the system (and not only to drivers who never practiced with the system before the experiment). Then, based on this study, it should be stressed again the relevance of a proper trust in the system for its correct usage and in order to avoid behaviours that might undermine road safety.

Concerning the still vehicle in the right lane, the results were quite surprising because, both for ACC users and regular drivers, the trust in the system did not decrease after experiencing the critical situation. This result might suggest that the trust in the system is a psychological construct more settled in the mind of the user compared to the mental model relative to the system (it might be possible that changes in the trust require more time compared to the changes in the mental model relative to the system) or that, in contrast with previous research (Beggiato &

Krems, 2013; Kazi et al., 2007), the trust in the system does not evolve over time. Further studies should address this aspect, especially with ACC users, once it was demonstrated that overtrust might bring negative consequences on the usage of the system.

Overall, analyzing the second and third aspect together, the driving simulator study warns about the possible negative effects associated to the usage of the ACC, during a critical situation originated by a functional limitation of the system, especially for drivers who are already accustomed to the ACC. Despite the experience acquired with the system and despite the accurate mental model relative to the critical situation (tested with the mental model questionnaire), the ACC users still presented a lower TTC_{min} and HW_{min} compared to regular drivers, during the driving with ACC, across the critical situation. This outcome might be explained assuming that, although the mental model was correct, the drivers did not exhibit proper situation awareness during the critical situation and this prevented a prompt reaction. The fact that drivers probably did not experience yet a similar critical situation with the system activated might have been the cause of inadequate situation awareness. As well, the research work underlines the relationship between the trust in the system and the driving performance during the utilization of ACC. Based on that, the study reaffirms the relevance of a proper trust for a correct usage of the system, warning against the development of overtrust in the system.

The driving simulator study presents some limitations. First of all, the sample was limitative because it involved 26 drivers and because all age and gender categories were not represented. Unfortunately, the small number of ACC users in Portugal did not allow a larger sample but, in the future, the system might be available on more vehicles and, therefore, it will be possible and necessary to conduct the experiments with wider samples and involving also young and novice drivers (that might become users of the system in the next years). In addition, although the research was designed as a matched sample study, some other variables that were not included in the matched sample procedure might have produced an effect on the results (for example, the level of education of drivers or the perceptual speed).

However, given that the matched sample procedure accounted for 6 variables (gender, age, driving experience and score on the DBQ questionnaire, T-LOC questionnaire and SS questionnaire) closely linked to the driving behaviour, the confounding factors might be limited and, therefore, the two samples may be considered enough similar for a proper comparison.

Although the usage of ACC demonstrated a positive effect on speed and time headway in this experiment, further research should be performed to confirm the results in different driving conditions (e.g., other simulated settings or in field tests). Finally, including only two trials in which one was with the system and the other one without, does not allow to draw conclusions about the evolutions over time of driver's reaction to the critical situation, of the mental model relative to the system and of the trust in the system for ACC users (for regular drivers, those aspects have been already studied). Indeed, following the critical situation occurred during the trial, drivers might be able to more promptly react to an analogous critical situation in a later trial. Future studies should address this aspect, in particular, to clarify whether the drivers' safe usage of the system can be induced by the occurrence of critical situations with the system.

5. Verification of hypothesis

This research work described the application of three methods for the understanding of behavioural adaptations to Adaptive Cruise Control and, partly, to Blind Spot Information System. Notably, focus groups discussions, a naturalistic Field Operational Test (nFOT) and a driving simulator study were conducted in Portugal.

The focus groups discussions were conducted with users of ACC and BLIS to determine drivers' opinions about the systems and patterns of usage of the systems. However, considering that the focus groups discussions are exclusively based on subjective opinions, an objective analysis was required and, therefore, the naturalistic Field Operational Test (nFOT) was conducted.

The nFOT was performed with a small sample of ACC users to determine the patterns of usage of the system, to spot possible improper usages of the ACC and to investigate the drivers' mental model relative to Adaptive Cruise Control. In the nFOT (and, as well, in the driving simulator study) BLIS users were not included because, from the focus groups discussions, the system did not seem to heavily influence the lane change behaviour. Besides, the vehicle used in the driving simulator is equipped with left and right mirrors but the side mirrors cannot display to the participants the traffic moving behind the vehicle (and, therefore, the simulation of the Blind Spot Information System is not possible). Despite the objective data collected with the nFOT, the main disadvantage of this method is related to the low experimental control. In order to fill this gap, the driving simulator study was performed to test the behaviour of drivers in conditions that cannot be recreated in natural settings.

The driving simulator study was conducted to determine the reaction of ACC users and regular drivers to a critical situation originated by a functional limitation of the system. As well, the study aspired to investigate the speeds and time headways maintained by ACC users and regular drivers while driving with and without the system. Finally, the driving simulator study also looked more in detail into the concepts of mental model relative to the ACC and trust in the system.

Overall, with respect to the hypothesis formulated in the first chapter, the following can be concluded.

Hypothesis_1_ACC – *The users of ACC will utilize the system not only in the appropriate driving contexts (major/larger roads, low density traffic situations) but, also frequently in situations in which the system should not be used (urban environment, high density traffic conditions).*

Based on the results of the focus groups discussions and of the nFOT, this hypothesis cannot be confirmed. During the focus groups discussions, the drivers admitted to use the system mainly in high speed supporting roads and with stable or low traffic conditions, confirming the findings of Strand et al. (2011). Those opinions were validated by the objective data collected through the nFOT and showing that the system is employed almost exclusively in motorways and in low traffic conditions. Overall, from the study, the users of ACC seemed to use the system in the appropriate driving contexts.

Hypothesis_2_ACC – *The users of ACC are not completely aware of the critical situations that might occur during the usage of the system. In particular, when faced with one of those critical situations (still vehicle in the right lane), the ACC users will stop closer to the vehicle ahead than in the situation of driving manually. Compared to regular drivers (people who never used the ACC before the study), the users of the system will stop closer to the vehicle ahead during the critical situation, while driving* *with Adaptive Cruise Control.*

Through the assessment of the drivers' mental model relative to ACC, it was proved, during the nFOT, that users of ACC, despite the practice acquired with the system, are not yet completely aware of the situations in which the functioning of the system might be limited. However, during the driving simulator study, there was not a significant reduction of minimum Time To Collision (TTC_{min}) and minimum space Headway (HW_{min}) while passing from driving manually to driving with ACC, during the critical situation represented by a still vehiche in the right lane of the motorway.

Regarding the comparison between ACC users and regular drivers, significant differences were found with respect to the minimum Time To Collision (TTC_{min}) and to the minimum space Headway (HW_{min}), with the ACC user stopping closer to the vehicle ahead. This last result might account for the fact that, due to the continuous adoption of ACC during their daily driving, ACC users might have lost their ability to promptly react to a critical event when driving with the system.

Hypothesis_3a_ACC – *ACC users will opt for speeds higher than the speed limits while driving with the system activated. Besides, they will increase the speed when driving with ACC as opposed to driving manually. Compared to regular drivers, the users of the system will opt for higher speeds while driving with Adaptive Cruise Control.*

Based on the results, this hypothesis is partly confirmed. During the focus groups discussions, the drivers did not mention about the maintainance of speed lower or higher than the speed limits. However, during the nFOT, the videos revealed that, when driving with the ACC activated, the participants mostly selected speeds higher than the speed limit.

On the other hand, differently from what hypothesized, during the driving simulator study, the usage of ACC did not cause an increase of speed compared to driving manually and no significant differences were found between ACC users and regular drivers.

Hypothesis_3b_ACC – *ACC users will adopt headways shorter than 2 seconds (safety critical value) while driving with the system activated. Besides, they will decrease the time headway from the vehicle in front when driving with ACC as opposed to driving without the system. Compared to regular drivers, the users of the system will opt for shorter time headways, while driving with Adaptive Cruise Control.*

During the focus groups discussions, the ACC users admitted to set short headways while driving with the ACC and, through the nFOT, this result was confirmed since the drivers mainly selected headways of about 1 second to the vehicle in front.
On the other hand, differently from what hypothesized, during the driving simulator study, the usage of ACC induced safer distances to the vehicle in front compared to the manual driving condition. Besides, no significant differences were found between ACC users and regular drivers.

Hypothesis_4a_ACC – *The drivers' mental model relative to the system will have an effect on drivers' ability to react to a critical situation. If the drivers' mental model relative to the system is not accurate, the driver's performance, during a critical situation with the system activated, will be affected. Besides, after experiencing a critical situation with ACC, the drivers' mental model relative to the system will change and become more accurate.*

Differently from what supposed, the driving simulator study showed that the mental model questionnaire (or, better, the item of the questionnaire related to the reaction of ACC with a still vehicle), assessed before the route with ACC, did not relate neither with the minimum Time To Collision (TTC_{min}), nor with the minimum space Headway (HW_{min}). This result suggests that the mental model did not directly influence the driving performance with the ACC during the critical situation.
Besides, consistently with the hypothesis, after the critical situation, the mental model relative to the system was modified for ACC users and regular drivers to

indicate the change of opinion about the statement (possibility for the system to react to a stationary vehicle), due to the critical event experienced by the drivers.

Hypothesis_4b_ACC – *The trust in the system will have an effect on drivers' ability to react to a critical situation. The more drivers trust the system, the worse will be the driver's performance during a critical situation with the system activated. Besides, after experiencing a critical situation with ACC, the trust in the system will change and a lower trust in the system will be shown.*

According to what supposed, during the driving simulator study, the trust in the system correlated negatively with the TTC_{min} and with the HW_{min}: the more the drivers trusted the system before the route with ACC and the more they revealed lower values of TTC_{min} and HW_{min}. This outcome confirms the results found by Rajonah et al. (2006) but it extends them also to users that already have a certain experience with the system (and not only to drivers who never practiced with the system before the experiment).
Differently from the hypothesis, the trust in the system did not decrease after experiencing the critical situation. This result might suggest that the trust in the system is a psychological construct more settled in the mind of the user compared to the mental model relative to the system or that the trust in the system does not evolve over time.

Hypothesis_1_BLIS – *The users of BLIS will utilize the system in any road environment, in any traffic conditions and in any weather conditions. However, they will switch off the system in some occasions, due to the annoyance caused by the blinking lights (that warns the driver about the presence of a vehicle in the left/right blind spot) on the left/right A pillars of the vehicle.*

During the focus groups discussions, the BLIS users reported to keep the system always activated and, therefore, as supposed, they use it in any road environment, in any traffic conditions and in any weather conditions. They admitted to switch off the BLIS exclusively when it gets confused (such as when there is hard rain outside). Regarding the warning on the side mirrors, differently from what hypothesized, the users of BLIS did not consider it annoying but useful and situated in the appropriate location.

Hypothesis_2_BLIS – *The users of BLIS will show behavioural adaptations to the system during the usage of BLIS in the driving task. Notably, in some occasions, they will trust the system and not look anymore at the side mirrors before performing a lane change.*

This hypothesis was not confirmed by the results of the focus groups discussions. The users of BLIS stated that the lane change behaviour is not modified by the introduction of BLIS because drivers do not completely trust the system and, therefore, they always look at the mirror before changing lane. However, some users mentioned about the possibility to incur into behavioural adaptations in the long-term (e.g., not confirming anymore in the mirror about the presence of a vehicle in the lane). Such aspect should be evaluated by further research.

Hypothesis_3_BLIS – *The users of BLIS are aware of the limitations of the system.*

Based on the results of the focus groups discussions, it is possible to state that the BLIS users are aware of the limitations of the system (e.g., not proper functioning with hard rain, false detections of vehicles). However, they seemed confident about the fact that the system won't create any critical situations (incidents, accidents, etc.), considering that the BLIS does not heavily interfere in the driving task.

As mentioned earlier in the text, the hypotheses concerning the BLIS were verified only looking at the results issued by the focus groups discussions.

6. Limitations

Some shortcomings about the study should be mentioned. The main limitation is represented by the fact that the sample of ACC and BLIS users was small. However, it should be considered that, in Portugal, the ACC and BLIS are niche systems because the number of vehicles equipped with those systems is quite little. Then, in the future, with the increasing spread of those systems, further studies might be conducted to confirm / reject the results produced by this study.

A further limitation of the proposed research is that, during the nFOT, it was not possible to acquire a baseline measurement of participants' behaviour while driving without the ACC activated, due to the limited availability of the experimental vehicle. Later studies might preview a baseline period before the driving with the system activated in order to compare the behaviour of drivers with and without the system.

Finally, another limitation is linked to the driving simulator study: this experimental part was designed as a matched sample study to compare the behaviour of ACC users and regular drivers. However, some other variables not included in the matched sample procedure might have produced an effect on the results (for example, the level of education of drivers or the perceptual speed). In the future, similar studies might take into account also other variables to set up more homogeneous groups.

PART 4: FINAL CONSIDERATIONS

1. Conclusions

Overall, based on the study conducted, it is possible to state that ACC and BLIS users are globally satisfied about the systems. The former is considered especially useful to increase the comfort of the driving task. On the other hand, the latter is deemed convenient to assist the driver during the performance of a lane change, reducing the risk of lateral accidents. For both systems, functional limitations are recognized but accepted by the users. In future, some improvements might be brought by car makers in order to improve the drivers' acceptance of the systems. Regarding the ACC, the braking behaviour of the system should become smoother, increasing even more the comfort offered to the drivers. With regards to the BLIS, the main enhancements could be the increase of the angle of the camera (in order to detect larger blind spot areas) and the improvement of the efficiency of detection (in order to reduce the false alarms).

Regarding the utilization of the system, the users seemed to activate the ACC and the BLIS in the appropriate driving contexts. Based on subjective and objective data, it was shown that the ACC is employed almost exclusively in motorways and in low traffic conditions. On the other hand, relative to the BLIS, the users stated to adopt it during the lane changes and to switch off the system only in some particular occasions, in which the BLIS is not properly operating (with hard rain and when driving close to a barrier between lanes). The results on BLIS are, however, based on subjective assessment and, therefore, should be confirmed by further research.

Concerning the behavioural adaptations to the ACC, this study focused on three aspects:

- **Secondary tasks and usage of ACC controls**: behavioural adaptations were reported since the ACC users admitted to engage more frequently in distracting tasks (calling with the mobile phone, surfing on the internet) while driving with ACC compared to driving manually. According to the opinions of the users, this behaviour is due to the more relaxed attitude induced by the usage of the ACC. Besides, the ACC users reported some improper usages of the system, as driving the car using only the ACC controls without pressing the accelerator and brake pedals. Those results (on secondary tasks and usage of ACC controls), however, are only based on the focus groups discussions and not proved through objective assessment. Therefore, further research should be dedicated to confirm/reject those conclusions, through the performance of naturalistic studies or driving simulator studies.

- **Speed and time headway**: there is no evidence to suppose that behavioural adaptations to the system can occur in regard to speed and time headway. Indeed, the usage of ACC did not provoke an increase of speed and, on the other hand, it induced safer distances to the vehicle in front compared to the manual driving condition. Besides, no differences were found regarding speed and time headway between ACC users and regular drivers.
- **Reaction to a safety critical event**: a small reduction of minimum Time To Collision (TTC_{min}) and minimum space Headway (HW_{min}) was found while passing from driving manually to driving with ACC. Nevertheless, this effect did not result significant and, therefore, it does not allow us to report behavioural adaptations to the system with respect to the driver's ability to react to a critical situation. On the other hand, significant differences were found between regular drivers and users of the system with respect to the TTC_{min} and to the HW_{min}. ACC users stopped closer to the vehicle ahead and this result might account for the fact that, due to the continuous usage of ACC during their daily driving, ACC users might have lost their ability to promptly react to a critical event when driving with the system. Further research is suggested to investigate if behavioural adaptations to ACC can occur during other critical situations, considering larger samples of ACC users.

With respect to the BLIS, the users stated that the lane change behaviour is not modified by the introduction of the system. However, they also mentioned about the possibility to incur into behavioural adaptations in the long-term (e.g., not confirming anymore in the mirror about the presence of a vehicle in the lane). Considering the last comment and taking into account that the results are based exclusively on the focus groups discussions, this study suggests the performance of further research on the topic.

Finally, exclusively focusing on ACC, the driver's mental model relative to the system and the trust in the system were investigated.

Concerning the former, based on the data collected during the nFOT, it was proved that the ACC users, despite the practice acquired with the system, are not yet completely aware of the situations in which the functioning of the system might be limited. This result was supported by the driving simulator study: not all the drivers were conscious that the system does not react with still vehicles and some of them only learnt it after experiencing the critical situation with the system activated (as a consequence of which, the mental model relative to ACC of the users improved). However, despite the relevance of the mental model construct for a safe usage of the system, the drivers' mental model relative to ACC did not seem to have a significant effect on driver's performance during the critical situation tested (still vehicle in the right lane).

Concerning the latter, ACC users (and, also, the regular drivers), showed a high trust in ACC, both before and after experiencing the critical situation. This result might indicate that the trust in the system is a concept more settled in the mind of the user compared to the mental model relative to the system. Besides, during the driving simulator study, it was found that the trust in the system has a relevant impact on the driving performance during the critical situation. Indeed, the trust in the system correlated negatively with the TTC_{min} and with the HW_{min}: the more the drivers trusted the system before the route with ACC and the more they revealed lower values of TTC_{min} and HW_{min} during the critical situation with the system activated.

2. Implications

Globally, based on the results obtained through this study, some implications for car makers should be considered. First of all, some improvements could be brought to increase the comfort of the ACC (through a smoother braking behaviour of the system) and the capacity of detection of the BLIS (through a wider angle of the camera). Besides, some actions could be taken by car makers to improve the drivers' mental model relative to ACC, since the first usage of the system:

- The customers completing the purchase of the car might receive a clear explanation from the dealer about the working principle of the system (or, even better, an on-road demonstration);
- The customers might be provided with some leaflets, describing the situations in which the system should not be used (such a description should be shorter than the one reported in the owners' manual).

Besides, in order to guarantee a safe usage of ADAS, the car makers might financially support research to be conducted on the long-term effects induced by those systems on drivers' behaviour.

3. Future perspectives

Considering that the main limitation of this work consists in the small number of ACC and BLIS users involved in the study, future research should consider larger samples, including also enough participants representing different age categories (e.g, young and elderly drivers) and gender (e.g., male and female).

Regarding the performance of the nFOT, due to some limitations, it was not possible to establish a baseline measurement of participants' behaviour while driving without the ACC activated. Then, the on road results simply describe the behaviour of drivers during the interaction with the system, missing the comparison between diriving with and without the assistance of ACC. Further research should dig into this topic to investigate if behavioural adaptations to the system are identified, during on-road driving.

Besides, it should be remarked that, in this research, the conclusions drawn on behavioural adaptation to BLIS are exclusively based on the results of the focus groups discussions. Further investigation should embrace other types of assessment, including NDS, nFOT and driving simulator studies to evaluate if the usage of the system could cause any change to driver's behaviour compared to driving manually.

Overall, additional research should be carried out to confirm the results obtained in the present work, in different experimental settings and with other samples of users. In addition, similar research should be performed taking into consideration other ADAS, to ensure that the market introduction of those systems do not cause any negative effects on driver's behaviour.

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APPENDICES

Appendices

Appendix I Questionnaire 1 - Information about the participant

Questionnaire - Information about the participant

Name _ _ _ _ _ _ _ _ _ _ _ _

Surname _ _ _ _ _ _ _ _ _ _ _ _

Year of birth _ _ _ _ _ _ _ _ _

Gender ☐ Feminine ☐ Masculine

In which town are you living? _ _ _ _ _ _ _ _ _

Mobile phone number (for further contact) _ _ _ _ _ _ _ _ _ _ _ _ _ _

Profession _ _ _ _ _ _ _ _ _

Academic qualification _ _ _ _ _ _ _ _ _ _ _ _ _

Do you have a driving licence? ☐ Yes ☐ Not

For how long do you have your driving licence? _ _ _ _ _ years

Approximately, how many kilometers have you been driving since you have your driving licence?

- ☐ Less than 10.000 kilometers
- ☐ 10.001 - 30.000 kilometers
- ☐ 30.001 - 50.000 kilometers
- ☐ 50.001 - 100.000 kilometers
- ☐ 100.001 - 150.000 kilometers
- ☐ More than 150.000 kilometers

Do you frequently drive? ☐ Yes ☐ No

If you answer affirmatively, how frequently do you drive?

- ☐ Every day
- ☐ Several days per week
- ☐ Several days per month
- ☐ Very rarely

In average, how many kilometers have you been drinving in the last 12 months?

- ☐ Less than 5.000 kilometers
- ☐ 5.001 - 10.000 kilometers
- ☐ 10.001 - 20.000 kilometers
- ☐ More than 20.000 kilometers

Is your vehicle equipped with any of those systems (questions 1. and 2.)?

1. Adaptive Cruise Control (ACC) ☐ Yes ☐ No

1.1 How long have you been using ACC? _ _ _ _ _ Months

1.2 How frequently do you use ACC?

- ☐ Every days
- ☐ Some times per week
- ☐ Some times per month
- ☐ Some times per year
- ☐ Never

1.3 How did you learn to use ACC?

- ☐ Using the system
- ☐ Reading the owner's manual
- ☐ Explanations from the car vendor
- ☐ Explanations from friends
- ☐ Other (please specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _

Appendix II Questionnaire 2 – ACC usage

Questionnaire - ACC usage

1. Approximately, how many kilometers have you already been driving with ACC?

- ☐ Less than 50 kilometers
- ☐ 51 - 200 kilometers
- ☐ 201 - 500 kilometers
- ☐ 501 - 1.000 kilometers
- ☐ 1.001 - 3.000 kilometers
- ☐ More than 3.000 kilometers

2. In which type of road do you use ACC? You can select more than one option.

- ☐ motorways (maximum speed limit: 120 km/h)
- ☐ roads reserved to cars (maximum speed limit: 100 km/h)
- ☐ other roads (maximum speed limit: 90 km/h)
- ☐ urban roads (maximum speed limit: 50 km/h)
- ☐ none of them
- ☐ other (please specify) _______________

Comments _________________________________

3. In which weather conditions you don't use ACC? You can select more than one option.

- ☐ light rain
- ☐ sunny
- ☐ intense fog
- ☐ hard rain
- ☐ light fog
- ☐ I use ACC in any weather condition
- ☐ I never use ACC
- ☐ other (please specify) _______________

Comments _________________________________

4. In which light conditions, do you use ACC? You can select more than one option.

- ☐ during the day
- ☐ at night
- ☐ never
- ☐ other (please specify) _______________

Comments _________________________________

5. In which traffic conditions do you use ACC? You can select more than one option.

- ☐ very ligth traffic
- ☐ ligth traffic
- ☐ stable traffic
- ☐ heavy traffic
- ☐ very heavy traffic
- ☐ never
- ☐ other (please specify) _______________

Comments _________________________________

6. When you use ACC on main roads (roads with speed limit equal or higher than 90 km/h), how do you set the ACC speed?

- ☐ in most cases, a speed lower than the speed limit for that road
- ☐ in most cases, a speed equal to the speed limit for that road
- ☐ in most cases, a speed higher than the speed limit for that road
- ☐ other (please specify) _______________

Comments ________________________________

7. When you use ACC on urban roads (roads with speed limit equal to 50 km/h), how do you set the ACC speed?

- ☐ in most cases, a speed lower than the speed limit for that road
- ☐ in most cases, a speed equal to the speed limit for that road
- ☐ in most cases, a speed higher than the speed limit for that road
- ☐ other (please specify) ___________

Comments ________________________________

8. Concerning the vehicle travelling ahead, what is the headway that you usually set when you use ACC? (considering roads with speed limit equal or higher than 90 km/h)

- ☐ 1 interval
- ☐ 2 intervals
- ☐ 3 intervals
- ☐ 4 intervals
- ☐ 5 intervals
- ☐ other (please specify) _______________

Comments ________________________________

9. Concerning the vehicle travelling ahead, what is the headway that you usually set when you use ACC? (considering roads with speed limit equal to 50 km/h)

- ☐ 1 interval
- ☐ 2 intervals
- ☐ 3 intervals
- ☐ 4 intervals
- ☐ 5 intervals
- ☐ other (please specify) _______________

Comments ________________________________

Appendix III Questionnaire 3 – BLIS usage

adaptation
A Marie Curie Initial Training Network

Questionnaire - BLIS usage

1. Approximately, how many kilometers have you already been driving with BLIS?

- ☐ Less than 50 kilometers
- ☐ 51 - 200 kilometers
- ☐ 201 - 500 kilometers
- ☐ 501 - 1.000 kilometers
- ☐ 1.001 - 3.000 kilometers
- ☐ Mais de 3.000 kilometers

2. In which type of road do you use BLIS? You can select more than one option.

- ☐ motorways (maximum speed limit: 120 km/h)
- ☐ roads reserved to cars (maximum speed limit: 100 km/h)
- ☐ other roads (maximum speed limit: 90 km/h)
- ☐ urban roads (maximum speed limit: 50 km/h)
- ☐ none of them
- ☐ other (please, specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Comments _

3. In which weather conditions you don't use BLIS? You can select more than one option.

- ☐ light rain
- ☐ sunny
- ☐ intense fog
- ☐ hard rain
- ☐ light fog
- ☐ I use BLIS in any weather conditions
- ☐ I never use BLIS
- ☐ other (please, specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Comments _

4. In which light conditions do you use BLIS? You can select more than one option.

- ☐ during the day
- ☐ at night
- ☐ never
- ☐ other (please, specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Comments _

5. In which traffic conditions do you use BLIS? You can select more than one option.

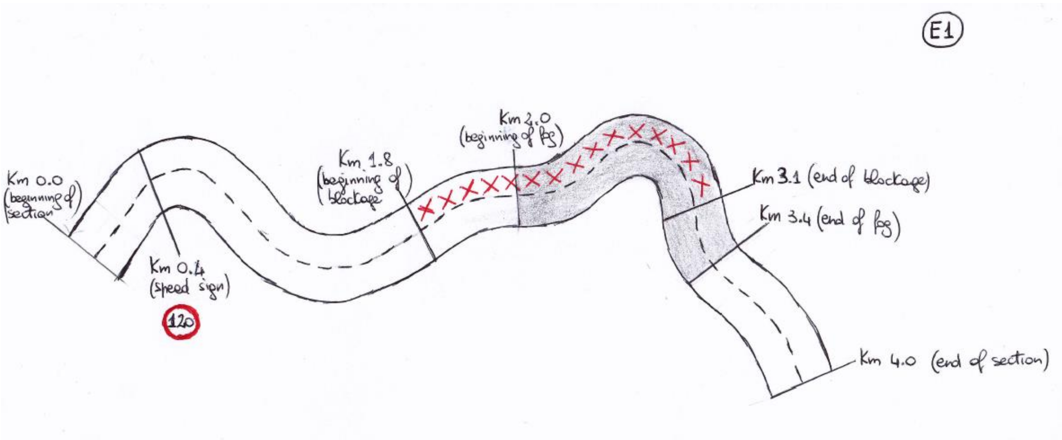
- ☐ very light traffic
- ☐ light traffic
- ☐ stable traffic
- ☐ heavy traffic
- ☐ very heavy traffic
- ☐ never
- ☐ other (please, specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Comments _

Appendix IV Detailed description of the sections in the simulated test route

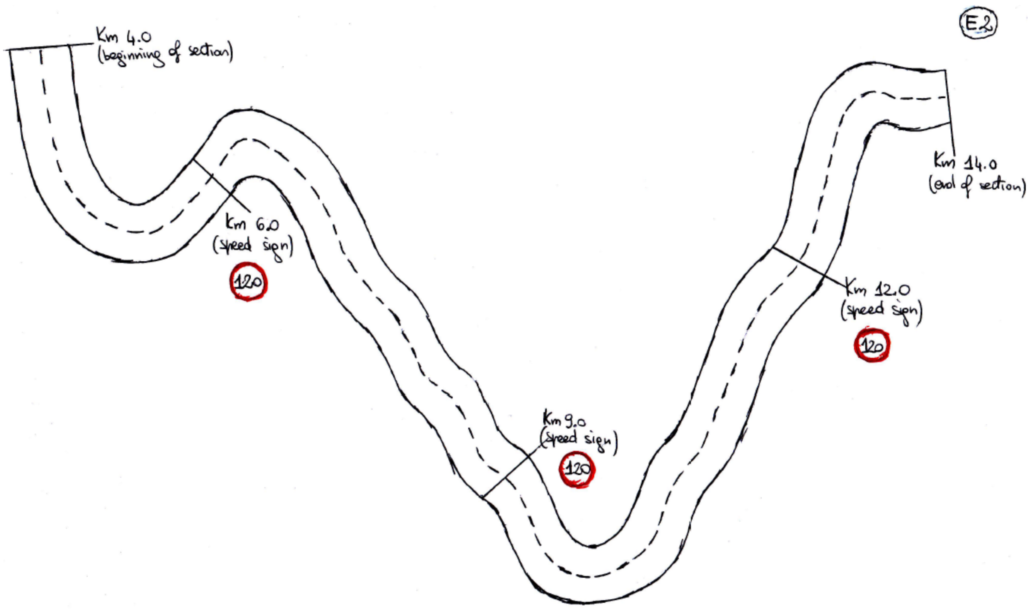
Section 1

Element order in the scenario	E1
Name	Start up
Situation	Normal driving in 2-lanes motorway
Expected driver's reaction	Regular driving
Environment: length of road segment	4 km (start km 0.0 – end km 4.0)
Environment: speed limit of road segment	120 km/h (100 km/h and 80 km/h during roadworks)
Environment: level of traffic	Low traffic conditions
Environment: weather	[Cloudy: from km 0.0 to km 2.0 & from km 3.4 to km 4.0] & [low intensity fog (200 m visibility): from km 2.0 to km 3.4]
Environment: traffic signs	• Speed limit (120 km/h) at km 0.4 • Traffic information regarding the roadwork (including 100 km/h and 80 km/h speed signs)
Environment: traffic modifications	In this section, obstacles (barriers or cones) will be placed on the left lane from km 1.8 to km 3.1 according to the Portuguese law



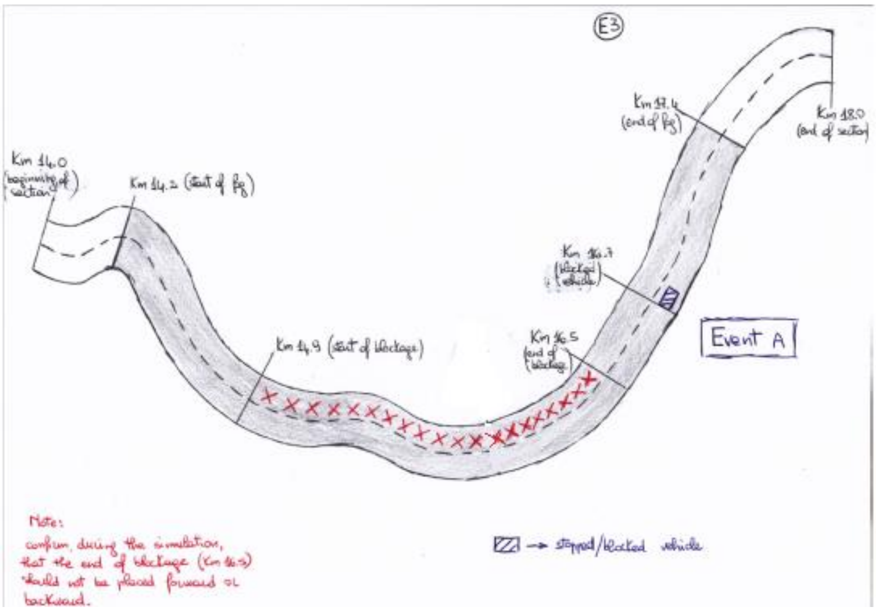
Section 2

Element order in the scenario	E2
Name	Normal driving 1
Situation	Normal driving in 2-lanes motorway
Expected driver's reaction	Regular driving
Environment: length of road segment	10 km (start km 4.0 – end km 14.0)
Environment: speed limit of road segment	120 km/h
Environment: level of traffic	Low traffic conditions
Environment: weather	Cloudy
Environment: traffic signs	• Speed limit (120 km/h) at km 6.0, km 9.0 and km 12.0
Environment: traffic modifications	No modifications to the route



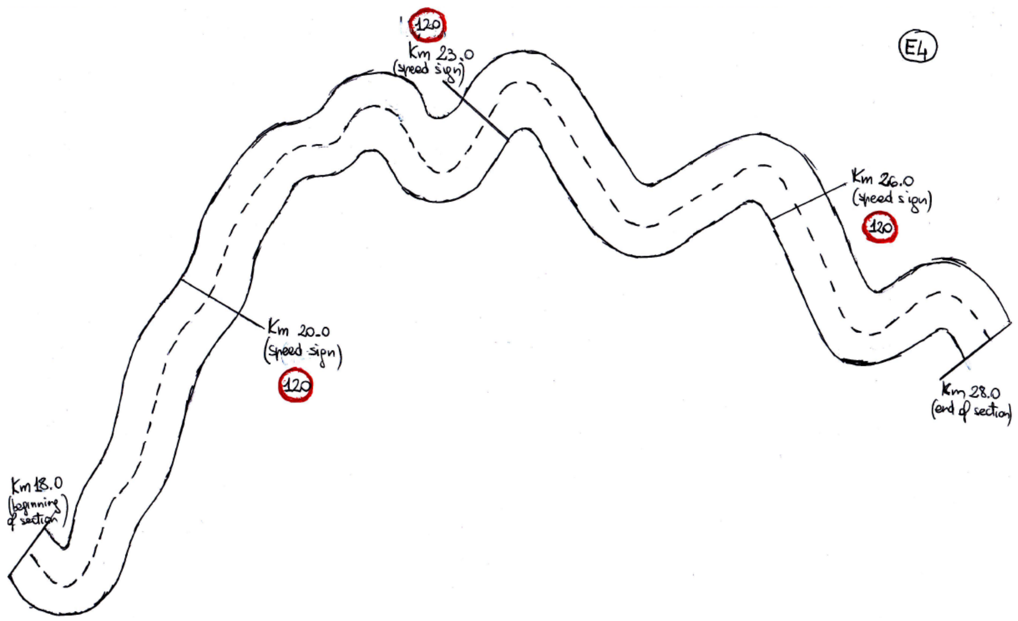
Section 3

Element order in the scenario	E3
Name	Event A
Situation	Vehicle stopped in emergency conditions in the right lane at km 16.7
Expected driver's reaction	Brake, avoid the vehicle going in overtaking lane
Environment: length of road segment	4 km (start km 14.0 – end km 18.0)
Environment: speed limit of road segment	120 km/h (100 km/h and 80 km/h during roadworks)
Environment: level of traffic	No traffic (only disturbing vehicle)
Environment: weather	[Cloudy: from km 14 to km 14.2 & from km 17.4 to km 18.0] & [low intensity fog (visibility at 200 meters) from km 14.2 to km 17.4]
Environment: traffic signs	• Traffic information regarding the roadwork (including 100 km/h and 80 km/h speed signs)
Environment: traffic modifications	In this section, obstacles (barriers or cones) will be placed on the left lane from km 14.9 to km 16.5 according to the Portuguese law



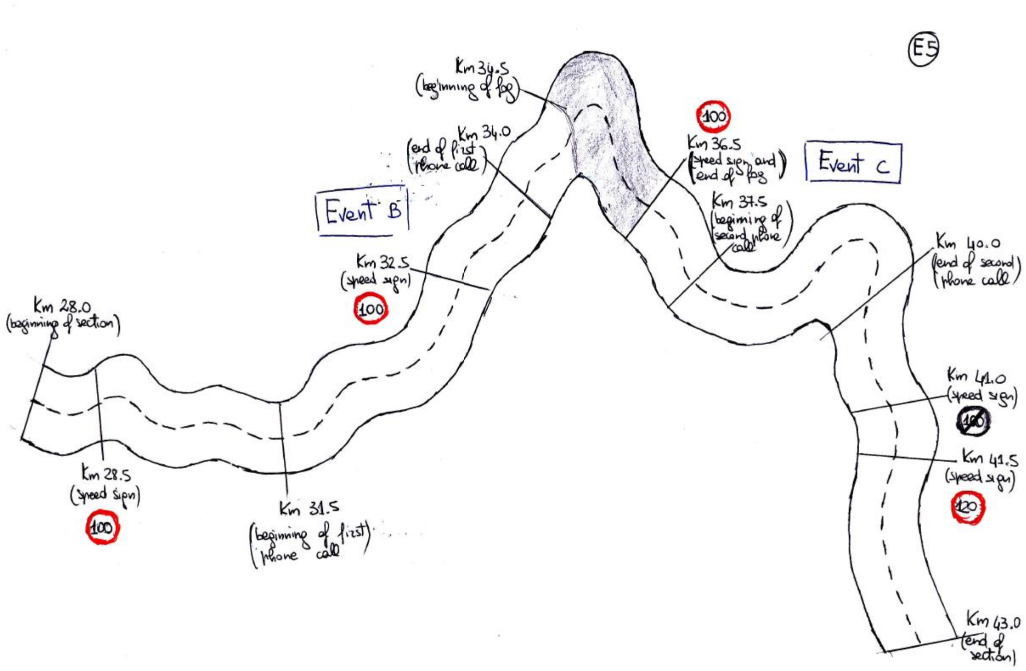
Section 4

Element order in the scenario	E4
Name	Normal driving 2
Situation	Normal driving in 2-lanes highway
Expected driver's reaction	Regular driving
Environment: length of road segment	10 km (start km 18.0 – end km 28.0)
Environment: speed limit of road segment	120 km/h
Environment: level of traffic	Low traffic conditions
Environment: weather	Cloudy
Environment: traffic signs	• Speed limit (120 km/h) at km 20.0, km 23.0 and km 26.0
Environment: traffic modifications	No modifications to the route



Section 5

Element order in the scenario	E5
Name	Event B and event C
Situation	Phone call to participants
Expected driver's reaction	The driver should keep good driving performance and use the remaining cognitive resources to speak
Environment: length of road segment	15 km (start km 28.0 – end km 43.0)
Environment: speed limit of road segment	100 km/h & 120 km/h
Environment: level of traffic	Low traffic conditions
Environment: weather	[Cloudy: from km 28.0 to km 34.5 & from km 36.5 to km 43.0] & [low intensity fog (200 m visibility): from km 34.5 to km 36.5]
Environment: traffic signs	• Speed limit (100 km/h) at km 28.5, km 32.5 and km 36.5 • End of speed limit (100 km/h) at km 41.0 • Speed limit (120 km/h) at km 41.5
Environment: traffic modifications	No modifications to the route



Section 6

Element order in the scenario	E6
Name	Event D
Situation	The system cannot detect the motorcycle located at km 45.450) and consider the car in front (located at km 45.5) as reference.
Expected driver's reaction	Brake by driver required to avoid motorcycle
Environment: length of road segment	4 km (start km 43.0 – end km 47.0)
Environment: speed limit of road segment	120 km/h (100 km/h and 80 km/h during roadworks)
Environment: level of traffic	No traffic
Environment: weather	Cloudy
Environment: traffic signs	• Speed limit (120 km/h) at km 44.5 • Traffic information regarding the roadwork (including 100 km/h and 80 km/h speed signs)
Environment: traffic modifications