

## Supporting acceptance of automated VEHICLE

### **Deliverable 3.1. Framework of the empathic module and preliminary relationship among automotive factors with cognitive and emotional passenger state**

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## Terminology and Acronyms

EU	European Commission
VRUs	Vulnerable Road Users
ALFRED	Level of Automation Four+ Reliable Empathic Driver
ECG	Electrocardiogram
HDD	Human-Driven Design
CAV	Connected Automated Vehicle
OCC	Ortony Clore and Collins
ACE	Adaptive, Cognitive and Emotional Interface
EmY	EMpathY Unit
HR	Hear Rate
RSP	Respiratory
GSR	Galvanic Skin Conductance

## EXECUTIVE summary

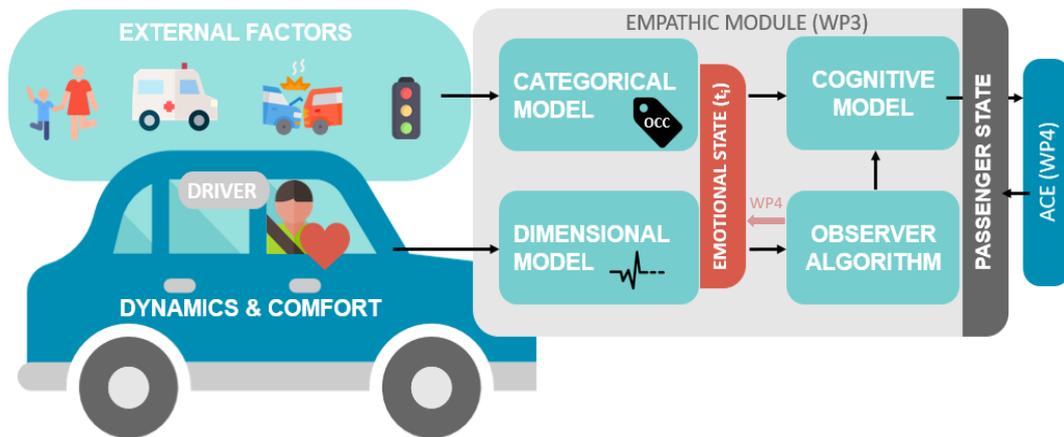


Figure 1. Illustration representing the elements defining ALFRED: Level of Automation Four+ Reliable Empathic Driver

In the present document, the framework of the emphatic module and preliminary relationship among automotive factors with cognitive and emotional passenger state are presented. The methods followed for creating the framework and its link with the factors, as well as the collection of factors will be based on literature research and on the experience of the partners involved in this work.

The **empathic module**, as it will be described in the document, combines the integration of an *emotional* recognition module, a *cognitive* module and an *observation* algorithm.

The IBV is in charge of the emotional package. In the document, there is a description of the approaches and procedures that will create the framework for the developing phase. On the one hand, the characterization of the emotion state of the passenger is built employing the structure of a ***categorical emotional model***. In the present deliverable, a revision of types of emotional models is included, together with the definition of the emotional model on which the firsts steps of the experimentation and on the implementation of an emotion classifier is based. On the other hand, it is also approached through a ***dimensional emotional approach***, based on the parameters arousal and valence obtained from the heart rate signal. The model will also include other additional biometric (breathing rate, temperature) and behavioural (facial expression, blinking, etc.) parameters to increase robustness in different situations when integrated with the categorical model.

In the document there is an introduction to the Observation Model, that will be developed by TUM to anticipate the passenger state. It will emulate the input-output dynamic map from external stimuli (road conditions, driving behaviour), to resulting human emotional and cognitive state. This will rely on the closed-form model, describing the dynamical relationship between relevant stimuli (the prioritized factors) and the dimensional model of passenger state. This input-to-state mapping will be gainfully exploited to achieve a reliable ALFRED passenger emotional state estimation in Real-Time.

Regarding the cognitive model elaborated by Bordeaux, the foundations and the development phases are presented to define the cognitive states of the user in any situation in real time. The definitions are focused on several cognitive states in particular, choosing the ones that have a strong impact on the user experience in the vehicle. Some of the mental

states assessed are: situational awareness, mental load level, cognitive task level, mental representation, perceived risk level.

At the end of the document, with the collaboration of IDIADA, a collection of factors is proposed as the inputs for the different models.

## 1. Motivation

One of the main causes of lack of acceptance in innovation is ignoring the needs and preferences of potential customers in the development phases. In the case of the connected automated vehicle (CAV), there is an important degree of user skepticism based on the awareness of the complexity and the risks of this technology. On the other hand, public acceptance is closely related to the emotions and trust on the technical and functional performance by users.

However, EU Member States do not have a specific policy to enhance public acceptance of CAV or to ensure user involvement<sup>1</sup>. Despite the fact that before users accept it, they should have the opportunity to become aware of what it is, avoiding the feeling of deception and distrust in the main stakeholders, public or private. The approach based on the technology push threatens social viability of innovative technology like CAV, as it creates a gap between the well-thought technical reliability and public acceptance.

SUaaVE aims at promoting a change in the current situation by leaning on a Human-Driven Design (HDD) approach, where the user is not only the center of the process but actively contributes and even leads the definition of concept, development of technology and participates in the validation. SUaaVE is focused on the human side, to improve more “intangible” aspects as safety perception, attitudes and, in general, emotional appraisal of CAV.

For this reason, the SUaaVE project is motivated to research the human-component concept in CAV and develop a model to monitor and interpret the passenger state based on the cognitive state and the emotional response. Accordingly, an emotional model composed is motivated so as to be able to monitor in real time the factors affecting the emotions of the passenger.

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<sup>1</sup> Eurobarometer (2017). Public support measures for connected and automated driving. Reference No: GROW-SME-15-C-N102.

## 2. Objectives

The main objective of this deliverable is the definition of the empathic module framework to develop a model to monitor and interpret the passenger state based on the cognitive state and emotional response.

For this purpose, a number of sub-objectives must be fulfilled:

- Definition of the framework of the emotional model to characterize passengers (adult supervisor in CAV L4) being defined as the way in which the “drivers” perceive events in the environment during the trip and the projection of their state in a close future. Emotional framework is defined by two complementary approaches:
  - Categorical emotional model: OCC (section 4.4).
  - Dimensional emotional model: valence and arousal (section 4.5).
- Definition of the approach to the observation problem to identify passenger emotional state and its dynamics (Section 5)
- Definition of the framework for the cognitive model of the representation of passenger, establishing the foundations and the development phases that will define the cognitive states of the user in any situation in real time (Section 6)
- Review of emotion recognition through sensors able to feed the models with reliable information to have robust estimations of the affective and cognitive states (Section 7)
- Identification, definition and classification of factors affecting the passenger state, divided in three categories:
  - The external factors (see section 8.1).
  - The factors regarding the Ego-CAV (see section 8.2):
    - Car dynamics parameters.
    - Comfort parameters.
  - Other factors (see section 8.3).

### 3. Framework of the empathic module

ALFRED is conceived as the fundamental architecture to understand the emotions and the cognitive state of the passenger(s) on-board of the CAV and to adapt the vehicle features to enhance the in-vehicle user experience, while increasing acceptance. Compared to the CAVs developed under the traditional approach, ALFRED will contribute with two artificial intelligence units in the decision-making processes of the CAV: An Empathy Unit (EmY) and an Adaptive, Cognitive and Emotional (ACE) Interface, defined as:

**“EMpathY” Unit (EmY)**, which will be in charge of understanding the **emotional and cognitive state** of the passenger, while considering **ethical principles** (*Sensing and interpreting*).

**“Adaptive, Cognitive and Emotional” (ACE) Interface**, formulated as the control strategies for the management of CAV behaviour to enhance trip user experience on-board (*Acting and communicating*). This will include the communication with the passenger via HMI and vehicular dynamic response.

The **“EMpathY” Unit (EmY)** is composed then by an **Empathic module** and by **Ethical principles**.

The framework of the **Empathic Module** is developed in the following sections and its structure is illustrated in the Figure 2.

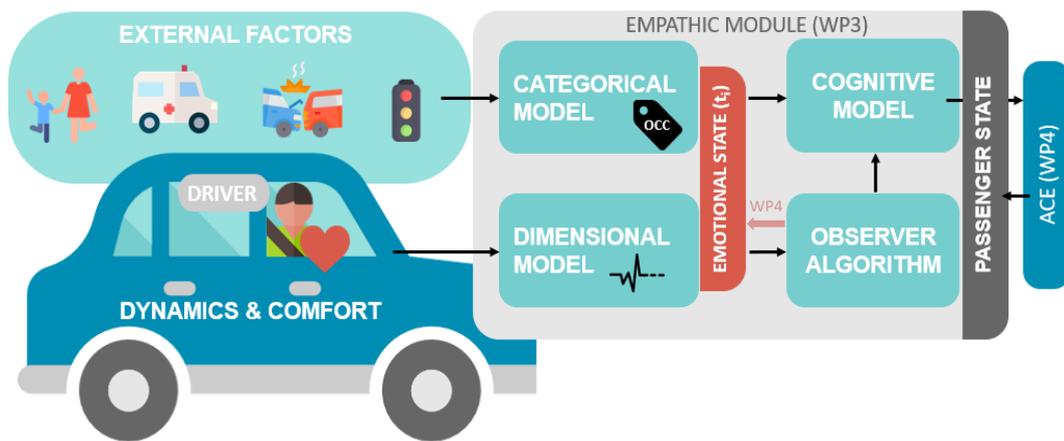


Figure 2. Illustration representing the elements involved and the work to be developed in the WP3

The module consists of 4 submodules that will integrate to each other with the objective of creating a map of the cognitive and emotional state of the passenger over time.

Main elements to cover:

- 4 submodules that build the Empathic Module:
  - Categorical emotional model
  - Dimensional emotional model
  - Cognitive model
  - Observer algorithm (both in WP3 and WP4)
- Environmental and ego-vehicle factors that affect the passenger's state

Emotional model

## 4. Emotional model framework in ALFRED

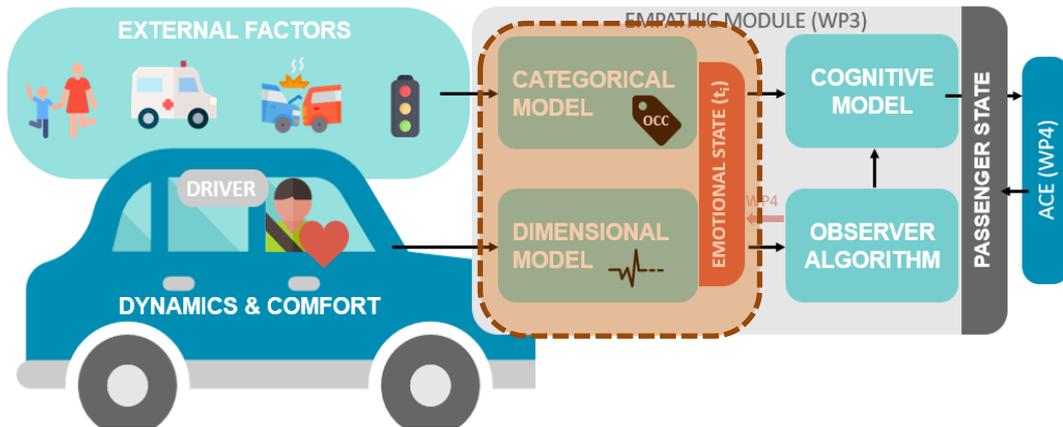


Figure 3. Emotional model inside the illustration representing the elements involved and the work to be developed in the WP3

### 4.1. Introduction to “Emotion”

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 4 (Scherer, Bänziger, & Roesch, 2010).

This project undertakes the emotion problem focusing on two of the “families” of models

PHASES COMPONENTS	Low-level evaluation	High-level evaluation	Goal/need priority setting	Examining action alternatives	Behaviour preparation	Behaviour execution	Communication - social sharing
Cognitive							
Physiological	Adaptational models						
Expressive		Appraisal models	Motivational models		Circuit & discrete emotion models		Meaning & constructivist models
Motivational							
Feeling	Dimensional models						

Figure 4. Table of types of emotional models in terms of phases and components (Scherer, Bänziger, & Roesch, 2010).

that are mapped in Figure 4. 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 emphasizes 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 with these theories focusses on the structure created by appraisal variables and the labelled emotions. It might be possible that the same situation could elicit many appraisals and it is still very difficult to theorize about how every appraisal combines to define a general state.

The appraisal theories use the so-called 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 on the link between the elicitation of the emotion with the characteristics of the response this is contrary to what **dimensional theorists** state.

The dimensional theories posit that the emotions are differentiated by their location on the bi-dimensional 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 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 feature extraction (Shu et al., 2018)

## 4.2. Emotion in driving

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 5, the design of the situations assessed depends on the goal blocking/goal

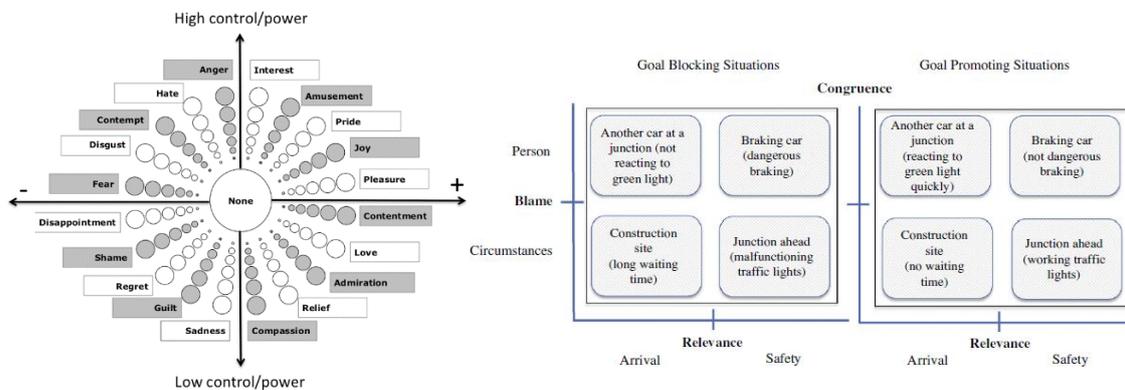


Figure 5. Geneva Emotion Wheel (GEW) that labels a group of emotions in terms of valence and control/power level (left). Classification of traffic events in terms of goals, person, circumstances and relevance by Roidl, Frehse, Oehl, & Höger (2013).

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. 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, 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 of emotion in driving. In a study, (Cai, Lin, & Mourant, 2007) 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 6).

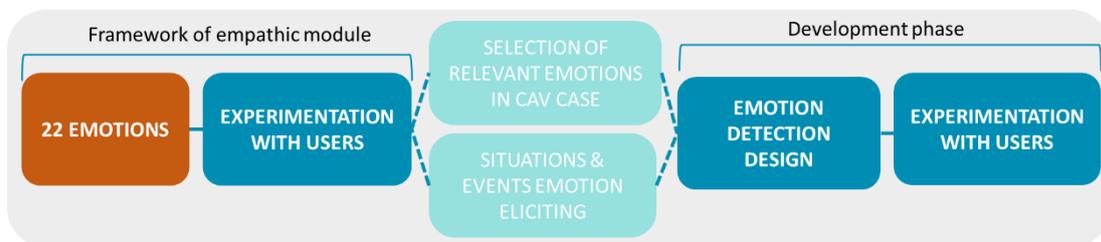


Figure 6. Process scheme of emotions in driving modelling in SUaaVE. The empathic module framework contains the evaluation of the 22 emotions by means of experimentation with users in order to have a selection of emotions and situations & events. The development phase will be carried out throughout next months.

The OCC model that describes the 22 emotions is developed in the later section 4.4.2

The first experimentation with users is described in the later section 4.4.4

The framework for the development phase and the foundations of the physiological signals processing is developed in later section 4.5 and section 7.

### 4.3. SUaaVE overview

SUaaVE will use two sources for a better understanding the passenger emotional state, much on the way on how emotions are treated in a social environment. From the one side, EmY will be aware of the **contextual factors** involving the experience in the Ego Car: the purpose of the trip (work travel, day shift, holidays, etc), the state of road (density of cars, weather conditions, safety envelop, etc). From the other hand, the Ego Car will be **monitoring the passenger** itself: behavioural aspects such as face expression, and bodily changes such as respiratory rate, heart rate and sweating.

These two sources complement each other to have a reliable understanding of the emotions on the passenger and allow ALFRED to use different approaches of emotion management. The analysis of the contextual factors allows an **anticipatory management** of the user state, while monitoring the passenger allow a **reactive management** of emotions.

A different methodology will be used in the analysis of emotions of these two sources. The analysis of contextual factors will use a categorical approach: The OCC model (Colby, Ortony, Clore, & Collins, 1989). The monitoring of the passenger will use a dimensional approach.

he OCC model presents a cognitive structure of emotions being one of the most used appraisal methods in the literature (Aly & Tapus, 2015; Becker-Asano, 2008; Gebhard, 2005).

Through this method, the passenger is described by a set of variables defining a group of individual categorized emotions. The trigger of the emotion is related to the events, agents and objects that surrounded the individual. A full description of this theory is developed in next subsection.

On the other hand, the dimensional model is a bi-dimensional model of valence-arousal dimensions. The passenger will be instrumented for recording several physiological signals (HR variability, GSR, among others) in order to obtain the individual's valence-arousal value and its trend in real time through signal processing and analysis. A full description of this method is developed in next subsection.

The data obtained via these two methods, together with extra information acquired by cameras, will be combined in order to achieve a more robust map of the passenger state Figure 7. with the objective, in following work packages, of designing strategies to recover from negative emotional states (i.e. provide more information about the trajectory to reduce the level of fear) and to reinforce the positive emotional ones (i.e. arrived in time successfully, give information of having saved time following that route).

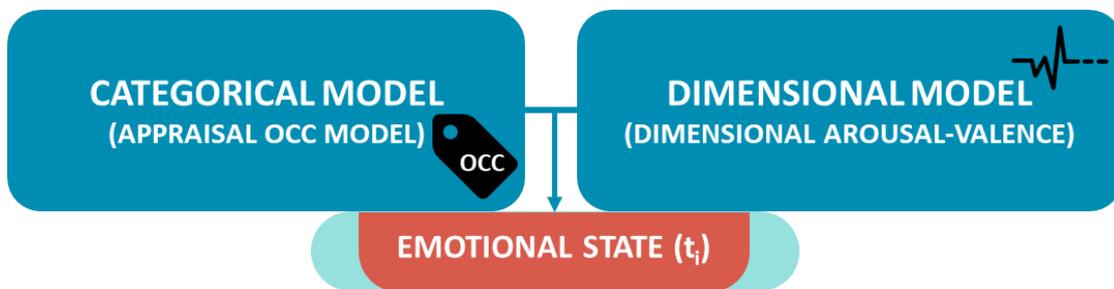


Figure 7. Schematic representation of the two approaches that build the emotion recognition model: categorical and dimensional model.

#### 4.4. Categorical appraisal emotional model: the OCC model

##### 4.4.1. Introduction

Appraisal theories treat the key aspects of situations as triggers that cause an emotion, which are conceived as a reaction that happens after the “bullet is fired”. Contrary to some constructivist point of view who defense that the emotions are reactions indeed, but constantly copied and learnt. So, the challenge to build such a theory, an appraisal theory of emotions is describing in which way the reactions are originated and organized, and in which way they are fixed or changeable,

The issue then becomes in answering how organized, routinized, and stereotyped such responses are; whether they are fixed or variable, individual-specific or universal. Different appraisal theories have their specific treatment of the issue, some emphasizing in the structure, other in the process. In definition, appraisal is the process that must occur before an emotion appears, being this process a fixed or a variable sequence (Scherer et al., 2010). In the literature, there are many authors who build a model adopting this (Bates, 1992; Becker-Asano, 2008; Gebhard, 2005), and the OCC model developed by (Colby et al., 1989) was chosen as the basis to build an affective model adapted to the Autonomous Car case.

#### 4.4.2. 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.

There have been many authors who implemented the model and attempted to apply the structure, although few developed it in a complete and logical way.

The present methodology pursues 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 six global reactions are the ones that are differentiated in more specific reactions that will be the ones defined as “emotions” (Figure 8). The reactions to **events** that cause the pleased vs displeased reactions can be divided into three groups:

**Fortunes-of-others:** this group focuses on the consequences for oneself of events that affect an external agent. Example: Feeling pleased/displeased because something good/bad has happened to one’s relative, “the girl felt pity for his brother when he failed an exam that he had been preparing for a very long time”.

**Prospect-based:** This group focuses on the consequences on one-self related to a preconceived prospect. Example: Feeling pleased/displeased because something good/bad has happened to one-self, “the girl felt disappointed when her flight was cancelled”.

**Well-being:** This group also focuses on the consequences on one-self related to the well-being. For example: Feeling pleased/displeased because something good/bad happens to me, “the girl felt joyful for she got a message informing her of an inheritance she got”.

The reactions to the actions of **agents** are included in the **Attribution:** this group focuses on the judgement of the action of other. For example: Feeling approval/disapproval for the good/bad action of someone (one-self included), “the girl felt reproach to a driver who did not stop to let a pedestrian cross a crossing-zebra”.

And the reactions to **objects** are in the group called **Attraction:** this group focuses on the reaction produced by a passive object. For example: Feeling likeness/dislikeness for an object, “the girl loved the song she was listening to”.

There are also compound groups:

**Well-being and Attribution:** this group involves both well-being and attribution, that is to say the reactions to both an agent action and an event. For example: Being pleased/displeased for the consequence of a good/bad consequence of a good/bad action of someone (one-self included), “the girl felt gratitude to her mentor because thanks to his good teaching, she did a perfect work with her master thesis”.

In fact, the emotions tend to be elicited in order: first as a reaction to an event, then to someone’s action, then to an object. There are some who talk about basic and complex emotions, but the definition of each it is still not clear. In this approach it is conceived a complex emotion as the one that involves more than one of the branches of the system (Event-based and Agent-based). The names of all 22 emotions classified in the different branches are shown in Figure 8.

This theory excludes of being named emotions to those states that are associated with a valenced reaction. For instance, being abandoned that implies a displeased state, can give rise to other emotional states like resentment or reproach.

### How are the reactions appraised?

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 (Table 1).

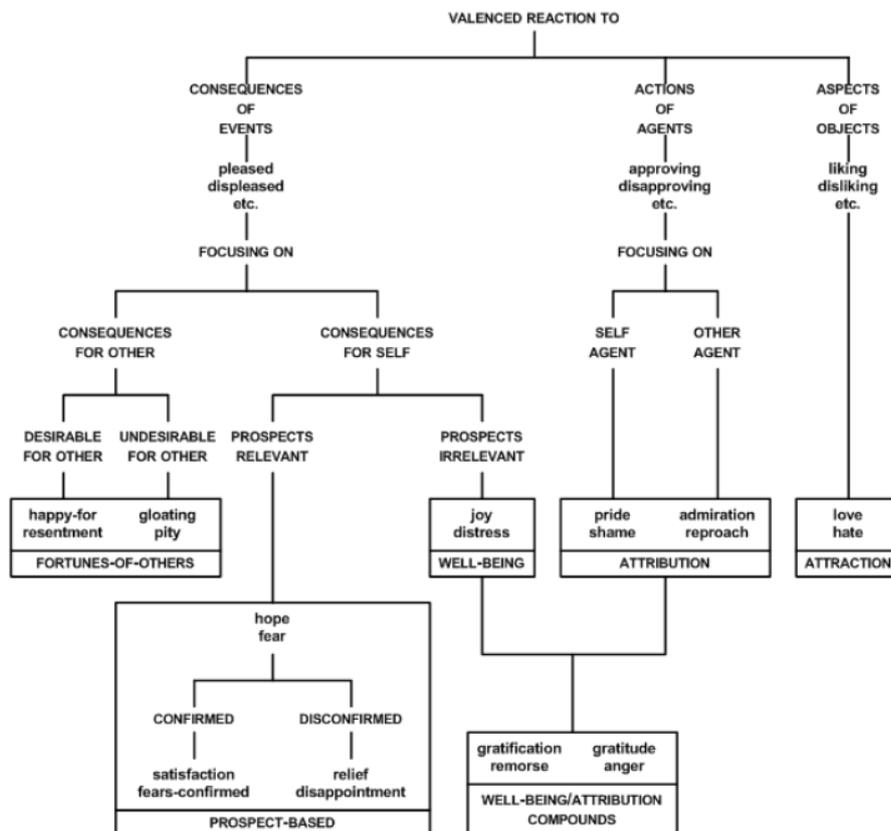


Figure 8. Whole representation of OCC model, in which the emotions are defined depending on the elicitor of the reaction and on the receivers of consequences (Colby et al., 1989).

### With how much intensity?

The intensity of the emotions is defined by **local variables** and by **global variables** (Table 1). The **global variables** affect to all groups of emotions and tells the degree of intensity of the experience:

**Sense of reality**: depends on the degree in which one believes the situation inducing the emotion is real.

**Proximity:** depends on the degree of psychological proximity one has to the situation inducing the emotion.

**Unexpectedness:** depends on the degree in which one is surprised by the situation inducing the emotion.

**Arousal:** depends on how much one is aroused before the situation inducing the emotion.

The local variables affect to specific groups of emotions:

- Related to prospect-based:

**Likelihood:** degree of belief that an anticipated event will happen

**Effort:** degree in which the resources were invested in obtaining or avoiding the event

**Realization:** degree in which the event actually occurs

- Related to Fortune-of-others:

**Desirability-for-other:** the evaluation of the desirability of others' goals

**Liking:** the degree in which one is attached to the other person

**Deservingness:** the degree in which one thinks the other person deserves what occurred

- Related to Attribution:

**Strength of cognitive unit:** how much one identifies with the agent

**Expectation-deviation:** how much the agent's action deviates from ones' standards

- Related to appealingness:

**Familiarity:** the degree in which an object is familiar

Variables	Indicates the degree to which	
<b>Global</b>	Sense of reality	emotion-inducing situation is real or not
	Unexpectedness	situation is surprising or not
<b>Central</b>	Desirability	an event is desirable or undesirable
	Praiseworthiness	an agent's action is or isn't praiseworthy
	Appealingness	an object or a concept is attractive
<b>Local</b>	Desire-for-other	an event is desirable for the other person
	Liking	the other person is attractive
	Deservingness	the other person deserves what happened
	Likelihood	belief that an anticipated event will occur
	Effort	resources were expended in obtaining or avoiding an anticipated event
	Realization	an anticipated event actually occurs
	Strength of Cognitive Unit	one identifies himself with the person or the institution who is the agent of the emotion-eliciting event

Expect-Dev	an agent's action deviates from expected norms
Familiarity	an object is familiar

Table 1. definition of variables 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).

<b>Joy</b>	(pleased about) a desirable event
<b>Distress</b>	(displeased about) an undesirable event
<b>Happy-for</b>	(pleased about) an event presumed to be desirable for someone else
<b>Pity</b>	(displeased about) an event presumed to be undesirable for someone else
<b>Gloating</b>	(pleased about) an event presumed to be undesirable for someone else
<b>Resentment</b>	(displeased about) an event presumed to be desirable for someone else
<b>Hope</b>	(pleased about) the prospect of a desirable event
<b>Fear</b>	(displeased about) the prospect of an undesirable event
<b>Satisfaction</b>	(pleased about) the confirmation of the prospect of a desirable event
<b>Fears-confirmed</b>	(displeased about) the confirmation of the prospect of an undesirable event
<b>Relief</b>	(pleased about) the disconfirmation of the prospect of an undesirable event
<b>Disappointment</b>	(displeased about) the disconfirmation of the prospect of a desirable event
<b>Pride</b>	(approving of) one's own praiseworthy action
<b>Shame</b>	(disapproving of) one's own blameworthy action
<b>Admiration</b>	(approving of) someone else's praiseworthy action
<b>Reproach</b>	(disapproving of) someone else's blameworthy action
<b>Gratification</b>	(approving of) one's own praiseworthy action and (being pleased about) the related desirable event
<b>Remorse</b>	(disapproving of) one's own blameworthy action and (being displeased about) the related undesirable event
<b>Gratitude</b>	(approving of) someone else's praiseworthy action and (being pleased about) the related desirable event
<b>Anger</b>	(disapproving of) someone else's blameworthy action and (being displeased about) the related undesirable event
<b>Love</b>	(liking) an appealing object
<b>Hate</b>	(disliking) an unappealing object

Table 2. Definition of the OCC model 22 emotions.

The whole definition of the emotions includes the type specification (Table 3), tokens and the variables affecting intensity, as an example:

RESENTMENT EMOTION	
TYPE SPECIFICATION	(displeased about) an event presumed to be desirable for someone else
EXPRESSIONS	Envy, jealousy, resentment, etc.
VARIABLES THAT AFFECT THE INTENSITY	The degree to which the desirable event for the other person is undesirable for oneself
	The degree to which the event is presumed to be desirable for the other person
	The degree to which the other person did not deserve the event
	The degree to which the other person is not liked
EXAMPLE	The executive resented the large pay raise awarded to a colleague whom he considered incompetent

Table 3. Example of full definition of emotion in the OCC model.

The process planned to detect the emotions using the OCC model can be split into five phases:

1. Classification: In the classification an event, action or object is evaluated, and through the information it is determined what emotional categories are affected. **Example: “A car gets into the lane where the CAV is at high velocity”. In terms of the OCC, this is a goal blocking event, produced by the action other car, who is the agent.**
2. Quantification: In the quantification phase, the intensity is also quantified depending on the affected emotional categories and on the specific user. **Example: The passenger experiences fear, because of the prospect of suffering an accident, that involves injuries, which implies high intensity of emotion felt.**
3. Mapping the OCC model distinguishes 22 emotional categories. These need to be mapped to a possibly lower number of different emotional expressions. **Example: The emotions felt are fear and/or anger with a specific probability each, depending on the data on the database.**
4. The classification is evaluated through other detection methods or through the user’s feedback. **Example: through the detection methods such as cameras and physiological signals, and the profile of the passenger. It is discriminated that the emotion was fear.**
5. Classification tool is improved. **Example: the car learns that this event causes fear to this passenger, the probability of fear related to this event increases for the next time that happens.**

### 4.4.3. Related work using the OCC Model

It is interesting to review other authors who based their work on the OCC Model. In the work Reichardt (2008), the purpose was to generate a believable behaviour of a simulation of a driver by using the OCC model to describe the emotional influence on the decisions when driving. In their work, they build learning algorithms that are intended to be used later for designing adaptive driver assistant systems. They use the OCC model for imitating the human reactions using a model of risk. They present a simulation of environment and the application to a case of driver assistance system.

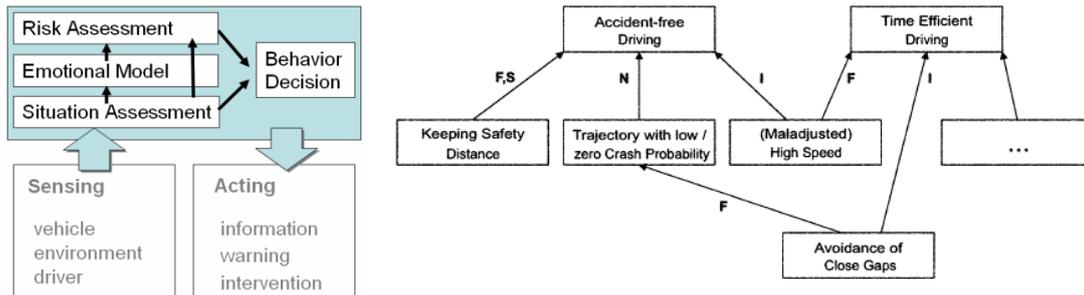


Figure 9. On the right, the scheme of interaction machine-user proposed by Reichardt (2008). On the left, definition of goals at examples of traffic situations by Kraus, Althoff, Heissing, & Buss (2009).

With the aim of increasing the acceptance of autonomous cars Kraus, Althoff, Heissing, & Buss (2009) worked to the idea of making the driving style more human-like. Also, when the actions and current state of the vehicle are more transparent to the passengers, the acceptance increases. They implement emotions basing on the OCC model in the autonomous car with the purpose to make it capable of adapt to situations in a specific way, they present the case of two lanes merged in one. The variables define the intensity of the emotions as described in the previous section. The elements and events happening in the driving environment were grouped and linked to the OCC model as follows:

Attitudes (evaluation of characteristics of an object):

- Number of lanes (higher number of lanes relate to a positive state).
- Width of lane (wider lane relates to a positive state).
- Curvature of road the better (Bigger curvature relates to a positive state).

Actions of agents (evaluation of the actions according to the norms):

- formal: complying with traffic rules (related to positive state).
- informal: having a solidary attitude with other drivers (related to positive state).

In relation to the events on the traffic scenario, there are defined a set of goals and subgoals:

Goals:

- Accident-free Driving.
- Time Efficient Driving.
- Avoidance of Close Gaps.

Subgoals:

- Keeping Safety Distances.
- Trajectory with low/zero Crash.
- Probability and (Maladjusted) High Speed.

In our project a similar procedure will be followed, the events and actions will be linked to the OCC model.

Besides, the work of Trabelsi & Frasson (2010) resulted really interested for the project and inspire some of the steps followed in the SUaaVE development phases involving the design of Use Cases, Experimentation Design and Classification tool.

In their work, the authors use the OCC model in order to build an intelligent algorithm “The Emotional Machine” that detects the emotion of an individual depending on the situation happening and on a series of parameters concerning the individual personality. The authors distribute their procedure in three steps.

- The first step consisted on requesting a group of users to describe situations that would elicit each of the 22 emotions proposed by Colby et al. (Colby et al., 1989).
- Then, a different group of users was asked to evaluate and give scores to the variables defining a selection of the situations described by the previous group.
- Later, a third group of users were asked to tell the emotion and the intensity of it when they were shown the battery of situations.

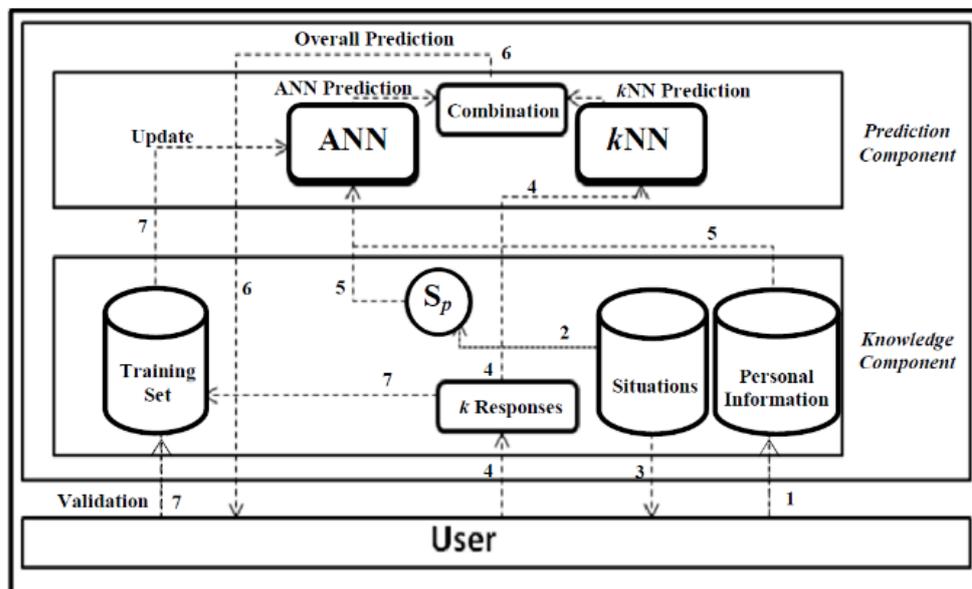


Figure 10. Classification algorithm designed by Trabelsi & Frasson (2010)

This way, the database created contained a bunch of described situations, parametrized in terms of OCC variables and with the associated emotions and intensity. The idea is to create an algorithm (Figure 10) that, being fed by these data, and using Artificial Neural Network algorithms (ANN) and  $k$ -Nearest Neighbors ( $k$ NN), is capable to tell the emotion felt by an individual knowing the situation he or she is experiencing together with some info about his or her personality and general characteristics like precedence or sex. They also obtain and show some attractive results, because they are capable of getting a 64.83% for 23 (22 of OCC

and the “no emotion” state) classes of emotions, 72.24% for nine, and 86.90% for three, all these results for intensities above 79.83%.

#### 4.4.4. SUaaVE approach

Based on the work Trabelsi & Frasson (2010), in the SUaaVE empathic module an emotion prediction machine will be build based on the OCC model. A methodology is designed for this purpose:

- A first experimentation with user was carried out with several objectives, such us:
  1. Build an OCC database with the entities of Emotion Elicitor Situation – Emotion elicited.
  2. Select and prioritize the most relevant emotions in the case of autonomous vehicle.
  3. Test and validate with users the selected as most relevant emotions & situations tested with the users that served as a base for OCC model structure aimed to build an emotion prediction framework for the autonomous vehicle.

#### Design of experimentation surveys

Based on different author’s frameworks, an ad-hoc methodological approach has been designed in order to obtain experiences linked with the 22 emotions proposed in the OCC framework.

In order to achieve objectives and obtain useful inputs for our OCC database it was crucial to plan an optimal research with users. In this sense, following topics related to the research with users are explained more in detail:

1. Digital qualitative research (Recollective) as the proper tool to collect information from users on experimentation surveys.
2. Participants profile and recruitment specifications: screening and recruitment procedure.
3. Research design and procedure.
4. Results obtained.

#### Digital qualitative research: Recollective

Among different methodologies and techniques to obtain information from users, qualitative research was considered the optimal one in this case, as open-end comments, feedback, ideas were the most suitable approach in order to get real and proper situations linked with the 22 emotions from users and their experience with driving. Also, digital qualitative research with bulletin boards was elected as the proper tool, as allows participants to answer and share with researchers information during several days (5 days in this case) and in different moments of the day. A digital approach enables reflex ion and think more about the situations as gives freedom to participants to answer in different moments of the day without the handicap of being face to face with the researcher (for example in a focus group, interview, etc.) and this allows users to feel more comfortable and let them be more reflexive and creative in their answers.

Tool used in the research was Recollective, an online research platform for developing insights communities and conducting qualitative research studies. This platform enables us

to get Insights in real time, in real contexts of use (example: home, car, etc.) as well as the possibility of generating interactive engagement with users. It allows to obtain insights of users from different parts of the world and to obtain a wide variety of outputs.

Recollective is a powerful and flexible platform ideal to carry out a wide of qualitative research such us: concept testing, behavioral studies, customer feedback, Co-creation & ideation, ethnographic.

Recollective platform was used for participants in Spain, while in Italy the study was replicated with same procedure but with SurveyMonkey platform, also online.

### Participants profile and recruitment specifications

In order to get useful and rich information from participants is necessary to elect the most suitable profile, and in this stage of research participants elected must meet the following requirements in order to participate:

- Driving licence and being a driver of a regular car (it is usual to take the car as a driver at least once a week, no matter the route).
- Have a Smartphone and/or tablet and be an active user of it, as research was developed using a digital platform (Recollective).
- Person interested in trying new products
- A person with a certain creative sensitivity, imagination and who feels comfortable expressing themselves in writing.

Also, soft quotas based in gender and age were considered, being flexible in deviation but trying to reach these quotas (Figure 11):

- Gender: 50% sample women and 50% men approx.
- Age: 18-25 years old (20% sample) // 26-35 years old (30% sample) 36 a 49 (30% sample) // 50 and more years old (20% sample).

Image below show final participant's distribution in a sample of 45 participants in total, considering Spain and Italy.

### SAMPLE PROFILE: GENDER, AGE , COUNTRY & DRIVER PROFILE

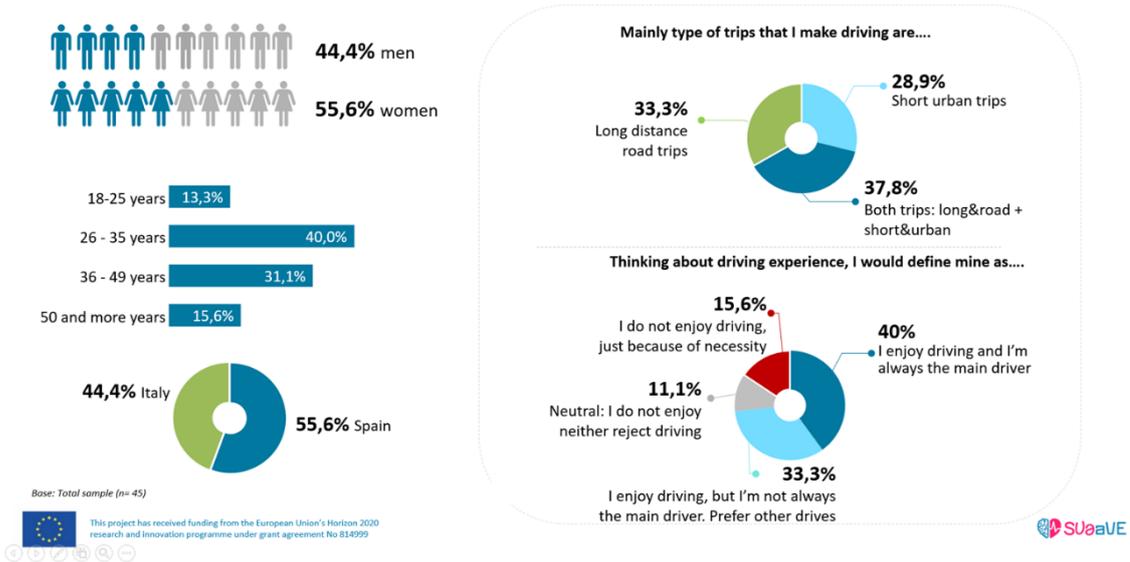


Figure 11. Final participants distribution in a sample of 45 participants (Spain and Italy)

### Research design and procedure

Research was planned in a temporary framework of 5 days and participants must enter to the platform each day and answer different tasks. 22 emotions questions linked to situations while being in the autonomous car that participants must imagine and describe, were divided in different blocks per days in a random way. Also, last day participants must prioritize and rank positive and negative emotions.

Digital qualitative research generates a close relation between participant and moderator and there is interaction during all 5 days enabling rich feedback and engagement with the study and most important with the topic of it.

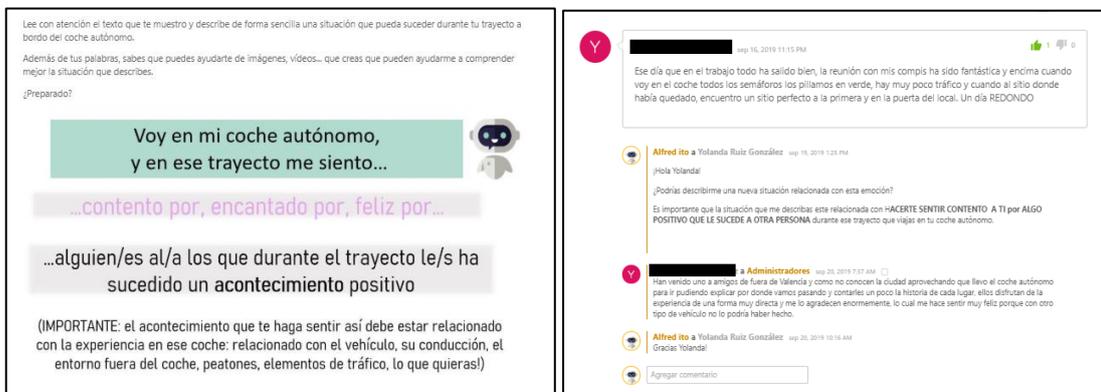


Figure 12. Screenshots of the Recollective study, to the left, the structure in which a question about an emotion is formulated in Spanish; in the right example of interaction with users

Platform also allow participants to support their description linked with the 22 emotions with different inputs such as videos, images to illustrate and support the idea and thoughts they were sharing in the study.

First day was presented a short introduction and a video (Figure 13) to present participant autonomous car in a simple way and made them feel immerse in the “story” that all situations they were going to describe might be keeping in mind that they were in their own autonomous car. It was a first day immersion session that enabled during the 5 days this feeling of immersion in the autonomous car driving experience and obtain all the information keeping this idea always in mind.

All 22 emotions were presented following the same structure, introduction text and image to avoid bias (Figure 12).



Figure 13. Immersive video presenting the scenario of travelling in the CAV result of SUaaVE project

### Results obtained

With a total simple of 45 valid participants that successfully finished the research, a total amount of 990 situations linked with 22 different emotions proposed in OCC model were satisfactory obtained.



Figure 14. Example of results obtained through the experimentation. Prioritization of emotions

These results obtained in this stage of experimentation with users served as an optimal base of information linked with driving experiences and emotions than enables prioritizing the most relevant ones in global terms (Figure 14), in order to proceed to test in a final stage of experimentation and testing with users in Spain and Germany to validate results.

#### 4.4.5. Example of link of scenarios with the OCC perspective (events, agents and

As stated by the authors Kraus, Althoff, Heissing, & Buss (2009), some of the factors are described in terms of the emotion elicitors of the OCC model.

Attitudes (evaluation of characteristics of an object):

- Number of lanes (higher number of lanes relate to a positive state).
- Width of lane (wider lane relates to a positive state).
- Curvature of road the better (Bigger curvature relates to a positive state).

Actions of agents (evaluation of the actions according to the norms):

- formal: complying with traffic rules (related to positive state).
- informal: having a solidary attitude with other drivers (related to positive state).

The most relevant goals and subgoals for a passenger in a driving trip are described as:

Goals:

- Accident-free Driving.
- Time Efficient Driving.
- Avoidance of Close Gaps.

Subgoals:

- Keeping Safety Distances.
- Trajectory with low/zero Crash.
- Probability and (Maladjusted) High Speed.

In Section 8.1, it will be elaborated a collection of factors. But, as a first approach in order to illustrate the point of view within the OCC model, find bellow in Table 3 with a first link among elements and OCC agents, actions, events and objects.

<b>Traffic</b>	- Group of Events (goal promoting or goal blocking)
<b>Road</b>	- Group of Events (goal promoting or goal blocking)  Attitudes (evaluation of characteristics of an object)
<b>Visibility</b>	- Group of Events (goal promoting or goal blocking)  - Attitudes (evaluation of characteristics of an object)
<b>Maneuver</b>	- Group of Events (goal promoting or goal blocking)  - Actions of agents (evaluation of the actions according to the norms)

Table 3. Link between environment factors and OCC model.

## 4.5. Dimensional emotional model

### 4.5.1. Introduction

As reviewed in previous sections, a dimensional model state that the emotional response can be continuously rather than discretely mapped in a n dimensions space. These kind of emotion models focus on the subjective component of emotion, the one that an individual is not aware of.

The emotions influence the autonomic nervous systems (ANS) implying an activation of the skin and on the cardiovascular and respiratory systems. There are sensors and particular design of measurements, in order to detect the emotions through this approach. The information is commonly obtained through questionnaires, in which the individuals can rate a certain number of emotions in a scale of intensity or valence, collects conscient perceptions of the individuals about their state. Also, by means of facial expression by movement on specific muscle regions, via brain activity detection, to characterize activations in the ANS in order to differentiate emotions. And finally, by heart rate and other physiological parameters that will be reviewed later on.

The dimensional theories criticize the straitjacketed labels proposed by the discrete theories that create strict relationships between ANS responses and specific emotions. Up to them, there is not a unique behaviour answer to a specific emotion, for some of them are believed to be a defense or an instinctive reaction. By contrast the dimensional theories see the emotions more like action dispositions, for instance towards something pleasant or against something negative. The valence-arousal is one of the most accepted dimensional theories (Lewis, Haviland-Jones, & Barrett, 2008). Describing the two behavioural features as follows:

- Affective **valence** (positive/negative).
- Intensity of activation, the **arousal**.

The **valence** is seen as either the response comes as an appetitive or an aversive action, and the **arousal** is the level of activation of the appetitive or aversive system. Many studies are centred in the heart rate changes due to the reaction and relate them mainly with the valence, and the changes in the skin conductance with the intensity.

The most common measurement is electromyograph (EMG) signals, heart rate (HR) variability, galvanic skin response (GSR), electroencephalography (EEG), respiration rate and temperature, among others (Berntson, Cacioppo, & Quigley, 1993).

#### 4.5.2. SUaaVE approach

The SUaaVE approach concerning the dimensional **Valence-Arousal** model of emotions is described in Section 8.

Steps that compose the workplan:

- Bibliographic review.
- Pilot measurements with users.
- First analysis.
- Refine model.
- Measurements of 1<sup>st</sup> loop.
- Definitive analysis.

## 5. Approach to the observation problem

### 5.1. Introduction

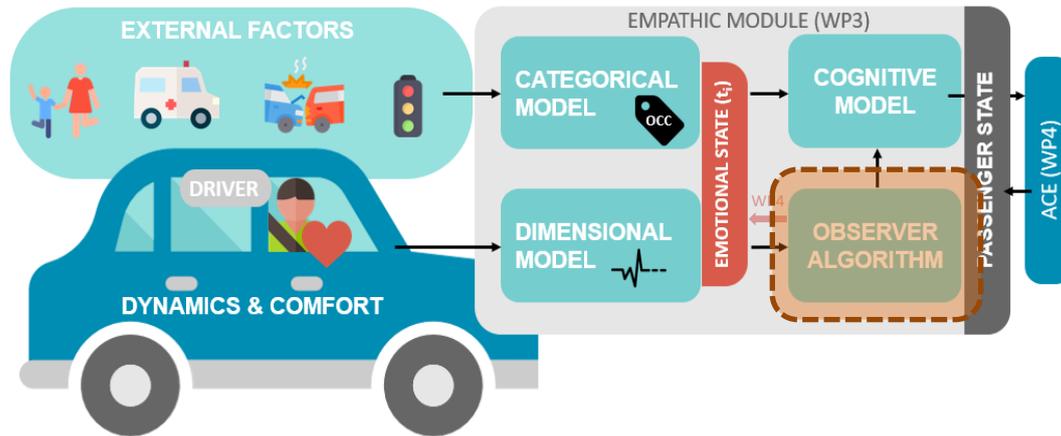


Figure 15. Observer algorithm inside the illustration representing the elements involved and the work to be developed in the WP3

In Section 7 we discussed the classification of passenger’s emotional state using physiological measures combined with cognitive approach. External stimuli, for example lateral/longitudinal acceleration of a vehicle, play a significant role in changing a passenger’s emotional state. Simple notions of cognitive psychology are sufficient to appreciate that our emotional response typically behaves in a dynamic manner; our emotional state is a direct function of influencing factors (external stimuli, or system input in a system-theory formulation, in particular when considering a state-space representation, see (Khalil, 2002)). External stimuli play a significant determining role in the evolution of our emotions; therefore, those factors are considered when determining a passenger’s emotional state. The relation from stimulus to state is not direct but described by a dynamic map explained in detail in next sub section.



Figure 17. Scheme of the workflow of the observer algorithm, being the stimuli the input, and the action of the dynamical model the output

## 5.2. SUaAVE approach to the dynamic emotion observation

External stimuli account for the reason to change in emotional state of passengers. The relation from stimulus to emotional state is described by a dynamic map (system-theory formulation) of the following form with some noise.

$$\dot{x}(t) = f(x(t), u(t)), \quad x(0) = x_0, \quad t \geq 0, \quad (1)$$

$$y(t) = h(x(t)), \quad (2)$$

Where  $x(t) \in \mathbb{R}^n$  represents the state vector that describes the emotional state of the passenger,  $y(t) \in \mathbb{R}^m$  is the output vector composed of physiological measures. Similarly,  $u(t) \in \mathbb{R}^p$  is the input vector that describes the relevant aspects of the vehicle's road behavior which has impact on emotional state i.e. external stimuli vector. The first part of (1) reflects the dynamics of the emotional response whereas the second part describes the impact of relevant variables of vehicle's road behavior, for example lateral/longitudinal/vertical acceleration of a vehicle, on the emotional dynamics of the passenger.

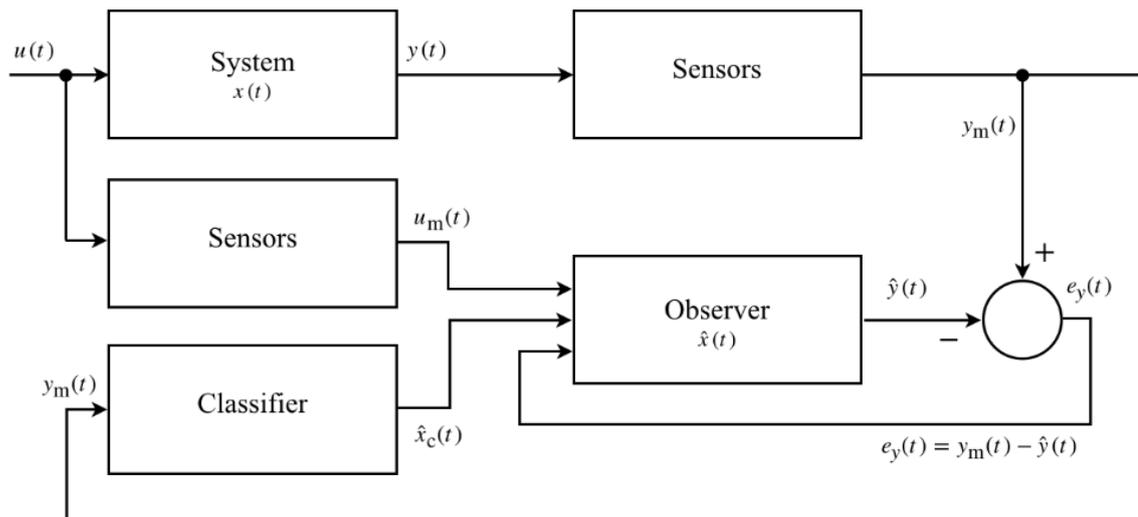


Figure 18 Schematic representation of considered observation problem

Figure 18 shows the schematic representation of the considered observation problem. The considered system describes the subject's emotional response. Its output  $y(t), t \geq 0$  is a set of physiological variables.  $u_m(t)$  is measured relevant stimuli and  $y_m(t)$  is measured output. Similarly,  $\hat{x}_c(t)$  is the outcome of the emotion classification procedure as discussed in section 5.

All these measures and estimates are used together to support observation of the system state  $x(t)$ . The model constitutes a tool that allows to gainfully exploit measures of relevant external stimuli to inform an emotional state estimate. The specifics of  $f(\cdot)$ , which describes the subject's emotional dynamics, provide information about on the way the person may react to a considered stimulus. It is a challenge to build a model that is faithful enough to appropriately describe the subject's reaction to external stimuli. Relying only on such a model may deteriorate the performance of this process. Thus, in order to exploit measures of

relevant external stimuli together with the measures of physiological signals an observer of the following form is constructed.

$$\hat{x}(t) = \varphi(\hat{x}(t), u_m(t)) + \gamma(e_y(t), \hat{x}_c(t)), \quad \hat{x}(0) = \hat{x}_0, \quad t \geq 0, \quad (3)$$

$$\hat{y}(t) = \chi(\hat{x}(t)), \quad (4)$$

Where  $\hat{x}(t) \in \mathbb{R}^n$ ,  $t \geq 0$ , is the observed estimate of the subject's emotional state  $x(t)$ ,  $u_m(t) \in \mathbb{R}^p$  represents the vector of measured relevant stimuli,  $\hat{y}(t) \in \mathbb{R}^m$  is the predicted output,  $e_y(t) \triangleq y_m(t) - \hat{y}(t)$  corresponds to an output error,  $y_m(t)$  is the measured output i.e. vector of physiological measures. Similarly,  $\hat{x}_c(t) \in \mathbb{R}^n$  reflects the outcome of a classification procedure (as discussed in section 5),  $\varphi(\cdot)$  is an estimate of  $f(\cdot)$  in (1),  $\chi(\cdot)$ , is an estimate of  $h(\cdot)$  in (2),  $\gamma(\cdot)$  is to be defined by designer, and  $n, m, p \in \mathbb{N}$ .

The set of equations (3)-(4) is typical form of Kalman filters or Luenberger-type observers (Kalman, 1960; Luenberger, 1966), where  $\varphi(\cdot)$  plays role of predictor (predicting expected change in state for measured stimuli), and  $\gamma(\cdot)$  that of corrector. The predicted emotional state is used in (4) to produce a predicted output (predicted value of physiological signals, for example, heartbeat rate, respiration rate, etc.), which is then compared to measured output (physiological signals measured using sensors). The resulting error  $e_y(t)$ ,  $t \geq 0$ , is used to correct the prediction. The corrective term  $\hat{x}_c(t)$  allows to consider the outcome of the emotion classification procedure, that is described in section 5, within the proposed observation framework.

As mentioned earlier, accuracy of the dynamics model i.e. how closely  $\varphi(\cdot)$  captures  $f(\cdot)$  is very important and the viability of the overall approach depends on it. More specifically, development of observation tools commonly relies on strong model knowledge assumption. To such an extent that, relaxing such assumptions typically undermines achievement of any type of observation guarantees (see the discussion in Morel & Leonessa (2009, 2010)). As pertains to the considered problem however, the existence of some measure of uncertainty on the system dynamics (1) is likely inescapable. Processes involved (of emotional response) are commonly described in cognitive psychology, but in qualitative terms. Quantitative representations or closed-form models, which may be of direct use in (1) are not common. Therefore, in the considered problem, the existence of some measure of uncertainty on the system dynamics is very likely.

Accordingly, we will follow a modelling process to develop sufficiently faithful models of the considered dynamics. Specifically, qualitative considerations developed in the cognitive psychology literature will be relied upon to define a general frame for the considered state-space model. A range of practical experiments will be conducted to collect the representative data, considering wide range of subjects. This data will be used to adjust the general model in such a way that it is represented. Different techniques like indirect adaptive approaches (Narendra & Annaswamy, 1989) supported by Q-modification scheme (Volyanskyy, Calise, & Yang, 2006) may be used for it. Alternatively, Gaussian regression (Rasmussen & Williams, 2006) may be used to adjust form of the model to reflect collected data, though such an approach requires transformation of the time-differential relation in (1) to an algebraic one. This is routinely achieved using, for instance nonlinear swapping (as discussed in (Krstić, Kanellakopoulos, & Kokotović, 1995)). Such techniques typically rely on nonlinear parametrization of uncertainty which is straight forward to satisfy. Right-hand-side of (1) can be approximated using a linear combination of unknown (uncertain) parameters and known nonlinear functions of the state and the input. The residual error, corresponding to the difference between this estimate (assuming ideal parameters) and the actual value of  $f(\cdot)$ , may also be represented (up to arbitrary accuracy) using such a linear parametrization

provided that  $f(\cdot)$  is a continuous function of its arguments. This directly follows from Weierstrass' approximation theorem (Jeffreys & Jeffreys, 2000).

### 5.3. Development phases

The development of observer algorithm in SUaaVE will be done in following four phases (Figure 19):

1. In the first stage we will build a closed form model, analyse it and develop the algorithm in such a way that we are able to guarantee its performance (accurate observation of passengers' emotional state). It involves step by step development of and testing of the different alternatives. We will try at least the following techniques: Luenberger, Bayesian and different approaches and derivations of Kalman filters.
2. After that, we will do numerical simulations in scientific software such as MATLAB.
3. In the third stage, we will bring hardware and computation in loop and improve the algorithm based on the experiments and the data gathered.
4. Finally, the algorithm will be tested on the dynamic testing platform and the final adjustments will be made. It is to be noted that after every stage, changes in the algorithm are very likely to be incorporated to improve its performance and make it more robust.

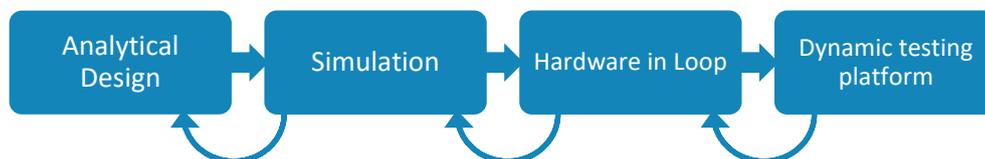


Figure 19. Scheme of development phases developed by TUM

## 6. Cognitive model framework in ALFRED

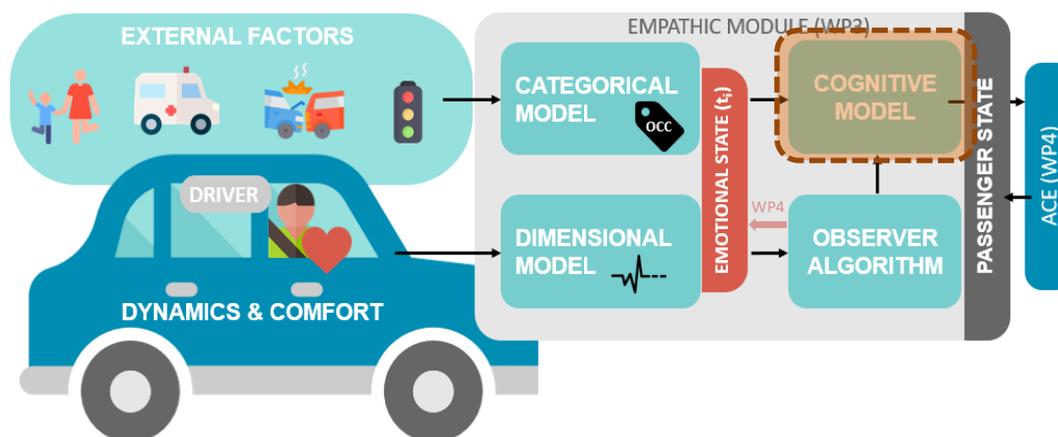


Figure 20. Cognitive model inside the illustration representing the elements involved and the work to be developed in the WP3

Bordeaux INP's participation in task T3.1 is part of the completion of task T3.3.

**Task T3.3** will allow to select the main factors of a general model specific to the driving situation and Test/update the cognitive model of the representation of passenger.

In the **Task T3.1**, Bordeaux INP will share its preliminary results to help IBV define of the Empathic Module framework. The work shared here is a preliminary synthesis of the reflection undertaken on the basis of the current state of the art. This state of the art was developed to enrich the preliminary model presented at the beginning of the study. A first model is proposed based on the state of the art. This model will be refined during the realization of the task T3.3.

### 6.1. Introduction: the preliminary model

#### 6.1.1. Context of the study

Alfred will serve the users by supporting and relaying them in various activities carried out during the trip. The execution of this service will be based, on the one hand, on settings made directly by the users, such as the choice of destination or ambient temperature, and on the other hand, on data that will provide Alfred with a representation of the cognitive state and information needs of the user according to the situation and the environment (e.g. traffic, weather, pedestrians, etc.). These measures may be based on physiological and behavioural indicators, or even on simple questions asked by Alfred to the user. However, Alfred's simulation of the user's mental representation may require extremely costly data processing in relation to the very large number of possible combinations.

However, since the objective of the SUaAVE project is based on a proof of concept, we will use a limited number of simplified models of mental representation (heuristics) of the user by Alfred. A processing based on heuristics will reduce the complexity of Alfred's input processing, while ensuring that the service he offers is representative.

### 6.1.2. Designing an HMI that simulates the cognitive representation of passengers

Besides conventional human-machine communication models, Alfred will be able to simulate and even anticipate mental states, such as stress, situational awareness or mental workload. To build an interaction based on models of mental representation of the user, it will be possible to rely on the research field relating to the processes of communication between humans. Some authors have described the construction of a common ground between two interlocutors, which corresponds, for example, to the activation in memory of concepts related to the discussion or context (e.g. Roger et al., 2013; Knutsen et al., 2019). Other authors have described the ability to simulate a speaker's perspective in order to better understand his intentions and actions in a given space (e.g. Schober, 1993; Tversky & Hard, 2009). This research area will be the subject of a bibliographic synthesis in order to select the main factors of a general model specific to the driving situation.

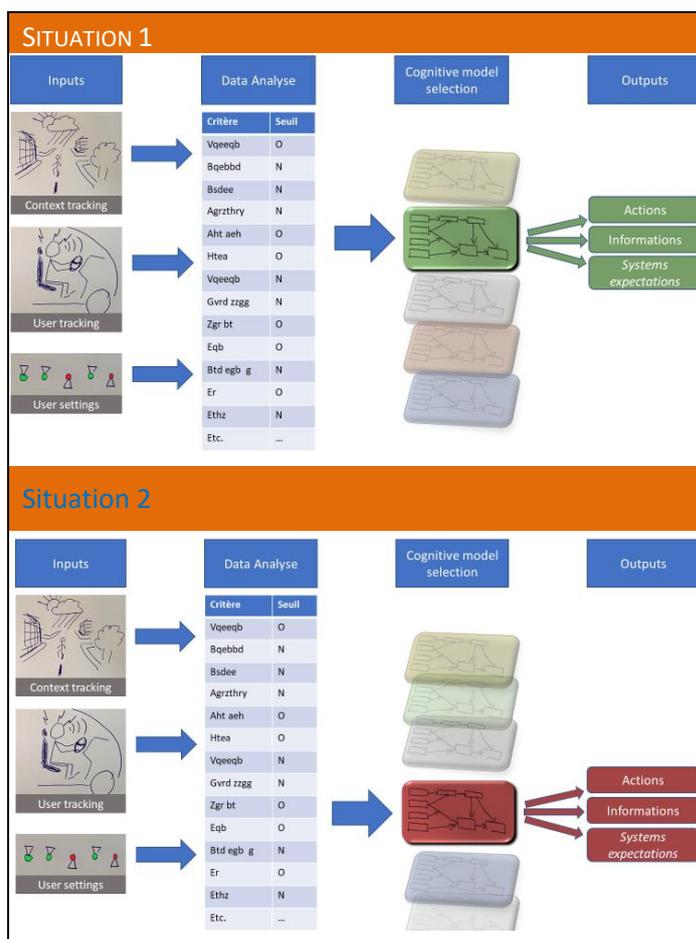
A second step of the study will consist to refine this initial model and to qualify the different variables/factors. For this purpose, interviews or focus groups will be conducted with role-playing exercises. They will make it possible to obtain the modalities of expression of each factor (variables), or even to complete the list of factors. Simulations can be made from driving videos. These would allow us to observe possible impacts of certain factors on mental workload or situational awareness. In addition, these scenarios will help to refine the user's "information needs", allowing him to act easily on the road situation (e.g. modify the route, retake control) or on the comfort setting.

In the end, from the data collected (e.g. stress, settings, objectives, road context, etc.), Alfred would be able to activate a cognitive model that is analogous to the user's actual cognitive state. As shown in Figure 21, the activated model will allow Alfred to adapt:

1. **The CAV "automatic" actions**, such as changing dynamics, paths, comfort parameters, etc.
2. **The salient information**, on the one hand to improve the user's situational awareness and the possibilities of interaction according to the situation, and on the other hand to reassure the user by informing him about the functioning of the autonomous system.
3. **Its expectations of data** (see Figure 21: system expectation), e.g. by prioritizing specific data, or even by directly asking questions to the user, in order to modulate its actions.

In other words, the user experience will be enriched, in one direction, by the mental representation model of the user that Alfred will have at his disposal, and in the other direction, by the information that Alfred will offer to the user so that he has an improved awareness of the situation and of the vehicle's actions. This reciprocity of representations will be included in the Empathic Module, that is a starting point for the principle of interaction with Alfred. It will also be necessary to take into consideration Alfred's choice of representation mode in order to be able to decide on his appearance (facial expressions, realism, empathic communication, Uncanny Valley paradox, e.g. Mathur et al., 2016).

**In the first example**, Alfred has selected a model in which (for example) the user wants to relax, but the deteriorated weather conditions can be a cause of anxiety. From a cognitive point of view, the user needs little information about the road, and needs maximum comfort to rest. Alfred then ordered the car to drive smoothly and played quiet music to reduce the sound of rain. If necessary, Alfred will favour a vocal/sound interaction to restore contact with the sleeping user. Alfred monitors the user's wake-up to possibly change some of the interaction modalities.



Block diagram of the integration of the cognitive model (Heuristic processing) into the Alfred system.

Inputs (environment tracking, user tracking/emotional model, setting...) are coded in a database. The database setting generates a heuristic selection in the cognitive model. This heuristic selection engages actions, information providing, and system expectations.

The drawings presented in inputs are not representative of the situations described in the examples below

Figure 21. Initial model of a heuristic processing of the passenger's cognitive state

**In the second example**, Alfred has selected a cognitive model in which the user is rushed, is out of time with his habits and the traffic context is complicated at the time of leaving school. Alfred activates dynamic driving mode but informs the user that conditions often require braking to anticipate any danger. Alfred provides the user with as much information as possible about the environment so that he or she is not surprised by the vehicle's reactions. This allows the user to anticipate the vehicle's movements. Thanks to the interface, the user can select a more comfortable driving experience at any time. Alfred does not drive the vehicle directly. But it remains attentive to a possible emergency situation to inform the user as soon as possible with a specific alert.

## 6.2. Main factors of a cognitive model specific to the driving situation.

To improve the acceptability of autonomous level 4 vehicles, the SUaaVE project is focusing in particular on the development of an empathic module. This module will make it possible to adapt the interaction and information offered by the vehicle in order to improve the comfort and quality of the information that the user can receive from the vehicle in different operating situations. This adaptation will be carried out by monitoring the activities and emotions of the driver and/or users, and by collecting data on the environment. To provide an effective and accepted assistance, the **principles of mental representation of space and action, user perspective by ALFRED**, as well as the **principles of trust** have been studied in detail to understand the cognitive processes on which the model presented below is based. This study is presented in the ANNEX 1 (A 1), and will be reported in detail in task T3.3

### 6.3. The preliminary model

Knowing a person's cognitive state is difficult both because of intra-individual variabilities and because of inter-individual variabilities. Indeed, everyone has variations during the day: level of fatigue (Marcora, Staiano, & Manning, 2009), stress (Selye, 1955), etc. In addition, there are differences between individuals: level of task control (Rasmussen, 1983), level of driver expertise (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010), work pace, attention capacity (Kahneman, 1973), etc. Nevertheless, many constants have emerged in the literature to estimate some cognitive components: visual behaviour (Freydier, 2014; Neboit, 1982; Wilson & O'Donnell, 1988), physiological reactions (Reimer & Mehler, 2011; Stasi, Antolí, & Cañas, 2013). It is these constants recognized and validated by the community that interest us in order to estimate the cognitive state of the subject.

#### 6.3.1. Purpose of the model

The purpose of this model is to determine when the driver is likely to have a poor situational awareness (Annex A 6). If all the conditions for the development of a good situational awareness are met, it is still impossible for us to determine with any confidence if the driver really has a good one. Indeed, despite the measurement of physiological and behavioural variables in correspondence with the elaboration of a good situational awareness, it is impossible for us to determine if the processing of sensory information is correct, if the selected situation schema is correct, if the selected action procedures are in correspondence with the goal (Annex A 1, A 2 and A 3). The solution would be to ask the driver to explain the recognized situation via the interface. This solution is time-consuming for the driver, who will be constantly busy with the assistant. In the best possible conditions, ALFRED cannot know the driver's situational awareness and cannot adapt the car as it should. In order to solve this, 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.



The initial model was modified according to the elements found in the literature (Annex A 5 and A 6). This refinement provides the basis for our reflection to follow this paper. Input estimates the cognitive components. These cognitive components are input into the algorithmic model. At the end of this model we find the cognitive state of the driver and the recommendations for ALFRED. It is possible to loop with the driver's current cognitive state and potential events to obtain the driver's future potential cognitive state.

In the following sections we explain the selection constraints and what are these cognitive components. Once the cognitive components were selected, we were able to determine the inputs, the acquisition of these inputs, the estimation of the cognitive components and the estimation of the cognitive state according to the cognitive components.

### 6.3.2. Concept selection: cognitive components and variables

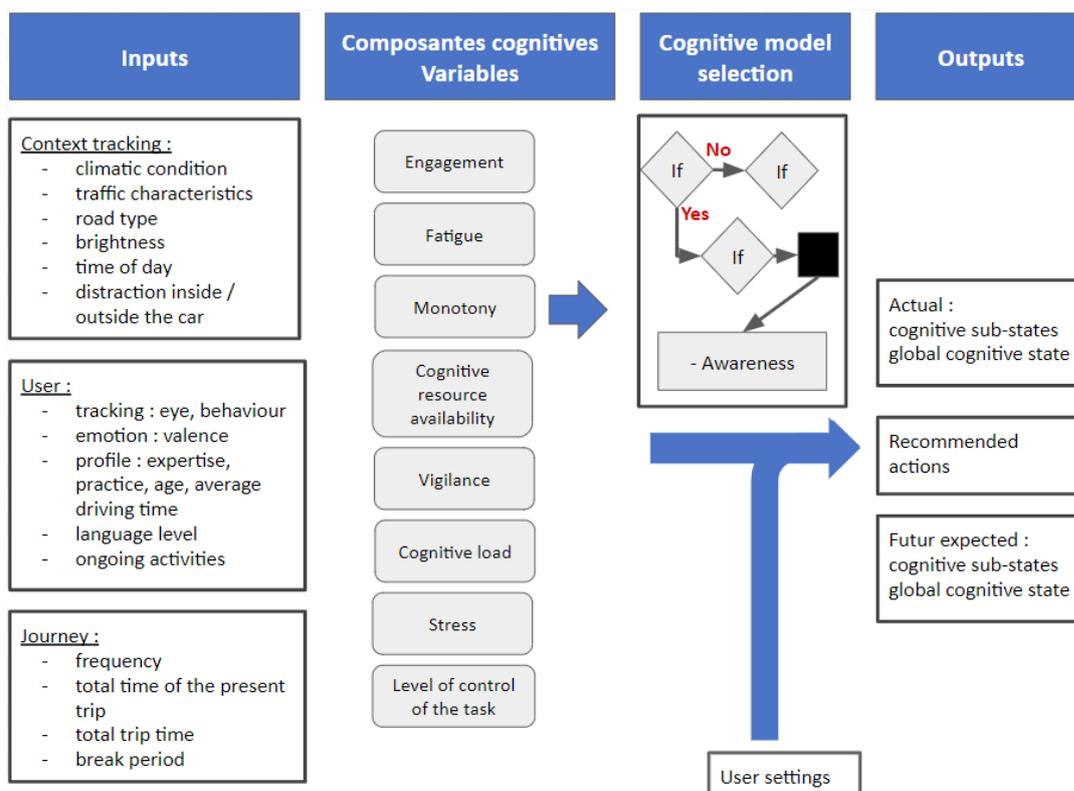


Figure 22. Update of the passenger's cognitive state model

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 and safe manner. These constraints limited the selection of concepts.

From the literature we have selected 10 cognitive components and associated variables:

- engagement (Witmer & Singer, 1998),
- fatigue (Marcora et al., 2009),
- path monotony (Manly, Robertson, Galloway, & Hawkins, 1999),
- cognitive resource availability (Brusque et al, 2011),

- vigilance (Coenen, 1998),
- cognitive load (Cegarra & Chevalier, 2008),
- stress (Selye, 1955),
- task control level (Tattegrain-Veste, Bellet, Pauzié, & Chapon, 1996),
- driver expertise (Leplat, 1995),
- distractions (nature and appearance time) (Shaffer & Shiffrin, 1972).

The majority of these cognitive and variable components are calculated directly with physiological and behavioural 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. And it is the state of this situational awareness combined with the cognitive components that define the cognitive state of the driver.

### 6.3.3. The model inputs

In the model determining this cognitive state, several inputs are required to calculate the variables and estimate the cognitive components. There are 3 dimensions:

- context tracking,
- user,
- and current journey and statistic.

#### Context tracking

The evaluation of this dimension consists on the one hand in evaluating the constraints and requirements of the situation: climatic condition, traffic characteristics, road type, brightness, time of day, distraction inside / outside the car. On the other hand, it makes it possible to estimate different estimators of the driver's mental load (Boag, Neal, Neal, Loft, & Halford, 2006): number of cars to monitor, increase in temporal proximity.

This dimension also makes it possible to contextualize other measures and identify situations at risk of over-resourcing for each driver.

#### User

Driver characteristics measured by observing the driver's behavioural and physiological changes assess the driver's sensitivity to the situation. The following data are measured or recorded:

- tracking (eye, behaviour),
- emotion (valence),
- profile (expertise, practice, age, average driving time, language level, capacity word load),
- ongoing activities.

### Current journey and statistics

This is a central dimension of the difficulty of the driving task. The journey and break times must be respected in order to prevent risky situations. The total time of the present trip, total trip time and break period are the elements for deducting cognitive exhaustion. Some statistics reflect the driver's driving habits: frequency of the trip and the portion of the road.

#### 6.3.4. Recording model inputs

We presented the different inputs of the model. We now detail the methods of recording the inputs, which can be used to calculate the various components and variables.

Some inputs are variables saved in the driver's profile. They must be recorded before the vehicle is used in circulation. These variables are measured or recorded using:

- questionnaires and cognitive tests during the initialization of the driver's profile: language level, working memory capacity, pace of life, etc.
- car initiation circuit: measurement of basic variables such as basic pupillary dilation, frequency of fixation of areas of interest, dispersion of the gaze, etc.

These variables should be compared with the variables recorded in real time during the journeys. These data are recorded by different sensors in the car: pupillary diameter, heart rate, visual behaviour, distractions, weather conditions, driving time, etc.

Once these data have been acquired, their integration will make it possible to estimate the cognitive components.

#### 6.3.5. Estimation of the cognitive components and variables of the model

A cognitive component is estimated with a set of inputs. 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.

#### 6.3.6. 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.

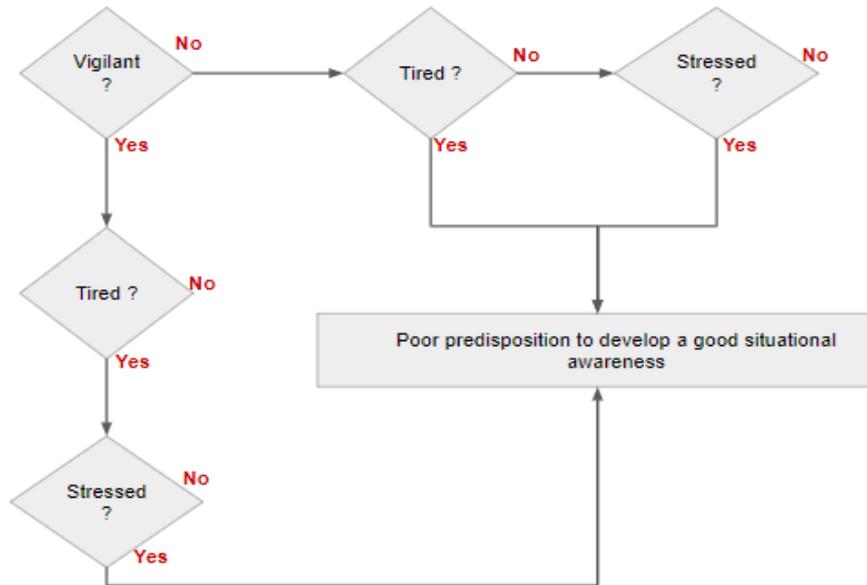


Figure 23: Estimate of the driver's initial condition when he gets into the car

The literature describes methods for stress regulation (Peressutti, Martín-González, García-Manso, & Mesa, 2010), 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

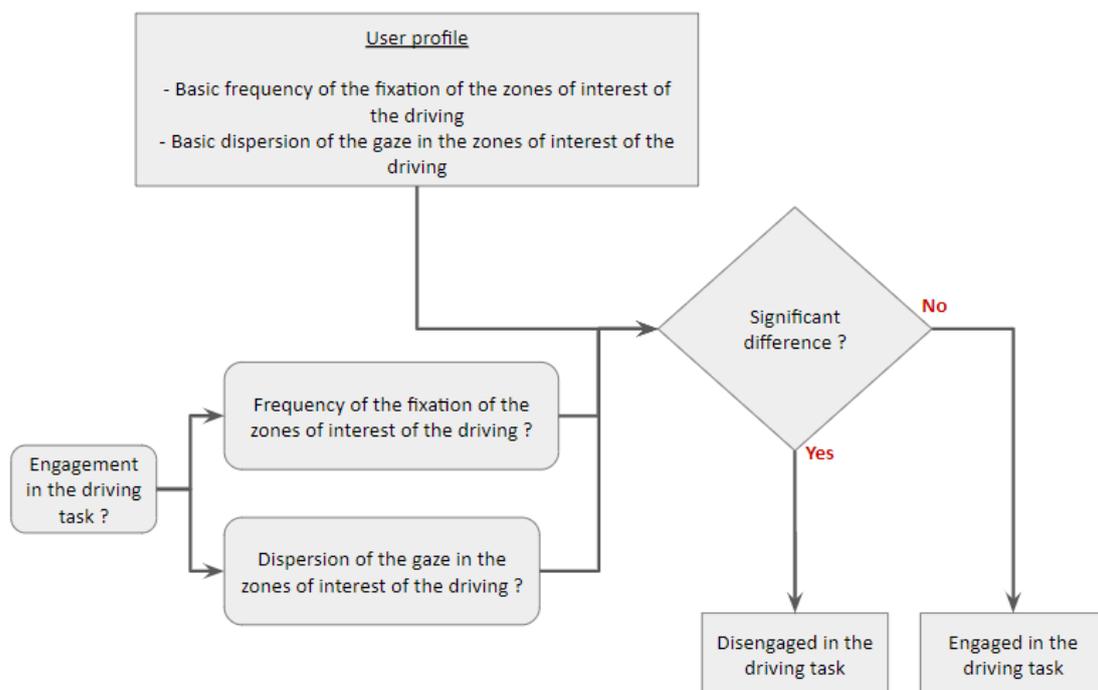


Figure 24. Estimate of the engagement in the driving task

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. For example, the task(s) in progress, driving or not, must be evaluated to determine the cognitive state of the driver. The example shown is a part of the graph that determines this state. It considers the unique task in progress, its level of control, the driver's expertise, the availability of cognitive resources and engagement.

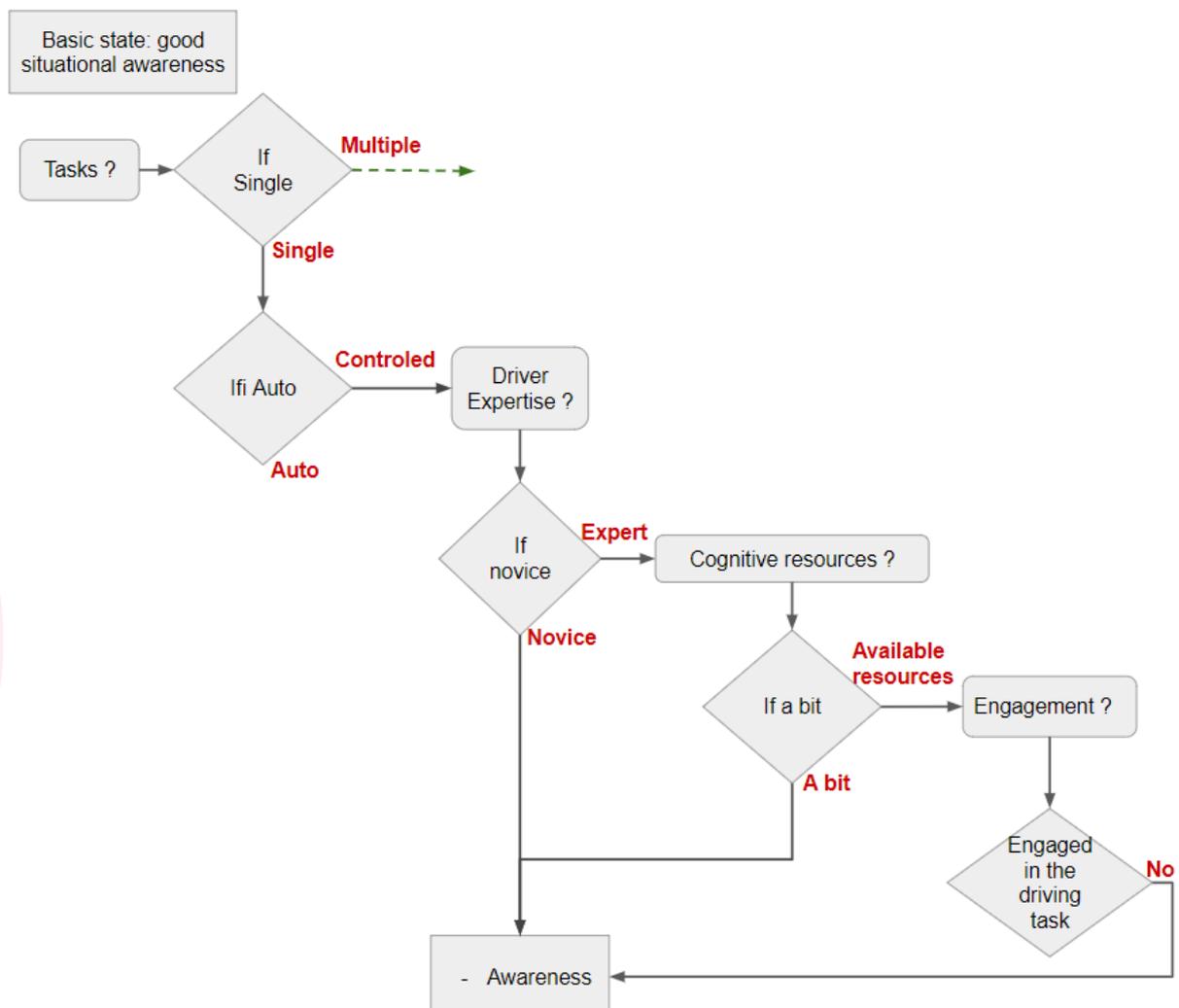


Figure 25. Part of the graph identifying conditions distorting the driver's situational awareness

### 6.3.7. 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. Development phases

A second step of the study will consist to refine the initial model. Simulations will be made from a simulator. These would allow us to observe the intended correlation between the driver's cognitive components and the driver's subjective state. The correlations will be updated according to the observations. For example, a weight to interaction will be added in order to identify the most impacting components.



## 7. Emotion measure

The detection through measurements wielded in the project can be arranged into two groups:

### Physiological Signals

These sensors acquire an objective measurement of physiological signals. In general, the signals collected through these sensors are involuntary, and then, they are hardly falsifying, so they can be used to assess emotional states in a continuous manner and they are non-disruptive to the performance of the task. As it will be reviews later in this section, there are many different signals that, requiring different processing and analysis could lead to the obtaining of comparable outputs among them.

Although one of their main inconvenient was the fact of being too invasive and could lead to an obtrusion of the user experience, there are more and more technics and products in the market that accomplish a compromise between being wearable and having a high quality of measurement.

### Behaviour

Via the behaviour sensors it is possible to track important sources of information from the human body. For instance, the analysis of facial image, which is one of the most powerful channels of communication. Facial image analysis can provide information about affective states, which is the concern of the present module, but also, information about intentions, alertness or personality. This is a hot topic, and many researches are carried out in this field, focusing in the development of better detection hardware, and of better software technics that could make the process more automatic, real-time and accurate.

### 7.1. Physiological Signals

Focusing in the multi-dimensional, and concretely in the Valence-Arousal bi-dimensional model, it is possible to review in the literature technologies and methodologies employed and developed by other authors to detect the emotional state measuring physiological signals. Emotion detection is, indeed, a hot topic and it can be applied to areas of great relevance in which many resources are invested for research. In the field of automotive and traffic security, the research in emotion detection on board elicits great interest, for the driving safety and well-being of the users are also at stake.

The versatility of measures, sensors or techniques of feature extraction in order to find out the winning combination invites to explore with experimentation in the field.

In the SUaaVE project, on depart of the review of the work already developed by other authors, and of the own work of partners participating on the project, it is intended to go a step further. The research in the measurement and analysis of physiological signals for detecting emotional states in one of the core group of tasks.

### 7.1.1. Review of emotion detection through physiological signals systems

In the Figure 26, different signals studied by many authors are shown. The signals are measure through sensors and, subsequently, processed and extracted the relevant properties from which the emotional state can be detected with a certain percentage of accuracy.

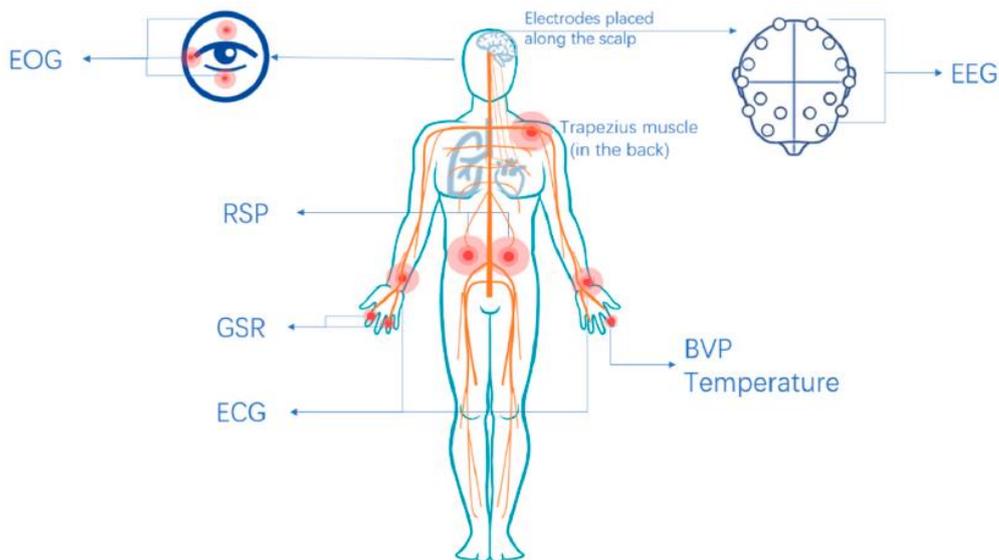


Figure 26. Scheme of the human body with the zones from where the different physiological signals are the measured for the emotion detection

The process from acquiring data to launching an emotion guess follows the steps shown in Figure 27. 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.

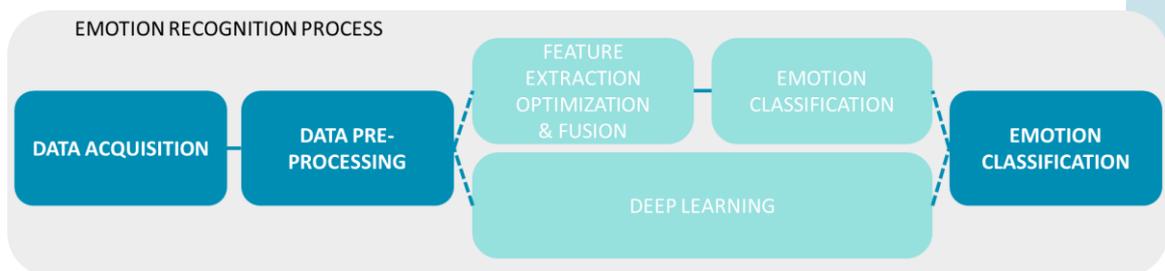


Figure 27. Emotion detection process using measurement of physiological signals (Shu et al., 2018)

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 physiological signal analysis investigation will focus on cardiovascular signals, electrodermal and respiratory (Table 4). The signals EEG and EOG are not included in the project because the sensors are not compatible with a real car environment.

	Anger	Anxiety	Embarrassment	Fear	Amusement	Happiness	Joy
<b>Cardiovascular</b>							
HR	↑	↑	↑	↑	↑↓	↑	↑
HRV	↓	↓	↓	↓	↑	↓	↑
LF		↑		(-)		(-)	
LF/HF		↑			(-)		
PWA				↑			
PEP	↓		↓	↓	↑	↑	↑↓
SV	↑↓	(-)		↓		(-)	↓
CO	↑↓	↑	(-)	↑	↓	(-)	(-)
SBP	↑	↑	↑	↑	↑-	↑	↑
DBP	↑	↑	↑	↑	↑-	↑	(-)
MAP			↑	↑	↑-	↑	
TPR	↑			↓	↑	↑	(-)
FPA	↓	↓		↓	↓	↑↓	
FPTT	↓	↓		↓		↑	
EPTT		↓		↓		↑	
FT	↓	↓		↓	(-)	↑	
<b>Electrodermal</b>							
SCR	↑	↑		↑	↑		
nSRR	↑	↑		↑	↑	↑	↑
SCL	↑	↑	↑	↑	↑	↑-	(-)
<b>Respiratory</b>							
RR	↑	↑		↑	↑	↑	↑
Ti	↓	↓		↓-	↓	↓	
Te	↓	↓		↓		↓	
Pi	↑			↑		↓	
Ti/Ttot				↑	↓		
Vt	↑↓	↓		↑↓	↑↓	↑↓	
Vi/Ti						↑	
<b>Electroencephalography</b>							
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 4. Table extracted from Shu et al. (2018) showing the relation between the emotions with some of the features of the most common used physiological signals

## ECG and HR

The electrocardiogram (ECG) is a recording of the electrical activity of the heart, consisting of a graph of voltage versus time. The recording is performed using electrodes placed over the skin. These electrodes detect the electrical changes consequence of cardiac muscle depolarization followed by repolarization for each cardiac cycle. The heart rate (HR) is the speed of the heartbeat measured by the number of contractions (beats) of the heart per minute (bpm).

Emotion recognition from electrocardiography (ECG) signal has become a very relevant research topic in the field of affective computing. Concretely, Heart Rate Variability (HRV) analysis is emerging as one of the main measures that regulates emotional responses (with appropriate timing and magnitude). It appears to be an index of individual differences in regulated emotional responses. A bibliographic review of other works focusing on this field is carried out. The data concerning the results obtained and the parameters observed are collected in this section (Valenza, Lanata, & Scilingo, 2012; Agrafioti, Hatzinakos, & Anderson, 2012; Guo et al., 2016; Cheng, Shu, Xie, & Chen, 2017).

ECG response observed depending on the emotion elicited are summarized in Table 4. Some of the most popular parameters extracted in the analysis of ECG and HR signals are collected in Table 5. The authors calculate features in both time domain (TD) and in time frequency domain (FD).

### ECG and HR Features/Parameters

(Inverse Gaussian) IG probability distribution Mean and standard deviation (STD)
Power of low frequency (LF) (0.04–0.15 Hz) band
Power of high frequency (HF) (0.15–0.4 Hz) band
LF/HF ratio
Instantaneous bispectral analysis
Bispectral invariants mean and STD
Phase entropy
Normalized bispectral entropy
Normalized bispectral squared entropy
Sum of logarithmic bispectral amplitudes
Nonlinear sympatho-vagal interactions

Table 5. ECG and HR Features/Parameters found in literature

Some of the classifiers used in the literature are SVM, KNN, RF, DT or GBDT (Shu et al., 2018).

## GSR

The Galvanic Skin Response (GSR) is the property of the human body that causes continuous variation in the electrical characteristics of the skin. As GSR sensor detects the changes in electrical (ionic) activity resulting from changes in sweat gland activity. The electrodes must be sensitive to these changes, and able to transmit that information to the recording device.

After a bibliographic review the data concerning the results obtained and the parameters observed are collected in this section (G. Wu, Liu, & Hao, 2010; Poh et al., 2010; Ming-Zher Poh, Swenson, & Picard, 2010; Monajati, Abbasi, Shabaninia, & Shamekhi, 2012; Das, Khasnobish, & Tibarewala, 2016; Wen et al., 2014).

On the one hand, electrodermal response changes depending on the emotion elicited are summarized in Figure 7. The results reveal that the sensing through GSR could have identical responses to different emotions, for this reason, the measurements have to be completed with the measures of other physiological signals. In short, according to these findings, the features in Electrodermal System almost have an identical trend for different emotions. There can be an auxiliary mean when using Sensors other physiological features to recognize the emotion. All studies found, developed systems of emotion detection that combined GSR with other signals like HR and RSP, and not GSR in isolation.

On the other hand, a table has been elaborated in order to summarize the parameters extracted in the analysis of GSR signals (Table 6).

### **GSR Features/Parameters**

Skin Conductance amplitude average, variance and standard deviation

Number of local maxima and minima

Mean conductivity difference (GF – GB) for consecutive pairs of local minimum-maximum

Global maximum GSRmax

Global minimum GSRmin

Ratio between the number of maxima and stimuli duration (peaks/time)

Average and RMS of 1st differences deviation of GSR

Mean of absolute values of 1st differences mean

Mean of GSR signal filtered by a Hanning window

Mean of absolute values of 1st and 2nd differences of normalized GSR

Normalization of max GSR-dif = (GSR-max) – (GSR-base)

**Table 6. GSR Features/Parameters found in literature**

The emotions more often observed in the work of other authors, are the general happy-sad, sad-neutral and happy-neutral, with accuracies above 90%. And more specific emotions like surprise, fear, disgust, grief, happy, angry among others, for which the authors achieved accuracies in the range of 40-70%. Also, although out of the scope of this project, it was used for monitoring epileptic seizures finding a significant change in the amplitude of electrodermal activity. The results will be treated through our approach attending to arousal and valence, an own result of accuracies will be drawn.

### **RSP**

The Respiratory Response (RSP) is usually acquired through the plethysmography, which is an instrument for measuring changes in volume within an organ or whole body (usually resulting from fluctuations in the amount of blood or air it contains).

Like with the other physiological signals, the authors who aimed to build a robust emotion detector, combined several kinds of signals and obtained data for valence and arousal as a combination of all (ECG, GSR, RSP), and so is the case of respiratory signal.

The respiratory feature changes versus emotions are shown in Table 4 (Mirmohamadsadeghi, Yazdani, & Vesin, 2016; (Wee Ming Wong, Tan, Chu Kiong Loo, & Wei Shiung Liew, 2010).

Using respiratory features to recognize different emotions is also a powerful method since the change of features is apparent and the measures of each features is accessible. It is advised to add the respiratory features to enhance the accuracy of the recognition. A table has been elaborated in order to summarize the parameters extracted in the analysis of GSR signals (Table 7)(Valenza et al., 2012)(C.-K. Wu, Chung, & Wang, 2012).

### Respiratory response features/parameters

Breathing rate, amplitude and other typical statistical features as mean and STD
The longest and shortest time between consecutive breaths
Deep breathing (RSPmax)
Shallow breathing (RSPmin)
Amplitude ratio of the RSA to the respiratory oscillation
Difference between the RSA and the respiratory frequencies
Phase difference of the RSA and the respiration
Slope of this phase difference and its STD
Spectral power and mean and standard deviation of the first and second derivative
High Order Statistics (HOS) as the third order statistics, the fourth order statistics and the standard error of the mean (SEM).
Functional residual capacity (FRC)
Inspiratory time (Ti)
Expiratory time (Te)
Post-inspiratory pause time (Pi)

Table 7. RSP Features/Parameters found in literature

Other analysis: Recurrence Quantification Analysis (RQA), Deterministic Chaos (DC), Detrended Fluctuation Analysis (DFA)(Valenza et al., 2012).

With liner features it has been obtained accuracies of 74% for valence and 74% for arousal. With unlinear features some authors obtained up to 90% accuracy for arousal and 92% for valence.

### 7.1.2. SUaaVE approach

After reviewing the articles concerning the analysis of relevant parameters of physiological signals, we ground to what could be a complete strategy from signal sensing to emotion classification. Machine learning methods are a highly topical matter, and offer new possibilities to inspect data in pursuit of trends, relations and hidden features that characterize clusters. In human emotion recognition is also showing good results, although in general for subject-specific methods. The model proposed by (Ali et al., 2018) raises a subject independent recognition system using the combination of two models: **Automatic feature calibration** and **Cellular Neural Networks (CNN)**. The physiological signals considered because of their good performance achieved are: electrodermal activity (EDA), electrocardiogram (ECG), skin temperature (ST), although we well add information from the respiratory signal (RSP).

The workplan then, is divided in the steps that are illustrated in Figure 28. Firstly the signal sensing (with sensors of section 8.3) with an appropriate preprocessing. After, the extraction of features, in the work of (Ali et al., 2018), they propose a specific set and it will be the first group of features to test in our work. Then, with the automatic calibration the outputs of all signals will be included in the classification tool of Cellular Neural Networks (CNN).

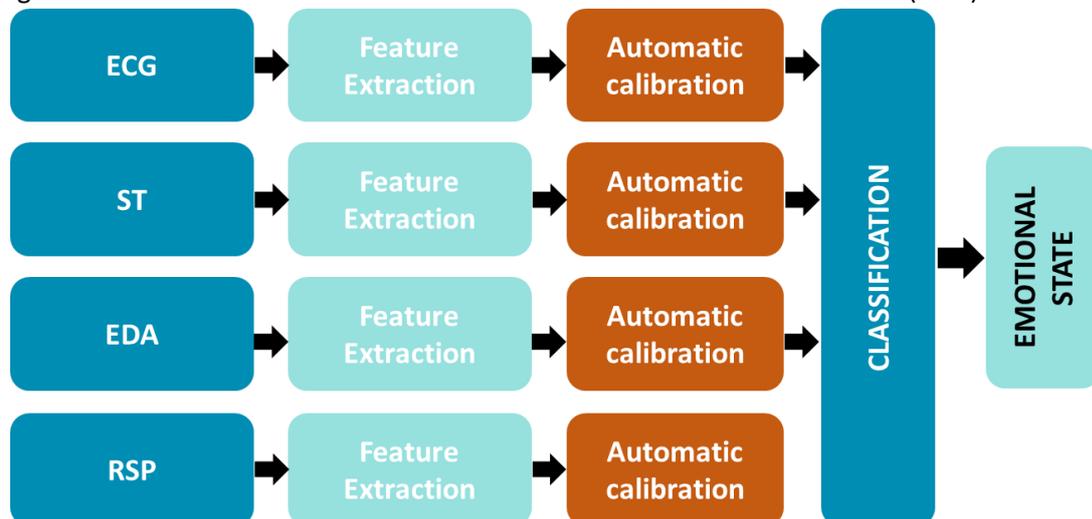


Figure 28. Illustration of workplan steps

### 7.1.3. Sensors

The measures that will be performed and the sensors employed in the project are the described as follows.

The **Empatica E4 wristband** (Figure 29)([Empatica website](#)) it is a wearable research device that offers real-time physiological data acquisition and software for in-depth analysis and visualization. The device counts with:

- PPG Sensor: Measures Blood Volume Pulse (BVP), from which heart rate variability can be derived
- 3-axis Accelerometer: Captures motion-based activity
- Event Mark Button: Tags events and link them to physiological signals
- EDA Sensor (GSR Sensor): Measures the constantly fluctuating changes in certain electrical properties of the skin

- Infrared Thermopile: Reads peripheral skin temperature
- Internal Real-Time Clock: 5ppm high accuracy time reference



Figure 29. Empatica E4 wristband

With this device, the relevant data acquired for our study:

- 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.

Also, 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) through sensors in the palm of the hand.
- Breathing rate through plethysmograph.

#### 7.1.4. First pilot measurements

A first pilot was performed in order to get a first battery of data in order to refine the project plan in this field. For this purpose, real drivers were measured during trips always longer than one hour.

There are two roles within this test: driver and co-driver. Both of them are monitored during a road trip. For this we are going to use the E4 wristband from EmpatICA. Also, another device is employed: The Polar V800 ([Polar website](#)), which is an advanced multisport tracking watch with GPS for sports enthusiastic and professional athletes.

The driver will be equipped with the E4 wristband. A maintained push on the button will power on the device, after that, the LED light will blink and change its color for 40 seconds while it is calibrating. After that, the wearable will enter in silent mode while it monitors the driver. When the road trip is finished, pushing maintained 3 seconds the button will power off the device. E4 has a button which sets a temporal mark when pushed. When this happens, LED will blink in red.

The data we are going to acquire are several .csv files with the initial time of the measurement and:

- Data from temperature sensor expressed degrees on the Celsius scale.
- Data from electrodermal activity sensor expressed as microsiemens.
- Data from photoplethysmography.
- Data from 3-axis accelerometer sensor. The accelerometer is configured to measure acceleration in the range [-2g, 2g].
- Time between individuals heart beats extracted from the BVP signal.
- Average heart rate extracted from the BVP signal.
- Event mark times.

For this experimentation the passenger will also be measured with the Polar V800 watch in order to acquire its heart rate variability and therefore its heart rate. The passenger must adjust the physical characteristics in the settings menu. When the pectoral band is well positioned, with the center of the sensor at the left of the sternum below the pectorals.

This second roll will have the responsibility to write the possible events of interest that could affect the behavior or perception of both of them. Below there is a list of these possible events to occur while being on the road.

- 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.

For us to monitor these signals and track their consequences, we will use the time stamps. Additionally, we will use an instant message application. There should be a message

registered in the log of the conversation for each temporal mark acquired. This message is going to be a brief explanation of the event that happened before. The passenger will be in charge of registering this information in the conversation while the driver sets the time reference.

Every stop must be recorded as indicated previously, with a message and its associated temporal mark. Not only that but also the beginning and continuation of the trip.

In case the road trip is large, and the pilot and passenger interchange their roles, this has to be registered and there will be a device's change also. Remember to update the physical settings on the Polar V800.

After that, we will save all the data registered in the computer, ready to be processed and analyzed.

## 7.2. Behaviour sensors

### 7.2.1. Introduction and approach

Existing emotion-detection methods rely on audio-visual cues or on-body sensors, as described in the previous section. There are downsides to both techniques, facial expressions are famously unreliable, while on-body sensors such as chest bands and ECG monitors are inconvenient to wear and become inaccurate if they change position over time.

Though arguably reductive, many facial expression detection tools lump human emotion into 7 main categories: Joy, Sadness, Anger, Fear, Surprise, Contempt, and Disgust. With facial emotion detection, algorithms detect faces within a photo or video, and sense micro expressions by analyzing the relationship between points on the face, based on curated databases compiled in academic environments.

One of the objectives of the project is to evaluate the “best in class” solutions of the emotions detection systems that are currently in the market. Even if they do not belong to the automotive field, the idea is to embark that systems in the tests and study which emotions are relevant to detect on board and which requirements does a camera should fulfill to detect emotions on board. Doing that, the interest is not only in positive or negative emotions as all systems, but in the study of which of them are really relevant. The intention is to cover the market needs, which are reducing the accidents by detecting the relevant emotions on board to take advantage of that, but with the new focus in the future autonomous car.

The benefits of the outcomes of the project are that by identifying relevant emotions on board, future systems can be designed by taking them into account and all that will lead to faster, cheaper, more reliable, more efficient, with less unwanted effects systems in the market.

### 7.2.2. Typical architecture of expression recognition systems and principal limitations

The Facial Action Coding System (FACS) describes facial expressions in 46 Action Units (AUs), which correspond to the individual movements of facial muscles. The usefulness of the FACS in behavioral sciences to discover typical facial movements of states cognitive and affective.

Most expression recognition systems follow the same processing flow represented in Figure 30. The input to the system is a sequence of 2-D frames, these can be consecutive frames of a video or independent image.

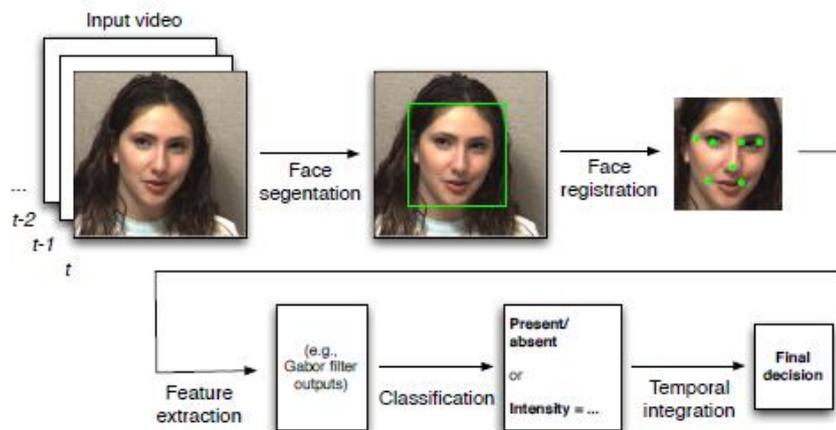


Figure 30. Typical architecture of automatic facial expression recognition systems

For each frame the system executes the following stages:

1. **Detection / Segmentation** of the face: The location of a face in the image is sought and this segment is cut out. This stage makes the system insensitive to the location of the face in the frame.

- **Absolute detectors:** determine the location of the face independently for each frame. They present as advantages that the calculation can be performed in parallel for several frames at once and is very sensitive to the appearance of several faces in the image. A drawback is that no temporary restrictions are used that could improve the speed and reliability of the detection.
- **Differential detectors:** accurately estimate the probable position of the face at time  $t + \Delta t$  from the information of time  $t$ . The main drawback of these techniques is that small errors in the temporary derivative accumulate and in a few seconds the drift is difficult to recover. One option is to combine the differentials, for short periods of time, with the absolute ones, to recover errors and quickly adapt faces moving outside and inside the image.

2. **Normalized registration** of the face: The segmented image of the face is normalized before changes in the scale, face geometry, and variations due to the head posture.

After the detection of the face in the frame, the area of the image containing the face is segmented. These zones are first scaled to a common measure, usually between  $16 \times 16$  to  $96 \times 96$  pixels, depending on the application. Next, the face is normalized to reduce variability in the geometry of the face or posture.

The most common method is by identifying features such as eyes, nose and mouth to deform the image and approach a common geometry, some of the most powerful feature identification systems are similar to those used in face detection (Fasel et al., 2005).

3. **Extraction of information** from the face and gestures.

The extraction of information of the characteristics of the face and / or gestures can be divided into two approaches; geometric and appearance.

The geometric approach is based on directly extracting the relative positions of facial features (eyes, nose, mouth, etc.) (Ryan et al., 2009). The problem with this approach is the difficulty of reliably detecting these face characteristics in all frames.

The approach based on appearance is currently more robust and with better results. The most common approaches are the following:

- Gabor filters. (Littlewort et al., 2006; Bartlett et al., 2006; Wu et al., 2006).
- Box / Haar-like filters. (Yang et al., 2009; Whitehill et al., 2009).
- Local binary pattern (LBP) features: 2-D spatial and 3-D spatiotemporal characteristics of the box filter (Zhao and M. Pietikäinen, 2007).
- Optic Flow features (Pantic and Patras, 2006; Koelstra et al, 2010)

The first approximations are applied to a single frame or dynamically to a sequence to recognize the expression. The last approach applies only dynamically.

4. Expression classification: The extracted characteristics feed a decision engine to classify the expression. The result can be a finite set of values (e.g., {Smile, Not Smile}) or an intensity value of the expression (e.g., Smile = 1.31).

5. Temporary integration (optional): The output of the classifier can be integrated over time to produce estimates of internal states, such as alert level, confusion, etc.

Some of the improvements, the application of artificial vision associated with the field of detection of emotions through real-time image suffers a series of drawbacks due to deviations from the capture conditions with respect to ideal or laboratory conditions. In this way, we can classify these problems into 3 basic types: user variability, variability of capture conditions and environmental variability.

Within the **user's variability**, we can basically mention some physical characteristics (skin colour, beard, shape and distribution of hair, etc.) and attire (glasses, scarf, scarf, etc.), or differences in mood and its repercussion in facial expression.

Regarding the **variability of the capture conditions**, problems of centring the objective image (head), relative orientation between the elements (decentring, distancing or approach depending on the driving position) or concealment (gestures or movements that stand between the camera and the user's face) are cited. These concealment problems appear as one of the main ones in artificial vision techniques, and the most robust systems are always those that have controlled conditions of orientation, position and lighting. In one of the studies, the camera is located behind the wheel, which causes the face to be partially hidden at times, and the authors themselves warn (Gao et al., 2014).

Finally, the **environmental variability** is evidenced as noise or lack of image sharpness due to the vibrations of the march, or as inadequacy or falsification due to the lack or excess of ambient light, reflections or smoke (if it is a smoker driver), or variability in the image background. Thus, the problems of non-uniform illumination are discussed as the most important in this area, although it depends on the specific casuistry to which the technique is applied. The problem of the high-frequency vibration of the camera due to the irregular and low-frequency firmness caused by the action of the vehicle's suspension system is also well known.

## 8. Factors affecting passenger state

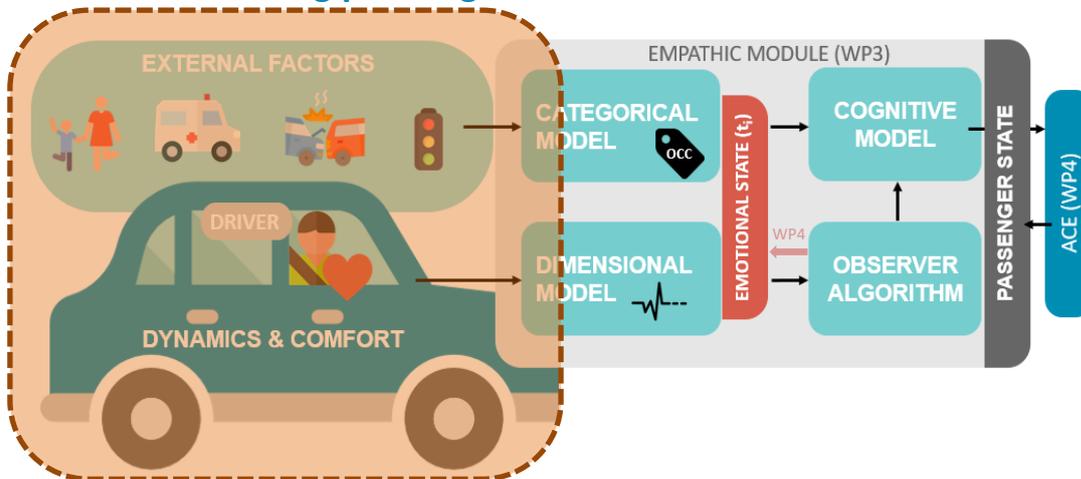


Figure 31. Factors considered inside the illustration representing the elements involved and the work to be developed in the WP3.

SUaaVE empathic module will use two sources for a better understanding the passenger state. From the one side, the Ego Car will be **monitoring the passenger** by behavioural and physiological variables, as described in section 7. From the other hand, EmY will be aware of the **contextual factors** involving the experience in the Ego Car.

**Contextual factors** will be used as input for emotional and cognitive models, thus we need to establish a common definition and classification.

In this section, we include a first approach for their identification and definition and we develop a structure for its classification along SUaaVE project.

The following point describe this approach, describing with more detail factors included in two main categories according if they are external to the vehicle or it is a factor related with the ego-vehicle conditions. Other categories of factors related with passenger profile and trip factors are defined, but they need to be refined during the development phases of the models.

### 8.1. External factors

External factors are defined those factors completely external to the driver and the vehicle.

A first approach to definition and classification of external factors for the autonomous driving is found in Adaptive project (FP7-ICT-2013.6.5: Co-operative mobility Grant Agreement No. 610428) in D2.1. System Classification and Glossary. This deliverable presented the systematic approach for the classification of automated driving and parking functionalities, as well as the glossary in the field of highly and fully automated driving functions.

The classification of the environment factors made by Adaptive project is appropriate to be used in SUaaVE approach in order to a first input to define the external factors. Additionally, manoeuvre factors defined by Adaptive related with the interaction with other vehicles has been included.

Following Adaptive project, external factors in SUaaVE parameter set are divided in four categories: Traffic, Road, Visibility and Maneuvers.

### 8.1.1. Traffic parameters

Main parameters to classify the traffic factors are: the *traffic participants*; the mix of participant according with automatization and *traffic flow*.

- **Traffic participants.** *This parameter describes* the type of road users in the environment. As a first approach it can be described in three values:
  - **Non-motorized:** Non-motorized road users, such as pedestrians and cyclists. Examples: pedestrians on a crosswalk, construction side worker, bicyclists
  - **Motorized, type A:** Motorized road users with vehicles whose means of propulsion maximum design speed not exceeding 50 km/h. Examples: Drivers of electric bicycles or small mopeds.
  - **Motorized, type B:** Motorized road users whose means of propulsion maximum design speed exceeding 50 km/h.

Remark: Engine type (electric, thermic) or number of wheels (2, 4) is irrelevant.

Remark: Motorcyclists belong to the group of vulnerable road users such as pedestrians or cyclists. Those have not been joined in a common group named e.g. “vulnerable road users” because the behavior of motorcyclists is more comparable to that of a car than that of a pedestrian or cyclists: motorcyclists do not abruptly change their direction of movement so that their behavior is more predictable compared to pedestrians or cyclists. This is also true from a perception perspective: motorcyclists are spatially wide extended objects which drive unhidden in the middle of the road so that they are easier to detect compared to pedestrians or cyclists.

- **Traffic flow:** This parameter describes the traffic flow mixing the concepts of traffic speed and density.
  - **Moving traffic:** Traffic is moving nearly with recommended speed of particular road type. Traffic density is low or medium.
  - **Slow moving traffic:** Traffic is moving distinctly below recommended speed of particular road type. Traffic density is medium to high.
  - **Stationary traffic:** Traffic is nearly at a standstill or is at a standstill. Traffic density is high.
- **Traffic mixed.** This factor defines if the environment is shared with not automated vehicles.
  - **With mixed traffic:** With active automation the vehicle is driving in an environment where also driver-controlled vehicles are present. Example: Motorway without dedicated lanes for automated vehicles.
  - **Without mixed traffic:** With active automation the vehicle is driving in an environment where only automation-controlled vehicles are present. Example: Parking garage with extra parking levels reserved for automated vehicles.

### 8.1.2. Road parameters

Main parameters to classify the road characteristics are: road type, road accessibility, road condition, road geometry and road infrastructure.

- **Road condition.** This factor describes the road according with smoothness and adhesion conditions.
  - **Good:** Surface of the road is smooth, with good adhesion.
  - **Slippery:** Surface of the road is slippery. Reduced adhesion. Examples: Aqua planning, snow, ice, dirt, leaves.
  - **Bumpy:** Surface of the road is not smooth but bumpy. Examples: Potholes, wavy asphalt.
- **Road accessibility.** This factor characterizes privacy of the road.
  - **Public Roads** and places without access limitations for vehicles. Examples: Public roads, public parking places.
  - **Private Roads** and places with restricted access for vehicles. Example: Private garage, company's car park.
- **Road geometry.** This factor synthesizes the geometry of the road in terms of curves and slopes.
  - **Straight:** Straight road without relevant curvature, ascend or descend. Example: Motorway.
  - **Curved:** Road with relevant curvature Examples: Motorway interchange, rural road, serpentine.
  - **Steep:** Road with relevant ascend or descend. Example: Mountain road, serpentine.
- **Road infrastructure.** This synthesizes the different elements in the road
  - **Physical cut-off:** Physical cut-off between oncoming lanes. Example: Guardrail, separating green area.
  - **Good lane markings:** White / yellow painted stripes or botts' dots to separate lanes of a road.
  - **Guard rails:** Mechanical construction to prevent vehicles from veering off the roadway into oncoming traffic, crashing against solid objects or falling into a ravine. Examples: Guard rails, mural, concrete wall, taut steel rope, mound
  - **Deer fences:** Fence at the roadside which prevents animals and pedestrians from entering the road. Remark: "No deer fence" does not mean "no automation". The evaluation of minimal infrastructure requirements for specific applications is a separate topic. Example: A Traffic Jam Pilot might not need a deer fence. For high speed application is has to be assessed if occurrence probability of deer in combination with perception performance results in an acceptable risk.
  - **Emergency lanes:** Separate lane at the roadside which is reserved for vehicles with technical defects. Remark: Hard shoulders is a synonym for emergency lane
  - **Traffic light:** Traffic light at intersections of e.g. urban or rural roads.

- **Road type.** Main road types are: Motorway, Highway, Interstate, Rural road, Arterial road, Urban road, Residential district roads, Parking area & parking deck and Garage.

However, Adaptive highlighted that *road accessibility*, *road geometry*, *road infrastructure*, accessibility and mixed traffic are strongly related with the road type and they were combined and refined in 17 categories of road classes.

In SUaaVE approach we consider that these factors as emotion elicitor are also interrelated and they have to be assessed globally in relation with other factors considered like car dynamics, environmental conditions and fulfilment of traffic norms. As an example, it is more probable a passenger could feel fear if it is driving too fast in a rural road, where the maximum permitted speed is 100 Km/h with medium curvature than in a motorway.

For more details, the description of each type of road and the 17 categories of road classes is included in D2.1. of Adaptive project.

### 8.1.3. Visibility due to external conditions parameters

Visibility factors are included in SUaaVE approach to define easiness of visibility of environment by the passengers inside the car due to the external conditions.

- **Good visibility:** Full visibility of vehicles and obstacles. Remark: Modest fog, spray, rain or snow shall not hamper system functionality.
- Poor visibility due to obstacles:
  - **Due to vehicles:** Visibility of vehicles and obstacles is masked by other vehicle. Example: Vehicle at standstill cannot be seen due to leading vehicle in front. If vehicle in front changes lane, then vehicle at standstill abruptly becomes visible.
  - **Due to infrastructure:** Visibility of vehicles and obstacles is masked by infrastructure. Example: Vehicle at standstill cannot be seen due to road curvature.
- Poor visibility due to weather conditions:
  - **Fog:** Reduced visibility of vehicles and obstacles due to fog.
  - **Heavy spray:** Reduced visibility of vehicles and obstacles due to heavy spray.
  - **Heavy rain:** Reduced visibility of vehicles and obstacles due to heavy rain.
  - **Heavy snow:** Reduced visibility of vehicles and obstacles due to heavy snow.

### 8.1.4. External parameters of Maneuver (related with other vehicles)

In Adaptive classification vehicle maneuver is characterized by the following parameters: maneuver time to collision, maneuver duration, maneuver automation, maneuver speed range, maneuver control force, maneuver time headway, maneuver trigger and maneuver coordination.

For external factors characterization in SUaaVE will consider only the parameters related with maneuver in relation with the interaction with other vehicles in the road, i.e. maneuver time to collision, maneuver time headway and maneuver coordination. Maneuver duration, maneuver automation, maneuver speed range, maneuver control force and maneuver trigger are included in dynamic comfort parameters.

- **Vehicle manoeuvre time-to-collision.** This factor characterizes if the collision is imminent or not.
  - **Large:** Collision is not imminent. Example: Driver assistance systems such as ACC, LKA, etc.
  - **Small:** Collision is imminent. Example: emergency braking e.g. if lead vehicle brakes hard suddenly
- **Vehicle manoeuvre time headway:** This factor characterizes the in seconds the distances between vehicles.
  - **Standard:** Time headway > 0,9 sec Examples: ACC, Traffic Jam Assistance (refer to A2.9)
  - **Reduced:** Time headway 0,5 ... 0,9 sec Example: truck platooning with 15m distance
  - **Small:** Time headway < 0,5 sec Example: truck platooning with 5m distance

Remark: Backing into a parking space, vehicle maneuver time headway is not applicable (n.a.) since distance control to a leading vehicle does not occur. Driving while searching a parking space, maneuver time headway is applicable, since distance control to a leading vehicle might occur.

- **Vehicle manoeuvre coordination:** This factor characterizes the coordination nature of the manoeuvre.
  - **With coordination:** Manoeuvre involves several vehicles which are coordinating their behavior. Example: Automated filtering at on-ramp of a motorway – vehicle that wants to enter motorway asks vehicles on motorway via V2V communication to increase headway so to ease filter-in manoeuvre.

Remark: The term “cooperation” has been deliberately avoided in this context because cooperative behavior can be also achieved without communication, e.g. facilitating merging at onramps by increasing ACC headway. For maneuver coordination the emphasis is on communication between vehicles.

- **Without coordination:** Manoeuvre is not coordinated between involved vehicles. Example: Lane change at overtaking manoeuvre – if the adjacent lane is not occupied the lane change is initiated without any coordination or communication between involved vehicles.

## 8.2. Ego Vehicle factors: Dynamic, and ambient comfort

### 8.2.1. Autonomous vehicle comfort

In one of the most complete and used model of comfort, Vick and Hellback (2012) suggested that the interaction a user has with the environment (person, product, usage) will produce subjective perception that, influenced by the user expectation, can result in comfort, discomfort or a neutral reaction. This model could be applied also to vehicle comfort, since the environment is composed by the car characteristics product characteristics such as 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 state (Psychological, physiological and physical), the product usage (i.e. driving style) and the infrastructure and environmental characteristics (road condition, weather...). These attributes will influence the

user perception, which with the influence of the user expectations, will create a sensation of comfort, discomfort or a neutral state. However, the introduction of automated vehicle shifts the focus on passengers' behaviour and perception. Factors, such as expected driving quality, motion sickness, communication, control and trust will either be introduced as new attributes of comfort or will increase their importance in the evaluation of passenger comfort. For instance, driver expectation will change focus point, as the passengers will not rely on a driver but they will rely on the car to behave in an acceptable and trustworthy way. Motion sickness will also have an impact on the user comfort, as research has shown that the absence of vehicle control (and therefore the impossibility to anticipate the trajectory of the car), the engagement in non-driving task and the new distribution of seats could increase the possibility to experience discomfort when being an automated vehicle user. In new connected autonomous vehicles, the user will also have to rely on the fact that the car has information on the intention of another vehicle and this could affect the feeling of safety of the passenger. The capability of the automated vehicle to adapt to the state and perception of the user will be of outmost importance for the perception of comfort and safety.

Another dynamic factor which could influence the user comfort is the autonomous vehicle motion planning, which includes attributes like speed, acceleration, jerk profiles, condition for overtaking, headway distance and traffic law abiding. Various motion planning models have been developed in the literature. For example, the Model Predictive Control (MPC) (Alcalá et al., 2018) 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 MPC, includes factors such as the boundary limits, the maximum speed, the sideslip rate, the longitudinal and lateral acceleration, jerks and time minimization and create an ideal path route. The advantage of route planning in automated vehicle is the possibility to modify the parameters described above depending on, for example, the state of the user.

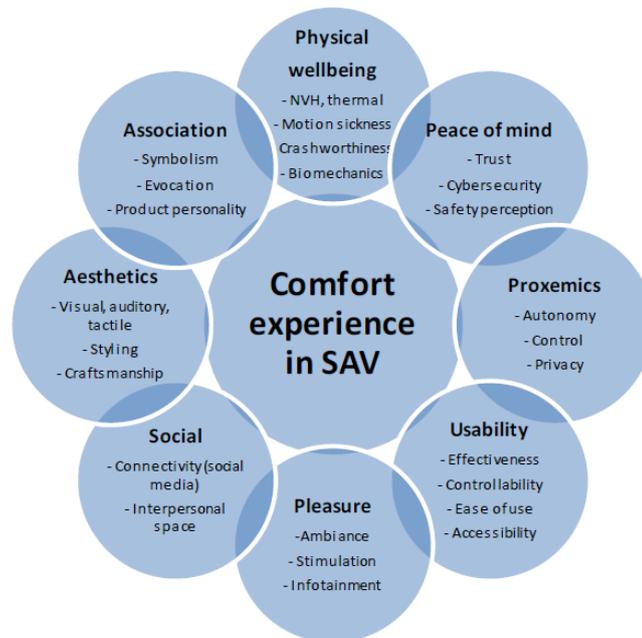


Figure 32. Map of factors describing the concept of comfort in a Shared Autonomous Vehicle (SAV), Diels et al. (2017).

Diels et al. (2017) developed an initial framework on the attributes that an automated vehicle, in this case Shared Autonomous Vehicles (SAV), should have to improve the users comfort. The model is described in Figure 32.

Considering this approach, in order to assess the overall vehicle comfort, ego vehicle comfort factors will be investigated in SUaaVE by two different points of views, the dynamic comfort and the ambient comfort. The following sections describes SUaaVE approach and main factors considered in dynamic and ambient comfort.

### 8.2.2. Factors of dynamic comfort

This section will describe the attributes and characteristics of vehicle comfort.

The attributes of dynamic comfort are divided into user experience attributes and vehicle dynamics attributes. The difference between the two groups rely more on the type of assessment they require. Specifically, user experience attributes can be assessed by non-expert assessors, while the vehicle dynamics attributes can only be assessed by dynamic experts. The figure below depicts the two groups of attributes and the factors included in these groups.



Figure 33. Scheme of the attributes concerning the user experience and the vehicle dynamics

A definition is given or the attributes listed in Figure 33.:

User experience high level attributes:

- **Ride Quality:** well-being of the vehicle's occupants by controlling levels of accelerations and vibrations during vehicle travel.
- **Motion Sickness:** well-being of the vehicle's occupants by controlling low frequencies body motion and absence of sickness.
- **Confidence:** Perception of a safe and accurate operation of the vehicle given by the absence of corrections and non-expected behaviour.

Vehicle Dynamics specific attributes:

- **Precision:** Capability to accurately follow a trajectory with minimum deviations of lateral error and yaw.
- **Stability:** Capability to maintain a controllable trajectory that is perceived as safe.
- **Smoothness:** Capability to perform trajectories within comfortable limits for vehicle states.

- **Disturbance sensitivity:** Capability to maintain trajectory and isolate passenger feeling from unexpected external inputs like cross-wind and changes in the road grip.
- **Body control:** Capability to control roll motion and pitch motion within comfortable limits.
- **Primary ride:** Capability to control low frequency vertical and longitudinal motion and acceleration within comfortable limits.
- **Vibration isolation:** Capability to isolate from sources of vibration and minimize accelerations.
- **Impact isolation:** Capability to isolate passenger from deterministic road inputs.

### 8.2.3. Factors of ambient and postural comfort

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 (Lavieri and Bhat, 2019). A level of spatial comfort can be evaluated based upon the following factors:
  - Headroom (Proximity of vehicle trim to head).
  - Vertical:
    - Longitudinal.
    - Lateral.
  - Body room (Proximity of vehicle trim to body).
  - Degree of spatial separation to other occupants (Proxemics).
  - Cabin lighting characteristics.
  - Exterior visibility.
- **Thermal Environment** covers the thermal environment of the vehicle cabin, following the individual characteristics and state of each user (Musat and Helerea, 2009). Thermal comfort evaluation is made up of the following components:
  - Ambient conditions meeting the occupant demands:
    - Ambient temperature.
    - Ambient humidity.
  - Airflow meeting demands of the occupant:
    - Speed.
    - Direction.
    - Temperature.
    - Humidity.
  - The capability for the cabin to adapt to a state which meets the context of use and the preferences of each occupant.

- **Acoustic Environment** refers to components of the vehicle cabin sound and vibration characteristics (Nor et al., 2008). Acoustic comfort attributes are:
  - Sound levels within the vehicle cabin.
  - Tonality and frequency characteristics of sound.
  - The capability for the cabin to adapt to a state which meets the context of use and the preferences of each occupant.
- **Visual Environment** refers to visible components of the vehicle occupant environment (Wienold, 2007). The measurement of visual comfort comprises of:
  - Lighting sources within cabin:
    - Natural light.
    - Artificial light.
  - Characteristics of light within the cabin:
    - Colour.
    - Intensity.
    - Source position.
    - Position of illumination.
  - Levels of discomfort glare.
  - The capability for the cabin to adapt to a state which meets the context of use and the preferences of each occupant.
- **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 (Parida et al., 2018). The quantification of postural comfort is based upon the following aspects:
  - The vehicle seat providing a seated position which is compatible with the occupant activity:
    - Productive tasks.
    - Inter-occupant interaction.
    - Media consumption.
    - Relaxing / sleeping.
  - The capability for the cabin to adapt to a state which meets the context of use and the preferences of each occupant.
  - Provides acceptable degrees of transient posture.
- **Environmental Hygiene** is comprised of a variety of factors governing the users sensation of cleanliness and hygiene whilst traveling within the vehicle (Lavieri and Bhat, 2019). The overall hygienic comfort of the vehicle comprises of factors including:
  - Air quality.
  - Cabin odor.

- Cleanliness of surfaces.
- Characteristics and behaviour of other users (shared use).
- Vehicle state.
- The capability for the cabin to adapt to a state which meets the context of use and the preferences of each occupant.

### 8.3. Passenger factors

There are other factors concerning the trip and the driver that are crucial when describing the emotional and cognitive state of the passenger.

The characteristics of the passenger could affect its perception of the driving experience. As a first approach the category “Profile-Passenger factors” will include these factors:

Profile-Passenger factors:

- Gender.
- Age.
- Origin.
- Culture.
- Experience in driving.
- Driving predisposition.
- Personality.
- Past experiences.
- Physical and cognitive characteristics.
- ...

As an example of the previous factors, the driving experience and how the passenger perceives it, has a great dependence on the driving rules of its country. In Germany there are some roads with no speed limit, on the contrary in Spain there are. Another example in the same line is that depending on the experience in driving and the predisposition of the passenger, a certain distance with respect to the car in front can be perceived as correct, or as dangerous, and the same with a certain speed.

On the other hand, trip characteristics: besides of the elements that conform the environment of the trip, such as the described in the previous section, there are some characteristics that are also of great relevance for the cognitive and emotional description of the passenger. Those characteristics are the ones related with the link between the passenger and the trajectory.

- Trip-passenger factors:
  - Time to complete the trip: from ample time, to very short time, to irrelevant.
  - Importance of get in time: from very important, to irrelevant.
  - Purpose of the trip: work, hospitalization, holidays, etc.
  - pre-journey and post-journey activity.

- Familiarity with the trip // with the environment: prompt, regular // very familiar, completely new.

As an example of the previous factors, the driving experience and how the passenger perceives it, can be crucially different according to the purpose of its trip. For instance, if the trip is of holidays, the dense traffic could not get on his/her nerves in the same way, as if the trip is to get to work being short in time.

During the development of the emotional and cognitive models these factors will be identified and defined according with their relevance in passenger state.

## 9. CONCLUSION

The definition of the empathic module framework has been developed in order to serve as the foundations of the prototype model that will be built in the following months. The model will be the tool to monitor and interpret the passenger state based on the cognitive state and emotional response.

The path followed throughout these months of work is reflected in this document and it starts with the emotional model. It has been presented the SUaaVE approach to recognize the emotional state of the passenger by means of the OCC categorical model, and the dimensional based on Valence and Arousal. It has been reviewed the works related to the treatment of the emotion from its description to the study of the emotions in relevant fields like in driving. Also, the first experimentation performed and the first results have been included in the document.

In addition, the foundations to define the cognitive states of the user are described in order to serve as the point of start of the cognitive prototype to be developed.

It is also described the observer tool, that will serve to anticipate the passenger state not only detecting their responses, combining categorical and dimensional approach.

A full review of the physiological signals in emotion recognition and an introduction to the detection of emotion through behaviour inspection is included in the last part of the document.

Finally, there is a collection of factors that could affect the passenger driving experience, and it was described in terms of dynamical and ambient comfort, and the factors concerning the surroundings of the car: traffic, etc.



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## ANNEX I

### A 1. Determinants of Mental Representation (MR)

#### Principles of object categorization and activation of related concepts

When a user interacts with a device such as a suitcase, the user codes the object and the environment in memory, and automatically activates different concepts related to the object that categorize it (Cross et al. 2012; Iachini, Borghi, and Senese 2008; Tijus and Cordier 2003). Concepts are reference units of a representation. They correspond to data stored in memory that are of various natures such as ideas, shapes, objects, events, emotions, etc. The target object is then linked and categorized with certain activated concepts, with which it shares one or more semantic, functional, morphological, emotional and other characteristics respectively. This categorization consists in dividing the world in order to better define it. An object generally has several characteristics, each of which links the object to one or more categories. For example, each of the following descriptions can be the subject of a category to which a target suitcase can belong. A suitcase...

- is a travel device,
- is a suitcase, just like suitcases with wheels, large and small, made of canvas, plastic, leather, metal, etc.,
- has an opening and closing interface, which can be secured with a key or code,
- is part of the *luggage family* (handbags, backpacks, trunks, document bags, etc.),
- can be used in a car, train, plane, hotel, on the street, etc.,
- Can activate a pleasant (e.g. travel) or unpleasant (e.g. luggage theft) concept depending on everyone's experience.

An object can be considered by a user as being at the center of a system of categories to which it belongs. The object belongs to a category because it has a discriminating property, but it is also possible to infer properties not perceived by the object, because of its affiliation in the category (Chaigneau, Barsalou, and Zamani 2009). For example, when you see a suitcase, you can infer the presence of a handle to carry it. The network of categories, and the inference of properties from these categories, contribute to the construction of a mental representation of the object. The mental representation is not a simple image created mentally, it allows to define the object in its relationship to the user's world (e.g. will this suitcase fit in the car's trunk?). The user builds a representation based on his or her experience and memories. The context, and in particular the context of use, also has an impact on the construction of its representations. The role of this context is presented in the next section.

#### Impacts of context and activity on the representation of the object

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, situations, 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 task concerning a target (e.g. an parking) is facilitated when it is preceded by a semantically related concept (a car) rather than by an unrelated concept (a soap).

The story of Proust's Madeleine illustrates the activation of concepts around the mental representation of an object. In this text, the madeleine is first described by intrinsic properties: a cake, with a wave shape. Then it is described in analogy with a very different concept but sharing some visual properties, the valve of a scallop shell. Finally, it is described as a moving memory of childhood inferred by taste (Proust 1988).

Proust's Madeleine also illustrates another property of mental representation: the possibility of evolving during an activity or as experiences unfold.

According to Tijus and Cordier (2003), a representation is modified and refined when, for example, the user moves around the object. In other words, when the user changes the physical perspective, i.e. the angle of view or focal point (distance, scale) on an object or environment, he/she visualizes new information that was previously hidden. During an activity, the representation is enriched by a variation of points of view, but also by the sensorimotor experience. The sensorimotor experience of interaction is an information characteristic of the object used to represent it, as well as visual, auditory, tactile information, etc. (Gallese and Lakoff 2005; Craighero et al. 1999). Interaction with an object enriches its representation with information of various natures (visual, sensorimotor, etc.). This enrichment can be understood according to different dimensions that characterize the object. For example, the user's representation of a car's temperature control can evolve according to 3 stages of his experience:

- (1) The initial expectation: quickly obtain the desired temperature (theoretical utility);
- (2) The ease of use for finding controls and settings for temperature and air flows (usability);
- (3) The result: the air conditioning was set up quickly and in accordance with expectations, or not.... (practical usefulness).

The mental representation of a device can then be considered on the one hand as a state or a "picture" at a given moment, and on the other hand as a process that makes this "picture" evolve as the flow of information received during observation or use. In other words, the mental representation of an object is impacted by the activation of related concepts and by the interaction with that object. Some types of concepts concern precisely the typical course of an interaction. 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 schema*. An event pattern is composed of a succession of actions that 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. In this sense, such a scheme determines how people plan future actions and evaluate past actions.

For example, when a driver is approaching a slower vehicle, the schematic organization of "overtaking" execution requires a series of specific actions. In this case it is necessary to check (1) if the central line is not continuous, (2) if there is no one in front, (3) check that no one is already overtaking, then (4) activate the indicator, (5) accelerate, (6) move to the other lane, etc. Before starting the "overtaking" event, the driver mentally plans his/her actions to follow this scheme. After the event, the driver (or a third party) can explain a possible bad operation by analyzing the differences between the actions performed and the actions dictated by the schematic organization.

The notion of schematic organization places the object (the car) in a typical usage context. Also, an unusual property of an object can impact the process planned by the schematic organization. If this impact has positive (or negative) consequences on the final result, the unusual property could be perceived positively (or negatively) in this context. In the example above, if the left mirror is out of adjustment, the driver may not see a vehicle that have started to overtake him. So, the driver followed the schematic procedure, but constructed an erroneous mental representation of the situation that could lead to the accident.

According to various authors (e.g. Chaigneau, Barsalou, and Zamani 2009; Chemlal and Cordier 2006; Kiefer and Pulvermüller 2012), concepts are rarely categorized only by "essence" or specific characteristics. They are defined more broadly in relation to context first, 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 and Pulvermüller 2012; Chaigneau, Barsalou, and Zamani 2009). For example, the driver of bus could perceive a given road as small, while the driver of a little car would perceive it as comfortable. This judgment can be accentuated in crosswind conditions or if there is a ravine on the side. The object and the environment imply a *relative* character in the mental representation, which can be modulated by the context. 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 A1), 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).

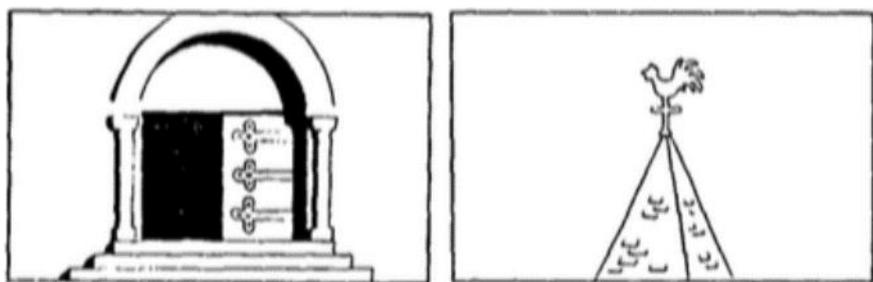


Figure A34. Examples of images presented in Phase 2 in Denis and Le Ny's experiment (1986)

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.

Similarly, the representation of the action as described by Zacks and Tversky (2001) is also composed of structuring elements (containers) such as the event, and component elements (contents) such as gestures or changes in body position. In other words, in a context of using

a target object, the user represents this object in particular on two dimensions. The first corresponds to the physical properties of the object and the context, the second to the properties of the activity carried out with the object in this context. The representation of an object or a situation according to these two dimensions (or more) can be apprehended to evaluate an object by taking into account, for example, the schemas implemented by users. The following section describes the evaluative process at work within the mental representation itself.

### Mental representation and evaluation

The mental representation of an object is determined in particular by the activation of concepts from memory, experience, context and activity. The object is associated with concepts with which it forms a category. Belonging to a reference category generates inferences of characteristics not perceived on the object (Barsalou et al. 2003; Chaigneau, Barsalou, and Zamani 2009). However, copies of a category do not necessarily have identical properties on a given dimension. According to Chemlal and Cordier (2006) *"If two representations are characterized by the same value on the same dimension, they have a common attribute. This attribute is distinctive if the two representations have different values on the same dimension"*. In other words, in an evaluation situation, the target object can be compared and qualified against other specimens used or observed in previous experiments.

In a context of use, the qualification of the object also implies a comparison between what is expected or predicted (e.g. characteristics, performance, quality of interaction, result) on the one hand, and what is perceived in a situation of use on the other hand. More precisely, Chaigneau, Barsalou, and Sloman (2004) showed that the perception of the function of an object was not only explained by an affordance but also by a user's goal. Planning for the achievement of this goal would allow the user to be more sensitive to the affordances of objects whose characteristics would be favourable to the achievement of the task. For example, a rock on the side of a road offers the possibility to sit down. If a hiker needs to rest, he will detect this affordance more easily than a hiker who is just beginning his route. More generally, the more useful an object's characteristic could be in a given situation, the better it will be detected by a potential user. With digital technologies embedded in cars, it is possible to provide users with the information or functions they need depending on the context. But the offered possibility must also naturally embrace the targeted action.

To conclude, the mental representation of an object involves several levels, with upstream, the elements of which it is constitutive such as context, and downstream, the elements of which it is composed such as a functionality or an interface. This representation also involves different dimensions, such as morphology or function in an action schema. In addition, this representation is involved in a categorization process that allows the device to be characterized. The categorization process involves a comparison process based on, for example, what we know (e.g., how to drive), what we predict or expect (automatic driving will provide this performance, this interaction, this result...), and what we finally perceive in the situation (characteristics, interaction, result). The mental representation would then carry a subjective a priori evaluation, i.e. the object is already pre-evaluated on the basis of the categories assigned to it. In a test situation (cf. SUaaVE WP6), this subjective evaluation could be questioned in order to target the user's judgment on different qualities of the system or device. In an ergonomic approach, these qualities can be related to dimensions related to effective use, such as utility, quality of experience or usability. Since the mental representation of the target object is context-dependent, the following section presents the spatial information coding processes that are involved in defining a particular business context.

## A 2. Representation of the activity space via the adoption of a spatial referential

### Definition of the main frames of reference

The driving situation often involves multiple road users. When a user performs an action, another one is able to observe him and evaluate his conduct or results and, if necessary, interact with him... Studies have shown that task and context have an important effect on the fundamental process of adopting a spatial frame of reference (e.g. Holmes and Sholl 2005; ter Horst, van Lier, and Steenbergen 2011).

A spatial frame of reference is an imaginary landmark, such as a 2 or 3-dimensional grid, that allows the characteristics of spaces and objects (e.g. location, size, shape, movement) to be determined according to reference points. Holmes and Sholl (2005), Sholl (2001), and Sholl, Acacio, Makar, and Leon (2000), described several types of reference frames, including two in particular. The first referential is said to be self-centered (fixed to the body), it uses points on the body as a reference to locate objects. The self-centred reference frame would be preferred when presenting a new environment (Holmes and Sholl 2005) or when acting on an object within reach (ter Horst, van Lier, and Steenbergen 2011). The second reference frame is called exocentric, it allows the representation of a large space from fixed reference points. The exocentric referential would be preferred in particular to describe large and known spaces (Holmes and Sholl 2005). Using a car involves a close space, the cockpit, and a wide space outside, the roads, the city... Therefore, the question of referentials is essential in the communication between the driver and the virtual assistant.

In the 2005 study, Holmes and Sholl worked on the effect of coding using an ego- or exocentric reference frame on the representation of space in case of disorientation. Using a joystick and blindfolded, participants were asked to locate 6 known places on campus, or 6 objects previously presented in the room. Participants were placed in a chair and their eyes were blindfolded. Then they were disoriented (several turns on themselves) or not, and repositioned either in the initial position or rotated 90 degrees. Finally, they had to perform localization tasks, always blindfolded. The analysis of the results showed that a location of objects is more resistant to disorientation for participants using an exocentric reference frame than for those using an egocentric reference frame.

In addition, this study observed that the exocentric reference frame could also be adopted to code a new space of limited size. Finally, according to the authors, this reference frame can be updated by recoding the perceived information in order to integrate it into environmental knowledge. With respect to the self-centered reference frame, the exocentric reference frame allows a more complete, broader, and stable representation of the environment, but as a result its updating during the activity could induce a higher cognitive cost. Consequently, depending on the activity carried out, the adoption of a reference frame is determined in particular by the quantity of remaining and available resources to process spatial information (e.g. Wickens 2002).

In summary, it is possible to have a mental representation of the environment and the vehicle coded from a frame of reference that is either self-centered and cognitively economic, or exocentric and robust and extensive. In 2004, Mou, Biocca, Owen, Tang, Xiao and Lim showed that the reference frame could change if there was a change in activity. However, level 4 precisely implies a critical change of activity when the user has to recover control. The design of an autonomous level 4 vehicle therefore faces this choice of perspective to describe spatial elements. This question must be addressed, in particular for the transition from autonomous to manual driving.

### Impact of action and situation on the adoption of a reference frame

The adoption of a reference framework can be linked to the needs of an action or a situation. For example, Schober (1995) studied a situation where one person (the director) asked another person (the Addressee or performer) to perform a series of spatial tasks. These tasks consisted in locating objects of different shapes and colors on a tray. The author was particularly interested in changes in spatial referential in the director's formulations. Depending on the positioning of the partners, the spatial reference frame used by the director corresponded to one of the four main patterns: *Speaker-centric*, *Addressee-centric*, *Common* or *Neutral*. The *speaker-centered* frame of reference referred to the speaker's body, with an egocentric formulation designating the objects in relation to the speaker himself. The *Addressee-centric* frame referred to the body of the Addressee, with an allocentric formulation designating the objects vis-à-vis the addressee. The *Common* Reference frame was a self-centered formulation referring to the two participants jointly when they were side by side. The *Neutral* referential corresponded to an exocentric referential that referred to elements of the environment. The analysis of the results indicates that during the first tests the director favours the Common reference frame if it exists, otherwise he chooses the one of the Addressee or a Neutral reference frame. The reference frame chosen by the addressee is the same as that adopted by the director. After several tests and several configuration changes (angle between participants, role reversal), the director prefers to adopt a Neutral reference frame. According to the author, an egocentric formulation is easy for the director to produce because it directly translates an egocentric/visual spatial coding, but the addressee must then recode or reinterpret it according to the reference frame accessible from his own point of view. On the contrary, if a speaker adopts the addressee's spatial frame reference, the addressee does not have to recode or reinterpret the information provided. The speaker then uses the Addressee's frame reference. As a result, the cognitive cost of treatment for the Addressee is lower (and vice versa for the speaker). Finally, the neutral formulation is directly based on an exocentric reference frame common to both participants. It allows the director not to make the effort to recode the space from the Addressee's point of view, and conversely it does not encourage the Addressee to recode the space from the director's point of view. The author concludes that the reduction of the total mental effort of the two participants required for their collaboration promotes the adoption of neutral wording by the speaker. In addition, the adoption of a frame of reference is determined by the task, but also by the context in which the task is performed.

According to some authors, the self-centered referential is often used in an action situation (ter Horst, van Lier, and Steenbergen, 2011; Sholl, 2001) for a reason of compatibility between body movements and the perception of the environment (Carlson, Hoffman, and Newcombe 2010). For example, when the driver inserts the start key he should use an egocentric reference, when he looks for his car in a parking he should use an exocentric reference. An action situation (actual or possible) has an effect on the spatial reference frame adopted, and consequently on the method of coding environment information. The presence of another active person can also have an impact on this process. More precisely, an observer or co-actor will not necessarily code space according to an egocentric referential carried by his/her own body. It can also code the space according to the other's body (allocentric), or according to an exocentric referential or even according to the car (car-centred). In this situation, as Schober (1995) mentioned, a person can adopt an actor's spatial referential, he/she takes his/her perspective. This is the case when someone guides a driver by phone, he or she will make it easier to understand the route by describing it from the driver's point of view. To facilitate the formulation, the speaker can mentally visualize the journey from this point of view, as if he or she were making the journey himself or herself. In other words, he can change his perspective on the world. By adopting a third party perspective, it is possible to adopt his mental representation of space, but also his other representations. This is the subject of the next part.

### A 3. Representation of a third party's activity through the perspective taking

#### Theory of mind (ToM)

The attribution of mental representation to a third person was the subject of research in the 1970s through the concept of Theory of Mind (ToM). ToM is defined for human beings as the ability to impute mental states to themselves and others. It can be used to make predictions about the behaviour of others. But also, the goals, intentions, knowledge, actions, beliefs, thoughts, doubts, guessing, etc. (Premack and Woodruff 1978). The mental states of others are not directly observable, but must therefore be inferred by observing their behaviour (decision-making, knowledge, actions, etc.). In 1983, Wimmer and Perner introduced the famous method of unexpected transfer to test children's acquisition of the theory of mind. In this test, participants must infer that a person unaware of the movement of an object will look for it where they believe it is and not where the participants know it is in reality. The following scene can be performed for children with toys and dolls:

- Max and his mom are in the kitchen; they store the chocolate in the refrigerator. Max goes to join his friends to play.
- While he was away, his mother decided to make a cake. She takes the chocolate from the refrigerator, uses some of it and puts the rest of the chocolate in the closet.
- Later, Max comes back; he wants to eat chocolate. Where is he going to get it?

This method allows to test the theory of mind on the mental representation of spatial information. On a similar principle, it is possible to test the theory of mind on other types of cognitive processes (e.g. emotions, mental load, etc.) occurring on the target (Max) or the level of empathic engagement in the participant (E.g. Hall et al., 2006).

Beyond the human, it is common to see people inferring mental states from animals, or even machines. Apart from any consideration of the validity of these inferences, it is quite possible to imagine an inverse process, according to which a virtual assistant would be able to infer mental representations of the user's space. A system with such a capacity may be able to improve its service in response to users' information or support needs.

From a practical point of view, the ability to formulate a theory on the thoughts of a target actor is based on a knowledge of the target's abilities (e.g. motor, sensory, cognitive, etc.). This ability is the result of the perspective taking process described below.

#### Perspective Taking Principles

Perspective taking is generally considered as "the tendency to spontaneously adopt the psychological point of view of others" (Davis 1983; Chevallier et al. 2010). This definition refers to a process that can operate for example in situations of observation of a person acting (e.g. Davis 1983; Chevallier et al. 2010) or in situations of dialogue (e.g. Deyzac, Logie, and Denis 2006; Roger et al. 2013). The perspective of an actor plays a particular role in the understanding of his/her actions by an observer (Lozano, Hard, and Tversky 2008), and more generally on the understanding of the world by the latter, as when he/she acts himself/herself. This observation is consistent with Chaigneau et al's (2009) description that action is a determinant of the mental representation of an object.

Neuropsychological researchers (e.g. de Bruin, van Elk, and Newen 2012) have described brain structures involved in perspective taking, such as mirror neurons and the pre-motor cortex. The process was also described from studies of patients with different types of disabilities. For example, in a study by Becchio Del Giudice, Dal Monte, Latini-Corazzini, and Pia (2011) hemiplegic patients were asked to describe rows of objects from their own perspective or from the perspective of a third party.

Patients' descriptions from their own perspective were less complete than those from a third party perspective. The authors suggest that perspective taking induces a reconfiguration of the representation of objects and space, the latter being coded according to a reference to the body of the person observed. In a study conducted in 2006, Hard, Lozano, and Tversky observed the effect of an actor's perspective on the reproduction of a spatial task. Participants were asked to view an actor assembling an object (seen from the front view in a film), describe the different steps, and then reproduce the assembly. Some participants used the actor's perspective to describe the actions, while others used their own perspective. For example, if the actor put a coin on his right, the first would say "he puts the coin on the right" while the second would say "he puts the coin on the left". Participants produced fewer assembly errors when they described the assembly steps using the actor's perspective rather than their own. The authors explain this effect by a better memorization of the task when it is observed from the actor's perspective. This example illustrates the potential gain of a change of perspective to mentally represent an object to be assembled. The following section highlights some of the mechanisms and determinants of perspective taking.

The perspective of a third party is a cognitive operation that can be facilitated by certain determinants. For example, Hard et al (2006) described verbalization as a determinant, i.e., an observer more easily adopts an actor's perspective if he/she verbalizes observed actions than if he/she does not verbalize them. According to Lozano, Hard, and Tversky(2007), it is the action observed in itself that is a determinant of perspective taking. These authors manipulated the effect of a third party's action (or non-action) on an observer's perspective taking through a series of experiments. Participants were asked to perform a spatial location task on a photograph. The photograph showed a figure (male or female) seen from the front, sitting at a table on which two objects were presented. Either the character made an action movement on an object, or he did not make any movement (see Figure A35).



Figure A35. Photograph from experimental material by Lozano et al (2007). In picture "a" the actor starts an action on the book, while he is inactive in picture "b"

The participant had to orally locate a target object in the photo (e. g. the book). The experimenter identified the location strategy, which could be described from the participant's perspective, or from the character's perspective. The analysis of the results showed that participants more often take the character's perspective when the character is active than when the character is inactive. These results indicate that an observer is encouraged to take a third party's perspective when the latter is active.

In other words, it is easier for an observer to take a third party's perspective if the latter is involved in an action. Perspective taking is also facilitated if the observer has experience of the action observed (Lozano, Hard, and Tversky 2008). This process would make it possible to assess a situation, and in particular to evaluate the actor's intentions (Davis 1983). According to some authors (e.g. Lebon 2008; Sinigaglia and Rizzolatti 2011; Lozano, Hard, and Tversky 2008), the mental representation of the scene is materialized in terms of activation of the brain zones but also of the muscles linked to the observed action. These activations would be the trace of a mental simulation of the observed action. This simulation would be involved in learning and understanding emotions and mental states (Desmurget 2006; Lebon 2008). Perspective taking is generally described as a process of simulating the actions of a third party on whom it depends. In other words, the simulation of an actor's actions is facilitated by the adoption of his perspective, which in turn is facilitated by the actor's action. The following section focuses on the mental representation of the observed action.

### Construction of the mental representation of an observed action

The mental simulation of an observed action contributes to the mental representation of this action. However, according to Desmurget (2006), the observer does not formally simulate the different stages of the gestures that make up the observed action. Otherwise, learning a sport, for example, would be immediate and this is not the case. Moreover, according to the author, the observer simulates the action before it is executed by the actor, and as he would have executed it in the actor's place.

This analysis can be supplemented by a study by Lozano et al (2008). These authors observed the effect of the experience of an observed sport situation on the perspective adopted by participants. In one image, a sportsman was presented from the front, with a *basketball* and *soccer* ball. He touched one of the two balls either with his foot (usual in soccer, but not in basketball) or with his hand (usual in basketball but not in soccer). Participants usually participated in one of the two sports. Participants were asked to indicate the position of one balloon in relation to the other. According to the authors, participants more often described the position of the ball from the actor's perspective if the situation corresponded to a usual situation in their sports practice. The experience of an active observed activity in the observer of possible action representations. According to the authors, when the actor acts in accordance with these representations, the observer can imagine the scene from the actor's perspective. In other words, the experience of an observed activity facilitates a representation of the environment and actions from the actor's perspective.

When a rally driver observes a race, his experience facilitates mental simulation and the anticipation of observed actions. When the simulation and observation of actions match, the observer is able to hold the perspective of the observed driver and evaluate the quality of his/her driving. On the contrary, if the observer is not used to watching rallies and have never driven, his simulation of the actor's perspective is more difficult to hold, since each phase of the action contradicts the simulation and the observation. Each phase of the action corresponds to a breakdown of the global activity involved in coding this activity.

### Activity coding process

Desmurget's (2006) proposal that the observer give priority to considering the sequence of actions as a whole rather than the different gestures that compose it is consistent with Hard, Recchia and Tversky's (2011) approach, which describes a coding of the observed activity in terms of goals and subgoals. In this study, the authors observed the attention paid to different phases of an activity by participants. Films showing sequences of domestic activities (e.g. making your bed) were cut into slideshows consisting of one photo per second of film

(a slideshow of 60 photos corresponded to an activity filmed for 1 minute). Participants were able to scroll freely through the photos, with instructions to memorize the activity presented.

The analysis of the results showed longer observation times at the end and beginning of the major phases of the activity ("goals"). These major phases generally corresponded to a significant physical change of the actor (e.g. getting up, sitting down, turning around). The analysis also showed intermediate breakdowns ("subgoals") relating to intermediate stages marked by less significant body changes (e.g. reaching out an arm, turning the head). For example, in an activity involving the assembly of a piece of furniture in kit form, the major phases could be marked by a displacement or reversal of the assembly in order to fix a new element. Such action involves large body movements. While the intermediate cut-outs could be marked by the initiation of screwing actions of this element. Placing a screw involves relatively smaller body movements than moving the assembly. Finally, the actions best recalled corresponded to the main phases of the activity such as fixing an element rather than the intermediate phases such as placing a screw. This example illustrates how the action is coded in memory. As with the representation of an object, which is constructed from comparative reference activations (of which the action is a part), the representation of the observed action is also made from references based on the observer's experience. These references may, for example, be a formally prescribed procedure, such as the QRH, or a less formal schematic organization, as described by Chemlal and Cordier (2006). As a reminder, the schematic organization corresponds to a sequence of events expected in a given situation. The schematic organization is the result of experience and stored in long-term memory. The effect of the experiment on the ability to take an actor's perspective could be based on a detailed knowledge of schematic organizations. The experience presented above could be transposed to analyze the schematic organization of different driving situations. This type of knowledge would allow us to design an optimized interface to support situational awareness.

#### **A 4. Driver's mental representation simulated by a virtual assistant**

A user does not directly apprehend the world he/she perceives, but he/she segments it and categorizes the elements that compose it. An object is represented mentally from an assembly of different attributes that refer to it in different categories. Interaction with the object and the context of use are important determinants of the user's mental representation of the object and possible actions (Gallese & Lakoff 2005; Kiefer & Pulvermüller 2012).

In a cooperative situation, each co-actor is able to mentally simulate the psychological and visual point of view of the other (cf. theory of mind by Wimmer & Perner, 1983) and thus to share his/her mental representations, understand his/her judgments, objectives, difficulties, etc. (e.g. Davis 1983; Lozano, Hard, and Tversky 2008). The reciprocal simulation of the actors' points of view forms a common ground on which everyone can carry out their task and at any time interact effectively with their partners. This common ground includes data of very varied natures such as the status and level of participation of the interlocutors, the activation in memory of previous shared interactions (Knutsen and Le Bigot 2015), the cognitive coding of visuospatial information (Schober 1995), etc. For example, the common ground built by a flight team integrates the roles of each person, the distribution of tasks, all the flight data to which they have access, the flight phase, the context (e.g. air traffic, weather).

To design an effective interaction between a driver and a virtual assistant as ALFRED, the establishment of a common ground seems to be an essential step. This includes event schemas (e.g. Zacks and Tversky 2001) resulting from driving learning, prescribed procedures, but also and especially from their experience. These schemes allow the assistant to adapt quickly the information process or his action, but also to anticipate the needs of the driver. The discrepancies between the schema and the actual action are clues to evaluate the action

and/or an unusual situation. The adoption of an action plan is based on hypotheses formulated on the basis of the situation indicators. Therefore, the quality of these assumptions is determined by the completeness and relevance of the indices. An interest in cooperation is precisely based on the ability of each party to enrich (sufficiently, but not too much) the common ground with clues and hypotheses that the co-actor would not necessarily have had if he/she/it had been alone. ALFRED will of course have access to all the car data and to some controls. However, only certain data relating to the situation should be accessible to the driver. In return, ALFRED will be able to analyze the driver actions (e.g. line crossing detection system), but also the driver's state data, (e.g. drowsiness, emotion). Driver's state data should be relevant to prevent difficult cognitive conditions (e.g. too many information at a time, guidance to the area of interest, stressful context, etc. ALFRED will be able to build a dynamic situation model by comparing the driver's analysis, prototype event schemas (T3.3) and all driving data (and this is its technical advantage). It will adjust its own actions and the transmission of useful information to the driver in real time.

The system's ability to simulate and anticipate the driver mental representations will make it possible to provide assistance that optimizes situational awareness depending on decision-making and action needs. However, the system must not only be reliable to assist a drivers, 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). Some authors have also studied the relationship between empathy and trust. However, it is important to identify other factors of trust because these can have an effect on the attitude towards autonomous vehicles.

## A 5. 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.

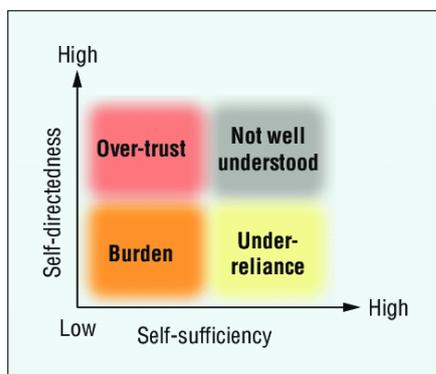


Figure A36. Challenges faced by designers of autonomous machine capabilities (Bradshaw et al. 2013; adapted from Johnson et al. 2012)

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 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. 2017) 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. Researchers in psychology and sociology often consider trust as one of the most valued qualities in any close relationship. For Liu, Yang, and Xu (2019) 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.

### 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 (2015) model incorporates the main concepts that are generally proposed. Ce model reprend par exemple l'idée, évoquée ci-dessus, de la confiance avant et après l'interaction, avec notamment une actualisation en fonction de la performance du système.

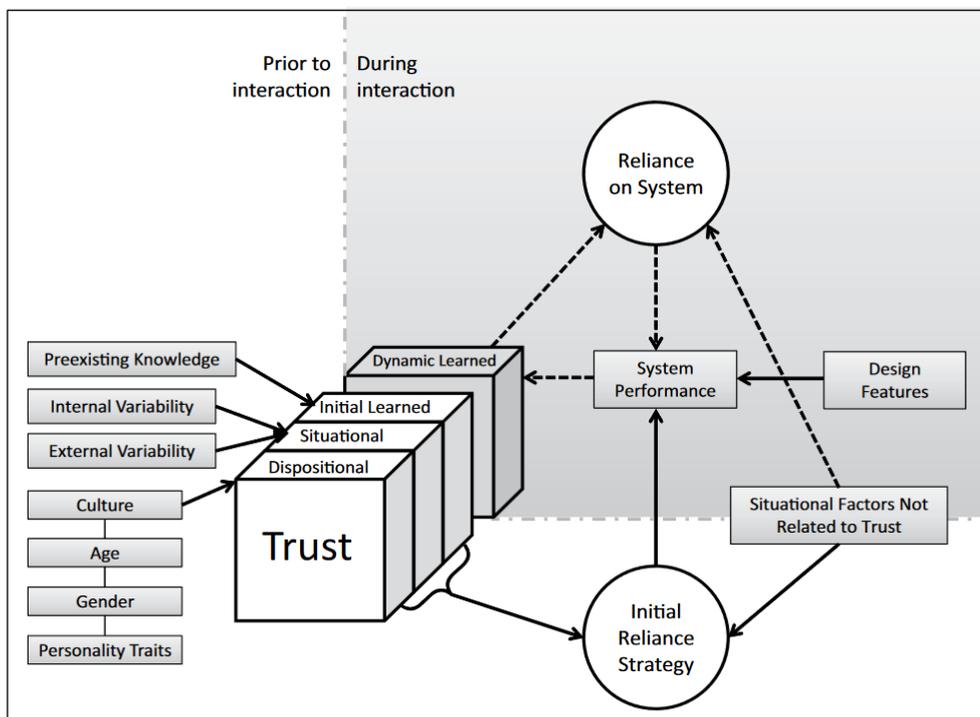


Figure A37. Full model of factors that influence trust in automation. The dotted arrows represent factors that can change within the course of a single interaction (Hoff and Bashir 2015)

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 learned*), 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, automatism, etc.).

### 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 rings 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.

### 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 or 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 behaviour. 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 behavioural 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.

As mentioned and as shown in the Figure A37, driver will have an a priori trust or distrust of the CAV. And a priori acceptability of the technology defined as the practical and social evaluation of that technology before interaction with it (Bagozzi 2007, Terrade et al. 2009). It will be necessary and even essential for them to have training sessions to use this new technology and develop the right level of trust.

## **A 6. Cognitive functions and concepts associated with the acquisition of situational awareness**

As mentioned above, 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. That is why we use the concept of situational awareness.

Mental representation is at the center of the situational awareness model often used to describe the driver's activity. Situational awareness is the permanent and necessary adaptation of the mental representation of the situation.

### Situational awareness as the continued construction of the situation

Situational awareness is the representation and understanding of the environment and the anticipation of changing situations (Tattegrain-Veste, Bellet, Pauzié, & Chapon, 1996). Situational awareness is a construction based on the continuous knowledge of the driver available in long-term memory. This construction is related to the situation's conditions. It is developed in the working memory and evolves according to changes in the situation. This representation guides the exploration of the environment and the treatment of new information. The anticipation, possible evolution of the situation can be represented according to a tree of representations and alternatives. Decision-making is the selection of one of the alternatives considered most appropriate by the driver.

Situational awareness is defined (Endsley, 1988) as the perception of the elements in the environment in a volume of time and space, the understanding of their meaning and the projection of their state into the immediate future. Situational awareness is composed of 3 steps:

- perception refers to the perceived information, status, attributes and dynamics of element in the environment;
- understanding refers to the integration of this information to explain the situation, the impacts of the elements on the situation and the objectives;
- the projection or anticipation is the expectation of a future state. The projection depends on the expertise and knowledge of the operator. The results of this evaluation initiate planning and decision-making for the next action.

Situational awareness uses cognitive abilities such as language, memory, intelligence, learning, reasoning, perception or attention. The person will evaluate all these aspects of cognition before making the decision and taking action.

Situational awareness in a dynamic environment is characterized by the discreet updating of information (MacIntyre et al., 2001). The management of complex dynamic processes requires the operator to make a compromise between "understanding" and "succeeding": the operator does not have the internal resources necessary for an exhaustive understanding, to a total reduction of the uncertainty of the situation in the pace required of him (Valot, 1996). Decisions are made in a short period of time, depending on an update of the situation analysis (Endsley 1988). Consciousness evolves and adapts over time.

The concept of a dynamic environment is characterized by the fact that dynamics is determined by other factors than the operator's actions: the situation continues to evolve with or without any intervention (Cellier, 1996, Amalberti & Hoc, 1998). In the case of car driving, the interventions are irreversible: it is not possible to return to the initial situation (Sébillotte, 1984).

Situational awareness is also explained in terms of the perception/action cycle. Situational awareness is both the product and the process (Adams et al, 1995)

The perception/action cycle consists of three elements:

- The **object**: the information available in the external environment.

- The **schema**: internal knowledge that is theoretically structured in an organized way, developed through experience or training, and stored in long-term memory when not in use.
- **Exploration**: a search for information in the environment by the observer.

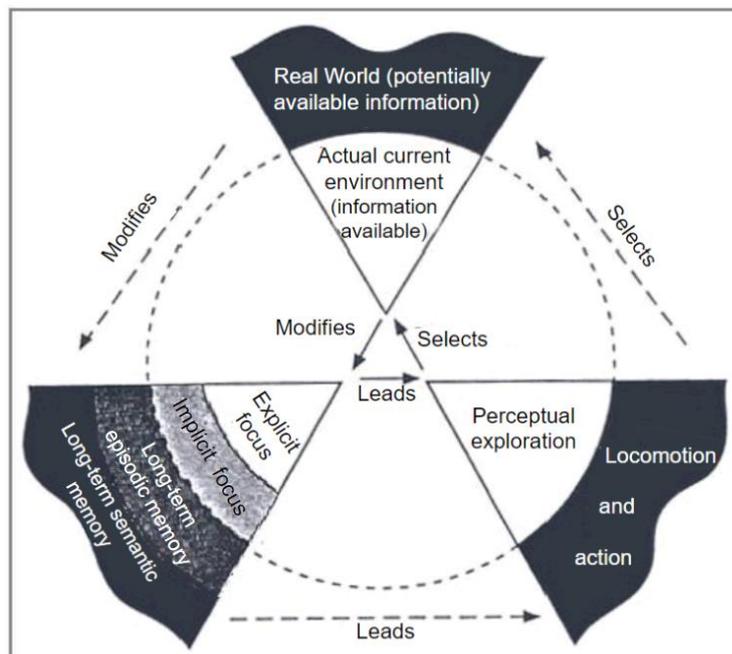


Figure A38. Extended version of Neisser's circle by Adams et al., 1995

According to Neisser (1976), the cycle works as follows: the object modifies the schema, the schema directs exploration, and exploration leads to the collection of information about the object in the environment. As its name suggests, the perception/action cycle suggests that the information gathering process is cyclical, neither the beginning nor the end of the process is indicated. Therefore, this approach suggests that the process of developing Situational Awareness is dynamic.

Adams et al (1995) extend the Neisser circle (Figure A38) by integrating the theory developed by Garrod and Sanford (1981). For Garrod and Sanford (1981), active memory is composed of two levels, one explicit and the other implicit. As a result, Adams et al (1995) divide the "schematic part of the current environment" into two boxes. The first box is called "explicit focus" and corresponds to the working memory for the authors. At any given time, it would contain only a very limited number of pointers interconnected with long-term memory knowledge. The second box is called "implicit focus". It contains the entire schema which is only partially represented in the explicit focus.

Adams et al also integrate two types of long-term memory. Still with reference to Garrod and Sanford (1981), they therefore integrate episodic and semantic memory. Long-term episodic memory contains all the schemas and procedures that have been constructed or activated during a task, and long-term semantic memory contains the general knowledge acquired during life.

The purpose of perspective exploration is not to provide a copy of the environment but to optimize the processing of the retinal image by affecting its perception even if this is at the neglect of a perfect copy. Visual search is our ability to detect, discriminate and locate a target that has known characteristics whose location is unknown among distractors with different characteristics. That's the role of attention. When researching, the priority for information processing should be on stimuli that contain at least one characteristic of the target in question. An early stage in the research process therefore aims to select these stimuli and focus attention on them in order to improve their representation as discussed above.

There are several tools to measure situational awareness: SAGAT (Endsley, 1988), SART (Taylor, 1990), SPAM (Durso et al., 1998), etc. 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.

### Perception - Attention - Attention Resources

Perception is an important step in building situational awareness. However, perception, visual exploration is limited. The first is the physical limit: degrees of the visual field (220 degrees without visual impairment), the fovea is the only part of the eye that allows maximum visual acuity. It is therefore impossible for us to perceive all stimuli simultaneously. The second is cognitive: limited attention capacity (Kahneman, 1973). It is impossible for us to qualitatively treat several stimuli simultaneously; and to perform a long task while maintaining good performance (Grier et al., 2003; Helton et al., 2005).

Environmental information is collected continuously both by selective and peripheral attention. This information is collected simultaneously via many channels: visual, auditory, tactile (MacIntyre et al., 2001). The information present in the environment is an external stimuli also called sensory information. Sensory memory stores much of its information (depending on its capabilities). Perceived stimuli compete to overcome the attention bottleneck (Awh, Vogel & Oh, 2006).

Attention is considered to be the selection mechanism, the attentional filter that allows us to process only a part of the sensory information present in the environment (James, 1890). This pre-treatment, this filter makes it possible to determine which sensory information is pertinent. This information will be stored in working memory for manipulation and is processed at a high level. Thus a limited number of information is treated. The selection of information of interest takes place before its semantic analysis (Laberge & Tweedy, 1964).

The attentional filter is applied in an:

- intentional and controlled way, when you deliberately choose to focus your attention on something, to be careful, for a more or less long time.
- Automatic way, if the stimulus is sufficiently salient or caused by an abrupt change in the environment.

The attention is responsible for selecting the information that enters the working memory.

### Selective attention

Selective attention or Top-Down allows you to select the information pertinent to the current task and the subject's objectives. The pertinence comes from the individual's knowledge of the target to be searched: he knows beforehand the object to be identified. He is looking for specific characteristics. The individual's objective assigns additional weight to information of interest.

This selective attention can be done unconsciously when driving (automatic panel search for example); conscious and voluntary when searching for an object. It is also called sustained attention. It is the ability to focus attention for a relatively long time. However, this period cannot be too long, as after a certain period of time, the concentration decreases.

### Peripheral attention

Not all the information retained is necessarily related to the purpose. If an information is of a dangerous nature then this information will be processed. For example, spatial proximity is a dangerous character because it can harm the individual's body.

Bottom-UP mechanisms refer to physiological constraints, visual item properties (Desimone and Duncan, 1995): spatial (around the object under study), salience (a distractor is red in colour which attracts the eye), very relevant to the subject (Moray, 1959). This is why some say that this filter is not a selective filter but an attenuation filter: only information above the threshold is processed (Treisman, 1969). Each information has a weight and if this weight exceeds the threshold then the information is processed. This responds to an adaptive need to always be aware of the dangers surrounding it.

People are generally aware of a lot of information that is not the focus of their attention. This peripheral awareness of background information allows people to quickly focus on new issues if they become important to them (Blandford A. & Wong B.W., 2004).

### Pre-attentive treatment

The attention is responsible for selecting the information that enters the working memory. In turn attention is oriented by the working memory: the elements present in the working memory guide the selection of the information present in the perception scene.

The goal of perspective research is to detect targets and distinguish them from distractions with the same characteristics. During a search, the priority of information processing is on stimuli that contain at least one characteristic of the target in question. Indeed, some primary characteristics do not require high processing in order to be identified (color, size, luminance) (Broadbent, 1958).

An earlier step in the research process is to select these stimuli and focus attention on them. Expectation or predisposition facilitates this pre-attentive treatment (Laberge, 1995). Selection is flexible according to the subject's strategy and the demands of the task (Yantis and Johnston, 1990).

### Attention Resources

Attention resources have limited capacity (Braoddbent, 1958; Gopher & Navon, 1980; Kinchla, 1980). These resources cannot be renewed because of the continued mobilization of the cognitive activity required by the task (Grier et al., 2003; Helton et al., 2005). It is therefore in the organization's best interest to be able to select, at a lower cost, the information that is most useful to it. The organization must prioritize information.

### Shadowing effect

Focusing on one element results, in some cases, in the inability to focus on other elements. This is called the shadowing effect (Wood & Cowan, 1995). The shadowing effect implies that trying to perform two tasks simultaneously has a cognitive cost to the person, which can result in decreased performance in either or both tasks. These results have pointed to the Psychological Refractory Period (PRP) during which a human cannot achieve two things at the same time (Pashler, 2000). After the occurrence of a stimulus, there is a period during which treatment of a second stimulus is impossible. However, following the work on the shadowing effect and on the PRP, it has been shown that if the occurrence of the second stimulus is delayed by a certain amount of time, it is possible to perform both tasks simultaneously (Salvucci & Taatgen, 2008). The decrease in performance in the second task is function of the time between the occurrence of the first stimulus and the second stimulus

### Measures of attention - Engagement in the task

There is no consensus on the dependence of eye saccades on attention displacement. Some say that eye saccades cannot move without being preceded by a shift in attention (Groner, 1989). On the other hand, it is suggested that attention can be displaced independently of the gaze (Hermann von Helmholtz, 1867). So, we can't measure attention with eye movements. On the other hand, we can introduce the concept of 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.

Driving engagement can be analyzed via visual behaviors. The frequency and duration of the fixation of the visual check areas of the driving indicates if the driver is engaged in his driving task. The frequency and duration vary according to the people and their experience. It is therefore important to measure basic variables for the driver's engagement in the task so that they can be compared to the observed variables.

The following areas represent the regular attachment points of a driver (Neboit, 1982; Freydier 2014): interior or exterior mirrors, vehicle control commands (turn signals, steering wheel, gear lever, pedals), speedometer, just in front of the vehicle, attachment far ahead, roadside, right and left at intersections, signs and ground marking.

Attention is both early with pre-attentive treatment and late with selective and peripheral attention. Selective and peripheral attention is considered a selective filter: after automatic

initial processing, the pertinent information is selected by an attentional activation mechanism. As irrelevant information is not activated, it is not treated by cognitive processing. This single flow path for information has a structural limitation of the flow modulated by attention. Measuring engagement allows us to determine whether the driver is providing attention resources for the task. If this is not the case, the driver is not attentive, so he is less likely to process the information pertinent to the task and therefore will not tend to have a good situational awareness.

### Cognitive resources

Having correctly directed attention does not allow us to infer the correct treatment and understanding of the driver. The driver needs cognitive resources to process the information. Detecting a low availability of resources allows us to say that it is in disabling condition for the development of a good situational awareness.

These cognitive resources are processing resources for a set of tasks. Not all activities require the same quantity 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, 1975).

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. The more resources are invested in a task, the better the corresponding processing. A subject may have to control two or more tasks (double task) simultaneously. In these circumstances, he must efficiently distribute processing resources between tasks performed simultaneously. With two or more different sources of information, attention resources are distributed between the different sources of information. The limited quantity of these resources would not allow them to be equally distributed between the different processing operations and so to carry out the tasks efficiently. Some information would have more attention resources than others. It is possible to observe a decrease in the level of performance at one of the tasks, due to the other.

Multiple resource theory considers that humans have a processor allowing parallel use of the different resources (Navon & Gopher, 1979). Cognitive resources are separated into different modules (Salvucci & Taatgen, 2008; Wickens, 2002, 2008). The human cognitive system has different reservoirs depending on the sensory modalities used, the nature of the task, the treatment to be performed and the modality of the response to be provided.

As a result, two tasks performed simultaneously interfere if they use the same functional and/or brain subsystems (Pashler, 1994). The interference between tasks depends on the sensory inputs used. Two tasks interfere less as they will have separate resource demands (Wickens, 2002). Negative interference on performance is more severe if both tasks use the same sensory input (Shaffer & Shiffrin, 1972); an audio-verbal task and a visuo-spatial task will be less degraded than two audio-verbal tasks. Interference can also result from conflict at the encoding stage (Hock and Egeth, 1970). For example, the color of the ink and the name of the color could generate a conflict situation during the early stages of perceptual information processing. Interference can also result from competition at the response stage (Posners and Snyder, 1975).

### Factors influencing available resources

There is an intra-individual difference in the available attention resources of the same driver.

- **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 et al, 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. 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 & al., 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.

All references in the Annex are include in the REFERENCES section.



Consortium:



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