SUaaVE

SUpporting acceptance of automated VEhicle

Deliverable 4.1. Conceptual framework of trip services and HMI

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Terminology and Acronyms

AI	Artificial Intelligence
ACE	Adaptive, Cognitive and Emotional Interface
ALFRED	Automation Level Four+ Reliable Empathic Driver
CAV	Connected Autonomous Vehicle
EU	European Commission
V-HCD	Virtual Human Centred Design

EXECUTIVE summary

The first task (T4.1) discussed here is to define "a new smart and multimodal HMI and strategies to ensure ALFRED user acceptability", based on the quality of comfort, interaction and information. This work is part of a long evolution of interaction with cars over the past century. But the difficulty lies in the break in the use and utilization that the Connected Autonomous Vehicle (CAV) implies. For this purpose, this deliverable reports on the work of the partners involved in order to (1) define the acceptability applied to CAVs, (2) define the conceptual framework for an interface based on users' cognitive needs, emotional responses and comfort, and (3) propose a new comfort management, taking into account in particular the management of dynamics that has been managed by the driver until now. Each theme studied is accompanied by examples and general proposals for the design of ALFRED. This work is followed by a synthesis of transversal solutions on which the WP4 partners can rely to carry out the tasks T4.2, T4.3 and T4.4, in other words to design their respective modules for dynamic comfort management (TUM & IDIADA), environmental comfort management (IDIADA), vehicle behaviour information management (linked to emotions, environment) and comfort management (Bordeaux INP).

In conclusion, the completion of this preliminary work was an important challenge in building a common reference system between partners with very different tasks and/or areas of expertise. They also identified the need to avoid excessive complexity of the data to be processed and the algorithms that could compromise the achievement of the project objectives. The scope will therefore be adjusted during the design phase to provide a system that is sufficiently functional to demonstrate it operationally, rather than a system with impressive functionality but uncertain reliability or relevance.

1. Motivation

The interaction between the driver and the vehicle is the subject of many innovations around the driver's activity, his comfort and road safety in general. Autonomous car projects have the advantage of relieving the main user of the driving task in order to enhance other activities such as rest, work or leisure. The management of the vehicle during the journey, relieved of driving, will be very different and will have to take into account these new activities in which users will engage their attention.

Public interest and fears about the autonomous vehicle are slowly improving. But the societal rupture at stake requires us to study the levers to ensure the best possible acceptability. This work package focuses on life on board, to explore new ways of interacting, staying informed and managing ambient comfort and dynamics. The preliminary studies presented here will be a common reference for the partners who will carry out each of the specific developments

2. Introduction and Objectives

The purpose of this document is to delimit the scope of future studies to design the ACE interface. This interface is a component of ALFRED that includes 5 modules:

- Ethical module,
- Empathic Module,
- Cognitive smart assistant,
- Ride comfort,
- ambient & postural comfort.

The design of each module is leaded respectively by RUG, IBV, Bordeaux INP, TUM and IDIADA. The preliminary work of each of these partners to define the scope of ACE is presented in this document, the editor of each part is identified in the title. (Except for Bordeaux INP).

This document first presents the context of the study, with the objectives and work plan previously determined. Then the framing relating to the notion of acceptability and the notion of interaction with a vehicle constitutes the basis for reflection of the T4.1 task. On this basis, the preliminary studies of the technical solutions are presented. These solutions focus on comfort, cognitive needs of users, and ability to adapt interaction based on emotions. The last parts of the document present recommendations that will be considered to design a practical and acceptable interface, as well as the transversal approaches proposed by the partners in task 4.1.

2.1. Objectives of WP4

2.1.1. Test

The WP4 objectives are mainly shared with IDIADA, which will work with TUM on vehicle dynamics comfort. CRF, IBV and RUG will be involved in specific tasks. The objectives are as follows:

1. Define a HMI conceptual model able to optimize user acceptance of ALFRED from complementary perspectives: user cognitive needs, user emotional response, ride comfort algorithms and ambient comfort; and identify the strategies and tools able to recover or avoid negative driver and passenger experiences.
2. Define control processes for managing the dynamic driving tasks (DDT), within acceptable thresholds of safety and comfort based on observed emotions.
3. Develop an ambient setting to maximize fine passengers comfort profiles based on ambient impact.
4. Design, prototype and develop iteratively a cognitive smart assistant.

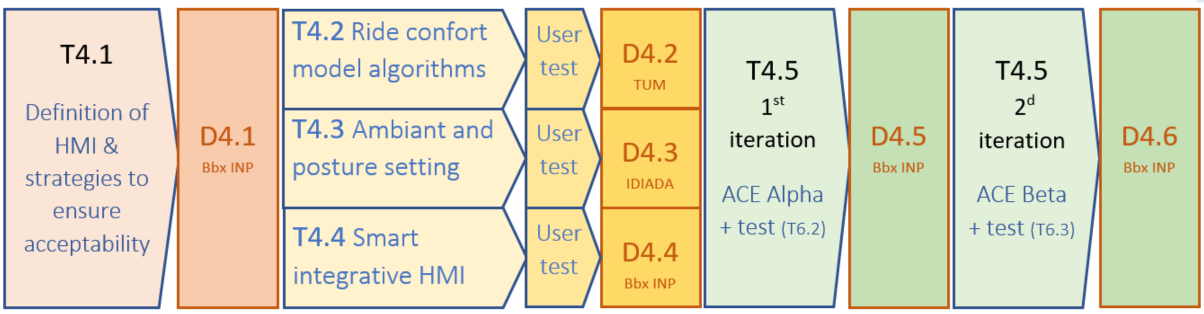


Figure 1: WP4 flow. The main successive steps in the WP4 processing

2.2. Task T4.1 description *(recall from SUaaVE proposal and from D8.1)*

[Task 4.1] DEFINITION OF A NEW INTELLIGENT AND MULTIMODAL HMI AND STRATEGIES TO ENSURE ALFRED ACCEPTABILITY BY USERS

The formulation of task 4.1 below makes it possible to identify 2 sub-tasks:

Task 4.1. Definition of a new intelligent and multimodal HMI and strategies to ensure ALFRED acceptability by users (Leader : BORDEAUX INP ; IDAIDA, TUM, IBV) m1-m6

T4.1.1 : BORDEAUX INP will develop a conceptual framework for ACE Interface, based on cognitive needs of users, users' emotional response, ride comfort and ambient comfort parameters. BORDEAUX INP will interact with T1.1 and T3.1 leaders to take into account partial findings as acceptance factors or relationships between situations and emotional responses. In particular, some answers concerning "cognitive workload and emotional response" or concerning the passenger behaviour under different scenarios will be found; therefore, the place and importance that the HMI should have in these situations will be established. The HMI can influence some passenger's emotions, the effects to prevent/avoid will be tackled.

T4.1.2 : On the other hand, IDIADA, supported by TUM (riding comfort) and BORDEAUX INP (HMI feedback), will work on defining the recovery and anticipatory strategies and tools to cope and/or avoid with negatives experiences and to ensure the user acceptance of ALFRED.

Next, it will be necessary to identify solutions able to recover/avoid negative experiences. In these situations, different methods will be defined to keep the control and reach a satisfactory situational awareness, such as a) specific strategies to advise the user and to augment his/her capabilities, b) training to optimize his/her confidence in the system; and c) specific tools and HMIs, with specific functionalities, specific control modes, new forms of interaction, different sensory channels, etc.

[Subtask 4.1.1] Develop a conceptual framework for the adaptive, cognitive and emotional interface (ACE) (Bordeaux INP)

The first subtask will be addressed by Bordeaux INP in order to determine the main principles of interactions that will be applied in ACE to optimize the acceptability of ALFED, and CAVs in general. SUaaVE's ambitions and time constraints will not allow an exhaustive number of scenarios to be studied, therefore a relevant sample of scenarios will be selected, in accordance with the provisions discussed at the KoM workshop.

The study by Capgenimi (2019) reveals that the attitude of the European population towards autonomous vehicles has increased over the past 10 years, but the idea of letting oneself be driven by an AV is still far from being unanimously accepted. Acceptability theories (e.g. Lazy User Model, Collan & Tétard, 2007/2009; Technology Acceptance Model 3, Venkatesh & Bala, 2008; Unified Theory of Acceptance and Use of Technology 3, Venkatesh, 2012) cover a variety of dimensions that can be considered to improve future users' attitudes (e.g. Usefulness, affect, hedonic, usability, social impact, etc.). The 3 axis of study that we can identify to design the ACE interface are the cognitive needs of users, The emotional response of users, The optimization of comfort. These axes have been mentioned in particular by major actors in the AV (Kyriakidis et al., 2019) and may relate to certain important dimensions (e.g. utility, usability) of acceptability models:

a) **The cognitive needs of users.**
This concept refers to the information offered to the user to increase his/her knowledge of the situation and thus better manage it. This support for the user's actions is similar to some of the usability determinants identified by Bastien and Scapin (1993), such as guidance or workload. It is possible to take into account the user's level of involvement in the driving task (e. g. sleep, work, active road

monitoring, etc.) and consequently his/her situational awareness (e. g. Kyriakidis et al., 2019).

The cognitive needs of users will be determined from the partial results of T3.1 and T3.3, and supplemented by elements from the literature. The proposals will focus on the following aspects:

- The activity of the user on-board. Depending on his/her activity, the user has only partial access to the HMI. In this sense, Wickens (2002) describes a competition between two information processing operations when they are of the same nature (e. g. verbal vs. verbal ; spatial vs. spatial) or when they use the same sensory channel (e. g. only visual ; only auditory). For example, a user may not see a visual indicator of the car if he or she is reading a document at the same time. He or she may not consider a sound indicator from the car if he or she is talking on the phone. The cognitive impact of the transition from an ongoing activity (e.g. playing) to the user's involvement in driving (e.g., taking control, consulting for a modified itinerary, etc.) involves a focus on appropriate requests from the HMI.
- The provision of the necessary information to effectively manage the situation when the user must be involved.
- The provision of the necessary information to the user to keep him/her informed of the current or future situation (e.g. traffic) and the actions taken by the CAV (e.g. overtaking) or by ALFRED (e.g. comfort adaptation, emotion management).

b) **The emotional response of users**

The development of the empathic module (WP3) will integrate the possibility of monitoring certain emotional and behavioural reactions of users (T3.1, T3.2). ALFRED may be able to make hypotheses about the causes of these reactions and produce different actions relating to dynamics (e. g. slowing down; see T4.2), comfort (e. g. ambient parameters; see T4.3), and the explainability of the situation (see T3.3). In addition, the identification of contextual factors will make it possible to anticipate certain situations in order to avoid undesirable emotional or behavioural reactions. For example, if an accident has been detected on the way, ALFRED could alert users in order to avoid a backlash or to expose them to shocking visuals. If the CAV suddenly had to avoid a pedestrian, ALFRED can immediately explain the manoeuver and its success to reassure passengers.

The interaction principles of the ACE interface will include feedback related to the driving and comfort actions guided by the empathic module.

c) **Optimizing comfort**

Well-being is an important factor in acceptability, which will be considered from the point of view of user comfort by IDIADA and TUM. The transition from a manual vehicle to an autonomous vehicle implies a new physical and psychological positioning of users. The current comfort management must be challenged to ensure a pleasant use of the autonomous vehicle. Based on current comfort parameters, the development of the ACE interface will focus on the following aspects:

- Integrate a new interaction related to comfort by taking into account new uses on the one hand, and users' interaction habits on the other

- Integrate new comfort parameters specific to CAVs, linked to ambient comfort and vehicle dynamics
- Integrate the CAV's ability to automatically adapt certain comfort parameters

Based on the preliminary results of these 3 areas of study, a conceptual framework will be proposed for on-board services and the ACE HMI. It will notably determine (1) the "families" of functions involved in the interaction, with (2) details of the main functions for each family, (3) the interaction modalities envisaged, and (4) the interaction alternatives according to the situation (road context, cognitive needs of the user, etc.). This conceptual framework will be the common basis for the work of T4.2, T4.3 and T4.4, which will be carried out simultaneously.

[Subtask 4.1.2] Identify solutions that can recover/avoid negative experiences. (IDIADA)

The information presented below have be corrected and completed by IDIADA.

Subtask 4.1.2 will be led by IDIADA, which will be supported by TUM (on driving comfort issues) and BORDEAUX INP (on HMI feedback issues). The realization of task 4.1.3 will be carried out in 2 steps:

<u>1-> Preliminary study</u>

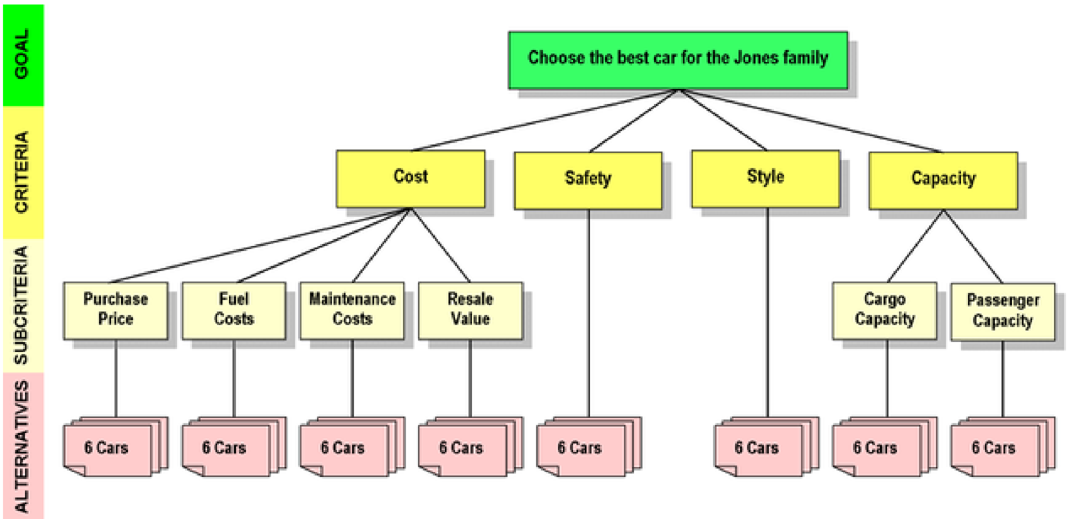
This study aims to define recovery and anticipation strategies and tools to face and/or avoid negative experiences and ensure user acceptance of ALFRED. It will be based mainly on a review of existing techniques and the preliminary results of WP3.1:

- Identify existing driving assistance and automated driving technologies and their interaction modalities (IDIADA). This study will focus on
  - the possible interaction modalities,
  - the categorization of these interactions,
  - and the cognitive, physical and behavioral implications.
- Identify non-invasive and valid measures of emotions and stress, (IBV) (see T3.1)
- State of the art on the determination of driving comfort and ambient comfort parameters (TUM) (see T3.1)
- Identify existing (and future) driving comfort settings and solutions (IDIADA). Research study about other transport modes comfort settings and solutions (airplane and train). Passengers Comfort Measurement.
- Define a typology of negative experiences in a vehicle (see T3.1)

<u>2-> Define methods (strategies and tools) to recover and anticipate negative experiences</u>

On the basis of the preliminary study, IDIADA will identify and select effective solutions able to recover/avoid negative experiences for CAV users. To achieve this, different methods will be defined to enable the user to maintain control and achieve a sufficient knowledge of the situation. These methods could be: a) study specific strategies to advise the user and increase his/her capacities, b) set up training to optimize his/her confidence in the system, and c) design specific tools and HMIs, with specific features, specific control modes, new forms of interaction, different sensory channels, etc.

This task will also be based on a variety of documentation as surveys, accident reports, interviews to Expert/Naïve drivers about experiences (this should be created by expert involved in this task) in order to find out similarities in operational event approaches.



The selection process will be based on a model such as the ANALYTIC HIERARCHY PROCESS:

Figure 2 : Analytic Hierarchy Process

3. First identification of potential psychological factors that influence acceptance of CAV among passengers and other road users *(from T1.1, RUG)*

It is estimated that in the near future Connected-Automated Vehicles (CAV) will dominate the road environment. Indeed major players in the automotive industry have already invested largely on designing vehicles with Level 4/5 automation and many started pilot testing these vehicles in designated areas. Hence a lot of resources and manpower are being allocated to realizing the goal of fully-automated vehicles. Yet, the success of these efforts depends on whether the public would accept connected and automated vehicles and whether they would adapt these vehicles. Indeed acceptance is an important barrier for the diffusion of any innovation in the society including CAV. If CAV is not accepted by people, then people would not adapt it or use it, meaning that the technology might fail to be put on use. How can we increase acceptability of CAV among people? What kind of psychological factors are particularly relevant to increase acceptability? In Deliverable 1.1. we aim at providing a summary of the current literature on psychological factors that influence the acceptability and acceptance of CAV. In addition, we aim at drawing certain conclusions for different road users, such as elderly drivers and pedestrians, whenever possible.

3.1. Acceptance and Acceptability

In the literature acceptability and acceptance is sometimes used interchangeably. We reason that acceptability refers to one's attitudes and evaluations before the implementation of an innovation whereas acceptance refers to one's attitudes, evaluations and behaviours afterwards, meaning having experienced the innovation (see Schade & Schlag, 2003). Acceptability could therefore be expressed as an attitudinal evaluation or intention (e.g. willingness to use CAV as a passenger), whereas acceptance could be expressed as an attitude as well as real behaviour (e.g., adopting an automated vehicle). In the remainder of the Deliverable we will be referring to post-evaluations and behaviour when we talk about acceptance and pre-evaluations and intention when we talk about acceptability. Yet, as people have experience with CAV mostly in experimental settings and not in real-life, the literature review will cover acceptability in the majority of the studies we will talk about.

3.2. Psychological factors that affect acceptance of automated vehicles

3.2.1. Perceived Control

Feelings of control is an integral part of driving. One barrier towards the acceptability of CAV is therefore low feelings of control associated with fully-automated vehicles. This is supported by findings which show that preference for an automated vehicle tends to get higher for lower-automation levels (38.7%) as compared to full automation (15.5%) (Schoettle & Sivak, 2016). Notably, the majority of the drivers indicate that they still would like to have some control over the pedals and the steering wheel, meaning that full-automation could indeed pose a threat to the basic need of feelings of control. Indeed, lack of control is rated as the least attractive feature of fully automated vehicles (Howard & Dai, 2014). Interestingly, in Howard & Dai's, (2014) study this was particularly the case among those who enjoy driving as a single driver, who enjoy car-use and associate it to be a luxury possession, indicating that when car is seen as a status item, lack-of-control that would come with full automation becomes concerning people.

In one study participants were asked when they would let an automated vehicle take full control of the vehicles. Responses indicate that people are more comfortable with giving away control on highways and rural and scenic roads, whereas they are less comfortable to do so on roads with higher traffic complexity (Bansal & Kockelman, 2016).

Menon (2015) found that the concerns which lowered adoption intentions of automated vehicles were related to control: respondents did not like giving up control of the steering wheel, were concerned that using automated vehicles would lead to a decrease in their own driving skills, and were concerned that the system could fail. However, a different study found that those who already use adaptive cruise control (ACC) would be more comfortable about driving without a steering wheel than those who do not currently use ACC (Kyriakidis, Happee, & de Winter, 2015).

3.2.2. Perceived Safety

How do potential users of fully-automated vehicles perceive the safety of these vehicles? Interestingly, previous studies indicate that there are a lot of individual variation when it comes to perceived safety of automated vehicles. For instance, while some people associate full-automation with high safety Zumud, Sener, & Wagner; 2016; Howard & Dai, 2014), some associate it with low safety (Zumud et al., 2016). A large scale survey with over 1500 participants revealed that a large body of respondents believed that fewer accidents will happen in the future thanks to automated vehicles, meaning that the expected safety increase was high (Schoettle & Sivak, 2014). In a study examining people's prioritization of benefits from automated cars, 51% chose 'highest possible level of safety' as their greatest priority (Lustgarten & Le Vine, 2018).

In a study where potential users experienced an AV with level 4 automation, it was found that perceived safety, trust, and acceptance were strongly correlated, and that they were all solid predictors of intention to use AVs (Zoellick et al., 2019).

In a Spanish sample a link between demographics, perceived safety, and intention of using AVs was found (Montoro et al., 2019). The more driving experience respondents had, the more often they drove, and the more often they had been involved in conventional car-based traffic crashes, the more likely they were to perceive autonomous vehicles as a safer alternative for their daily transportation. Those with a higher education level were also more likely to perceive AVs as more positive, as well as safer than conventional vehicles (both for themselves, as well as for other traffic).

The main reason why respondents of a survey conducted in major cities in Texas who had indicated that they were not likely to use self-driving vehicles, was a lack of trust in the technology (Sener, Zmud, & Williams, 2019). Other (less frequent) reasons were liking to drive, a desire for control over the vehicle, or seeing no need to use a self-driving car as long as they have the ability to drive themselves. Greater perceived safety was related to a greater intent to use a self-driving vehicle.

3.2.3. Perceived Trust

Another factor that plays a key role in acceptability of automated vehicles is perceived trust, which can be defined as whether the person believes that the automated vehicle will function as intended and without posing any danger to its occupants as well as other road users. Indeed, in an international survey 47% of all participants indicated that trust is the biggest barrier for automated vehicles (Jeon et al., 2018). There were some differences between countries: Americans believed trust to be the biggest issue more often than Austrians, Germans, and Koreans.

It has been found that people prefer manual control over automation if they believe that they are more capable of executing a behaviour themselves as compared to the automated system (Lee & Morray, 1994). This finding indicates that perceived capabilities or overreliance on one's driving skills, for instance, could appear as a factor impairing perceived trust.

Experience with automation might have an influence on perceived trust (Gold, Korber, Hohenberger, Lechner, & Bengler, 2015). Yet, the direction of the influence depends on whether negative or positive experiences are accumulated. The finding comes from a simulator study with Level-3 automation, where participants were exposed to several take-over scenarios in environments with different traffic complexity. Participants' evaluations regarding Level-3 automation were measured before and after the simulated driving. It was found that self-reported trust increased after the simulated driving as compared to before. In addition, participants, particularly elderly ones, had decreased horizontal gaze patterns during the course of automated driving, meaning that they trusted the automated vehicle to manage road situations. The authors reasoned that trust might have increased due to the fact that there were no malfunctioning of the equipment during automated driving. However, there were a couple of instances where participants experienced crashes during take-over scenarios, and such a crash experience was correlated with decrease in trust. Interestingly, some people were observed to fall asleep, meaning that there might be individual differences when it comes to trust in technology: some people might be more inclined to trust technology than others. This might also lead to the so-called over reliance on automation (Parasuraman & Riley, 1997) and might be particularly dangerous in situations where the interference of human controllers are needed despite the level of automation.

Finally, a simulation study with a high fidelity driving simulator showed that those who have less trust in automated vehicles, experience an additional increase in psychophysiological stress when the vehicle drives autonomously, than when the user is in control (Morris, Erno, & Philcher, 2017).

3.2.4. Perceived Intelligence

Perceived intelligence of the vehicle may play a role in acceptance. In two simulated road navigation tasks, those who rated the vehicle as more intelligent spent more time gazing at the surrounding traffic than those who rated the vehicle as low in intelligence (Thill, Nilsson, & Riveiro, 2015). Although not directed tested, this may indicate that a higher perceived intelligence of the vehicle is related to greater trust and acceptance.

3.2.5. Perceived Convenience

Convenience appears to be an important factor associated with fully automated driving (Howard & Dai, 2014). Notably, potential users seem to favour the idea that they would be able to multitask, such as reading and replying their emails, on the road. Aside from that, potential users think automated vehicles could improve traffic safety, and may increase the mobility of people who are unable to drive (Jeon et al., 2018). Notably, Korean respondents were less interested in improved safety, and more interested in multitasking than Austrian, German, and American respondents.

In a large study conducted by Menon (2015) the perceived benefits of automated vehicles that had significantly improved adoption intentions of automated vehicles were (1) fewer traffic crashes and increased roadway safety, (2) a less stressful driving experience, (3) a more productive use of travel time, (4) less traffic congestion, and (5) lower car insurance rates.

Potential users seem to believe fully automated driving would be easier than manual driving, while partially or highly automated driving is seen as more difficult than manual driving (Kyriakidis, Happee, & de Winter, 2015). This is also displayed in the secondary tasks they would be inclined to engage in while riding the vehicle: the higher the level of automation, the more potential users would intend to rest, watch movies, or read.

In a German sample, 21% of the respondents said they could imagine buying a car with high automation if the vehicle provides more opportunities and extended comfort (than a manual car) (Pfleging, Rang, & Broy, 2016).

In a study examining prioritization of benefits from automated cars, a majority (51%) expressed willingness to pay more, as well as a willingness to accept slower travel (54%) in exchange for greater comfort while traveling (Lustgarten & Le Vine, 2018).

Lee, Chang, & Park (2018) found in a Korean sample that acceptance of autonomous vehicles in general was determined by perceived usefulness, reliability, and legality. Acceptance of FAV specifically was determined by user convenience, perceived safety, costs, and compatibility with the existing environment (infrastructure).

3.2.6. Gender and Age

Female drivers were somewhat more concerned to be in a fully automated vehicle (Schoettle & Sivak, 2014). The literature review of Becker and Axhausen (2017) support this finding: males were less concerned to be in a fully automated vehicle. Males were found to be more concerned with liability issues and females with low-control (Howard & Dai, 2014). Differences in willingness to use between men and women can be partially explained with emotion. Men tend to assign positive emotions to automated driving, while women tend to assign negative emotions (Hohenberger, Spörrle, & Welpe, 2016). Men anticipated both more pleasure and less anxiety than women towards automated cars.

Comparison between age groups revealed equivocal results. Some studies showed that young people were more positive about automated vehicles as compared to people in older ages (see review by Becker & Axhausen, 2017). Interestingly, there were also findings showing the opposite. For instance, older people were found to be more interested in using an automated vehicle (Gold et al., 2015; Rodel et al., 2014). This might be because of the anticipated cognitive decline that comes with age, which would make driving difficult, and thereby making fully-automated driving a good alternative. Older people also rate potential safety gains of automation as higher than younger people do (Gold et al., 2015). In a sample from Australia and New Zealand, older people had a higher level of trust in CAV, but they also had higher levels of concern about their safe performance. All in all, older people had more positive perceptions of potential benefits of CAV, and showed a greater willingness to use them (Regan et al., 2017). However, in a later wave of the same study, younger people had more positive perceptions of potential benefits of CAV (Ledger, Cunningham, & Regan, 2018).

Rahman and colleagues (2019) found that older adults (60+) have positive attitudes towards autonomous vehicles when they would be a passenger, but negative attitudes towards autonomous vehicles if they would be a pedestrian. They argue that a lack of information regarding how pedestrians can safely interact with AVs may be the cause for this difference.

A meta-analysis of trust in automation showed that age had a moderate positive effect on trust in automation (Schaefer et al., 2014). In a survey among older persons living in Florida self-reported ease of new technology use had positive effects on willingness to use AVs and expected benefits from using an AV. Moreover, greater ease of technology use reduced concerns relating to AVs (Souders & Charness, 2016).

In preliminary results of a study on older drivers' (65+) acceptance of FAV, a negative correlation was found between years of driving experience and acceptance. The authors argue that older adults' low acceptance of FAV may stem, in part, from a lifetime of driving experience that governs their expectations of vehicle control (Haghzare, Campos, Bak, & Mihailidis, 2019). However, this research is still a work in progress, with currently valid data of only 10 participants.

In a large-scale survey on FAV in Japan, where elderly drivers are involved in 40% of all traffic accidents, it was found that almost half of the respondents thought FAV would be useful in the mitigation of mobility problems and accidents related to elderly drivers (Shin, Tada, & Managi, 2019).

3.2.7. Driving style

In a sample from Switzerland, respondents especially preferred driving an autonomous vehicle on longer trips (Becker & Axhausen, 2018). This was also found by Shin, Tada, and Managi (2019), who found that potential users of FADS have higher purchase intentions and greater willingness to pay when they regularly drive long-distances.

A simulation study assessed what type of driving style potential users would like in an automated car (Griesche et al., 2016). Most participants preferred an automation of their own driving style. Being in an automated vehicle that used a driving style with smaller safety margins was disliked by all participants.

In a simulation study by Hartwich, Beggiato, and Krems (2018) it was found that younger drivers preferred a familiar (their own) driving style for an AV, while older drivers preferred an AV-driving style that is not impaired by age (i.e. faster than their manual driving style).

3.2.8. Type of road user

Most studies on the acceptability of automation comprised potential buyers of these vehicles who will switch to the status of a "passenger". Yet, fully-automated vehicles will also impact other road users, such as pedestrians and cyclists. How do other users evaluate fully-automated vehicles? And are there any differences in judgements of future passengers of CAV and other road-users that will come across at CAV on the road?

In certain traffic situations (for example at low speeds and in ambiguous situations), pedestrians' decisions to cross a road and feelings of safety are affected by non-verbal cues given by the car's driver (for example eye contact, waving a hand, and posture). Pedestrians rate eye contact with a driving as promoting calm interaction, while a driver who appears distracted leads to stress for pedestrians (Habibovic et al., 2016). When pedestrians are faced with a CAV, they cannot rely on non-verbal cues. Habibovic and colleagues (2018) tested if they could make pedestrians feel safer when interacting with a CAV that was able to convey its intentions visually. Participants were trained to recognize the visual signals the CAV could send. After this training, participants (pedestrians) felt calmer, more in control of the traffic situation, safer, and more positive towards the CAV than when they interacted with a CAV that could not send out visual cues. This indicates other road users will be more accepting of automated vehicles when they can understand the behavior and intentions of the vehicles, and when the vehicles can communicate with other road users. Especially females and older populations (30+) rate the inclusion of external interfaces that can communicate with pedestrians on a FAV as positive, perhaps by increasing their perceptions of safety (Deb, Strawderman, & Carruth, 2018).

Potential users seem to dislike the idea of transporting their children in a fully-automated car (for example Regan et al., 2017).

Both pedestrians and cyclists who had interacted with an AV were more positive towards AVs than those who had not interacted with an AV (Penmetsa et al., 2019). Moreover, both pedestrians and cyclist who had an interactive experience with AVs were more likely to think that AVs have the potential to reduce injuries and fatalities than those who had not interacted with an AV.

Deb, Rahman, Strawderman, and Garrison (2018) argue that because most pedestrians prefer to interact with drivers before crossing the road, a decline in comfort and trust may arise when FAV are implemented. Moreover, pedestrians may be confused about whether they should interact with the driver or the vehicle itself when a person is sitting in the driver's seat in a FAV. Lagström and Lundgren (2015) found that pedestrians want some indication if a vehicle is in autonomous driving mode.

In a comparison between drivers' and non-drivers' opinions on AV, it was found that non-drivers (1) presumed that AVs would be less useful and less likely to enhance performance, (2) were more enthusiastic about AVs being applied for people who are not allowed or unable to drive regular manual vehicles, and (3) had greater concerns about the automated driving system itself, compared to drivers (Qu et al., 2019).

Deb and colleagues (2017) developed a scale to measure pedestrian receptivity towards FAVs. They found three major components that determined receptivity: safety (perceived safety for pedestrians), interaction (willingness to interact with FAV as a pedestrian), and compatibility (belief that FAV can be successfully implemented within the existing traffic system). Safety had the largest impact on acceptance, while interaction had the largest impact when looking at behavioral intention to cross the road in front of a FAV. Aside from that, they also looked at the effect of demographics on acceptance. Male pedestrians were more inclined to accept FAVs than female pedestrians. The youngest age group (between 18 and 30 years old) had significantly higher receptivity towards FAVs than the other age groups. People from urban regions were more receptive toward FAVs than people living in rural regions.

3.2.9. Vulnerabilities

In an analysis of text comments on fully automated driving, people with physical disabilities and/or bad eyesight seemed to be more positive towards CAV (Bazilinskyy, Kyriakidis, & de Winter, 2015).

In two waves of a study conducted in Australia and New Zealand, a high proportion of respondents agreed they would like to use a fully-automated car when they are physically and/or mentally unable to drive themselves manually (Regan et al., 2017; Ledger, Cunningham, & Regan, 2018). However, it was not assessed whether respondents were actually physically and/or mentally unable to drive.

In a sample from the UK differences in attitudes towards autonomous vehicles between people with physical disabilities that interfered with their ability to walk and people with no such disabilities was examined (Bennett, Vijaygopal, & Kottasz, 2019). Two-thirds of the sample of people with disabilities held either negative or ambivalent views of autonomous vehicles. People with disabilities were especially likely to make negative comments about autonomous vehicles when (1) they had high levels of generalized anxiety, and (2) when they had a low internal focus of control. Participants with disabilities were more positive towards autonomous vehicles when (1) they were more action oriented, and (2) they were interested in new technologies. The researchers believe that public information messages targeted at people with disabilities should emphasize the safety features of autonomous vehicles, the ease of use for people with disabilities, and AVs reliability and dependability. A main difference found between people with physical disabilities and people with no disabilities was that those with disabilities were more concerned with safety issues with AVs themselves, while those without disabilities were more concerned with adequate road traffic conditions and bad behavior of drivers of manual vehicles.

In a large-scale survey in Japan, approximately 19% of all respondents who did not have a driver's license chose being able to drive in a FAV without a license as one of the top three merits of FAV (Shin, Tada, & Managi, 2019).

3.2.10. Experience with the innovation

A large-scale survey in the United States revealed that most respondents were concerned to be in a fully-automated vehicle (AA, 2016). Interestingly, respondents indicated they would be more likely to use driver assistance systems such as Adaptive Cruise Control, which are in the market for a long period of time now, and therefore are not considered to be an innovation where people have no experience with. As such, having experienced the innovation could make a difference in people's willingness to use it. Indeed, with lower levels of automation in simulation studies, it was found that perceived trust or intention to use an automated vehicle increased after exposure to automation than before (Gold et al., 2015). Particularly positive experiences are important to have a positive influence on attitudes and evaluations, meaning that pilots with CAV or initial trials should make sure that the experience could be a satisfying and positive one.

In a study by Hartwich, Witzlack, Beggiato, and Krems (2018) participants' initial perceptions of HAD were measured, followed by experiences of HAD in a driving simulator, and finally system experience on a test track. The development of trust and acceptance towards HAD was assessed at several time points. Trust, acceptance, perceived usefulness, and satisfaction of HAD increased significantly after experiencing the driving simulator, compared to the a priori measurements. Moreover, they remained stable over time. Differences between age groups were also investigated. Although older drivers had a more positive attitude towards using HAD compared to younger drivers, they had less self-efficacy when handling HAD. These results indicate that letting people experience innovation leads to more acceptance.

An online survey found that self-reported familiarity with AVs was positively correlated with expected benefits (both in usefulness and in situations) of AV, and negatively correlated with concerns regarding AVs (Qu et al., 2019).

Intent to use self-driving vehicles was greater among those that own a vehicle with highly automated features (for example automatic lane keeping, adaptive cruise control, or automated parking) than those who own vehicles with no such features (Sener, Zmud, & Williams, 2019).

3.2.11. Motives and values

In an exploratory qualitative research in Germany, the underlying motives and values for potential users of autonomous vehicles were examined (Merfeld, Wilhelms & Henkel, 2019). Three overarching motives were found along with underlying values for each motive. The first motive was self-fulfillment: utilitarian and hedonic values; wanting to enrich one's life by using the freed up time from using an autonomous vehicle. This motive was strong among those who valued career success, social connections, and quality of life. The second motivation was security. This motivation was strong for those who valued personal integrity (improved security of the driver and fewer accidents) and weak for those who valued safety (not being in control when needed, proneness to hacking, and concerns about malfunctions). The final motive was responsibility. This motive was strong for those who valued social responsibility (enhancing third party road safety, sustainability of autonomous vehicles), and weak for those who valued accountability (being only an observer while wanting to take personal responsibility).

3.3. Models predicting acceptance of technology

Originally developed to investigate user acceptance to use computer-based technologies, the Technology Acceptance Model (Davis, 1993; see Figure 1) is based on the premises of the Theory of Reasoned Action (TRA; Fishbein & Ajzen, 1975). The TRA is a social-psychological model which aims at predicting intentions and behaviour (such as acceptability and acceptance, respectively). Notably, TRA posits that behaviour is directly predicted by intentions, and intentions are directly predicted by attitudes and subjective norm. Attitudes refer to any positive or negative evaluation of an object, such as automated vehicles. If a person has positive attitudes towards automated vehicles, then we might expect that acceptability of CAV would also be high, whereas a negative attitude is expected to decrease acceptability. Subjective norm refers to one's perceptions regarding what the significant others think the person should do. This construct is related to the social influence that others have on our decisions. Notably, if we think significant others, such as partners, parents, close friends, have a positive evaluation regarding automated vehicles, this would also affect our evaluations of this innovation. Similar to attitudes, a positive subjective norm would be positively associated with acceptability of automated vehicles. Later, TRA has been modified with the addition of a new construct called perceived behavioural control, and the model is renamed as Theory of Planned Behaviour (TPB; Ajzen, 1985). Perceived behavioural control refers to whether the person believes it is easy and difficult to execute a behaviour, and whether s/he is able to carry out the behaviour (Ajzen, 1991). Several external and situational factors could affect people's perceptions for ease or difficulty of executing a behaviour. For instance, if there is uncertainty in the market regarding the diffusion of automated vehicles, if there is no legislation yet around liability issues for users of CAV or if the financial cost of using the CAV is somewhat higher than conventional vehicles, individuals could perceive these as a barrier to adapting CAV. In this situation, a low perceived behavioural control would be associated with lower acceptability. Interestingly, TPB posits that perceived behavioural control might also affect behaviour directly, without the mediation of intentions, meaning that low perceived behavioural control could have a direct effect on acceptance, lowering the likelihood to actually use or adapt CAV.

Differing from TPB, according to the Technology Acceptance Model (TAM; Davies, 1993; Venkantesh & Bala, 2008) intention to use the technology is directly predicted by cognitive beliefs regarding i) perceived usefulness of technology ii) perceived ease to use the technology. The belief that the technology is high on usefulness would lead to high intention to adopt technology , while the belief that the technology is not so useful would lead to low intention to adopt technology. The concept of perceived ease in TAM partly corresponds to the concept of perceived behavioural control, and therefore incorporates both one's ability to use a technology and the perception of external barriers. A high perceived ease to use the technology would lead to high intentions. When the perceived ease is rather low, meaning the technology is perceived to be difficult to use due to external barriers for instance, then intention to use the technology would decrease. In addition, perceived ease is expected to

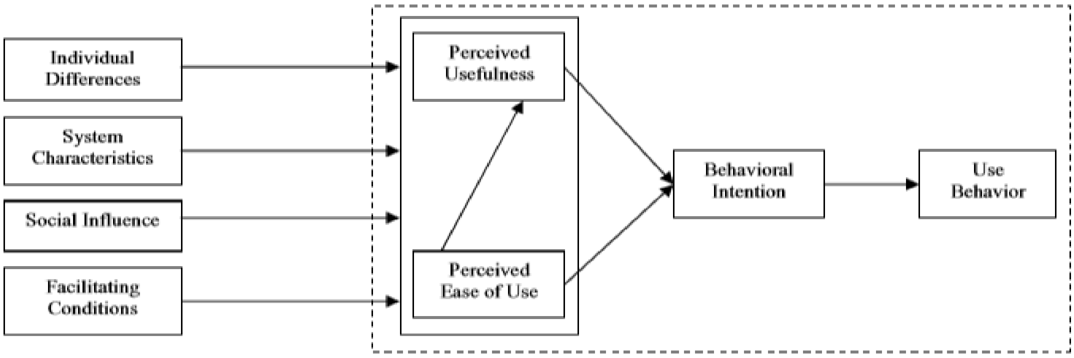


Figure 3: Technology Acceptance Model (see Venkantesh and Bala, 2008)

have a direct influence on perceived usefulness of technology. This is not surprising given that when a technology is difficult to use, its usefulness would decrease. Finally, TAM posits that these cognitive beliefs are to be determined by four factors: i) individual factors such as personality characteristics, gender and age, ii) system and design features of the technology, iii) social influence that is defined as the implicit influence of others in our decision-making, and iv) facilitating conditions such as legal and policy support around the new technology.

One could see that perceived usefulness and perceived ease of use are key determinants in the model as when these are not at desirable levels, both intention and therefore the actual adoption likelihood would decrease. The TAM is later modified (see Venkantesh & Davis, 2000; Verkantesh & Bala, 2008) to include other predictors in the model in an attempt to finetune what kind of characteristics or aspects are more related to perceived usefulness and ease of use. For instance factors such as whether adopting the new technology will improve one's status or whether it would help him to get social approval of important others (i.e.,, subjective norm) are included to predict perceived usefulness. In addition, several additional factors were depicted to predict perceived ease of use in the modified TAM (Verkantesh & Bala, 2008). One of these factors is self-efficacy, which is defined as whether the person feels able to use the technology. A second factor is perceptions external control; that is whether there is external support to use the technology. Notably, emotional factors are also included as predictors of perceived ease. For instance, when the person feels anxious or is scared to use the technology, then this is expected to negatively influence perceived ease. In contrast, is the person perceives using the new technology as enjoyable, then this would have a positive impact on perceived ease. The modified version of TAM also includes the variable of experience with technology. Experience is regarded as a moderating factor between perceived ease and perceived usability of the new technology: when someone is more experienced in using the technology, then it is more likely that perceptions regarding the ease of using the system will actually affect perceptions regarding usability. Mirroring this to the case of CAV, when people are not experienced with fully-automated vehicles, they might have some implicit and perhaps unrealistic assumptions regarding how easy or difficult to use such vehicles, which might impair beliefs on whether it is useful to adopt this technology. However, after some exposure to fully-automated vehicles, and if the experience is positive, then perceived ease could affect usability judgments more strongly.

A modified version of TAM has been used to measure behavior intentions for a shared AV that drove around in France and Switzerland (Madigan et al., 2016). Respondents enjoyment had a large impact on the desire to use a shared AV again, although this may be partly due to the novelty associated with the vehicle. Aside from hedonic motivations, the AV's performance, the resources provided to support their use, and the social norms surrounding the AVs also influenced whether or not respondents wanted to use the AV again.

3.3.1. Limitations

Findings that are discussed above are mostly from questionnaire studies and self-reports. As CAV is still a new technology, we can assume that the majority of the respondents do not have any real-life experience with these vehicles, but they rather respond based on their intuitions and interpretations. Needless to say, negative news in the media, such as a fully-automated car being involved in a crash, could have a negative influence on people's perceptions and evaluations. We therefore need more studies where participants could experience automation in a realistic setting, and measure their acceptance before and after experiencing driving in an autonomous vehicle.

4. Surroundings the conception of the interface in the SUAVE project

4.1. Human-vehicle interfaces, from the past to the future

4.1.1. Human Machine Interface in vehicle conception: an evolution that follows techniques and practices

From the first vehicles, before the 1900s, designers devised various devices to interact with the various components of the car. For example, joysticks were used to control the speed of the engine, the clutch and the brakes. The trajectory was controlled by means of a tiller or a crank handle. These interaction elements were all located within reach of the driver so that he could use them at any time during the journey. The search for improved control efficiency and technological developments have led to many improvements. For example, controls have become increasingly precise and reliable, thanks to complex mechanical devices such as the hydraulic braking system. The use has been made easier from a physical point of view, with, for example, power steering, but also cognitively with, for example, the automatic gearbox.

The increasing number of functionalities has led designers to adopt certain codes, particularly with the multiplication of electrical functions, such as headlamps, windscreen wipers, car radio, etc. Each command activates a feature, but can also activate feedback to control its status. Other feedback has also been integrated to control the state of the vehicle via a dashboard (speed, levels, activation/disactivation of various functions...).

In addition to developments that improved the quality of driving, the engineers looked for other ways to improve safety, especially in critical situations. Examples include crash protection devices, such as seat belts, or electronic devices that take over from the driver for certain complex actions, such as brake control (e.g. *Antiblockiersystem*, or ABS) or traction control (e.g. Electronic Stability Program, or ESP). In this sense, the previously mechanical interfaces are gradually becoming electronic, which makes it possible to insert more and more algorithms to improve the experience or security.

The constant increase in the functionalities available in vehicles has led designers to devise new ways of interacting. At the beginning everything was at hand, but the feet were quickly put to work to propose new ways of interaction. Today, designers are exploring new ways of interacting, such as voice and gestures to control new guidance and multimedia integration features. In other words, the representation of the body's action on the mechanics gradually loses its substance. Electronics and automatisms are interposed between the user and the mechanics, which offers new possibilities, especially with new sensory modalities of interaction.

4.1.2. Multimodal HMI : hierarchize information, adapt it to the expected activity.

Multimodality is a principle of human interaction since they have combined action and speech. Within the speech itself, we can distinguish between strictly verbal and tonic modality. HMI has experienced significant growth as a field of research since the 80's (e.g. Davis, 1989; Spérandio, 1987). At that time, some manufacturers such as Xerox or Apple understood that the possibilities offered by the new technologies would be multiplied if interaction with the user were improved. The keyboard/screen/mouse interaction has greatly improved the use of PCs, especially with the arrival of graphical interfaces that offered the user a representation of data and tools in analogy with the real world (icon, spatial layout, times, etc.). Then the arrival of tactile (e.g. iPhone) and vocal (e.g. Google Home) interactions opened up new possibilities. However, these new modalities have not always overshadowed the old ones, but have rather offered new possibilities in certain previously complicated situations. For example, using multimodal redundant warnings can be used to enhance road safety (Biondi et al., 2017).

This observation can also be made in the automotive industry. For example, recent GPS voice interfaces are used to control a new route without taking your eyes off the road. Interaction with GPS does not require manual or visual intervention. GPS responses are also vocal. Other modes of interaction are also present, sometimes with redundancy. For example, some interfaces display a visual signal when a user is not wearing a seat belt. This information is often communicated in redundancy with an audible signal. It is also possible to indicate the problem with a verbal-visual or -audible message. Multimodal redundancy is used in particular for information of great importance. It allows to touch several sensory paths, thus maximizing the chances of perception of the message on the one hand, and on the other hand to confirm the meaning of the message by inspecting the different modalities (e. g. Beep + belt light).

In addition to the interest of redundancy, the multimodality of interaction offers the possibility of carrying out several treatments of different natures simultaneously. Wickens (2002) describes, for example, the ability to process a non-verbal sound signal while performing a manual and a verbal task.

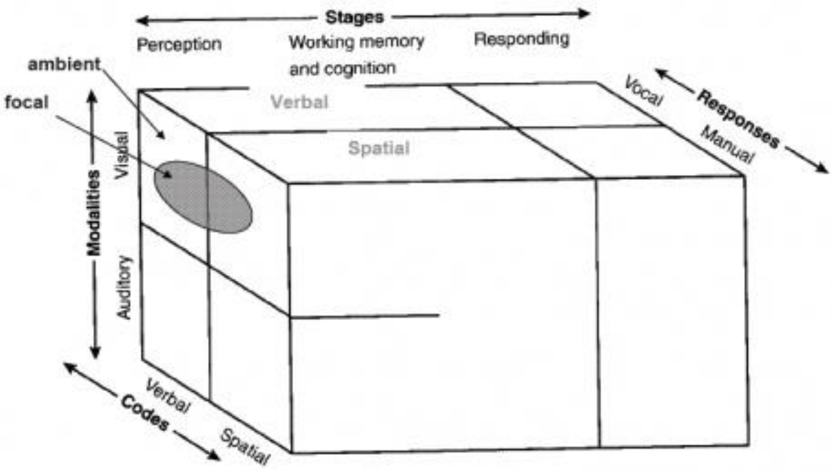


Figure 4: Multiple Resource Model, Wickens, 2002.

This model is an interesting reference for considering complex interactions within a vehicle, especially for autonomous vehicles. Indeed, these will be the place where various activities will be carried out far from the driving. But when the driver's recovery must be carried out or anticipated, it is important to provide him with information on the road situation without generating mental overload related to his activity. Therefore, in addition to multimodality, modern interfaces must have a certain "situational awareness".

4.1.3. Smart HMI : prioritize information according to the situation's needs and the cognitive state of the user

The concept of intelligent HMI can be the subject of many more or less commercial definitions. One might be tempted, for example, to describe an interface as intelligent if it gives access to a multitude of functions. In this case, it is rather the user who must be very intelligent to manage a large flow of information. On the other hand, it is possible to describe a classic, non-intelligent interface. Such an interface can be very efficient and intuitive if it has been carefully designed. The non-intelligent HMI will only offer modalities of action and/or response specific to each function. On the contrary, a more sophisticated HMI could adjust the interaction modalities according to the situation. Therefore, it must be sensitive to certain variables of the situation in order to adapt to them (e.g. Bohn et al., 2004, Ma et al. , 2005). For example, when important information must be communicated to the user, the visual mode will not be preferred if the user's eyes are turned away or closed. Intelligence resides on the one hand on the analysis of the situation, and on the other hand on the proposal of an adaptive interaction. The notion of intelligence often implies the ability to invent new solutions. For the HMI of a car this will probably not be the case for a long time for several reasons. First of all, current technologies are not advanced enough to quickly invent satisfactory answers. Secondly, for safety reasons it is not possible to propose answers that have not been validated in the design process. Intelligence is therefore based on the choice of factors by designers, the reliability of measurements and the relevance of the responses envisaged. The SUaaVE project will specifically explore the following 4 factors:

- **The cognitive needs** of users, i.e. the ability of the interface to provide at all times the information necessary to maintain a satisfactory awareness of the road situation and the state of the vehicle.
- The users' **emotional responses** will be monitored in order to explore solutions to remedy negative reactions, for example by adapting colours, sounds, comfort, etc.) (see SUaaVE Work Package 3)
- **Driving comfort (vehicle dynamics)** is an important element to consider in order to allow users to find a compromise between the time constraint of the journey and an acceptable intensity of movement of the vehicle, induced by its dynamics. The compromise may evolve according to the situation and the travel objectives (work, walking, travel...).
- **Ambient comfort** can be adjusted adaptively, taking into account external factors (weather, noise, etc.), the condition and activity of users (fatigue, work, games, telephone, etc.). The adjustment would be based on various parameters such as sound environment control, air temperature and humidity, chair temperature, light, odours, etc.

4.2. Identification of information sources and factors involved in an intelligent and multimodal interface.

In the very essence of a HMI, the input data include user commands to obtain answers (actions, information). When humans interact with each other, they are also able to receive and respond to stimuli. But unlike non-intelligent systems, humans are able to adapt the interpretation of information and adapt the response (action or information) according to the situation and the interlocutor. For example, if a speaker says "I drank too much tonight", a different state can be inferred if this sentence is the answer to the proposal of an herbal tea or cognac (cf. Grice, 1989). To qualify a system as intelligent, it must be able to adapt the nature of its responses to the situation.

The diversity of situations implies a diversity of hazards and misuses, therefore sources of risk to jeopardize the interaction with a vehicle. According to Bastien and Scapin (1993), the quality of an HMI is based on a certain degree of adaptability according to the characteristics of the context and the users. For example, vehicles adapt the brightness of the on-board display according to the external brightness, in order not to glare the user at night, and to provide good readability in direct sunlight. In the SUaaVE project, the "intelligence" of the ACE interface that will be developed will be based on an adaptability that will be automated based on different factors. Characteristics of the context, the vehicle and the user will be monitored in order to propose at any time an optimal interaction to meet the objectives of the moment.

Designing an interface involves taking into consideration the input data, which may determine:

- **the information** (e.g. the indicated speed differs if the data comes from wheel rotation or geolocation),
- **information processing** (e.g. calculation of speed from wheel rotation is based on a linear ratio on 1 dimension, while geolocation involves a calculation of vectors in 3 dimensions).
- **the presentation of the information** (e.g. the display of the speed from a GPS can be coupled with an indication of the authorised speed, the absence of geolocation does not allow this indication).

Most of the important information and functions for using a vehicle can be grouped into 3 logical categories: the environment, the vehicle and life on board. These categories are defined below using a few examples.

4.2.1. Environment

First of all, the environment. The environment is the first data to be processed because it determines the need and the possibility of making a journey. Concerning the need, the choice of a transportation means arises when the travel time and/or effort may hinder the objective pursued. The possibility of using a car is based in particular on the presence of suitable road infrastructure. The use of these infrastructures is facilitated by markings that offer the user a better physical and social representation of the road space. The perception of these marks and the quality of the coating may, however, be affected by the climatic situation (humidity, temperature, light, etc.). Moreover, some devices improve the perception of the environment, such as headlights, cameras, etc...

In addition to the physical environment, the driver also evolves in a social space. Road use involves sharing with users of more or less varied means of transport (cars, trucks, bicycles, trams, pedestrians, etc.). Traffic density is a major constraint to evolve while guaranteeing the safety of all. The driver must continually update his/her representation of his/her trajectory, and that of any object he/she may catch. The social environment is also governed by a certain degree of interaction between users. These interactions are partly facilitated by codes (e. g. STOP panel), but they are also enhanced by devices such as turn signals and claxons.

The physical and social environment determines a context of use that the user needs to know at all times the elements that will guide his actions. When a user has to (or wants to) take control of an autonomous vehicle, he/she must first reconstruct important representations to act, such as planning the necessary actions and representing the context. This construction requires a delay that depends on the user's previous activity. This delay can be a few seconds if the user was attentive to the road, several tens of seconds if he was engaged in another activity (reading, rest...). Reducing this recovery time and increasing the quality of representation is a key issue in the design of future vehicles (e.g. Zang et al., 2019)

4.2.2. The vehicle

With nearly 150 years of evolution, the car is designed on fundamentals that have certainly evolved, but which have been enriched above all. In the past, the innovative addition of controls to the dashboard was welcome, but the current trend is towards simplification. The multiplication of available information tends to generalise the use of scrolling menus, in particular to display certain information of secondary importance (e.g. consumption, distance travelled, etc.). However, most information relating to the car remains within the immediate reach of the driver. Critical information is always available. Some remain visible (e.g. fuel level), others are turned off and only turn on if an activation (e.g. headlights) or a problem (e.g. battery failure) is detected.

With the addition of new measures, new technologies and new automatisms, the possibilities and requirements for controls are increasing. This is particularly the case for the delegation of the driving task. To understand and trust the operation of the autonomous vehicle, the user must be able to monitor the actions and decisions made. In addition to adding devices to improve the perception of the environment, the design of an HMI will also have to include information on an increasingly complex vehicle operation. However, the interest of the autonomous vehicle is not necessarily to move from a driving task to a monitoring task. Instead, the autonomous vehicle promises to imagine new uses for life on board.

4.2.3. Life on board

There are many parameters and features to improve driving comfort, and more generally the life of passengers on board. First of all, some parameters aim to optimize the driving position to allow the driver to have quick access to the main controls (steering wheel, pedals, etc.). On some cars, the seating comfort of users is enhanced to improve comfort (e.g. heated seats), safety (e.g. head restraints), or even reduce fatigue (e.g. lumbar adjustments).

Besides the seat, temperature control is one of the main functions, and often has a central position. In its simplest version, the device allows the temperature and air flow in the passenger compartment to be adjusted. More sophisticated versions offer multi-zone configuration, with which each passenger can have their own setting...

Another central control is usually the car radio, which is also controllable by the front passenger. Often the driver has steering wheel controls to avoid distracting his/her visual attention. Now the car radio is almost always integrated into an on-board computer that offers a GPS, a hands-free telephone kit and various vehicle settings (e. g. choice of screen interface).

Finally, life on board is conditioned by the vehicle dynamics induced by the driver. For example, smooth driving in the city can allow passengers to relax their attention from the road and focus on other activities.

The usefulness of each information or order, and more broadly of each category of information, varies greatly depending on the activity carried out. Especially on a level 4 autonomous vehicle, the takeover phase requires a series of actions each involving different information and commands. Smooth highway driving makes it possible to do activities such as reading a book or watching a movie, which implies a different distribution of information.

5. Taking into account comfort in the use of a vehicle (IDIADA)

5.1. Definition of Comfort

5.1.1. General definition and attributes

There is not, in the literature, a clear definition of comfort, although various fields have studied and applied this concept. In their work, Shen and Vértiz (1997) list some definition of comfort dividing them in two categories: comfort as a state of ease and comfort as absence of discomfort. In the first category comfort is defined as a state of ease or well-being (Oborne and Clarke, 1973); as the physical, psychological and physiological harmony between a person and the surrounding environment. In this definition, physical comfort refers to the lack of disturbance in a person personal environment, the psychological comfort refers to the concepts of well-being and satisfaction and the physiological comfort refers to the lack of illness and the general state of good health (Slater, 1985); as an empirical perception of being at ease (Reynolds, 1993). The second category includes definition that highlights how comfort is just a lack of discomfort (e.g. Heirtzberg, 1958; Branton, 1969). For these authors, comfort is a "false sensation" as it is simply the starting point of the discomfort continuum. If comfort is just the absence of discomfort, it means that comfort can be thought as the origin point of a scale of discomfort. Shen and Vèrtiz (1997) partially disagree with these definitions and defined comfort as both a physiological and psychological state derived from the relief of discomfort and the achieving of "corporal homeostasis". To summarise, there are two different views on the definitions just described. One that considers comfort and discomfort as opposite ends of a continuum (Figure 5) and one that considers comfort as the origin of a discomfort continuum (Figure 6).

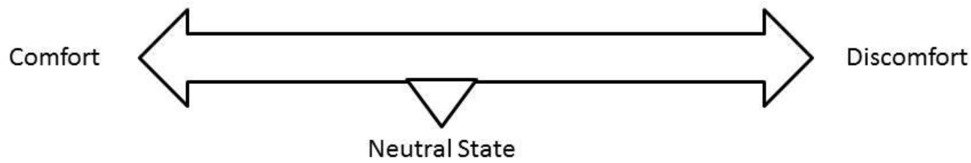


Figure 5 First type of continuum Comfort-Discomfort.

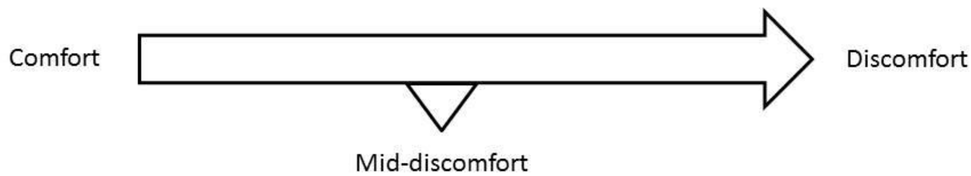


Figure 6 Second type of continuum where comfort is the origin.

More recent definitions of comfort try to separate the two concepts of comfort and discomfort. Vink and Hellback (2012) define comfort "as pleasant state or relaxed feeling of a human being in reaction to its environment" (p.271) and discomfort "as an unpleasant state of the human body in reaction to its physical environment" (ibidem). These definitions are derived by models in the literature, which describes the factors influencing comfort and discomfort. De Looze et al. (2003) developed a model where both comfort and discomfort are influenced by human, product and environment characteristics. However, the characteristics of the two are different and the two concepts are thought as separated.

Vink and Hellback (2012) developed a model which takes into consideration the De Looze et al. (2003) model and other similar theories by other researchers (e.g. Moes, 2005). The model developed by the authors states that the interaction with the environment (I) (composed by the human, product and task characteristics) produces a physical effect (H) which influenced by the user expectations (E) produces a subjective perception (P). This perception can result in three different states: comfort (C), discomfort (D) and nothing (N). Extreme discomfort can result in musculoskeletal pain (M). The model is depicted in Figure 7.

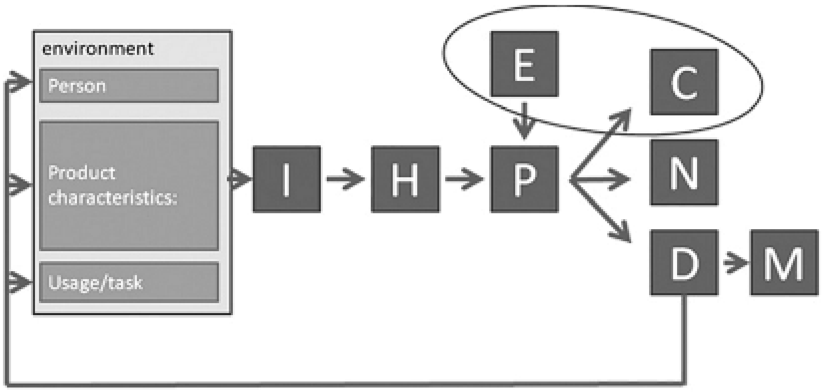


Figure 7 Vick and Hellback (2012) Model

Summarising, there is not an agreed definition of comfort, however the literature seems to agree that various factors such as physiological, physical, psychological and emotional influence in the perception of comfort. Moreover, environment user characteristics and product characteristics are attributes of how comfort and discomfort is perceived.

5.1.2. Vehicle comfort

Vehicle comfort has been widely studied in the history of automotive research with studies dating back to the beginning of the 20th century (Warner, 1924). In the last decade, with the introduction of technology advancements, new and improved methods to enhance a vehicle comfort have been added. The implementations of sensors and adaptive systems made it easier to improve the drivers' and passengers' experience in the vehicle (Cieslak et al., 2019). The definition of vehicle comfort is strictly connected with the definitions described in the definition section above and the Vick and Hellback (2012) model. As an example, the product characteristics are several, for example the seat comfort (Elbanhawi et al., 2015), the acoustic comfort (Zhang et al., 2018), temperature (Danca et al., 2016), ride comfort (Cieslak et al., 2019) etc. The users' characteristics depend on the physiological, psychological and physic state of the drivers/passengers (e.g. state of stress, presence of pain derived from other activities, tiredness…). The usage characteristics could be connected to the user's driving style and user situation (rush, calm, road trip…). Environment characteristics could be added to the equation, such as state of the road, weather condition, car condition. The overall comfort of the drivers and the passengers of a vehicle have to take all these aspects into account.

5.1.3. Vehicle comfort factors / dimensions

In order to specify the vehicle comfort factors it is worth considering the commonly shared aspects that appear in the majority of definitions of comfort, as identified by Looze et al. (2003): comfort is influenced by internal and external factors, and it is experienced as a reaction to something.

Although the road can been considered the major external cause for vehicle unexpected motion or vibration and, therefore, discomfort, any action undertaken to change vehicle trajectory such as steering, braking or accelerating can be also treated as source of changes in the vehicle and passenger states (Burjhard et al. 2018). Consequentially, both drivers and passengers have the capability to judge vehicle reactions to any external sources like a speedbump; however, passengers might also evaluate the driving skills of a driver or even the followed trajectory within the infinite possibilities for a set of environment conditions.

Consequently, comfort evaluation factors can be classified in in 4 groups:

- **External Environment factors:** Completely external to the driver and the vehicle. Related to weather, road and traffic conditions.
- **Driving factors:** Related to the driver skills that allow executing driving tasks without having a negative effect in comfort. Mostly related to smoothness.
- **Trajectory factors:** Those related to the chosen driving conditions like position, or speed that leads to specific vehicle states and the execution of driving tasks.
- **Vehicle factors:** Related to the performance of the vehicle treated as a system that reacts to external inputs of forces and the isolation of those forces from the passengers perception.

These four groups are depicted in Figure 8.

It is expected that engineers have traditionally focus on the study of the vehicle performance and the characterisation of external factors in a deterministic matter. However, the consideration of autonomous driving will imply a change in the paradigm as it is explained in section 4.1.2.

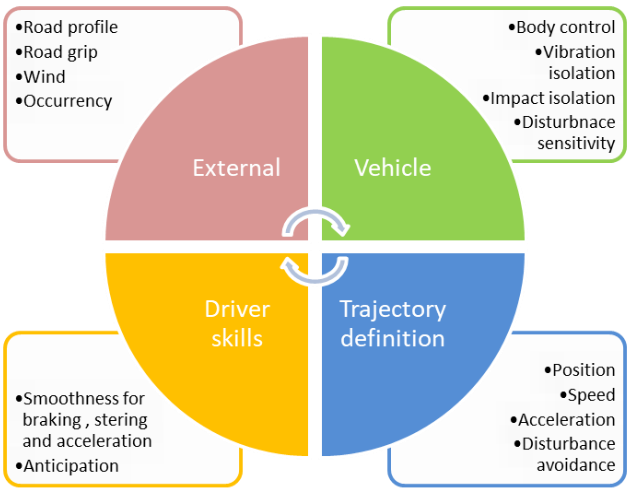


Figure 8 Comfort evaluation model

5.1.4. Assessment of vehicle comfort

Given that comfort is influenced by subjective and objective factors, comfort assessment can be measured objectively and subjectively.

Subjective assessment:

The subjective assessment requires the consideration of specific performance characteristics that are to be rated with a numerical value. The characteristics are also called subjective attributes and they help to describe the overall performance. The rating value is chosen based on a scale that provides equivalence between the numerical value and an attribute that describes the perception with a key word. The SAE provides a proposal of such type of scale in the standard SAEJ1060 that is commonly used in the industry and also in some academia studies that focus on correlation between subjective and objective data.(Cieslak et al., 2018).

1	2	3	4	5	6	7	8	9	10
UNACCEPTABLE				BORDER LINE	ACCEPTABLE				
CONDITION NOTED BY									
ALL OBSERVERS		MOST OBSERVERS		SOME OBSERVERS	CRITICAL OBSERVERS		TRAINED OBSERVERS		NOBODY
Intolerable	Severe	Very Poor	Poor	Marginal	Barely Acceptable	Fair	Good	Very Good	Optimal
1	2	3	4	5	6	7	8	9	10

Figure 9 SAE J1060 rating scale

However, the definition of attributes needs to be adapted to the sample being questioned. Hence, a possible strategy consists in adapting the evaluation by using questionnaires that facilitate the rating from non-experts users, including commonly used vocabulary and giving the possibility to select from a multi-choice answer. Nevertheless, the evaluation undertaken by experts and non-experts must be related in order to build the reasoning to support technical discussions as well as market-ability activities. The table below shows a list of high level attributes that can be potentially easily answered by non-expert passengers, and a list of vehicle dynamics specific attributes that might require either an expert assessment or more specific preparation of the evaluation method to obtain subjective ratings. It is also expected that high level attributes ratings can be explained by the assessment of specific attributes, and that statistical and machine learning methods are used to describe the relationship between them as well as the relationship with objective metrics (Cieslak et al., 2019).

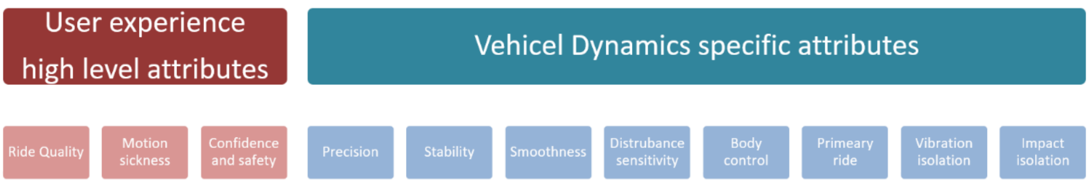


Figure 10 High level attributes and Vehicle dynamics specific attributes in the subjective assessment of vehicle comfort.

Objective assessment

Form the objective point of view it is necessary to consider that Humans perceive vibrations by combining visual, vestibular, somatic and auditory signals. However, engineers have historically focus on more easy-to-acquire signals like position, motion and accelerations applied on the body. Thus, the lack of technology to acquire biometrics and the complexity added while testing has led to the definition of objective metrics that are only based on vehicle signals processing.

In addition, recent studies show the possibilities of measurements based on human body like the ones obtained by accelerometers at the passengers head, and how that information can be integrated with other methodologies in order to improve the prediction of the ride and comfort level (Burkhard et al, 2018).

The study of the different ride and comfort phenomena from a mechanical or vibrational point of view promotes the consideration of different factors depending on the frequency of processed signal or the degree of freedom excited. Following this approach, the ISO 2631 (ISO, 1997) proposes a solution for comfort objective characterisation that consists in the analysis of acceleration data which can simply acquire with accelerometers. The standard also proposes weighting factors that allow to compensate the post processed results based on the sensitivity of humans to different frequencies, and to provide a better correlation of the comfort predicted values. Also some comparison studies show that the ISO 2631 standard method perform better than other standards like the VDI-2057 (Association of German Engineers, 2002) and the BS 684 (British Standards, 1987), when characterising ride and comfort (Enders 2019).

It is also necessary to show that acquiring objective data from motion sickness occurrences must require additional measurements on the human body and the use of techniques allowing the assessment of humans through a machine interface. As an example, the use of electronic devices to execute simple tasks and the assessment of the performance during the execution can be used to assess the occurrence of motion sickness, or the lost or attention by the subjects.

Regarding specific performance metrics, some of the methods applied to the calculation of metrics are based on pseudo-spectral density calculations on an acquired signal, but metrics an also be refereed to maximum values of a time-based signal (Brandt 2011). Nevertheless, the use of one objective metric or another should be ideally be justified by the level of correlation achieved with a subjective rating linked to a specific subjective characteristic.

In any case, a very important point when planning objective data is the definition of load cases and scenarios that are representative of the use of the vehicle and its life. The combination of both, stochastic roads as well as deterministic events with pre-defined conditions can help to acquire the necessary data and to validate the correlation of objective metrics that are used in the process of analysis and subjective prediction. In the same way, the consideration of other factors such as the orientation of the seat, the subject gender and the level of attentiveness can be very relevant in the analysis and the prediction, so they need to become variables to be acquired during the testing (Salter et al, 2019).

5.2. Definition and attributes of future autonomous vehicle comfort

As explained previously in point 4.1.2, comfort is associated with a feeling of well-being and an attribution of positive valence or, depending of the point of view, the absence of discomfort. This definition applies also for automated vehicles; however comfort strategies aiming to provide a comfortable experience differ significantly. Traditionally, vehicles are designed to fulfill a set of driving dynamics metrics and have a very developed passive safety elements. The development of automated vehicles comfort performance will not only take into account vehicle dynamics but also will potentially increase the focus on passenger's behavior and perception, in order to directly improve their comfort feeling.

New internal and external factors influencing comfort will appear and aspects that in non-automated vehicles had small impact will become very important. The relationship between expected and actual driving is exposed as a factor that will become much more important. Passengers in automated vehicles are expected to question the decisions taken by the machine more strictly than if they would be taken by a human driver. Hence, automated vehicles will have to outperform the level of comfort achieved by non-automated vehicles and traditional vehicles in order to provide a similar feel of well-being.

Furthermore, relevant to highly automated driving, a close relationship has been seen between comfort and trust as well as acceptance of automated vehicles. Both trust and acceptance will take a fundamental role and will represent a barrier to be surpassed to finally adopt the technology. In Bellem et al. (2018), passenger personality has been seen related to acceptance.

Another factor which may have a significant impact on acceptance is motion sickness. Several studies show how motion sickness can appear in automated vehicles and describe the key aspects to overcome the issue. In Diels and Bos (2015) three general situations are described. The first one is the absence of vehicle control in the sense of reduced ability to anticipate the future motion trajectory. One possible option to overcome this problem, among others, would be to have a display showing the trajectory planned by the vehicle to the passengers. The second one is the engagement in non-driving tasks like reading or using a mobile phone. The freedom passengers will have to engage in different activities will increase the frequency of head movements, which has been seen as a factor inducing motion sickness. The third and last source of discomfort that automated vehicle may introduce is the new distribution on the seats displacement. In most futurists automated vehicle prototypes some of the seats are facing backwards to promote non-driving tasks, however, some studies suggest that this can cause discomfort at some extend.

Another interesting feature of automated vehicles is that they will be able to communicate with each other. To see how this can affect comfort in Oliveira et al. (2019) is explained how connected vehicles can give a feeling of unsafeness in some maneuvers if the passenger does not take into consideration that the vehicle itself has information of another vehicle intention. This also needs to be investigated as not so much research has been done in this field.

From all factors affecting comfort commented in the last sections, it can be concluded that automated vehicles will need to have the capacity to control the vehicle adaptively in order to give a high level of comfort for different types of passengers and different driving situations, taking into consideration the surrounding vehicles or the attention that passengers pay on the road. As an example, it was found in previous research that drivers profiles where divided by how they manage the following variables: minimum distance to front vehicle, desired speed, time gap to front vehicle and desired maximum acceleration and deceleration and each driver has some specific values for this parameters. However, in congested traffic the little differences between them leads to the creation of the typical shockwave traffic jams. This phenomenon does not affect the average speed of the vehicles, which is dependent directly to the density of vehicles in a road as the capacity is limited, but changes drastically the accelerations and jerks profiles which affect the comfort (Hoogendoorn and Knoop, 2013). In other words one strategy would be to have an adaptive control that in regular driving situations has a profile based on a particular passenger but in congested road vehicles would communicate and could try to uniform their behavior to improve to overall comfort.

5.2.1. Criteria to design a comfortable vehicle

As said in section 4.1.2, the factors influencing comfort in a vehicle are several and concerns different aspects of the car, the environment, the user and the car usage. However, even though almost the entire body of research focuses on the driver comfort (Diels et al., 2017), as said in the previous section, the implementation of autonomous cars such as CAV (Connected Automated Vehicles) and SAV (Shared Automated Vehicles) changed the focus point to a passenger comfort perspective (Diels et al., 2017). The change of focus is important as it influences the attributes for a vehicle to be comfortable, since the driver becomes the passenger and the machine becomes the driver.

Since the new automated vehicles and their introduction as a research topic is relatively recent, the research on the comfort of users in CAV and SAV are mostly taken from the aviation field where factors such as peace of mind, physical wellbeing, proxemics, satisfaction, pleasure, social, aesthetics, and association are considered important (Diels et al., 2017). However, there are differences between the experience in an aircraft and in an automated car. Factors such as the perception of movement, the increased danger of road travel and the lack professional figures (i.e. pilots) to take over in case of emergency, are fundamental in the definition of the criteria for a comfortable vehicle. Diels et al. (2017) developed an initial framework of requirements for users' comfort in automated cars. The model is depicted below in Figure 8.

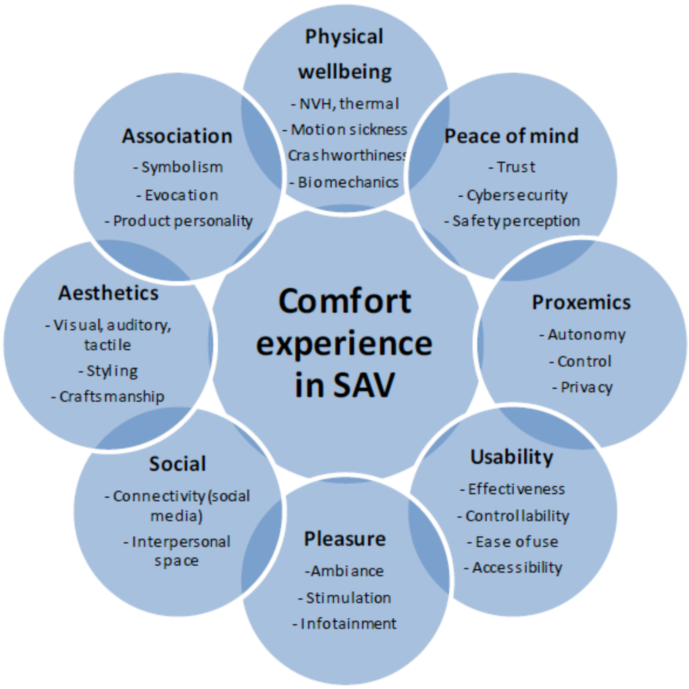


Figure 11 Diels et al. (2017) requirements for comfort in car design.

Physical well-being during travel refers to the perception of the car environment. It is influenced by factors such as temperature, motion sickness perception, and acoustics. Moreover, together with peace of mind, it is associated with trust in technology, which is one of the most important aspects in the actual use of the systems (Salanitri et al., 2018). Proxemics and social refer to the sensation of privacy, both in the relationship with the automated vehicles and in the relationship with other unknown passengers (especially in SAV). Usability is related with the efficacy, effectiveness and satisfaction (Bevan, 2009) in the use of the vehicle. Pleasure is one of the novelties of automated cars. The fact that the users can take advantage of not driving will increase the sense of pleasure giving by doing other activities. Aesthetics is also an important factor in the perception of comfort and should be taken into consideration in interiors design. Finally association, which also has connection with trust, refers to the sensation of connection with the vehicle.

Moreover, the way that autonomous vehicles interact with the external factors of the environment can have a big impact in comfort felt by passengers. Hence, manipulating driving style seems to be the most promising option for substantially influencing passenger experience in automated vehicles.

Passive safety systems of the vehicle and seats are not very likely to change substantially in higher automation levels, however, acting on the driving style entails modifying the trajectory as a key factor of comfort. For example, modifying the driving style includes finding the preference of speed, accelerations and jerks profiles, as well as the conditions for overtaking, preferred headway distance and abiding traffic laws, among others. In general this automated vehicle task is known as motion planning.

Paden et al. (2016) showed an overview of typical strategies for motion planning, divided motion planning in automated vehicles in several layers. The higher layer decides the overall route to take as a GPS would do. This layer, at some extend, can improve comfort by choosing a better maintained road or avoiding congested streets for instance if the vehicle has information about it. Once the general route is picked, the other layers take into consideration data acquired by perception sensors (surrounding vehicles, traffic signs, etc.) to decide the actual path and speed profile used within the route.

In Alcalá et al. (2018), a motion planner based on a Model Predictive Control (MPC) is proposed to improve comfort. The logic includes finding the future vehicle states using a dynamic model of the vehicle. This strategy was chosen to ensure that the vehicle path accomplishes specific motion requirements of a vehicle and that is achieved by considering lateral and longitudinal dynamics simultaneously. In other words, path and speed profile are defined at the same time.

The motion planner takes a reference path as an input, for example boundary limits, and the maximum speed at each path position and outputs the optimized path and final speed profile. To do so MPC is divided into two sections. On one side there is a cost function and one the other side the constraints. This cost function can have different terms like efficiency states (time minimization), stability states (sideslip or sideslip rate) and comfort states (longitudinal and lateral accelerations and jerks). Each term is associated with its corresponding weight. On the constraints side, there are the lateral boundary limits, the maximum speed for each prediction, also maximum accelerations and jerks can be set and finally the vehicle model.

An important feature of this motion planner is that the weights associated to the states in the cost function can be updated online while driving. This means that the vehicle could modify the path and speed profile based on passenger preferences or state. For example, the detection of a passenger whose state is being affected to the longitudinal jerks could be used in pre-defined algorithm that adapts the vehicle path and speed to minimize longitudinal jerks and provide a more pleasant feel. The development of that algorithm as well, as the collection of data to support its validation is proposed as part of the Suaave project activities.

5.2.2. Solutions investigated by IDIADA to improve comfort

As stated thorough this document, the implementation of autonomous vehicles is hugely changing the concept of in-car comfort and the characteristics that the vehicle has to respect in order to maximize comfort (Burkhard et al., 2018). The solution investigated by IDIADA will be focused on the vehicle adaptability to the user and environmental factors. Regarding comfort, based on the literature described in the previous section, there are seven main attributes that will be investigated by IDIADA:

- **Spatial Environment** defines the level of perceived space within the occupant environment, with relation to the demands of the user.
- **Thermal Environment** covers the thermal environment of the vehicle cabin, following the individual characteristics and state of each user .
- **Acoustic Environment** refers to components of the vehicle cabin sound and vibration characteristics.
- **Visual Environment** refers to visible components of the vehicle occupant environment.
- **Contact Surfaces (Tactile Interaction)** concerns the comfort in interacting with systems requiring touching (e.g. touchscreen).
- **Postural position** refers to components of the occupants physical position when traveling inside the vehicle cabin, following the characteristics and state of each occupant.

- **Environmental Hygiene** is comprised of a variety of factors governing the users sensation of cleanliness and hygiene whilst traveling within the vehicle.

The underlying methodology proposed by IDIADA is the assessment of comfort with subjective and objective measures during the participants' interaction with a drive simulator. The participants will be able to adjust aspects of the car in order to improve their perception of comfort. The characteristics are described below.

Occupant comfort will be controlled by a model taking inputs from:

- The occupant state and characteristics.
- External factors.

For the model used for SUaaVE, only comfort components that can be manipulated by the relevant features will be included. The model proposed by IDIADA is depicted in the table below.

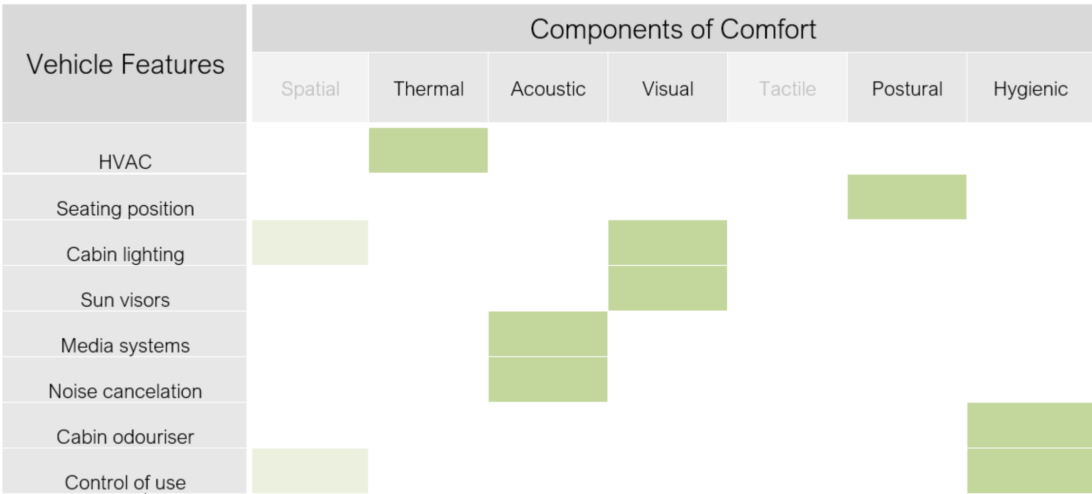


Table 1 IDIADA comfort model

From a vehicle dynamics point of view, the vehicle behavior will be adapted in a scale which goes from pure trip efficiency or promptness to pure comfort behavior (traditional quality ride and motion sickness). The trip efficiency is related to the time to destination and the use of maximum speeds to define trajectories. Also, a trip efficiency oriented strategy would allow more aggressive changes of longitudinal acceleration, as well as higher levels of lateral acceleration that would potentially reduce the level of comfort.

On the contrary, a pure comfort behavior would minimize the longitudinal jerks, and define a trajectory that provides the most comfortable feel, while increasing the time of the trip.

As a proposal, passengers would be able to adjust the performance based on their preferences by using a simple slider between the extreme conditions (Figure 11).

Figure 12 Example of a possible comfort bar.

The proposed strategy to make an assessment of comfort on automated vehicles is based on evaluating the subjective feeling of a representative sample of people that will experience a set of deterministic events and occurrence of comfort violations. The goal is to evaluate as many cases as possible to cover the main situations a passenger would experience in an automated vehicle.

With this purpose simulation environments are chosen to recreate the comfort evaluations. Simulations environments offer plenty of advantages. On one side simulations can assure a good repeatability between tests for each single individual. Also for easiness of implementing all algorithms required is important to take into account. On the side of safeness simulation environments are the most suitable ones. In addition there will be no dependency on climate weather that could affect the functioning of test in real .

In the proposals we have the usage of Idiada's Dynamic Driving Simulator Dim 250 to get a realistic vehicle model. With specifications that allow it to reach accelerations of 2.5G, it is a simulator conceived to reproduce transient behavior very precisely, which translates to accelerations and jerks that has been found as main comfort variables. On the scenarios side Scaner Studio is also proposed. A software with plenty of capabilities to reproduce any kind of urban or long-distance travels and also any kind of events as it could be the surrounding traffic of dynamic obstacles to avoid during ride.

6. Cognitive determinants of interaction with an autonomous vehicle

First of all, interaction with an autonomous vehicle mainly concerns settings (comfort, travel, etc.), requests for information from the user or system, access to on-board services (e.g. music, films, games, tourism, etc.). Interactions related to manual driving are not specifically targeted in the SUaaVE project. However, autonomous level 4+ vehicles have the necessary controls for manual driving. This manual driving can be done either throughout a journey or over a part of it. The latter case involves a transfer between automatic and manual mode. However, this transfer corresponds to a change in activity and representation on the part of the user, which must be taken into account when designing the vehicle's HMI.

When you take a car in hand, it is necessary to carry out a certain number of operations in order to set up in the driving position. The main operations are to ensure a good distance from the controls and good visibility (adjusting the mirrors, removing the fog, turning on the headlights, etc.). During the first steps, the driver is also able to plan his driving (route, dynamics, etc., according to the context and objectives) and the first maneuvers. Autonomous level 3 and 4 cars may require a takeover while driving. Some adjustments have already been made if the driver has already had a hand since starting. In other cases, the correct settings are not ensured. Then, as with the first steps, the recovery requires planning the very first actions that will be done. To do this, the driver needs to be back in the driving loop, i.e. to reinvest the controls and decisions. This operation involves some cognitive work to reconstruct appropriate mental representations.

In autonomous driving, the user is in a situation of "letting go" of the driving, for which he/she relies totally on technology. In the short term, taking control implies a change in the user's attitude towards automation. In the long term, as the experience with automation increases, the user paradoxically loses experience with manual activity (Bainbridge, 1983). To prevent this impact in the aviation sector, airline pilots are required to carry out at least 10% of landings in manual mode. We will see below that experience is an essential determinant of representation and action planning.

6.1. Mental representation

The processes of mental representation of interactions will be described in more detail in T3.3, but some reminders about the concepts at stake are formulated here for the purposes of conceptual framing.

6.1.1. Mental representation of objects

When a user interacts with an object, he(she codes the object and the environment in memory and automatically activates different concepts related to the object that categorizes it (Cross et al. 2012; Iachini, Borghi, and Senese 2008; Tijus and Cordier 2003). Concepts are various data stored in memory such as ideas, shapes, objects, events, emotions, etc. The target object is then linked and categorized with certain activated concepts, with which it shares different characteristics or values. This categorization consists in dividing the world in order to better define it.

The object belongs to a category because it has a discriminating property, and it is possible to deduct properties not perceived by the object, because of its category (Chaigneau, Barsalou, and Zamani 2009). For example, when you see a suitcase, you can deduce the presence of a handle to carry it. Categorizations and inferences contribute to the construction of a mental representation of the object, especially from previous experiences. The context of use also has an impact on the construction of representations, especially when they involve a particular use. This is called affordance.

6.1.2. Principle of affordances.

A user can distinguish two objects on the basis of physical characteristics such as colour, size, shape, and use-related characteristics. Some characteristics may in particular highlight an affordance, i.e. suggest a use or invite to use (see in particular Gibson, 1977). Norman (1998) describes affordance as a reflection of "possible relationships between actors and objects". According to the author, artificial conventions learned such as some icons of a computer interface, do not make real affordances. This is the case for most of the interaction elements present in vehicles. Norman describes the icon as a perceived affordance, but the real affordance lies in the effect produced when the user clicks on the icon. A real affordance can be foreseen by the designer, in which case he/she imagines a shape of the object, a color, a material, which suggest a function, the implementation of a gesture, a force, a precision, etc. For example, in a boat, the steering wheel on some watertight doors suggests an opening with a rotating gesture. An affordance can also be incidental in the environment, for example a rounded rock on the side of a road that offers an opportunity to sit down. In any case, the action that can be performed with the object will be all the more prominent if it meets a user's goal. In addition, a device on which an affordance has been provided can be evaluated, for example in terms of utility and ease of use. The characteristics perceptible in an interaction situation make it possible to apprehend the real use of the object, and to verify the quality of the affordances, and in particular the negative affordances. A negative affordance corresponds to an unforeseen and potentially damaging possibility of action. For example, it is common to see store doors equipped with a handle that can be pulled while the door must be pushed.

Whether or not they provide an incentive to be used correctly, the objects and functions offered in vehicles are intended to be used in a certain way. As a result, their mental representation implies an essential part linked to the actions they enable.

6.1.3. Mental representation of actions

Objects are often designed to be used. The use allows to have different angles of view and different perceptions on the object that enrich its representation (Tijus and Cordier, 2003). The representation will thus be enriched by new visual, auditory, tactile and other information, but also by the sensorimotor experience of interaction (Gallese & Lakoff, 2005, see also Craighero, Fadiga, Rizzolatti, & Umiltà, 1999). In addition, there is the more global experience of usage, which adds to the representation the different ways in which an object can be used. Some of the bricks of the representation concern precisely the typical course of an interaction in a given situation. Chemlal and Cordier (2006) described the activation of a "schematic organization" that corresponds to the "theories that subjects construct about the world". A schematic organization can be described as a typical situation in which a user performs tasks using well-defined objects and procedures. Zacks and Tversky (2001) and Zacks, Tversky and Iyer (2001) use the term "event schemata". An event schemata is composed of a succession of actions to achieve a defined goal. According to these authors, the typical pattern of an event influences both the realization of actions by an actor and the perception of actions by an observer. Such a scheme determines how people plan future actions, or evaluate past actions. For example, when a driver moves to a new driving seat, he/she must perform an action sequence: check and adjust his/her position with respect to the pedals and steering wheel, then adjust the mirrors, then buckles up, then start and check the indications on the dashboard, and so on. Each of these steps can be split in turn. From these schemas, a user is able to plan future actions, evaluate the successful completion of a past action, and transpose the use of one object to another that shares certain characteristics. On the contrary, the action scheme with an object in one context may be ineffective in another context. In other words, a variation of the context may impose a variation of the action scheme, and more generally of the representation of the object.

6.1.4. Impact of context on mental representations

The categorization of an object is necessarily carried out in the user's field of knowledge. Categorization is carried out with regard to known concepts such as objects, but also more broadly with regard to knowledge about events, emotions, procedures, etc. This process of concept activation around a target object has been studied in psychology, for example with so-called priming methods. In this type of study, according to Heyman, Rensbergen, Storms, Hutchison, and De Deyne (2015), the realization of a memory task concerning a target (e.g. a steering wheel) is facilitated when it is preceded by a semantically related concept (e.g. a car) rather than by an unrelated concept (e.g. a table). In the representation of an object, it is quite possible that similar processes may be at work. For example, if a user watches a road safety documentary before trying a car, his/her representation of the car could be coloured by a sensitivity to safety elements.

According to various authors (e.g. Chaigneau et al., 2009; Chemlal & Cordier, 2006; Kiefer & Pulvermüller 2012), concepts are rarely categorized solely according to an "essence" or specific characteristics. They are defined more broadly in terms of context first of all, and then they are integrated into the system of knowledge, experience and beliefs. In other words, knowledge about an object depends not only on its intrinsic properties, but also on its links with other components of the environment, and in particular on the interactions in which it is involved (e.g. Kiefer & Pulvermüller, 2012; Chaigneau et al., 2009). For example, the representation of the time saved by the car will not be the same if the user is placed on a country road or on a congested interurban road.

The link between the context and the representation of the object was highlighted in a study by Denis and Le Ny (1986) based on a comprehension test. In a first phase the participants listened to a story. This story evoked a target object ("church") cited in one of two contexts ("Every Sunday morning in front of the church a beggar stood..." vs. "As he approached the village, the first building in sight was the church..."). In a second phase, the participant had to observe the image of a part of the target (a church porch or bell tower, see Figure 2), and he had to indicate if this object was mentioned in the text. Participants responded more quickly when the photo was compatible with the context described in the story (beggar-porch vs. village bell tower).

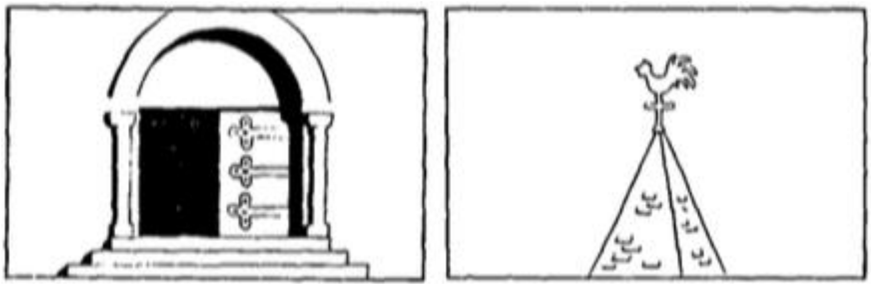


Figure 13: Examples of pictures presented in phase 2 in Denis and Le Ny's experiment (1986)

Denis and Le Ny's (1986) study highlights the relationship between object and context. The presentation of a typical context activates the representation of the elements that compose it. The elements that make up a context are themselves made up of characteristic elements. For example, the panorama is composed of a village, the view of a village is characterized by the emergence of a bell tower, the bell tower is composed of a pointed roof, topped by a cross, this cross is topped by a weather vane, this weather vane has the shape of a rooster. The representation of a target involves containing elements such as context or space, and contained elements, such as characteristics, structuring elements.

Application to the autonomous car

The impact of actions, activity, experiences and context implies the possibility of proposing orders and information on the environment that adapt not only to the context, but also to the current action and experience. Wickens' (2002) multiple resource model allows different HMI options to be considered depending on the constraints that the vehicle would be able to detect. Most of the data would be processed by ALFRED and transmitted to the user would come from the different modules that manage driving (radars, lidar, gps...), comfort, dynamics, emotions, etc. Here are some possible solutions that could be considered depending on the actions, activity, experiences and context:

- For actions, the HMI could be adapted to the nature or purpose of the ongoing interaction. For example, the HMI could highlight different information if the user plans the route (entering the destination, taking information on traffic conditions, etc.), gives a driving order (e.g. order entry, information on the current process), or takes over driving (e.g. assists in taking information and offers appropriate incentives), etc.
- For the activity, the HMI could, for example, favour either sound information channels (non-verbal or verbal) when the user is reading or sleeping ; or visual information (e.g. flash, lights, spots) when talking face-to-face with another passenger
- For the experiment, the HMI would initially provide access to guidance and some parameters necessary for a novice or unfamiliar, and access to advanced parameters for the more experienced. Also, a user who is not used to taking control of the vehicle could benefit from additional support (taking information on the situation, using certain functions, etc.)
- For the context, one could imagine, for example, that when traffic is heavy, the vehicle has a system that allows users to understand the situation, and thus the vehicle's movements and a possible change of route. In certain situations (e. g. snow, heavy rain, degraded or absent pavement), the user could be invited to assist the vehicle by monitoring the road or by helping it with simplified controls.

6.2. Situational awarness

As mentioned in D3.1, mental representation is both an "image" (of an object, a procedure, etc.) and a process (a dynamic construction). Part of the mental representation is not accessible to the consciousness (e.g. stereotypes, heuristics). That is why we use the concept of Situational Awareness (SA) that is more practical to apply, especially to describe the driver's activity. Situational awareness is the permanent and necessary adaptation of the mental representation of the situation, and the understanding of the environment and the anticipation of changing situations (Tattegrain-Veste, Bellet, Pauzié, & Chapon, 1996). This construction is also based on the continuous knowledge of the driver available in long-term memory.

Cognitive functions and concepts associated with the acquisition of SA (perception, attention, cognitive resources, etc.) are describe in D3.1, but it is necessary to recall some elements here. The main element of SA that are summarized in the Endsley model (1998, 2012, cf. Figure 14). The model present 2 sets of determinants that impact the situation awareness, the decision and the performance of action.

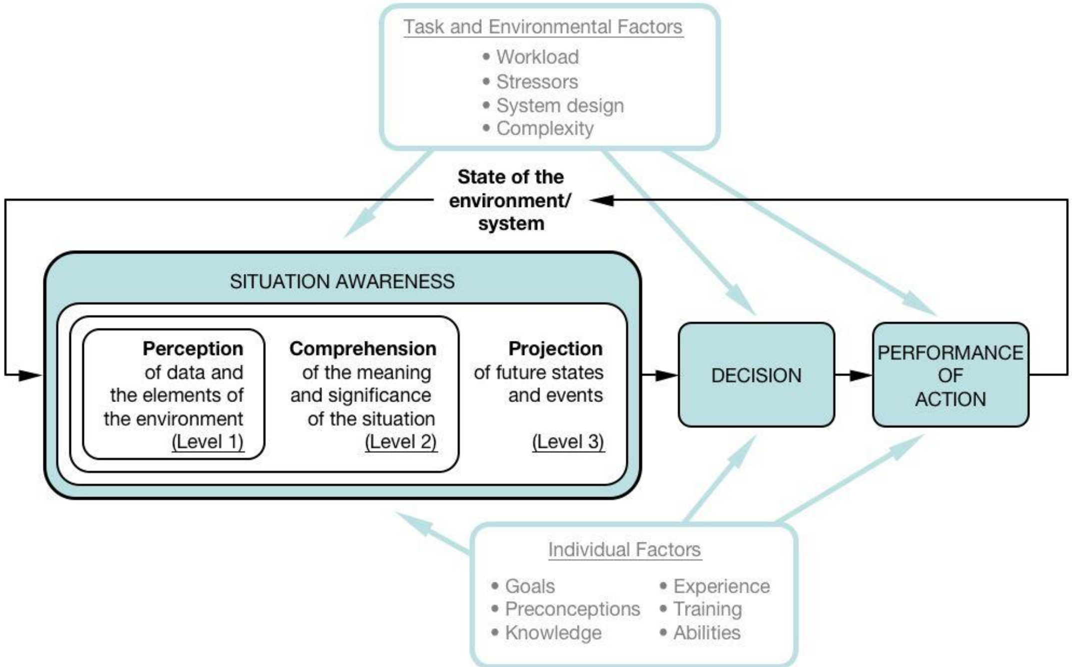


Figure 14: Situation Awareness Model

According to this model, the performance of the share corresponds to the desired end state. The performance of the action is mainly determined by the choices made by the driver. And the operation of these choices is mainly based on 3 levels of situational awareness:

- perception of the elements of the environment (level 1)
- understanding the meaning and meaning of the situation (level 2)
- projection of future state and events (level 3)

Each level can be impacted by several factors. Endsley describe 2 sets of factor that can impact each level, but also on decision and action performed:

- Task and environment factors (workload, stressor, system design, complexity)
- Individual factors (Goals, prisonizations, knowledge, experience, training, abilities)

So, the management of control between the autonomous car and his/her driver become important from a cognitive point of view also for the SA point of view. The transitions between different level of autonomous driving, and also the whole L4 driving have to take into account all the variables linked to the dynamics of cognitive control, where expertise, routines, and the environment play a big role in affecting the user action in a reactive or anticipatory terms (Hollnagel and Woods, 2005), because it will impact the level of SA and in particular its third level. For instance, when the driver begin to make experience of the autonomous driving he starts also to raise up his cognitive control level, detaching himself from the manual actions linked to the driving situation and leaving space (cognitive space) for more complex cognitive processes, in particular for long-term predictive reasoning, reaching the highest levels of situation awareness. This can turn in being a problem when the driver is requested to take back the control (e.g. for emergency situation) of the driving task, because the mentioned detachment could bring to higher response time, having to lower the cognitive level of information processing (Vicente & Rasmussen, 1988). The reactive/anticipatory capability of the interaction between the user and the events also depend on the temporal span in which the events occur: shorter is the temporal window more reactive is the answer of the user (Tanida & Poppel, 2006).

In a L4 perspective and taking into account all the possible transitions to lower levels, to call back the user control in case of an unexpected event it is necessary to take into account the SA needs in terms of expertise, time availability and specific HMI oriented to all the three levels of SA. In this sense, a predictive HMI, designed on the specific information (e.g. situational cues, scenarios dynamics forecasts) could help to handle the control transitions.

6.3. Trust

The system's ability to simulate and anticipate the driver mental representations will make it possible to provide assistance that optimizes situational awareness by adapting it to decision-making and action needs. However, the system must not only be reliable to assist a user, it must also create the confidence to be taken into account. Reliability is an important determinant of a user's trust in a system (Hegner, Beldad, and Brunswick 2019) or a third party (Karsenty 2015). However, users may have other reasons for not trusting a reliable vehicle, which may impact its acceptability. This chapter present the main factors of trust.

Karsenty (2015) defines trust as a form of voluntary dependence on a third party entity, resulting from a dynamic process, both social and psychological. In this sense, the author describes trust within a work team as the ability to delegate certain tasks to a third party. Trust is necessary to share a workload that would be complicated or impossible to handle alone. But the author particularly emphasizes the importance of trust in critical situations, such as the manifestation of a significant risk of failure or injury.

In other words, trust implies an expected effect on a situation (Lount 2010), which will be followed by a real effect. For example, when parking a vehicle, the driver can delegate part of his/her visual attention to a "parking radar" system and thus reinvest more attention on the sides of the vehicle. In this case, the expected effect could be a better placement and a faster maneuver. Given the commercial success of this option, the expected effect is probably often observed in reality. However, the level of trust may vary depending on the driver, situation or device, and may impact the final action. And an inappropriate level of trust can lead to underuse or worse, misuse of the device (Parasuraman and Riley 1997). For example, if the radar alerts on the proximity of an obstacle that is actually far away, taking into account the information does not allow the available space to be used correctly and the user is led to ignore the device. On the contrary, excessive confidence (e.g. Krausman, 2019; Kyriakidis et al. 2019) could encourage the driver to "save effort". In other words, a lesser effort would be the quality sought instead of the quality of the parking. In this case, the user may disinvest the situation, and not be able to manage a hazard, such as the occurrence of a distracted pedestrian.

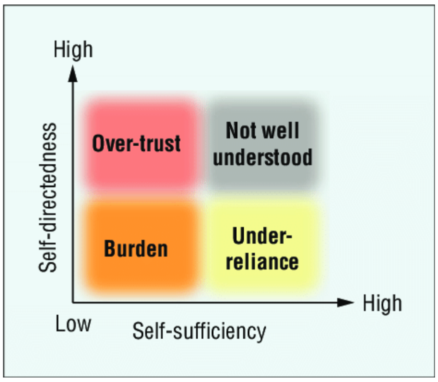


Figure 15: Challenges faced by designers of autonomous machine capabilities(Bradshaw et al. 2013; adapted from Johnson et al. 2012)

Researchers in psychology and sociology often consider trust as one of the most valued qualities in any close relationship. For Liu, Yang, and Xu (2018) about technologies, trust predicts acceptability, i.e. a positive attitude towards the target. To offer this type of relationship, a driver assistance system must therefore offer an appropriate level of trust, especially since there is generally a certain distrust of algorithms (Önkal, Gönül, and De Baets 2019). This level of trust must be consistent with the tasks it is able to accomplish, particularly with regard to critical situations that it helps anticipate/avoid or manage. Therefore, the quality of a steering aid system is optimal if it is highly reliable, but also if it is subject to an appropriate level of confidence. For this reason, the main determinants of trust can be taken into account when designing and evaluating these technologies.

6.3.1. Determinants of trust

There is an abundant literature on trust. This bibliographical study is not exhaustive in view of the many sources available. Hoff and Bashir's (2014) model incorporates the main concepts that are generally proposed. This model takes up, for example, the idea of trust before and after the interaction, with an update based on the performance of the system.

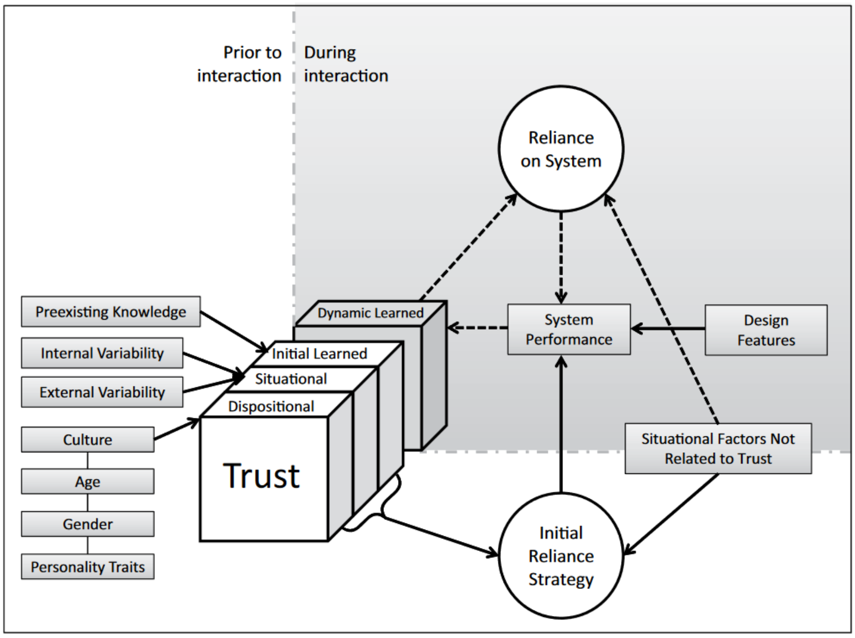


Figure 16: Full model of factors that influence trust in automation. The dotted arrows represent factors that can change within the course of a single interaction (Hoff and Bashir 2014)

The determinants of trust will be addressed from the point of view of both parties involved: the operator (*Dispositional*), i.e. the one who trusts or not, and the target (*initial lerned*), i.e. the one in whom/which the operator trusts or not. The description of the determinants of trust here focuses on the two main targets that can be questioned in SUaaVE project: the human*, the trustor* (e.g. users, society, etc.) and the technology, *the trustee* (e.g. instruments, automatisms, etc.).

6.3.2. On the side of the Trustor

Regardless of the operational qualities of the object, the trust attributed by the operator (trustor) is impacted by various factors of social, psychological or cognitive origin.

From a social point of view

A first factor of confidence is the status of the target (trustee) in relation to the situation (e.g. Liu, Yang, and Xu 2019). This factor is a prerequisite for interaction and is strongly rooted in heuristics processing (Alvarado-Valencia and Barrero 2014). This is the case, for example, of prejudices (stereotypes): a resident could show greater trust in a man that ringing the doorbell if he is dressed in firefighter than dressed in punk clothes. Regardless of stereotypes, the culture to which the trustor belongs can also have an impact. The level of pre-interaction trust is higher in some cultures than in others (Lee & See, 2004). This may concern the cultural context of a people, but also of a company or any other social organization.

Another social and pre-interaction factor is the sharing of common goals. According to Verberne, Ham and Midden (2015), the level of trust is higher when the target shares a goal identical or close to that of the trustor. This notion is consistent with team spirit, in which trust is attributed prior to any judgment on performance, based on a sense of belonging to the same social group. Close to team spirit, physical similarity is also a factor of trust. Verberne et al (2015) manipulated this purely social effect on trust, but towards a virtual assistant. Using a morphing tool, this wizard could look like the user or not. Two key results of the researchers are: (1) participants respond in a similar way to the VA (Virtual Assistant) and a human; and (2) the confidence in a similar VA is higher than that in a non-resembling VA.

From a psychological point of view

Different psychological profiles or feelings of a person have a potential impact on the trust they can attribute. According to Rotter (1971), each person's personal history determines an ease or difficulty in trusting. This predisposition to trust is independent of the object itself. By considering a lower level of representation, it could potentially be linked to a category, such as technology, politicians, firefighters, etc. Other psychological determinants can be considered, such as the emotional bond (McAllister 1995) that would have a positive impact on trust.

Close to the affects, stress leads to a heuristic treatment of the situation. In such a situation, the quality of trust is essential to make the right decisions. If the mental states felt by the operator as a whole potentially determine his/her confidence, those displayed by the target are also a determiner discussed in the literature. The following section describes the perceived characteristics of the target that impact the confidence formulated by the operator.

6.3.3. On the side of the trustee

Regardless of the trustor's social or psychological situation, the trust he/she allocates to a target is strongly impacted by the representation he/she has of it. More precisely, the representation that can be made of the future state of the situation, with regard to the current state and the entities (human, technological) involved in the activity. McAlister (1995) refers to "cognitive trust", which he distinguishes from the "emotional trust" presented above. Cognitive trust involves the trustor's knowledge of the target, particularly in terms of competence and reliability.

According to Lee and See (2004, citing Mayer et al., 1995), the precursors of trust (on trustee side) are…

"ability, integrity, and benevolence. *Ability* is the group of skills, competencies, and characteristics that enable the trustee to influence the domain. *Integrity* is the degree to which the trustee adheres to a set of principles the trustor finds acceptable. *Benevolence* is the extent to which the intents and motivations of the trustee are aligned with those of the trustor".

Capacity is often involved in the status of the trustee, in relation to that of the trustor. This status may involve "theoretical competence". This is the case, for example, of institutions, which are by definition, theoretically trustworthy (e.g. Shapiro 1987). In this sense, a patient who goes to the hospital is predisposed to trust this institution, even if he/she has never been there. This trust is consistent with the principle of voluntary dependence described by Karsenty (2015). This principle governs different situations in which a person relies on a target designated as competent by status or qualification (doctor, plumber, firefighter, hairdresser, etc.) to treat a given problem.

The consultation of an expert initially involves a prediction of the future state, by the trustor (the claimant), then this prediction is readjusted by the trustee (the expert). Trust is then based on the ability to formulate a consensual, coherent, precise and meaningful future state (e.g. (Weick 1995).

But trust is not always fully granted in the first instance. Trustor generally needs to rely on a first experience that is not very engaging, or on the feedback from others (reputation, recommendations, external image, etc.). According to Shockley-Zalabak, Morreale and Hackman (2010), the perceived experience of the target allows it to be categorized into 5 dimensions essential to trust:

- concern for the other
- sharing values and
- sharing beliefs with the other
- openness and honesty
- reliability and ability

In other words, these dimensions concern operational qualities (utility), related to the execution of the task, and human qualities related to social desirability (Cambon 2006).

Following an initial experiment, the trustor is able to refine his/her representation of the trustee. In addition to the quality of the target representation, the trustor is able to see the differences between the initial projection of the end state achieved through the target and the actual end state. However, when the end state is very different from the desired state, the operator may renew his/her confidence provided that the deviations are justified and/or understood (Nooteboom and Six 2003).

The explicability of the results is a guarantee of renewed trust for a subsequent interaction, but explicability during the interaction may also be a prerequisite. To maintain confidence in a target, the trustor sometimes needs explanations when the actions performed differ from the action plans he/she had anticipated. In other words, the Meaning construction described above impacts confidence before the action to make the prediction, and after the action to explain the gaps, but also during the action to understand the new data (G. Klein et al. 2007) and readjust the predictions. To illustrate this dynamic process of trust during the action, it is possible to use the study by Cheshin et al., (2018). In this study, participants were in a fictitious situation of buying a phone with a seller who displayed emotions whose intensity and valence were appropriate or not to the situation (e.g. the desired phone is not available). In this situation, we can assume that a customer has a positive a priori confidence in the brand. But the authors observed that trust is impacted by an inappropriate emotion displayed by the seller. This observation is in line with the concept of action plans, which makes it possible to predict behavior. And the evaluation of a situation is based on the differences between the predicted actions and the observed actions (Château 2015).

Trust is a process that evolves between initial expectations and the final result. Beyond the simple gap between prediction and observation, we have just seen that this dynamic is at work during the target's activity, especially when the operator and the target are in continuous interaction. When the target is human, the operator can rely on behavioral cues (emotions, gestures, procedures at work...). But when the target is technological, the processes are often hidden under an envelope (box, bodywork...) or behind an interface. Many authors in the field of design (e.g. Norman 2004) or ergonomics (e.g. Bastien and Scapin 1993) insist on the notions of transparency or explicability in the design of complex systems, to make them easier to use and better accepted. In recent news, the opacity of technologies has led the United States to ban certain Chinese network technologies that have a potential spy capability. This event illustrates the effect of transparency, or the possibility of explaining how things work, on the trust placed in a technology. In a philosophical approach, Krausman (2019) emphasizes the importance of sharing information and perspectives to support trust. This approach is theoretically supported in the previous section on mental representation. According to Krausman (2019), this sharing involves sharing feedback on current actions and objectives on the one hand, but also explicit sharing of uncertainties and problems of understanding, dialogue or data processing on the other. Communication must be both verbal and non-verbal. In particular, a constant communication makes it possible to confirm or update the planned action models, and thus to carry out more efficient monitoring. In this case, a detailed inspection is only necessary in the event of a significant difference between the predicted and actual actions.

6.4. Cognitive model

6.4.1. Purpose of the model

The purpose of this model is to determine when the driver is likely to have a poor situational awareness. We propose a model that determines the conditions in which the elaboration of situational awareness is altered. This will allow the interface to be adapted to deal with or anticipate problematic situations.

6.4.2. Situation awareness in the model

The consctution of the model weel be proced based on the understanding of the cognitive needs and capacity on the situation. This need Will be studied in the task T3.3 with an evaluation in several situation.

There are several tools to measure situational awareness: SAGAT (Endsley, 1988), SART (Selcon & Taylor, 1990), SPAM (Durso et al., 1998)... These tools are not usable in real time: a posteriori questionnaire, self-confrontation interviews, freezing of the action (possible only in simulator). Measuring, analysing a driver's situational awareness in real time in a real driving context is currently impossible. On the other hand, the identification and measurement of the different factors influencing this situational awareness makes it possible to deduce the potentiality of obtaining a good/bad situational awareness. We will not measure situational awareness in real time we infer according to the factors influencing this situational awareness.

For example, the first step in obtaining situational awareness is the driver's perception of the environment. The correct functioning of this perception is a prerequisite for the acquisition of a correct situational awareness. From the literature, we know that many factors influence this perception.

For this reason, we select observable, measurable factors that can be used to infer on the driver's situational awareness.

6.4.3. Concept selection: cognitive components and variables

The cognitive state of a subject is estimated with several concepts: cognitive resources, cognitive load, expertise in the task, attention, alertness, fatigue, situational awareness... We must estimate the driver's cognitive state in real time so that we can react immediately if necessary, and in a non-invasive. These constraints limited the selection of concepts. From the literature we have selected 11 cognitive components and associated variables: **engagement** (Witmer & Singer, 1998), **cognitive resource availability** (Brusque et al., 2011), **vigilance** (Coenen, 1998), **cognitive fatigue** (Marcora, Staiano, & Manning, 2009), **cognitive load** (Cegarra & Chevalier, 2008), **task control level** (Tattegrain-Veste et al., 1996), **driver expertise** (Leplat, 1995), **stress** (Selye, 1955), **anxiety** (Eysenck et al., 2007), **distractions** (nature and appearance time) (Shaffer & Shiffrin, 1972), **inter-individual differences** (Brusque et al., 2011).

Engagement : Engagement is a psychological state. It is the consequence of focusing one's energy and attention on a coherent set of stimuli and related events. Engagement depends on the degree of importance or significance that the person attaches to stimuli and events (Witmer & Singer, 1998). We will not be what kind of attention the engagement implies because the tasks performed can be more or less automatic. Nevertheless, engagement appears to be a good measure to reflect attention in the driving task.

Cognitive resource availability : These cognitive resources are processing resources for a set of tasks. Not all activities require the same quantity of cognitive resources. Humans have a limited reserve of available "capacity". There is a limit to a subject's general capacity to perform mental activities (Kahneman, 1973). These resources are invested in more or less large quantities. This quantity of available resources is determined by the level of activation (vigilance level). If the subject's activation level is not sufficient then few or no resources can be allocated to the task. According to the activity, the subject's intentions, the expected amount of resources needed, and the available resources, a quantity of resources is attributed to the task.

Vigilance : The level of activation of an individual is influenced by (Brusque et al., 2011) the vigilance. Vigilance is the state of alertness of the organism, modified by the sleep-wake rhythm. It can be reduced when an individual lacks sleep (night driving) or suffers from sleep disorders. Vigilance can also decrease in monotonous driving situations: the feedback loop that increases the level of vigilance no longer has any information to process.

Cognitive fatigue : The level of activation of an individual is influenced by (Brusque et al., 2011) the cognitive fatigue. This notion is linked to the depletion of cognitive resources. A driver may have resources at the beginning of a journey, but these resources can decrease quickly in the context of a busy road (McCartt, Ribner, Pack, & Hammer, 1996) . Cognitive fatigue causes changes in selective attention: alterations in the suppression of irrelevant stimuli (Faber, Maurits, & Lorist, 2012). Thus, the driver must treat more information and therefore use more cognitive resources.

Inter-individual differences : It is important to consider inter-individual differences in the available resources: this depends on the individual's brain condition. Indeed, the double task is more difficult in the older population and even more so for people with certain neurological diseases (Brusque et al., 2011).

Cognitive load / Mental load / Workload : These types of loads represent at least the relationship between the demand for the task and the available resources (Cegarra & Chevalier, 2008). In some situations, an increase in the workload associated with the task would increase activation and allow more resources to be made available (Navon & Gopher, 1980). Cognitive load theory allows us to consider the investment of cognitive resources (Puma, 2016). To engage in a task involving a more or less important cognitive load is costly in cognitive resources. During a driving task, a driver must continuously and safely control the vehicle in a dynamic environment. Therefore, it is essential to assess changes in drivers' mental load during the driving task.

Level of task control : Identifying the process used to perform the task allows us to deduce on the use of cognitive resources. Some cognitive processes are "automatic" and consume very few resources, while others are called "controlled" and require a lot of resources (Posner, Snyder, & Solso, 1975). If the driver performs a task requiring a controlled process, attentional control then we will assume that he already uses cognitive and attention resources (Schneider, Dumais, & Shiffrin, 1982).

Level of expertise in driving : Experts can maintain more activated information for longer than novices (Cowan, 2014). This improved robustness of working memory traces in the event of a time decline allows experts to start processing a task, stop and resume it with less difficulty than novices.

Stress : Stress has been found to affect performance and attention and memory (McEwen & Sapolsky, 1995), and to contribute to an increase in human error and accidents. In general, stress affects the perception and processing of information and the decisions we make, resulting in an increase in the number of errors and mistakes.

Anxiety : Anxiety increases the subject's mental workload (Eysenck, Derakshan, Santos, & Calvo, 2007). Indeed, it degrades the functions of executive control of working memory, which is involved in attentional control. It alters the attentional filter process that tries to filter irrelevant information. It also alters the change function allowing the flexibility of attentional control to remain focused on the important stimulus. Therefore, the subject is subject to task interference: anxiety can produce an attentional bias that causes the individual to change his or her initial focus to the task, directing it to the external (distractors) or internal (worries) threatening stimuli (Eysenck et al., 2007). His mental load is therefore increased. Anxiety particularly affects performance when the task requires attention (Derakshan & Eysenck, 2009).

Distractions : A distraction, when added to the main driving activity, steals cognitive resources from the main task (Bailly, 2004). So it is important to identify them in order to estimate the availability of cognitive resources.

The majority of these cognitive and variable components are measurable in real time or can be estimated : calculated directly with physiological and behavioral variables, as well as with quantitative variables such as age or driving time. The cognitive component "availability of cognitive resources" is estimated indirectly: it is defined by the cognitive components "vigilance" and "fatigue".

The state of each component, the variables and their interactions allow us to determine if the development of situational awareness is altered. They represent the internal and external factors influencing the cognitive state of the driver. The state of this situational awareness combined with the cognitive components that define the cognitive state of the driver. In order to model this cognitive state according to these factors, it is necessary to analyze them. This will allow us to understand all interactions: interactions between the concept and cognitive resources, interaction between concepts. This analysis requires for each concept a definition of the concept, a definition of the different states of this concept, an identification of all the factors influencing it and its modeling. This work is reflected in Task 3.3.

6.4.4. Estimation of the cognitive components and variables of the model

Take the engagement component, for example. To estimate it, the model requires two behavioural variables observed in real time: the frequency of the fixation of the zones of interest of the driving, and the dispersion of the gaze in these zones. These observations compare with the baseline values. These basic values are stored in the driver profile. A statistical comparison is used to determine the significant difference between the visual behaviour of engagement in the driving task and the current visual behaviour. If the difference is not significant the driver is engaged in the driving task. If the difference is significant the driver is not engaged in the driving task. If he is not, when the situation requires it, ALFRED will modify its interactions to try to fix it. The recommendations are not yet in the model. They will be found in the deliverable of task 3.3. The frequency of updating the calculation of the cognitive components of the model will be found in task T3.3.

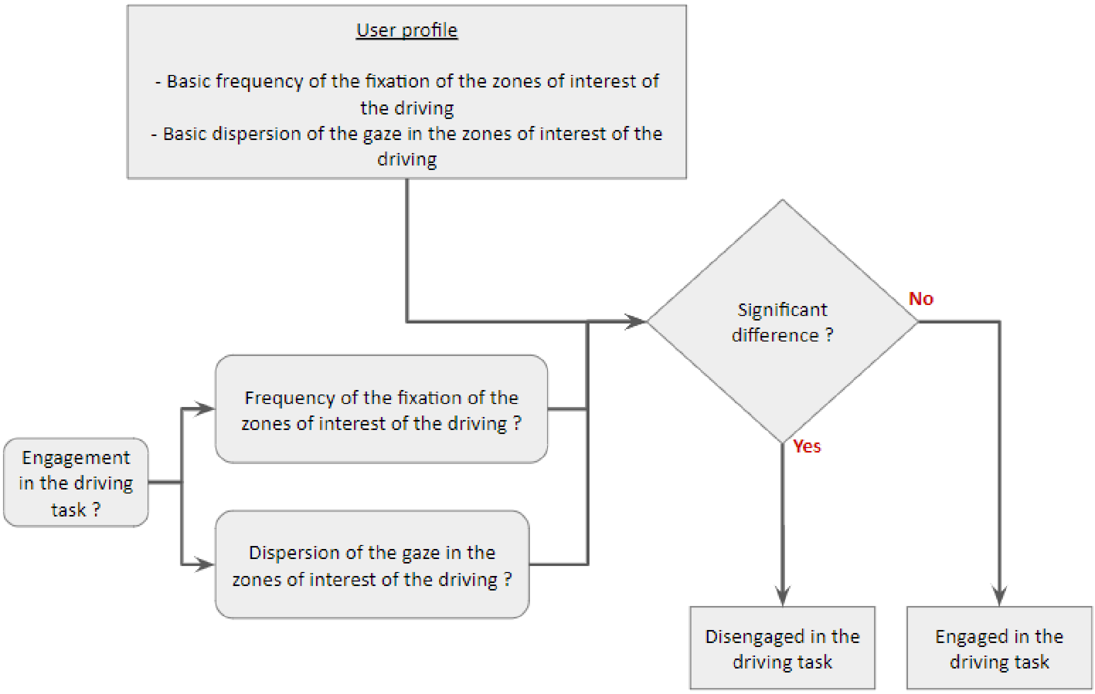


Figure 17: Estimate of the engagement in the driving tack

6.4.5. Estimate of the driver's cognitive state

Once all the cognitive components have been calculated, a graph will be used to define if the driver is in good condition to have a good situational awareness. For example, this is the first version of the model that concludes on the cognitive state of the driver as he sits in the car. This state is not related to any event in the car, it is the driver's basic state before the journey.

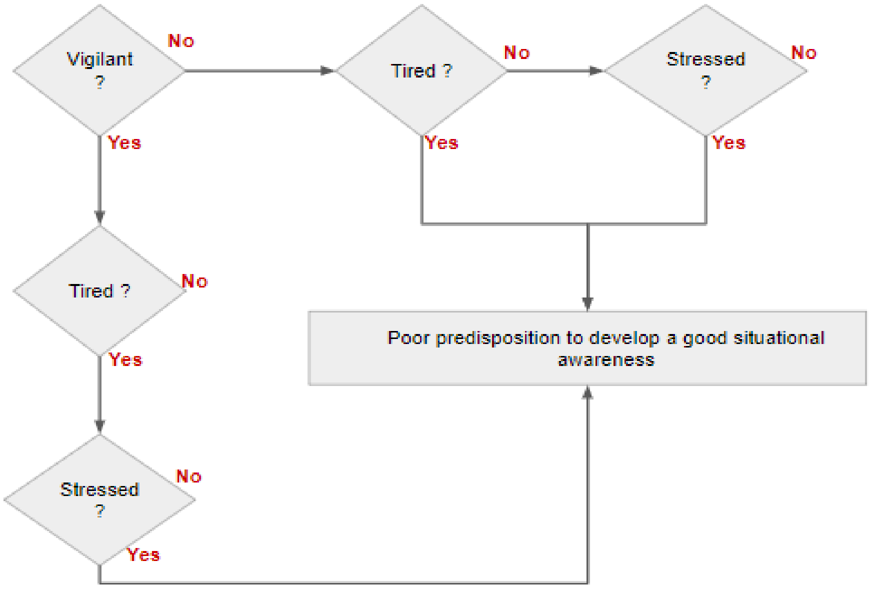


Figure 18: Estimate of the driver's initial condition when he gets into the car

The literature describes methods for stress regulation (Peressutti, Martín-González, García-Manso, & Mesa, 2010; Rennie et al., 2003), cognitive load (Vicente & Rasmussen, 1992), vigilance (Jewett & Kronauer, 1999). All methods were studied independently : the study of combinations or merging of several methods was not made. This is why we assume that an altered cognitive component can be regulated, but more than one component, the regulation of the driver's cognitive state is compromised. This is why we consider that two altered cognitive components lead to a poor predisposition to develop a good situational awareness.

The passenger's cognitive state measured by the car and the cognitive components must be updated regularly, especially during the journey.

6.4.6. Anticipation of the driver's cognitive state

This model is also used to input potential events occurring in the very near future. Potential events combined with the driver's current cognitive state can estimate the potential cognitive state resulting from these events. So ALFRED can anticipate the needs of the driver in order to improve the cognitive state of the future driver.

6.4.7. Anticipation of the driver's cognitive state

ALFRED will be able to activate a cognitive model that is analogous to the user's actual cognitive state. When the context and state of the driver generates a poor condition for the development of situational awareness then ALFRED must activate a set of actions according to the cognitive state of the driver: it will be found in task T3.3.

7. Emotion Tracking

7.1. Definition of emotions

An emotion is a very complex concept to define, the existence of a wide variety of emotion theories is caused by the fact that there are many ways to assume the components of emotions. An emotion implies a cognitive process, some kind of physiological response, motor expression, an impact or an influence of motivation, and a subjective feeling. How to deal with the quantification of these components and its weight in the emotional state as well as in the process from one state to another is the challenge of the authors who build the theories. There are multiple phases in the process of the elicitation of an emotion, such as low-level or high-level evaluation, the prioritization of goals or the needs, the examination of alternatives of an action, behaviour preparation, behaviour execution or communication and social sharing. Basing on the dimensions compounded by components and phases, there are main "families" of theories collected and classified on Figure 19 (Scherer, Bänziger, & Roesch, 2010).

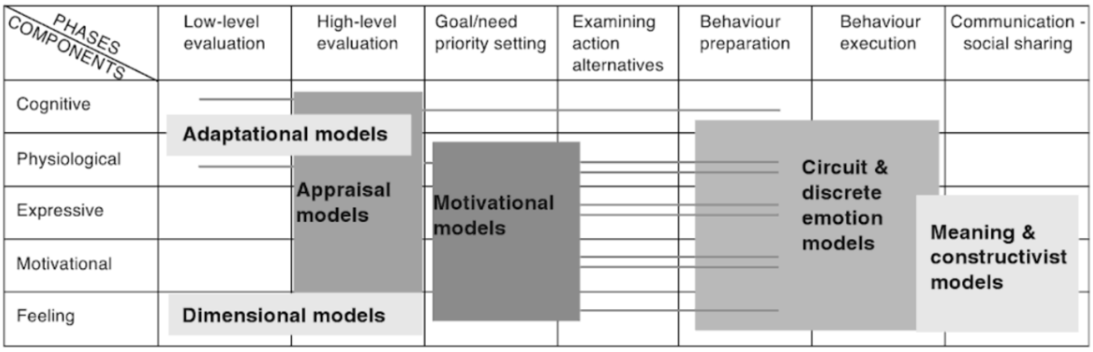


Figure 19. Families of emotions in relation with the phases and components focus

This project undertakes the emotion problem focusing on two of the "families" of models that are mapped in Figure 19. The justification relies on the possibilities that offers approaching a problem from very opposed directions. This allows a study to draw more robust results because the conclusions of one can be validate when resulting consistent with the conclusions from the other. The methods that will be developed in SUaaVE lean on the philosophy of the **appraisal** and the **dimensional models**.

The **appraisal theories** treat the emotions as the result of the cognitive evaluation of situations and events that the person experiences. These theories consider that the characteristics of the reactions to situations are derived from the results of their evaluation process. This psychological perspective on emotion is the most suitable source for those interested in the design of systems involving human-computer interaction.

It emphasises and explains the connection between emotion and cognition. Emotion is related to the individual judgement concerning the relationship between events and individual beliefs. The work of some of these theories focusses on the structure created by appraisal variables and the labelled emotions, the so-called **categorical appraisal theories**. It might be possible that the same situation could elicit many appraisals and it is still very difficult to theorize about hoy every appraisal combines to define a general state.

The appraisal theories use the appraisal variables that consist of a set of estimators that the agent can use to assess different emotional responses. The variables are generated as a result of an appraisal-derivation model, that builds a representation of the person using a set of variables. For instance, if the goal of an individual is about to be facilitated by an event, the model must describe the degree of the desirability, the likeliness and how the individual confronts it. Different appraisal models adopt different sets of appraisal variables and some of the most adopted variables will be discussed in following sections.

While the **appraisal theories** focus mainly on the link between the elicitation of the emotion with the characteristics of the response, the dimensional theories try to find the measurable parameters of the response that define different states of the individual. Both theories are not opposed, there are **dimensional appraisal theories**, which do oppose to the **categorical appraisal theories** mentioned before, which try to label discrete emotions.

For their part, the dimensional facet of a theory puts the effort in studying the differentiation of emotions by their location on the bidimensional space created by the pleasantness-unpleasantness (**valence**) and by the activation (**arousal**). The variation among emotions is continuous and goes from negative to positive in the case of the valence, and from passive to active in the case of the arousal. It is a very convenient for the easiness to capture arousal and valence, but there is still a lot to explore in the verbal labelling that rely with the arousal-valence map.

As a summary:

SUaaVE approach of emotions will be carried out through two different methods that will complement and validate each other:

A. **Categorical appraisal method**: The methodology developed is based on the OCC model (Colby, Ortony, Clore, & Collins, 1989)
B. **Dimensional appraisal method**: The methodology is carried out using physiological signals measurements

A. Categorical appraisal method: OCC model

The OCC model develops a convincing cognitive structure of emotions in terms of the eliciting conditions of emotions and the variables of their intensities. The authors elaborate a systematic description of the cognitive generation of emotions and it is quite popular among researchers building systems that try to understand an individual emotion and its interaction with an artificial character. For this reason, the model served as a basis in the challenge of creating an empathic module in the autonomous car that could detect, anticipate and provide answers and recovery strategies for the emotional state of the passenger.

The present methodology pursuits to build a construct about reactions to events, agents, their beliefs and actions and objects that will draw a complete list of emotions. To each of the elements, namely events, agents and objects, there is a different kind of reaction, pleased vs displeased, approving vs disapproving and liking vs disliking, respectively. Those 6 global reactions are the ones that are differentiated in more specific reactions that will be the ones defined as “emotions” (Colby et al., 1989).

The appraisal is based on three **central variables**: desirability, praiseworthiness and appealingness, applying respectively to events, agents and objects. The **desirability** is assessed in terms of the complex **goal** structure, and concretely a focal goal which is the one interpreting the event. So, it depends on in which way the event is facilitating or obstructs the goal. The same way, the **praiseworthiness** is evaluated as the judgement of an agent’s action in the framework of the individual **norms** and standards, and how it is judged good or wrong. In the case of the **appealingness**, it depends on ones’ **attitudes**, in the sense of his or her preferences or likings. The intensity of the emotions is defined by **local variables** and by **global variables.** The **global variables** affect to all groups of emotions and tells the degree of intensity of the experience. The local variables affect to specific groups of emotions

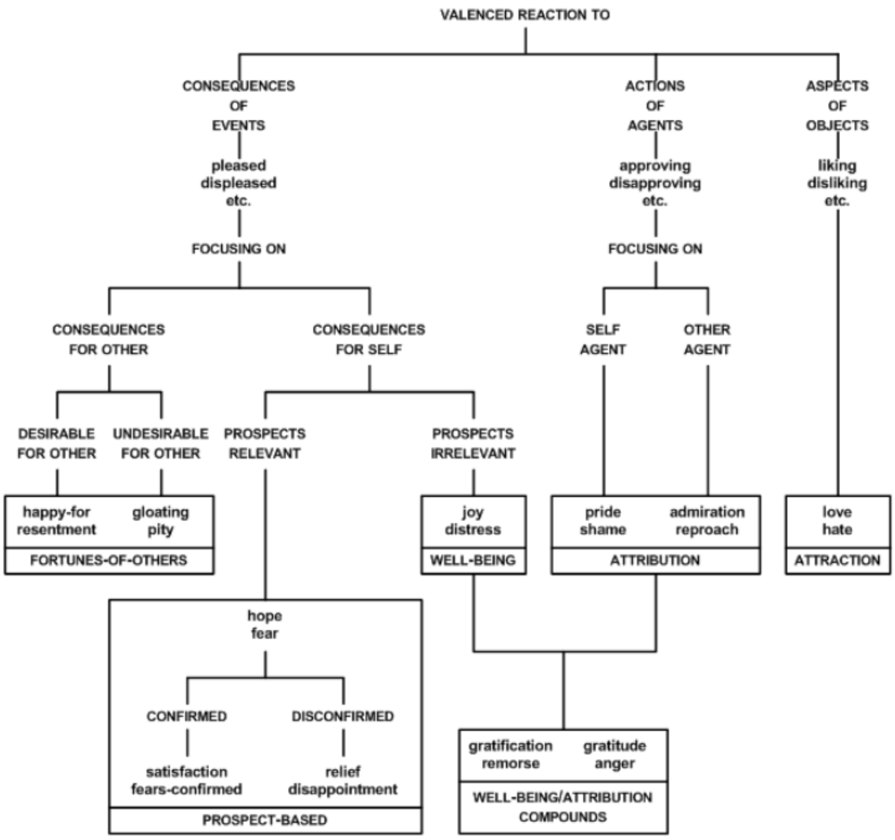


Figure 20. Classification of the 22 emotions in the OCC model.

From the definition of the three elements: events, agents and objects; and the three groups of variables: central, global and local. The authors of the model defined 22 emotions written as follows (Table 2. Definition of the 22 emotionsTable 2):

Joy	(pleased about) a desirable event
Distress	(displeased about) an undesirable event
Happy-for	(pleased about) an event presumed to be desirable for someone else
Pity	(displeased about) an event presumed to be undesirable for someone else
Gloating	(pleased about) an event presumed to be undesirable for someone else
Resentment	(displeased about) an event presumed to be desirable for someone else
Hope	(pleased about) the prospect of a desirable event
Fear	(displeased about) the prospect of an undesirable event

Satisfaction	(pleased about) the confirmation of the prospect of a desirable event
Fears-confirmed	(displeased about) the confirmation of the prospect of an undesirable event
Relief	(pleased about) the disconfirmation of the prospect of an undesirable event
Disappointment	(displeased about) the disconfirmation of the prospect of a desirable event
Pride	(approving of) one's own praiseworthy action
Shame	(disapproving of) one's own blameworthy action
Admiration	(approving of) someone else's praiseworthy action
Reproach	(disapproving of) someone else's blameworthy action
Gratification	(approving of) one's own praiseworthy action and (being pleased about) the related desirable event
Remorse	(disapproving of) one's own blameworthy action and (being displeased about) the related undesirable event
Gratitude	(approving of) someone else's praiseworthy action and (being pleased about) the related desirable event
Anger	(disapproving of) someone else's blameworthy action and (being displeased about) the related undesirable event
Love	(liking) an appealing object
Hate	(disliking) an unappealing object

Table 2. Definition of the 22 emotions

In the first loop of the project and after a first experience with 50 users, the emotions have been prioritized and the focus will be in 13 of the 22 emotions. The emotions relating to aspect of objects and actions of others are removed from the objectives. The ones that catch the interest of the project are the emotions that are a consequence of an event.

B. Dimensional model

The dimensional model is based on the measurement of physiological signals and it is developed in the later section 5.5.4

7.2. Emotions on the road

The study of emotions in drivers has great relevance for many concerns. Heretofore, it has been researched mainly for its influence in the driving behaviour that could potentially produce traffic accidents. As reviewed in the previous subsection, there are multiple ways to structure the emotions and to deal with them. And so, one can find in literature approaches of emotions in driving that are founded in the theory of the author's choice.

Some authors (Roidl, Frehse, Oehl, & Höger, 2013) applied two different versions of the Geneva Emotion Wheel (GEW) that is made up of 16 emotions, being controllability and valence the dimensions. They developed experimentation with users in which they were shown traffic scenarios and they had to assess by means of an online-questionnaire. As see in Figure 21, the design of the situations assessed depends on the goal blocking/goal promoting situations, classified depending if persons or circumstances are the causal and the relevance. The users could choose three most relevant emotions of the GEW and its intensity.

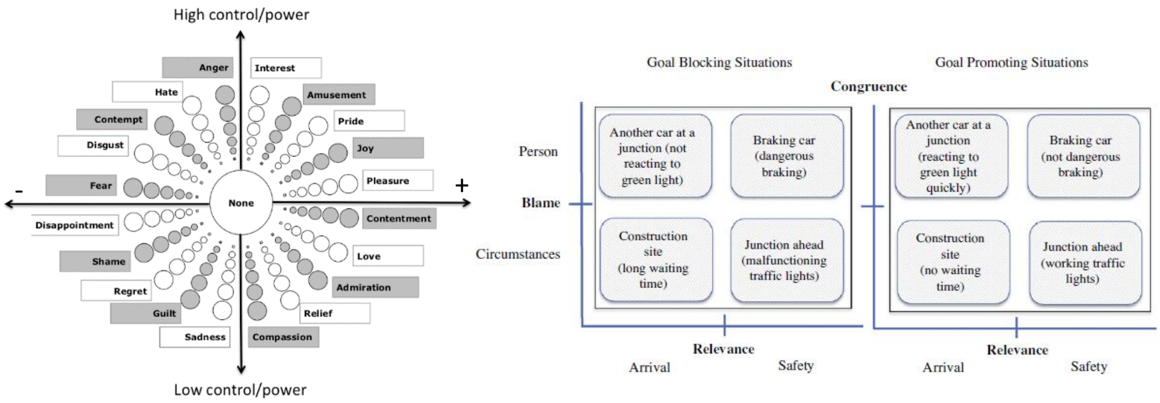


Figure 21. Geneva Emotion Wheel and factors to classify emotions

The conclusions the authors drawn were that the emotions are influenced by traffic situations' factors goal blocking/promoting and also by the blame. Anger, anxiety, hope and relief are influenced by situational factors, and pride, guilt and shame are associated to the situational characteristics' appraisal. The authors do not have a clear answer to what the implications for the driving behaviour are, and point the importance of continue the research to respond these questions.

In the work of Mesken et al. (Mesken, Hagenzieker, Rothengatter, & de Waard, 2007), with the objective of determining the frequency, factors and consequences in the driver's emotions, they focused on three emotions in traffic: anger, anxiety and happiness. In this case, they conducted their study using the principles of an appraisal theory, and used the variables of goal congruence, blame and threat. In their experimentation the users first filled a questionnaire with personality and other variables. Then, they drove a car while instrumented (HR variability) and the speed was tracked. The users reported verbally the scoring of emotions and risk, while a camera recorded the traffic situation. Some of the conclusions were that the emotions felt are related with personality characteristics and with traffic events. Anger is related with pass blocking situations and anxiety with lose of safety, and only anxiety is associated with increased heart rate. Also, the anger is more reported by people who exceed the speed limit more often. So, for the SUaaVE point of view it is drawn that the test of personality is a must when developing experimentations to study the emotions.

The use of driving simulator is of great interest for the present project and this technique has been employed in other investigation studies concerning the detection of emotion in driving. There is a study (Cai, Lin, & Mourant, 2007), where the proposal was a multiple, in particular three, participant-operated simulators that could communicate to each other in order to investigate the effects of the driver-driver interaction in realistic scenarios. Through this experimentation they aimed to investigate the emotional behaviour, focusing on three states: anger, neutral and excitation. The methods used to collect information were physiological signals and eye motion data. The analysis of data is perform using the valence-arousal model (Russell, 1980).

The studies reviewed involve driving and although our problematic has some points in common, the approach is completely different. In our case, the emotions might not be the ones previously assessed as: fear, anger or happiness/joy, due to the fact that the case of being the passenger of a car you do not control, can open a different variety of emotions to observe. That is why the starting point of SUaaVE is user-centered and the discrimination of emotions is done through feedback obtained from real future users through experimentation and analysis.

The question is "which emotions are relevant in the challenge of the autonomous car?" For answering this question, a first experimentation is developed. On the basis of the 22 emotions proposed by Clore et al. (Colby et al., 1989), a survey has been designed and performed in Spain and Italy (first stage), and Spain and Germany (second stage). Only with the first stage of the experimentation, nearly 1,000 description of experiences in driving have been collected, around 50 for each emotion. By means of a Latent Semantic Analysis (LSA), conclusions have been drawn to prioritize and describe the relevant emotions and their associated events and scenarios (Figure 22).

Figure 22. Process scheme of emotions in driving modelling in SUaaVE

The whole description of the framework experimentation is included in Deliverable 3.1.

7.3. Emotion monitoring

The same way the theoretical introduction described, the emotion problem is approached through two different perspectives. In the same way, the emotion monitoring is carried out through different methodologies that can be grouped as follows:

A. **Prediction through events: categorization of emotions**
B. **Measurements through physiological signals: obtention of valence and arousal**

A. Prediction through events: categorization of emotions

Basing the design in the numerous works found in literature (Scherer et al., 2010; Trabelsi & Frasson, 2010) about emotion computing, an algorithm is developed with the purpose of predict an emotion departing from the information got from the environment and from the user personality and learn from the decision either it is correct or not. The idea is to train the algorithm through the experimentation in order to create a vast enough database to achieve predictions with considerably good accuracy. In the Figure 23 it is presented a scheme of the different elements of the algorithm. In the algorithm it is included the box of "decision making" that will also consider information from other modules such as the cognitive module.

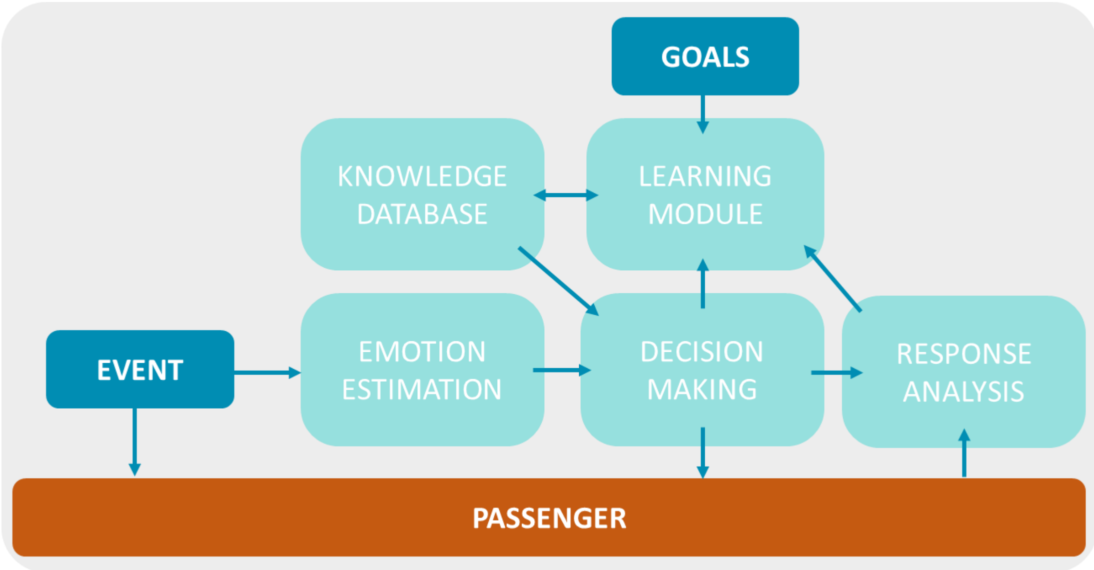


Figure 23. Process template of the event – emotion estimation – learning algorithm

The arrow that connects the passenger with the response analysis concerns the physiological response, together with the information captured through cameras. That information will help to validate if the decision made based on the actual event and the knowledge database is correct or not. And that will feed the learning module to strengthen the algorithm capability to predict.

B. Measurements through physiological signals: obtention of valence and arousal

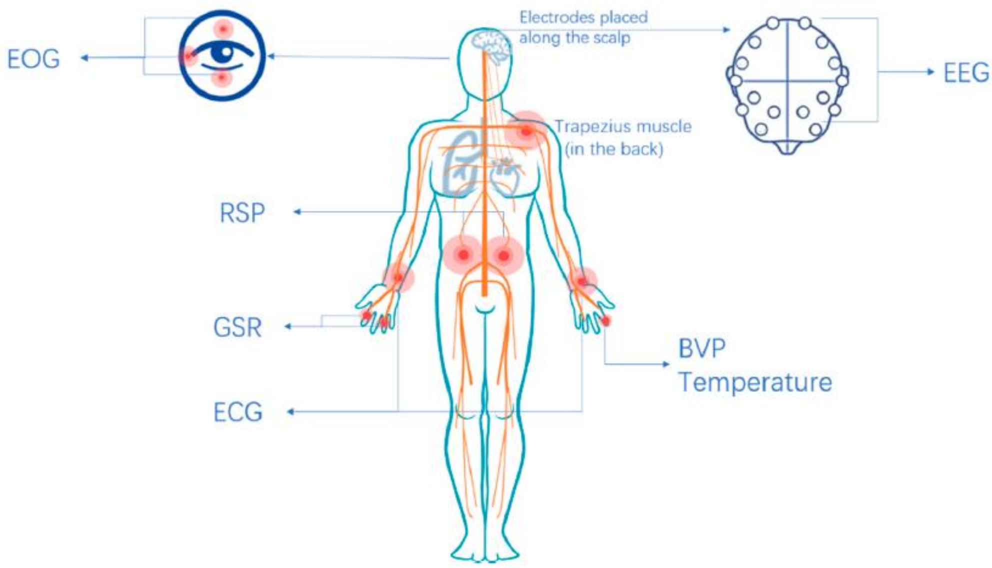


Figure 24. Scheme of the human body with the zones from where the different physiological signals are the measured for the emotion detection.

Focusing in the multi-dimensional, and concretely in the Valence-Arousal bi-dimensional model, in the literature it is possible to review the technology and methodologies to detect the emotional state measuring physiological signals. Emotion detection is a hot topic and it can be applied to many areas like safe driving among others. In Figure 24 it is shown the different signals that is being measured by many authors, subsequently processed and extracted the relevant properties from which the emotion can be detected with a certain percentage of accuracy.

As a point of departure, the table elaborated by the authors Shu et al. (Shu et al., 2018) indicate the factors studied by authors in order to assess certain number emotions. In the case of SUaaVE, the EEG will not be measured, and will focus in the measurement and analysis of cardiovascular signals, electrodermal and respiratory (Table 3).

	Anger	Anxiety	Embarrassment	Fear	Amusement	Happiness	Joy
Cardiovascular							
HR	↑	↑	↑	↑	↑↓	↑	↑
HRV	↓	↓	↓	↓	↑	↓	↑
LF		↑		(–)		(–)	
LF/HF		↑			(–)		
PWA				↑			
PEP	↓		↓	↓	↑	↑	↑↓
SV	↑↓	(–)		↓		(–)	↓
CO	↑↓	↑	(–)	↑	↓	(–)	(–)
SBP	↑	↑	↑	↑	↑–	↑	↑
DBP	↑	↑	↑	↑	↑–	↑	(–)
MAP			↑	↑	↑–	↑	
TPR	↑			↓	↑	↑	(–)
FPA	↓	↓		↓	↓	↑↓	
FPTT	↓	↓		↓		↑	
EPTT		↓		↓		↑	
FT	↓	↓		↓	(–)	↑	
Electrodermal							
SCR	↑	↑		↑	↑		
nSRR	↑	↑		↑	↑	↑	↑
SCL	↑	↑	↑	↑	↑	↑–	(–)
Respiratory							
RR	↑	↑		↑	↑	↑	↑
Ti	↓	↓		↓–	↓	↓	
Te	↓	↓		↓		↓	
Pi	↑			↑		↓	
Ti/Ttot				↑	↓		
Vt	↑↓	↓		↑↓	↑↓	↑↓	
Vi/Ti						↑	
Electroencephalography							
PSD (α wave)	↑	↑		↓	↑	↑	↑
PSD (β wave)	↓				↑		
PSD (γ wave)				↓	↑	↑	↑
DE (average)	↑	(–)		↓		↑	↑
DASM (average)	(–)			↑	↓	↓	↓
RASM (average)	↑			↑		↓	

Note.* Arrows indicate increased (↑), decreased (↓), or no change in activation from baseline (–), or both increases and decreases in different studies (↑↓).

Table 3. Table extracted from [32] showing the relation between the emotions with some of the features of the most common used physiological signals

The process from acquire data to launch an emotion guess, follows the steps shown in Figure 25. Each signal will be studied and processed by different ways and it is of the core research work developed in the framework of the project.

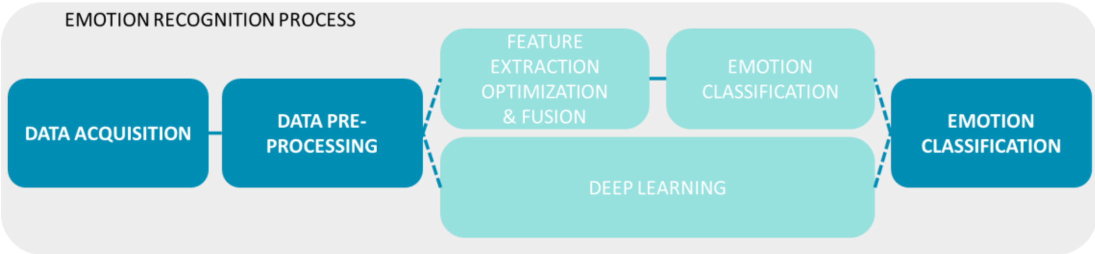


Figure 25. Emotion detection process using measurement of physiological signals

7.4. Emotion monitored in SUaaVE

The emotions are detected through three methods:

A. Valence and arousal through Physiological measurements
B. Audiovisual information
C. Categorical prediction through events

A. Valence and arousal through Physiological measurements

The physiological data acquired through a wireless measurement device:

- Data from temperature sensor expressed degrees on the Celsius scale: Skin temperature
- Data from electrodermal activity sensor expressed as microsiemens: EDA, property of the human body that causes continuous variation in the electrical characteristics of the skin
- Data from photoplethysmography: detection of blood volume changes in the microvascular bed of tissue
- Data from 3-axis accelerometer sensor. The accelerometer is configured to measure acceleration in the range [-2g, 2g]: to detect how much the subject moves the part where the sensor is placed, generally the wrist)
- R-R signal
- Time between individuals heart beats extracted from the BVP signal: to measure heart beat rate and heart rate variability
- Average heart rate extracted from the BVP signal: also, to study the heart rate variability

Using a Digital Biosignals Plux or similar, invasive measurement techniques will be carried out in the first loop of the experimentation in simulator:

- Heart rate through sensors in the pectoral zone
- Skin conductivity (GSR) though sensors in the palm of the hand
- Breathing rate through plethysmograph

B. Visual information

* Cameras. The images obtain by the cameras is processed through the approaches of geometric (relative positions of facial features) and appearance (using filters and finding patterns) in order to extract the characteristics of gestures and of the face

C. Event record information

* Event mark times: this is important in order to explore specific fragments of time of the signals and for the categorical classifier algorithm. In the case of the simulator, these events are programmed and include different configuration of traffic states, other driver infringements, pedestrians, broken windshield, etc.
* In a first approach, we have measured real drivers while the co-driver writes the relevant events that could elicit an emotional response to the driver. Events such as:
    - Weather circumstances: Storms, heavy rains, excessive heat, etc.
    - Road incidents: Car-crash, bad conditions of roads, closed road, traffic jams, etc.
    - Changing events: Change conditions of roads, a very aggressive incorporation, changing from urban to interurban, excessive noise, traffic lights ignored, etc.
    - Pilot and passenger perceptions: Feeling stressed, sleepy, exhausted, lack of turning signals use, other driver making easier the traffic flow, etc.
    - Other events: For example, presence of legal authorities in the roads, velocity control radars, etc.

7.5. Factor of this emotion

As reviewed in section 5.5.3., the physiological signals treatment allows the extraction of certain parameters that are related with emotions.

The IBV-Methodology to recover a positive state

Once the emotion is known the main question is related on the response of *ALFRED* for the improvement of the emotional state. This is a matter dealing with emotional management of the passengers.

The emotional management, however involves acting before the detection of the emotional state of the passenger and will be goal-based. The range of action depends on the goals of the trip for the passenger of the vehicle.

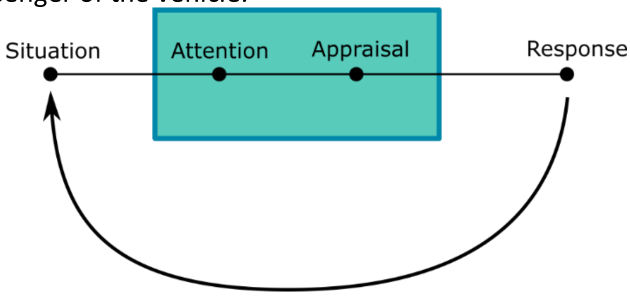


Figure 26: The Modal Model of emotion (Gross & Thompson, 2007). The emotions are elicited from situations, the Attentional processes direct the emotions and are mediated by the goals of the person. Then the appraisal model is where the emotion raises and a response is elicited. This response, dynamically changes the situation and influences on the emotion. The green box is for the intrinsic factors, while extrinsic factors remains out of the box.

According with the modal model of emotions (Figure 26) from Gross and Thomson (Gross & Thompson, 2007), the emotion management can be performed in several places of the whole dynamic cycle of emotion elicitation (Figure 27).

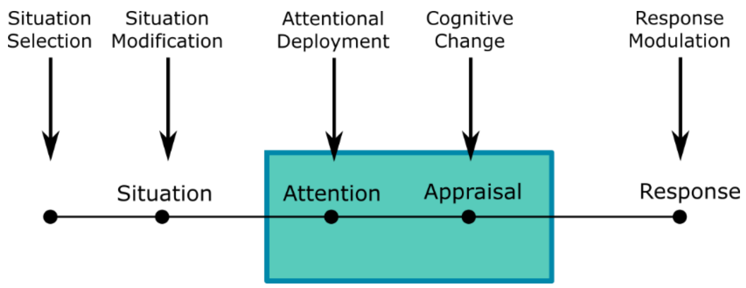


Figure 27: Emotional management model (Gross & Thompson, 2007), highlighting where the different strategies for emotion management are applied in the cycle of emotion elicitation. The strategies to be applied when the emotion has been already detected are Response Modulation, while the others imply understanding in advance what emotion will be raised in the passenger in order to be able to act before the elicitation of the emotion.

To understand how this approach will act, we can the following example

John Doe is willing to arrive at his workplace before 9:00 am, because there is an important meeting at the office.

*At 8:45am ALFRED information system is aware that an accident has occurred in the usual route to the office that could delay the arrival more than 30 minutes. Subsequently, ALFRED suggests John an alternative route with an estimated arrival time at 9:05. This strategy is a **Situation Selection** strategy, the system is trying to reduce the negative emotions associated with a late arrival at work changing the situation.*

*Once in the new route, the traffic begins to get dense as many cars are trying to avoid the route of the accident. The arrival estimated time continues to be at 9:05, but ALFRED, before any change is detected in the passenger suggests to make a call to the workplace informing about a minor delay This is a **Situation Modification**. The passenger decides to make the call, and the administrative of the Office confirms that due to the accident, the others attendants of the meeting are also arriving late. Despite of the news, ALFRED detects an increase in the arousal of the passenger and suggest switching on the radio to listen to some music. This strategy is **Attentional Deployment**. This reduces the arousal of the passenger. But as the time is approaching the 9:00am the arousal of the passenger increases again. As soon as ALFRED detects the new increase suggest the passenger to make a new phone call to the administrative in order to know if the others have already arrived. The passenger rejects the new phone call because he's aware that he already talked with the administrative and at the workplace everybody knows the situation. This strategy is **Cognitive Change.***

Few minutes later, the passenger receives a phone call from the workplace and is informed that the rest of the participants have already *arrive. This produces an **increase in the arousal** of the passenger, then ALFRED decides to modify the dynamics of the car and the safety envelop in order to deal with the emotional state of the passenger. This strategy is **Response Modulation**.*

SUaaVE will use a repertoire of actions to incorporate all the strategies dealing emotion management that we have seen in the above scenario. In particular, SUaaVE integrate a dimensional model of Arousal-and-Valence and an Emotion Appraisal Categorical model of emotion.

The dimensional model of emotion will be in charge of the strategies for *Response Modulation* while the Emotion Appraisal Categorical model will be in charge of the rest of the strategies. Both will be incorporate in the project as different Use Cases that will respond co-ordinately.

Emotion management with the dimensional model of emotion

The emotion management of the emotion with the dimensional model will act as a predictive filter (1), to deal with the dynamical aspect of emotions highlighted in the Modal Model of emotion.

$$\begin{gathered} X(n+1) = F_1[X(n)] + F_2[U(n)] \\ Y(n) = H[X(n)] \end{gathered} \qquad (1)$$

Where $X(n)$ is the vector with the (emotional) state of the passenger; $Y(n)$ is the vector with the physiological parameters related with the emotional state of the passenger; $U(n)$ are the aspects of vehicle dynamics affecting the arousal and the valence of the passenger.

Therefore, we need to include to dynamics of the emotions (F_1), the relationship between the arousal and the valence with the physiological signals measured (H), and the relationship between vehicle dynamics and the arousal and valence (F_2).

Emotion management with the categorical model of emotion

The categorical model of emotion to be used in SUaaVE is a cognitive appraisal model of emotions, it is well known as the OCC model (Colby et al., 1989).

According with this approach the emotions are related with goals and are elicited by events, agents and objects. Therefore, as ALFRED will be aware of the **goal** (the purpose of the trip) and the **environment**, ALFRED could anticipate the emotions of the passenger and apply strategies of *Situation Selection* and *Situation Modification*. Besides, ALFRED will be aware of the physiological measurements of the passenger, that will allow the system to refine their predictions of emotions and apply strategies of *Attentional Deployment* and *Cognitive Change.*

The responses of ALFRED will be feedback-based (providing feedback to the passenger) with a Machine Learning module to improve the response provided to each passenger of the CAV.

There would be four sources of feedback incorporated in ALFRED.

1. Information provided to the passenger.
2. Alternatives to be chosen by passenger.
3. Actions.
4. Modifications of feedback parameters

Information provided to the passenger

The main pieces of information provided to the passenger will be the ***state of the traffic*** and ***warnings and alerts***.

The verbosity on the information about state of the traffic will be selected according to passenger preferences and the importance of the trip, and will include the information of changes in the estimation time for arrival-

Warning and alerts will encompass information of external events such as accidents, traffic jams or forecasting of strong climate condition (blizzard, hail, etc) and information of internal events such as breakdowns or malfunctioning of any of the subsystems.

Alternatives

The alternatives to be chosen by the passenger will include:

- Alternative routes
- Driving mode (i.e. sportive or relaxed)
- Increase or reduce the safety envelop

Actions

There are a number of systems that ALFRED can actuate in order to improve the emotional state of the passenger:

- Multimedia: Switch on and of the multimedia system: radio, music, video or electronic books.
- Air conditioning system.
- The communication system to make phone calls and send and receive messages and emails.
- Safely stop the car.

Feedback parameters

The way the feedback is provided to the passenger will be modified according to the emotional state of the passenger in particular:

- **Voice feedback**: Intonation and prosody
- **Audio feedback:** Volume, and type of sound for alert (beeps, rings and alarms).

8. Ergonomic criteria to design technologies applied to the autonomous car

8.1. Definition of design criteria

The design of a device often involves different specialists, each of which deals with a specific dimension of the product. For example, some specialties seek to integrate the best of technology to offer a leading-edge product, while others seek to minimize the risks associated with the normal, abusive or even diverted use of the future product. The consideration of quality and interaction often comes last, but it lays the fundamental building blocks of the future product and very often gives a common thread to all the design actors. Among the leading authors to propose solutions, Norman (1986) recommends placing the user at the center of the design process. Other authors followed, proposing different strategies and guides from design (e. g. Maeda, 2006 ; Norman, 1988, 2004) or cognitive psychology (e. g. Bastien & Scapin, 1993 ; Nielsen, 1993, Venkatesh et al., 2008, 2012) to improve the quality of use. Some authors speak of usability (e.g. Nielsen, 1994), others speak of simplicity (e.g. Maeda, 2006).

In any case, the objective is to reduce the mental effort that will be required to learn to use and use the future device. Nielsen (1994) has a rather psycho-technical approach, while Maeda (2006) has a more intuitive approach, but their proposals share a general consensus spirit, and sometimes similar proposals. For example, the law of CONTEXT (Maeda) assumes that the relationship to the product and its perception is strongly impacted by the context. Maeda presents the example of a Japanese meal, with shimmering colors (red, pink, silver fish; green algae...) which is magnified by an exclusively bench environment (plates, chopsticks, tables, chairs, walls...).

Nielsen considers the context through 2 heuristics. The heuristic "**Match between system and the real world**" (#2) evokes a coherence of use, between the product and the way it is used. For example, the earphone volume setting (see figure) considers the position of the control in space when used: increase at the top, decrease at the bottom. It is because this configuration seems obvious that it is well thought out. The heuristic "**Consistency and standards**" (#4) evokes a more normalist coherence, from both an internal and external point of view. From an internal point of view, a specific function is part of a set of functions proposed by the product and which is a context in itself. For example, a function accessible by different paths must always have the same label; a function must be part of a similar logic with other similar or linked functions in the action. For example, the controls for the different lights in a car are often located on the same comodo. Access to the various exterior lighting via a single comodo constitutes both an internal coherence, via a grouping of functionalities, but also an external coherence because this arrangement is very frequent, and a new user of a new vehicle will expect to find these functions at this location.

The design of the ACE HMI will be based on these design criteria in order to organize the innovative functions that will be proposed by autonomous vehicles, and more specifically the functions that are under study in the SUaaVE project.

8.2. Bastien and Scapin (1993) criteria applied to the ACE interface

Providing an interface with adaptive capability is essential to offer an experience that changes dynamically according to events, the cognitive state of the user or the general road context. It is also possible to plan an adaptation to the user profile. By default, the interface could be adapted according to certain criteria specific to certain categories of users, depending for example on age, size, experience with ALFRED, assumed culture (depending for example on language and location), visual abilities, etc. The description of the criteria presented below is intended to define a general design framework to optimize interaction with future autonomous vehicles.

To begin with, the ability to adapt to the user is prescribed by Bastien and Scapin (B&S) in the criteria of adaptability and compatibility. These two criteria can be confused, but the first one refers to a parameter setting offer while the second one refers to an inclusive design, adapted to the user and his environment of use.

8.2.1. Adaptability criteria

Adaptability includes 2 sub-criteria: flexibility and experience. Flexibility (similar to Nielsen, 1993) refers to the possibility offered to the user to make usage parameters according to his/her habits and strategies. The experience refers to the possibility of evolving the interface according to the skills that the user will develop as it is used. However, B&S indicate that they must be careful that the adaptability of the HMI does not impact the compatibility criterion.

The adaptive nature of the ACE interface will be based in particular on a possibility of configuration. A start-up phase could be proposed during the first use to explain to the user the general operation but also to carry out a first configuration adapted to his characteristics (e. g. travel habits, illness, disability, preferences, etc.)

8.2.2. Compatibility criteria

Compatibility refers to "the adequacy between the characteristics of users (memory, perceptions, customs, skills, competencies, age, expectations, etc.) and the characteristics of tasks, on the one hand, and the organization of output, input and dialogue for a given application, on the other hand. The compatibility criterion also concerns consistency between environments and between applications."

Beyond the initial configuration made by the user, the compatibility criterion can be translated by a dynamic evolution of the interface according to the user's state, his/her activity and the road context. For example, regarding the user's condition, adaptive capacity could be supported by monitoring instruments, but also by playful programs that would be offered from time to time to the driver to distract him/her but also to carry out measurements (e.g. cognitive abilities, affects, etc.), establish correlations with the monitored data and refine the interface's adaptive capacity.

In addition to behavioural and declarative measures, ALFRED may be able to take habits into account to make appropriate proposals in terms of interaction but also in terms of comfort. For example, if the user has been to tennis 2 Saturdays in a row at 10:15 am, this route will automatically be offered to him/her when he/she gets back in his/her car at the same time the following Saturday. ALFRED recorded that the user listened to rhythmic music with high volume last week and that it had a positive impact on his/her mood and wakefulness, this musical style could be offered on the 3rd trip, and possibly every time he/she goes to the tennis club.

8.2.3. Guidance criteria

The criteria of adaptability and compatibility will be in the very essence of the ACE interface. The contextual dynamics of the information and orders made available will generate regular changes that aim to facilitate interaction. But these changes may also lead to a loss of reference points. To avoid a degradation of the interaction, the interface will have to offer strong incentives to bring the user to the information and commands he needs in real time. Guidance is defined by B&S as "the means implemented to encourage users to take specific actions" and "identify the state or context in which they find themselves". Guidance is initially prescribed to facilitate navigation and learning and avoid mistakes. For ACE, guidances will be important to limit the negative effects of a possible loss of benchmarks related to the dynamic adaptability of the interface.

From a practical point of view, guidance would be the enhancement of the information and orders necessary to deal with a situation. This enhancement can be achieved from a morphological point of view (e. g. size, colour, salience) but also from a spatial point of view, by gathering for example information/orders to be processed simultaneously, by placing information/orders in analogy with the characteristics of the target concerned or areas of interest. For example, if the air conditioning has been switched off and the outside temperature is higher than usual, the list of comfort parameters can put the temperature setting in the first position. The first position is an incentive.

8.2.4. Workload criteria

The user's ability to process information is a central criterion for designing an effective interface. According to B&S, a complexity or amount of information that exceeds the processing capabilities of the user is a significant source of user errors and decreased efficiency.

The Cognitive character of the ACE interface is based precisely on a prediction of the cognitive resources and information available to the user. From this prediction, ACE will be able to propose an optimal interaction to deal with a situation.

For example, when the user enters his/her vehicle, the HMI can highlight an interaction that involves planning the trip according to a "step-by-step" approach that corresponds to the user's habits. The "step by step" method avoids displaying a multitude of options that the user does not use in this situation, such as "adding a step" when the user is used to entering the main destination first.

8.2.5. Explicit Control

The presence of a function to perform a necessary action is generally well perceived by the user. But the latter may feel frustrated when the manipulation does not allow him/her to carry out the action as he/she wishes or to obtain the desired result. According to B&S, the gap between what is proposed and what is desired lies in two notions induced by the term "control": the possibility of control adapted to the user's objectives and in an explanation of the actions adapted to the feedback he/she needs.

The notion of user control allows to give access to the level of interaction needed. For example, the sound power setting is often translated into a numerical value that refers to power levels. A user can be frustrated if the desired power is between two levels.

The notion of explicit actions refers to a notion of monitoring the system's actions, in other words the ability of the interface to inform the user about the current processes.

For example, the cockpit temperature of a car is 35°C and the user wants to quickly obtain a temperature of 22°C. It may be tempting to set the thermostat to a minimum (e.g. 15°C) thinking that the expelled area will be colder and the car will reach the temperature of 22°C faster. In reality, the air conditioning works in a binary way, it will not be more powerful if the user programs 15°C or 22°C. On the other hand, the user may obtain a too cool temperature, which will inconvenience him/her and require a new intervention on his/her part.

One solution would be to indicate the effort provided by the air conditioning, and possibly an estimate of the time required to obtain the desired temperature. Thus, the user could see that the device is working at its maximum and he/she would be reassured to see that the comfort time is reasonable. A "QUICK" function could allow the user, for example, to play on the opening of windows at first to evacuate air that is too hot (if the outside air is cooler), and send a fresh breath on the driver while waiting for the cockpit to cool off.

8.2.6. Error management criteria

Error processing often leads to the identification of possible sources. For example, when the user is inattentive and omits information, when the action is diverted by an unpredictable movement of the vehicle, or when an ambiguity causes a discrepancy between the expected result and the result obtained. B&S of course prescribe to deploy the necessary means to avoid making mistakes, but like Nielsen, they also stress the need to explain them and the possibility of correcting them.

For example, when you want to create a new route for a new journey, you are often asked to choose a "new route", then search for the target city, then the street, etc. When you start entering the city name, GPS often provides a list of cities with a similar beginning of name. All you have to do is stop the entry and choose the city you want. However, the transition from input to choice is often a source of error. On some GPS, a city selection error means that you have to repeat the procedure at the beginning: "new route". In this case, not only is the entry a source of error, but there is also no way to correct the error (e.g. return to the search screen)

8.2.7. Consistency criteria

This criterion underlines the need to group together under the same presentation and/or in the same space information/functions that have a certain link, for example from a functional, procedural, semantic, etc. point of view.

For example, access to a contact list is possible via a "Contact" link on the phone function, and access to the same list is accessible via the "address book" link on the email function. In this case the user may think that these are 2 separate lists, or even may not find the label he is looking for. This problem points to a lack of consistency.

8.2.8. Significance of codes criteria

Some codes (e. g. icons, labels) are not always transparent, i.e. their meaning is ambiguous. The link between the code and meaning can be quite obvious in a given situation (for example, a crossed-out cigarette symbol to indicate that smoking is prohibited). The link can also be socially acquired, as the symbol of a crunchy apple symbolizes Apple brand products, not a fruit cooperative. The creation of new codes requires either checking their perfect understanding with a sample of users or a guided learning phase.

9. Synthesis of ACE Interface and strategies to ensure ALFRED acceptability by users

The SUaaVE project proposes to study the possibility of designing an interface that would be able to adapt to the road situation and the user's activity situation, according to the user's cognitive needs and emotions. In other words, the ACE interface would be able to modify the way the user interacts with the vehicle to put him/her in the best possible position to control travel and life on board, depending on the needs of the situation and his/her activity. The acceptability and adaptation of ACE would be based on 3 prerequisites: cognitive needs, multimodality and comfort.

9.1. Cognitive needs

Cognitive needs are the level of information and cognitive processing necessary to understand and act in an optimal way. In other words, the user requires certain information and cognitive resources to deal with a given situation. A device that optimizes the flow of information can be useful, especially if it is usable, i.e. it does not generate an excess mental load to be used. Optimizing the flow of information (utility) and interaction modalities (usability) are essential issues to promote the acceptability of ALFRED by users.

9.1.1. Usability optimization

Optimization of usability will be based first of all on the design criteria presented. To ensure optimal adaptation, different interaction modalities (information transmission and ordering modalities) will be proposed for each function. In other words, a given function will be accessible differently depending on the user's situation and activity. However, in order not to lose their references, the user should always have access to the basic interaction, which will be supplemented by a redundant interaction adapted to the situation. For example, if the vehicle calculates that the trip will be impacted by a significant weather event, it can either display it only on a screen if the user is monitoring the road, or announce it with oral redundancy if the user is distracted (e. g. game, video) or if the event has a significant impact (e. g. risk of late).

9.1.2. Explicability of the system

The term "Explicability" commonly refers to a quality related to artificial intelligence (AI) (e.g. Denis & Varenne, 2019). AIs, and more generally complex systems, are able to collect and process such a large amount of data that it would be impossible to describe the machine's operations step by step. Explanability has become an essential quality for the user to quickly understand the operations performed in order to make the necessary trade-offs (e.g., taking control, manually changing routes, etc.). According to Denis and Varenne (1019), "The operational acceptability of such applications is largely determined by the ability of engineers and decision-makers to understand the meaning and properties of the results produced by these tools". With 25,000 deaths on European roads in 2017 (European Commission, 2018), the risk leaves little room for uncertainty about how cars will work for users. These uncertainties are a source of anxiety that impact acceptability.

Understanding how a system works involves important factors in its acceptability such as anxiety (Osswald et al., 2012), usability (e.g. Venkatesh, 2012) and trust (Beggiato and Krems, 2013. And according to Boelhouwer et al (2019), an explanatory manual is not sufficient to understand the vehicle's capabilities in a given situation. The authors recommend a dynamic system that helps the user to enrich his mental model of the vehicle. Such a device would allow the driver to understand in real time the vehicle's operation, capabilities and limitations. In addition to the issue of acceptability, if the system helps the user to understand how it works, the user will acquire the expertise to make the best use of it.

As RUG explains in Task T1.1, acceptability concerns not only the user, but also other road users. However, it seems that it is on this side of the cabin that the reluctance towards the autonomous vehicle is strongest. This reluctance is also due to a lack of explainability:

pedestrians, for example, cannot rely on a glance game or manual signs to ensure that the vehicle has understood its intention to cross the road. Interaction with the CAV will therefore have to involve external third parties as described in some studies. And this communication with external third parties could be reported to the user so that he or she can better understand the interactions between the vehicle and the physical and social environment, and their impacts on driving.

9.1.3. Information flow optimization

The optimization of the information flow aims to support the user's situational awareness in order to allow him/her to have an optimal understanding of the situation and the functioning of the vehicle. The optimization of the information will be based on (see T3.3):

1. The identification of the information necessary for the user to understand the situation, and if necessary to plan an action.
2. Simulation (prognostic) of the user's mental representation to improve its representation by filling a possible information gap.

To treat situational awareness, it is possible to rely on a critical case which is the regaining control of a level L3 automatic vehicle. This type of vehicle is able to operate completely autonomously under very standardised conditions (e.g. motorway). However, L3 does not allow certain hazards to be managed (e.g. accident, poorly marked work area). In this case the vehicle requests the driver to take control. This phase of regaining control can be complicated if the driver is completely detached from the driving (e.g. sleeping, working). He must take back the information necessary for manual driving, such as information about the environment (e.g. other vehicles, the obstacle), or the state of the vehicle (e.g. speed, delays before taking over, identification of the problem, etc.). Based on the problems of L3, it is also possible to cover the takeover in L4, but also simply the support of the user who wants to be quickly informed about the situation.

Cognitive needs for situation awareness must be supported by the usability and utility of the device, not only to provide optimal interaction, but also to avoid negative emotions related to the use of the vehicle (stress, nervousness...). The consideration of emotions is the subject of the following point.

In addition to the processing of information by the user, the information flow also needs to be optimized in order not to overload the processing performed by the system. During the workshop held with the partners of Task 4.1 (July 2019), it was decided to try to limit the complexity of the processing algorithms, for example by limiting to the most significant indicators (for example, keeping only the most relevant and reliable measures of emotion) and by favouring the processing of category data rather than continuous data.

9.1.4. Emotions management

The measurement and management of emotions in the SUaaVE project is not intended to satisfy users or tenderize them with a couple of superfluous gadgets. Emotions towards a target are above all a precursor of the attitude towards this target, and consequently of its acceptability (Park et al., 2015).

As described above (Lee et al., 2019), the designing of an HMI can anticipate certain types of emotions through 2 design strategies:

1. *Meaning design (organized, pragmatic, ergonomic, clear*) is based on the understanding of information and interaction by impacting emotions on a continuum ranging from low positive (calm, satisfaction) to high negative (excitement, nervousness, stress). In other words, a device that offers a meaningful interaction (clear and intuitive) will allow the user to achieve his/her objectives. And achieving his/her goals will have a positive but moderate emotional impact on him/her. On the

contrary and above all, failure will have a strong negative impact on emotions. This effect reinforces the need to design a clear and effective interaction. Outside perhaps from the first moments of use, a design of meaning will promote an impression of control: in case of control, there is little emotion outside of quietude, on the contrary the absence of control can be very stressful.

2. *Exploration design (rich, hedonic, complex*) is based on an incentive to discover the device through experience. This type of less guiding interaction induces emotions on a second continuum, which ranges from strong positive (joy, fun) to weak negative (disappointment, sad). In other words, this more complex type of interaction involves less negative feeling if the user fails to achieve a goal, and it can support strong positive emotion if successful. This type of interaction is interesting for designing playful devices, but it is complicated to implement when designing objects such as a car, whose use efficiency is an important criterion.

The rules of ease of use are now better described than the rules of emotional design. It is technically easier to propose a meaningful design that is objective and will generate low positive emotions, rather than an exploratory design that has a high positive emotional potential, but is more subject to subjectivity. A compromise between the interaction of meaning and the interaction of exploration would be to focus on meaning for sensitive interactions (navigation, regaining control, diagnosis), and to put a touch of exploration (optional) for on-board life functions such as comfort and entertainment...

However, the user may be exposed to external sources of emotions (e.g. contextual, relational, professional, etc.). The exploration design can then be used to try to correct a negative emotion caused by the road situation, for example.

The author describes the possibility of simultaneously experiencing emotions from each continuum. In particular, a user can be both playful in a situation and stressed.

Acceptability models such as Nielsen's (1993) describe different dimensions of an object that impact its attitude and intent to use. These dimensions include the utility and usability described above. Among the components of usability, we often find the comfort dimension, which is the subject of a particular axis in SUaaVE.

9.2. Multimodality

Multimodality is applicable according to two distinct principles, each of which supports driving and situational awareness in a different way: multimodal redundancy and alternative modality.

9.2.1. Multimodal redundancy

Multimodal redundancy consists in providing information or control via two distinct sensory channels. It makes it possible to secure interaction thanks to three principles:

- Reinforce the message: simultaneous use of two sensory (e.g. sound and visual) or semantic (Symbolic and Verbal) channels. The more important the cognitive processing, the stronger the cognitive coding of the information. In other words, important information transmitted in a multimodal manner will be more strongly encoded, and will be less subject to interference from a secondary event than unimodal information.
- Secure transmission: in case of failure of an interaction channel (e.g. audio system failure, screen failure), the second channel is always present to relay the information.

- Secure reception: If the user's activity overloads one of the two channels, the information can still be captured via the available channel. For example, if the vehicle has to indicate a low energy level, it can indicate it visually with an icon and a particular lighting effect, and orally with a voice message. If the user is on the phone, he/she will not hear the voice message, but will be sensitive to visual information. If the user rests with his/her eyes closed, he/she will not be sensitive to visual information, but auditory information may be perceived.

9.2.2. Alternative modality

Alternative (multi)modality would consist in proposing several different channels to transmit the same information. But the information is only transmitted once. This strategy is often used on websites, for example by offering a description of an image as an alternative display of that image. The alternative text allows access to the information using a web browser for the visually impaired (the texts are read) or when the connection does not allow the images to be loaded. Within the software interface, some functions accessible in the drop-down menus (e.g. File, Edit, Display, etc.) via a verbal label (e.g. "Copy"; "Paste") are also accessible via a visual symbol in the window header (banner), or using a key combination. The use of the "Copy" function, for example, borrows only one mode, but the user can choose the mode most compatible with the current action.

To design the interaction with each sensitive function of ALFRED, we should build a solution for each relevant channel available in each situation (cf. T6.1 : Use cases). The result from T3.3 (cognitive needs) will be helpful for the first draft of the ACE Interface (D4.4).

9.3. Comfort management

When a driver makes a trip, he/she has a choice between different driving styles. For example, it can promote effectiveness (quick arrival), a comfortable journey, efficiency (low energy impact) or ethic (low social impact). TUM and IDIADA will propose a device that will optimize the comfort linked to the dynamics of the autonomous vehicle. The dynamic comfort of the vehicle can be translated into the more or less sudden acceleration experienced by the user during acceleration, braking, cornering and road irregularities. One could consider that the vast majority of users would adopt the comfort mode; however the choice of comfort may contradict some of the users' priorities. For example, if the vehicle slows down too much in certain curves, the loss of speed generates a loss of time for a hurried user, and requires a high acceleration energy after the turn. On the contrary, maintaining the maximum authorised speed would be less comfortable but would allow less time and acceleration energy to be lost after the turn...

However, the addition of services and functionalities would be a possible solution to guarantee comfort, respect for time, energy and social aspects. Here are some examples that will be explored:

- Route scheduling: routes could be scheduled in advance. Thus, the user would be asked to slightly adjust his/her departure time to avoid traffic, he/she would receive an alert to indicate the imminent departure, and he would not waste time planning his route at the beginning of the trip. In this way, comfort would not be sacrificed for the benefit of a few minutes that are difficult to catch up on.
- Eco-driving has 3 advantages according to Bison Futé:
  - Fuel consumption up to 40% lower than sporty or nervous driving
  - A smoother and softer ride that spares mechanics and tyres; and reduces maintenance costs
  - A reduction in accidents by an average of 10 to 15%, in particular because a smooth and soft ride makes it easier to anticipate and reduce stress.

In other words, eco-driving is more in line with comfortable driving. Alone in some situations, route planning may favour the use of smoother but longer roads (motorway) rather than a shorter and less energetic but less comfortable road (e.g. secondary road). This situation will not be addressed by the SUaaVE project's comfort algorithms.

- Intelligent sharing of road space: Road sharing trade-offs involve respecting vulnerable third parties (e.g. pedestrians, children, bicycles), respecting virtuous third parties (public transport), by respecting travel objectives (arrival time). Currently, the driver only has the blinkers and the horn to interact with other users. It is not possible to add functions that will be cognitively complicated to manage. But when driving independently, it is quite possible to add various communication methods to optimize road sharing, and thus avoid braking / acceleration, traffic jams, accidents and their effects on comfort, stress and energy consumption. Such a communication system could be optimized in the same way as the interaction between the vehicle and its user: adaptation to the situation, multimodality, etc.

10. GENERAL CONCLUSION

Deliverable D4.1 presented the preliminary work of the WP4 partners, as well as the work from tasks T1.1 and T3.1. The first results presented are very important to align the tasks T4.2, T4.3 and T4.4 on a common reference frame. This will provide everyone with a sufficient understanding of their partners' developments (Dynamic Comfort Module, Ambient Comfort Module, and Cognitive Assistant Module) in anticipation of their integration into a single system: ACE interface (T4.5). The elements presented made it possible to present the precise bases of the developments that will be carried out.

However, this initial work also highlighted risks of complexity related to the large amount of information to be processed by ALFRED, which could make it too complex to integrate or even ineffective. The developments that will be carried out will therefore take this risk into account by limiting the number of variables used and of modalities in each variable, in order to avoid failures in information processing. The complexity will be adjusted according to the results of the first experiments and the integration constraints within ACE.

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