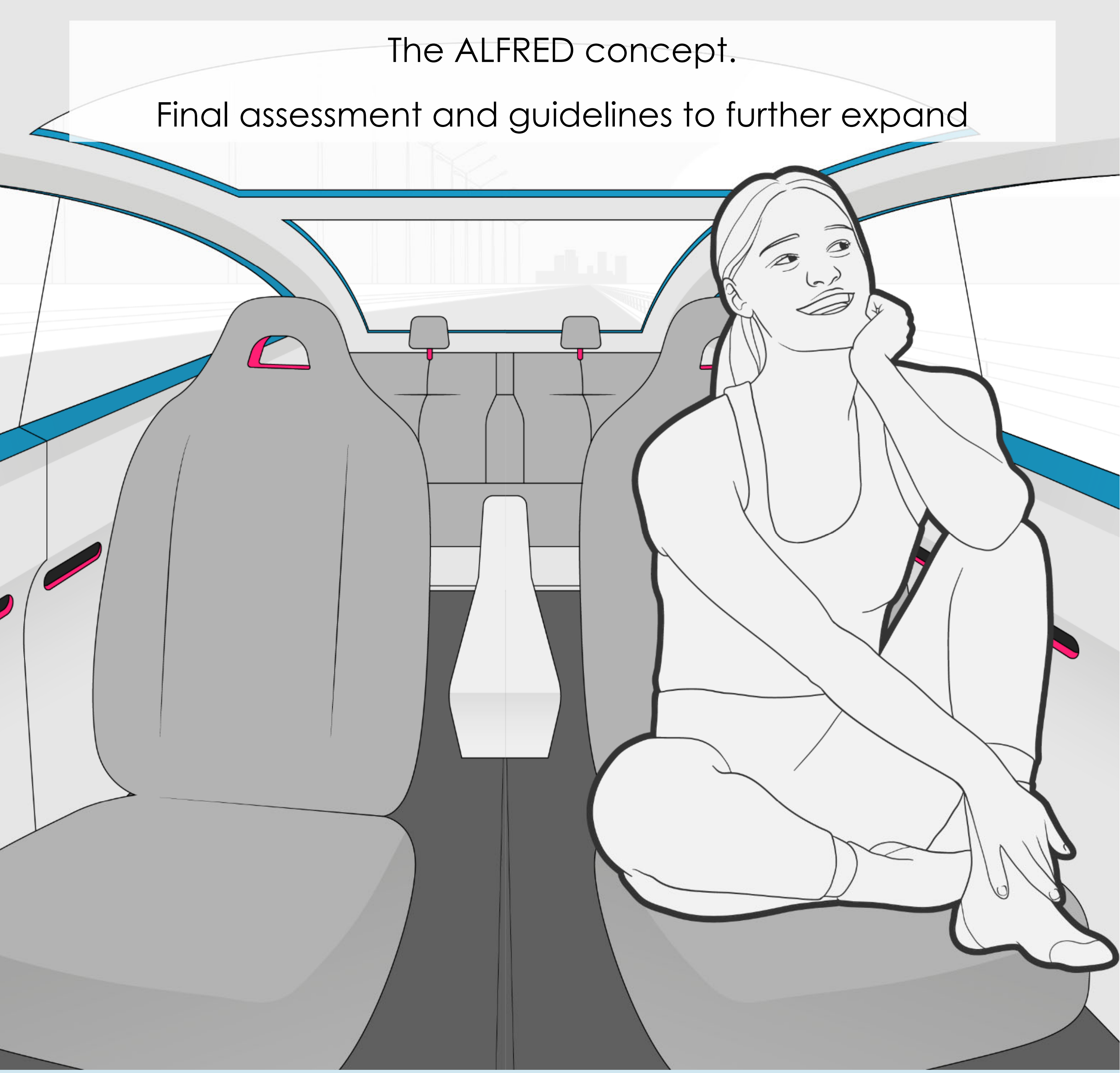
SUaaVE SUpporting acceptance of automated VEhicle

An EU Project to colour automated driving with HUMAN emotions

The ALFRED concept.

Final assessment and guidelines to further expand



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SUaaVE project
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Note

1. Introduction

In the near future, **the traditional driver will take the role of a passenger in highly autonomous vehicles**. Some of their primary benefits include safer roads, eco-driving, less congestion and leisure time. However, new aspects such as the lack of vehicle control, the absence of information about the intention of the ego-vehicle, the engagement in non-driving tasks and the change in the interior design with flexible seating configuration could lead to **low perceived safety and trustworthiness**, which is detrimental for the acceptance of highly autonomous vehicles. Acceptance is tightly related to emotional processes and trust in a new technology beyond the accomplishment of functional performance. To face this challenge, empathic vehicles seek to understand the emotions of the passengers and to adapt the vehicle features to enhance the in-vehicle user experience, while enhancing acceptance.

The automation of driving is changing the role of humans in such a way that SAE levels L4 and L5 of automated vehicles[1] will take over all control and monitoring tasks for specific applications performed by humans in conventional motor vehicles [2]. However, the lack of control can lead to lack of trust among users of fully automated vehicles (Lee & See, 2004), which has been identified as a key issue in the acceptance and adoption of this emerging technology [3]. In this regard**, trust in automation is strictly related to "emotions on human-technology interaction, which is a key factor for acceptance, but is also important for safety and performance"**[4]. For this reason, it should be a factor considered when designing complex, high-consequence systems like Connected Automated Vehicles (CAVs)[5].

The research on autonomous vehicles has mainly focused on technical solutions without considering new "intangible" aspects from the perspective of human factors (such as safety perception and the absence of information about the intention of the ego-vehicle), which could be detrimental for the acceptance of this emerging technology. **A way to enhance the user experience is through the development of empathic vehicles: Understand how the passenger feels** with high levels of automatization and respond to those feelings while taking into account the environment and context. Furthermore, with the introduction of autonomous vehicles, a new era of connected mobility is emerging, transforming journeys into tailored riding experiences. In the future, artificial intelligence must transform safe and efficient transport into delightful, enticing experiences.

The SUaaVE project (SUpporting acceptance of automated VEhicle), funded by the European Union's **Horizon 2020** Research and Innovation Programme, aims to lay the basis for empathic vehicles through the formulation of ALFRED, which is a human centred artificial intelligence to **humanize the vehicle's actions by understanding the emotions of the passengers** of the connected automated vehicle and managing corrective actions to enhance the trip experience.

[1] SAE, I. (2021). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles J3016_202104 (p. 41). *SAE International*.
[2] Drewitz, U., Ihme, K., Bahnmüller, C., Fleischer, T., La, H., Pape, A. A., ... & Trende, A. (2020, July). Towards user-focused vehicle automation: the architectural approach of the AutoAkzept project. In *International Conference on Human-Computer Interaction* (pp. 15-30). Springer, Cham.
[3] Bazilinskyy, P., Kyriakidis, M., & de Winter, J. (2015). An international crowdsourcing study into people's statements on fully automated driving. Procedia Manufacturing, 3, 2534-2542.
[4] Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. Human factors, 46(1), 50-80.
[5] Paddeu, D., Parkhurst, G., & Shergold, I. (2020). Passenger comfort and trust on first-time use of a shared autonomous shuttle vehicle. Transportation Research Part C: Emerging Technologies, 115, 102604.

2. The SUaaVE ambition

The main **objective of SUaaVE** is to **investigate, support and enhance the public acceptance of connected and automated vehicles (CAV)** both at a societal and individual level with the integration of the human perspective. To achieve this, SUaaVE will generate a framework to incorporate the human factor (emotion, comfort and ethics) in CAV decision-making processes. This will be the basis to increase trustworthiness via generating strategies and policy recommendations for different groups of decision makers that encompass ethical and legal dimensions, and which will effectively enhance public acceptance.

The SUaaVE project aims to make a change in the current situation of public acceptance of CAV by leaning on a Human-Driven Design (HDD) approach, where the user is not only the centre of the process, but actively contributes and even leads the definition of concept and development of technology, and participates in its testing. SUaaVE focuses on the human side, working to improve more “intangible” aspects such as safety perception, attitudes and, in general, emotional appraisal of CAV.

SUaaVE has involved more than 6900 citizens from seven EU countries and the UK, as future users in a broad sense: current drivers, new drivers and passengers (children, senior citizens and people with disabilities) and other road users like Vulnerable Road Users (VRU).

The **SUaaVE outcomes that will enhance the acceptance of CAV** are:

1. **Guidelines to support Public Authorities**, representing a breakthrough in the public acceptance of future CAVs for both society and, in particular, for all road users.
2. A **virtual driving simulator**, called the Immersive **Virtual Human Centred Design (V-HCD) platform**, specially designed for the **assessment of public acceptance**, through the involvement of future users, taking into account the perspectives of all road users. It will offer advanced features for immersive experiences, simulating a human-automated vehicle interaction not only from the in-vehicle point of view (passengers), but also from the other road users’ point of view as traditional car drivers interacting with the CAV and/or as pedestrian.
3. The **new paradigm** of automation: **ALFRED - Automation Level Four+ Reliable Empathic Driver**. It is conceived as the fundamental architecture of the artificial intelligence in automated vehicles to understand the emotions of the passenger on board and to adapt the vehicle features to enhance the user experience. This will be achieved by a) an Empathic Module, to consider the ethical boundaries of society and the emotional and cognitive state of the passenger; and b) an Adaptive, Cognitive and Emotional Interface with a set of services (such as vehicle dynamics, ambient comfort, entertainment and adaptive communication) to make the ride enjoyable and to continue enhancing the “driving experience”.

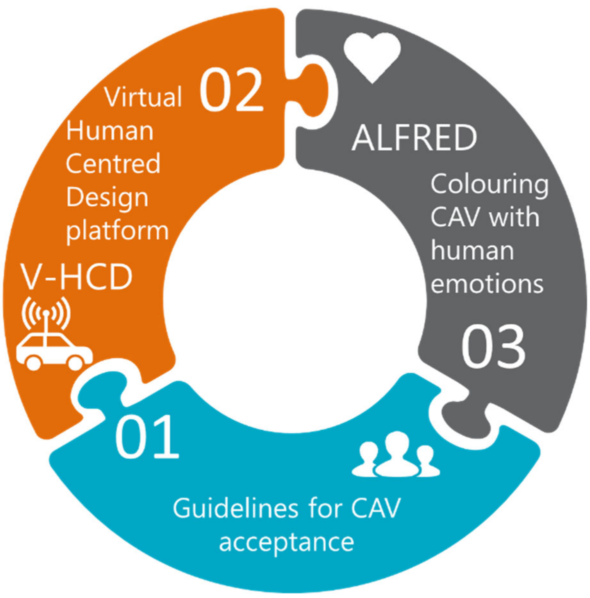
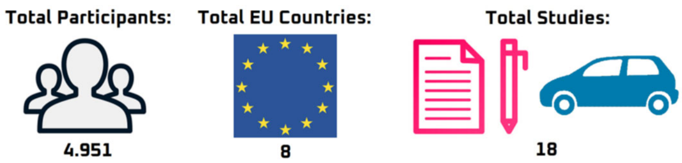


Figure 1: SUaaVE: The path to acceptance.

3. Guidelines for CAV acceptance

Different studies and experiments have been conducted within the SUaaVE project relating to the acceptance and acceptability of CAV and ALFRED, with the participation of several user groups from several European countries. These include the following activities:

- Focus Groups.
- Large Scale Survey.
- Scenario Study with Cyclists.
- Anthropomorphism Study.
- Wizard of Oz On-Road Experiment.
- CAV & ALFRED Study.
- 1st and 2nd Loop Driving Simulator experiments.



Based on the results, we have formulated several strategies and interventions to increase the acceptability and acceptance of CAV and ALFRED among both potential users (current drivers and non-drivers) and other road users (pedestrians and cyclists). A selection of these strategies is presented in the Table below. The full list can be found in D1.6 on the SUaaVE website.

Strategy	Vehicle	User
Focus on increasing **perceived safety, perceived convenience, perceived pleasure.**	Both	All
In marketing, **emphasize the environmental sustainability** of the vehicle (e.g. mentioning its fuel efficiency; adding a sustainability logo). More environmentally friendly vehicles are evaluated higher on acceptability for potential users, as well as for cyclists.	Both	Potential users;cyclists
Present the vehicle as a **luxurious status product at deployment,** when few people have adopted the vehicle.	Both	Potential users
Let potential users experience the vehicle to increase perceived safety and trust in the vehicle's technology.	Both	Potential users
Demonstrate the vehicle in a complex traffic environment first (instead of a low traffic complexity environment) in order to increase perceived pleasure.	Both	Potential users
The vehicle should **avoid crashes or damage** (even minor), and **the first experience should be positive.**	Both	All
The vehicle should have **medium to low speed and acceleration levels,**and should not have a fast vehicle motion.	Both	All
Allow users to personalize the vehicle's driving style (for example sporty or cautious)	Both	Potential users
ALFRED should **use the eHMI developed within the project** to increase the acceptability of pedestrians.	ALFRED	Pedestrians
Present ALFRED as more human-like, as it increases perceived status-enhancement, environmental sustainability, and trust in the vehicle's technology, especially among people with a high need for control.	ALFRED	Potential users
Different users' groups may have different needs for the vehicle. For example, current drivers prefer the possibility to drive manually, while current non-drivers prefer a vehicle without a steering wheel and pedals.	Both	Potential users

4. Virtual Human Centred Design (V-HCD) simulator

SUaaVE pivots on a Human-Driven Design (HDD) to support the progressive design of innovative empathic functionalities and an HMI, aiming to increase end all road users' acceptability and acceptance of future automated cars (i.e., ALFRED). This method places the human not only in the centre of the design process of CAV, but also as an active member and data generator for the definition of concepts, the development of technologies, and for evaluation tests.

To support this HDD process, the **V-HCD simulation platform was developed to allow experiments with scientifically specified scenarios** (the exact description of the car's potential behaviours at any time of the simulation) and to create demonstrations and shows (dynamically editable behaviours at any time of the simulation by users) to explore new concepts connected to the platform, that can be widely spread across the public through simulations (Figure 2).

Figure 2: V-HCD simulation for pedestrians' and drivers' roles

The V-HCD simulation integrates many different actors: **Vehicles** (cars, emergency vehicles, trucks, busses, etc.), **pedestrians** (walking, running, waiting, etc.), **bikes, or cyclists**. Each actor has spatialized sounds (engine sounds, footsteps, etc.).

The V-HCD also integrates simulation of the **time of the day**, allowing to configure the sun by hours and geographic coordinates (latitude & longitude). Simulation of daylight can be seen in Figure 3.

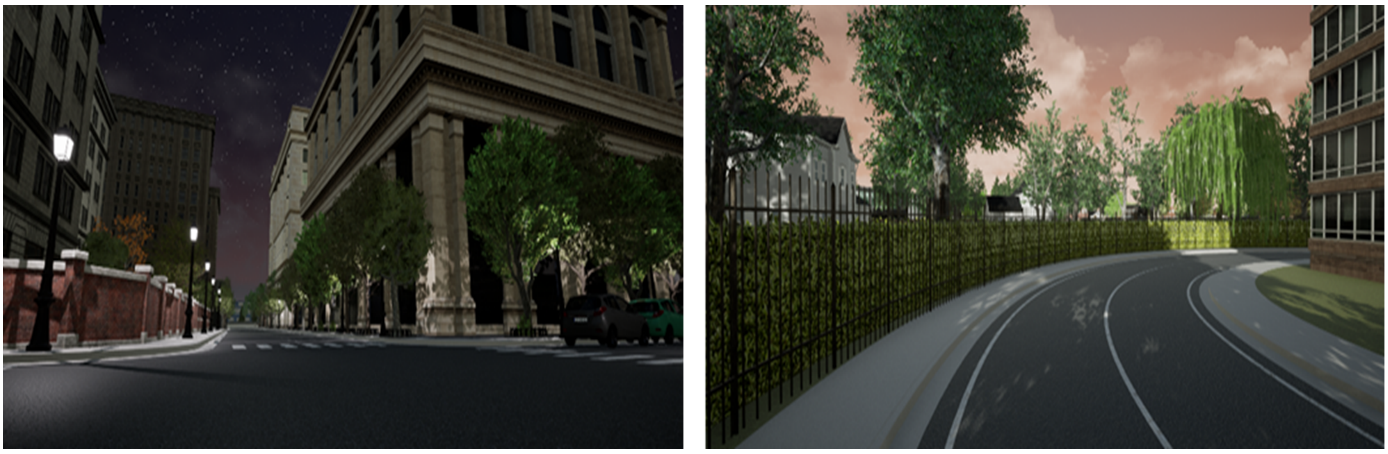


Figure 3: Time of the day, from dawn to night

A **weather system** allows the simulation of a clear day, partially cloudy, cloudy, rainy, heavy rain, fog or thunderstorm weather. Examples of a rainy scenario are shown in Figure 4.

Figure 4: Rainy weather conditions

The system controls the inputs of the car, allowing the possibility to define a certain speed to reach in a specific distance or time, or **more high-level control of the car,** like following a lane of the road network. The controls include high level parametrization of lateral control (control of the steering wheel) and longitudinal control (control of the gas pedal and brake pedal). This allows scenarios to define multiple behaviours for the autonomous car, and to select the behaviour in real time during the simulation.

Pedestrians' and other VRU's (e.g. cyclists) behaviours can be defined in a similar way as the behaviours of vehicles. For example, a pedestrian can "follow the sidewalk" at a given speed, and then "follow a specific spline" to cross a road.

The V-HCD's controls of a scenario's actors allows to create simulations with tools according to the specifications. It also gives the possibility to create **every needed behaviour that must be tested**, as opposed to software with only their own predefined behaviours.

External control of the car also allows the **simulation of functionalities associated with the passenger's experience** during the simulation. These systems are:

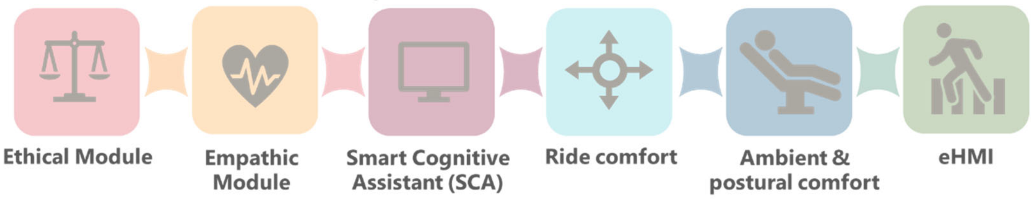
1. Dynamic driving modes: control ego's car behaviour during scenarios.
2. Glasses tinting system: tint the windshield and all the car's windows from 0% (full transparent) to 100% (opaque) (Figure 5 a).
3. Active Noise Cancelling system: decrease the volume of ambient sounds from 0% to 100%.
4. Interior lights: 4 lights inside the cockpit (Figure 5 b).
    a. Toggle ON/OFF.
    b. Lights' intensity in lumens.
    c. Lights' colour control (Temperature from 0K to 12000K for easy control, or Red Green Blue values for full control).
5. HMI head unit display (Figure 5 c).

Figure 5: (a) Glasses tinting system; (b) Interior lights with customizable colors; (c)HMI integration

The V-HCD was considered **highly immersive** and obtained an immersiveness score of higher than 60/100 for 94.4 % of the participants on average. Experiments in a **dynamic or static simulator or through a VR headset** for passengers or pedestrians all obtained similar levels of immersiveness.

5. ALFRED Automation Level Four+ Reliable Empathic Driver

ALFRED is composed by the following modules (Figure 6) to **understand the passenger's state and to adapt the vehicle's features** to enhance the in-vehicle user experience, while increasing acceptance.



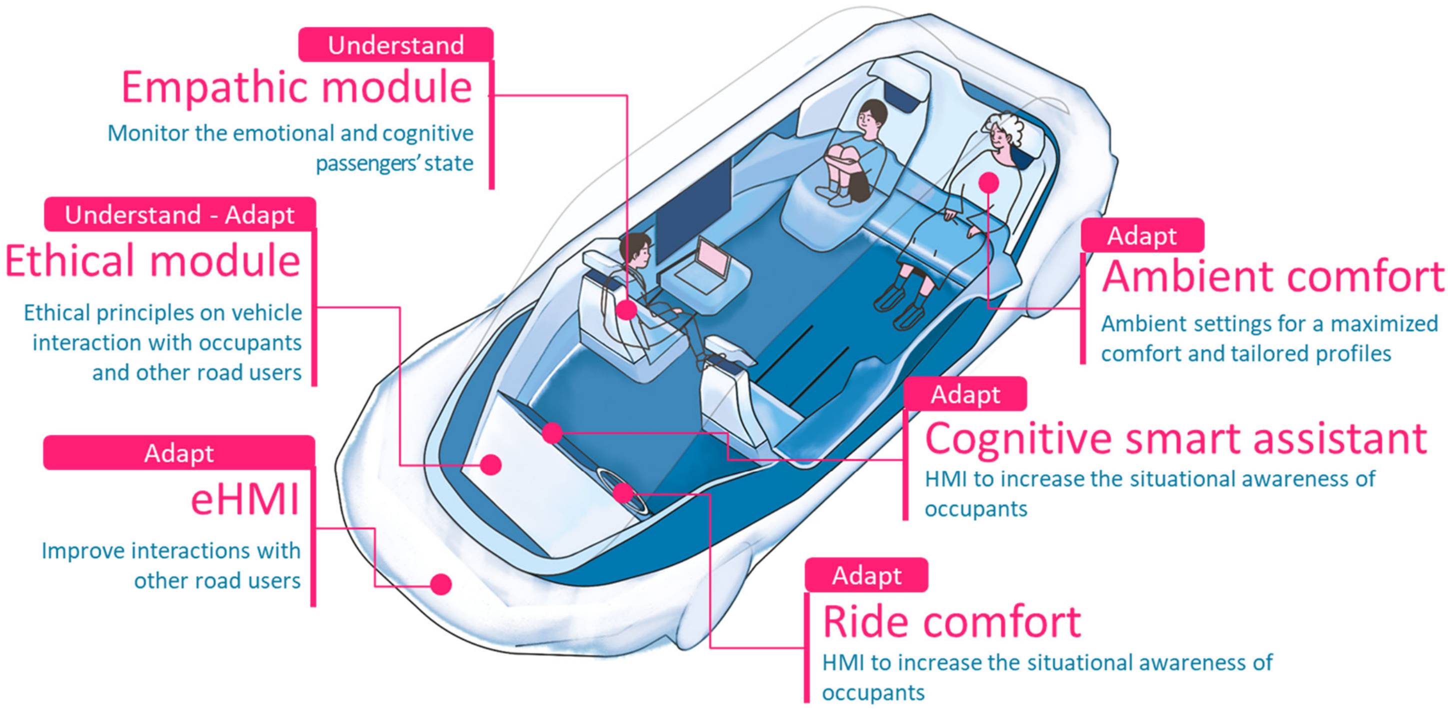


Figure 6: ALFRED modules

The **ethical module,** which aims to **ethically manage relevant situations**. Its core comprises a set of ethical principles formalized by algorithms and is integrated inside the decision making of the CAV.

The **empathic module** of ALFRED intends to understand the passenger's emotional and cognitive state during the trip. It is composed of the following models:

- **A Dimensional Emotional Model** to estimate the emotional state of the passengers in real time based on the analysis of their physiological signals.
- **An Observation Model** to estimate the emotional state of the CAV passengers and other relevant individuals in the scene (i.e. VRU and drivers of other vehicles), using available measures to describe the vehicle's road behaviour and the information needed for characterising context.
- **A Cognitive model** (developed by Bordeaux INP/CATIE) to characterise "drivers" (adult supervisor in CAV L4) from the perspective of Situational Awareness (SA), which is defined as the way in which the "drivers" perceive events in the environment during the trip.

The Smart cognitive assistant (SCA) effectively communicates to the passenger information about the current behaviour and future intentions of the CAV in an appropriate and relevant manner. The estimation of the passenger's state is used by the cognitive smart assistant to (1) increase user **situational awareness** in anticipation of potentially critical events, warning and assisting the "drivers"; and (2) to adapt the communication in noncritical events to make the **CAV experience more enjoyable**. This approach allows the interface to keep the passengers efficiently informed about the status of the CAV, and its actions and intentions, to enhance their level of trust.

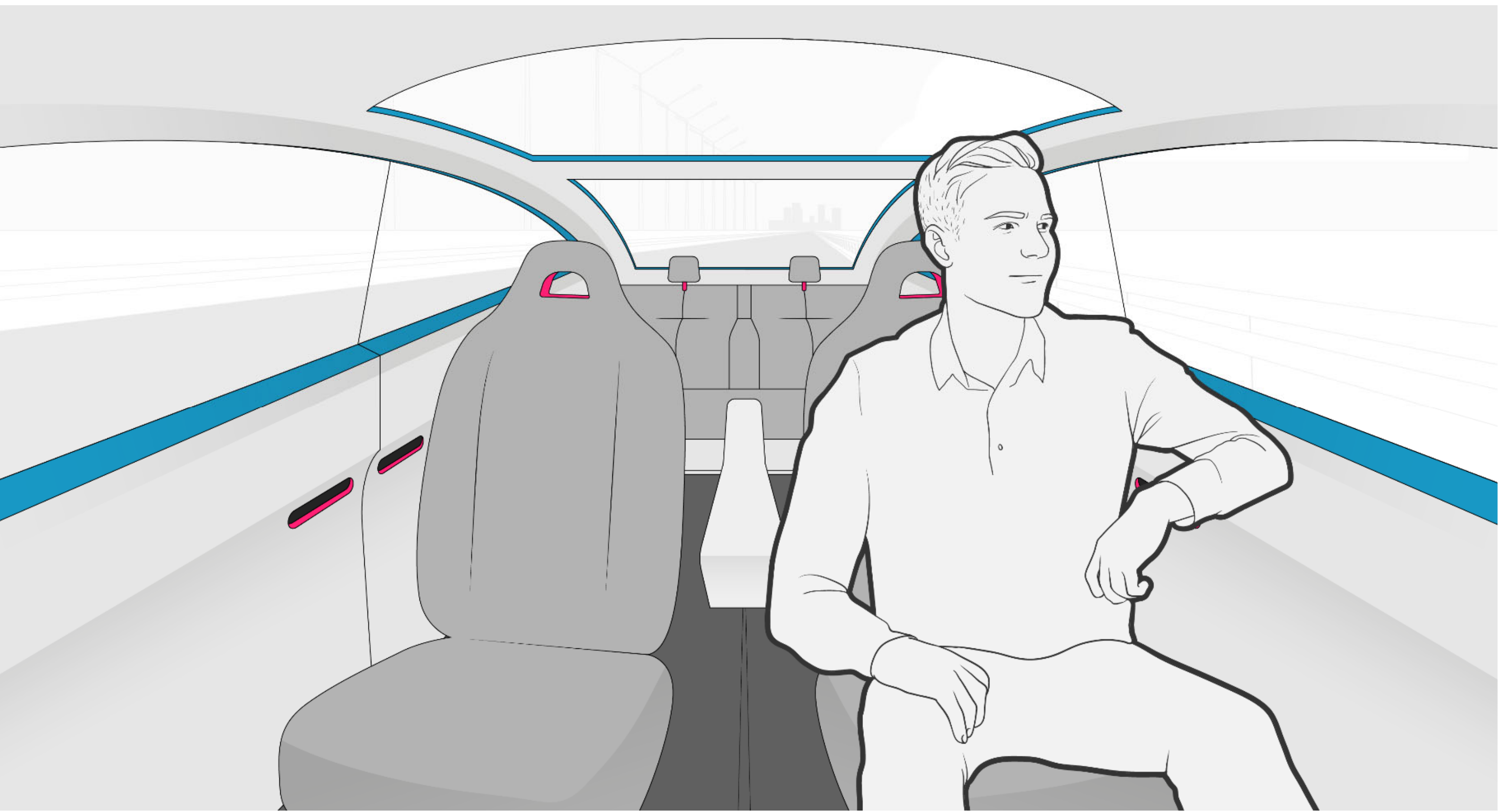
Ride comfort. Development of **algorithms** to adjust the **vehicle dynamics in Real-Time**, within the definition of acceptable thresholds of safety and comfort. This covers real-time operational and tactical functions required to operate the vehicle in traffic (including longitudinal and lateral vehicle motion) with the objective of enhancing perceived safety and comfort throughout the trip.

Ambient and postural comfort. Settings to enhance comfort and a more effective/pleasurable use of the time spent travelling, aiming to guarantee the feeling of well-being. The emotional state of the passenger is used as a reference for setting ambient condition in the vehicle (lighting, heating and air conditioning, postural preferences) as well as considering their combination, incompatibilities and threshold values.

The eHMI aims to build an "empathic CAV" in terms of its interactions with other road users, both for the CAV passenger and for the pedestrian. The eHMI is in charge to explicitly inform pedestrians about the CAV's intentions and CAV's braking behaviours to yield (i.e. implicit cues, related to CAV deceleration and stop distance).

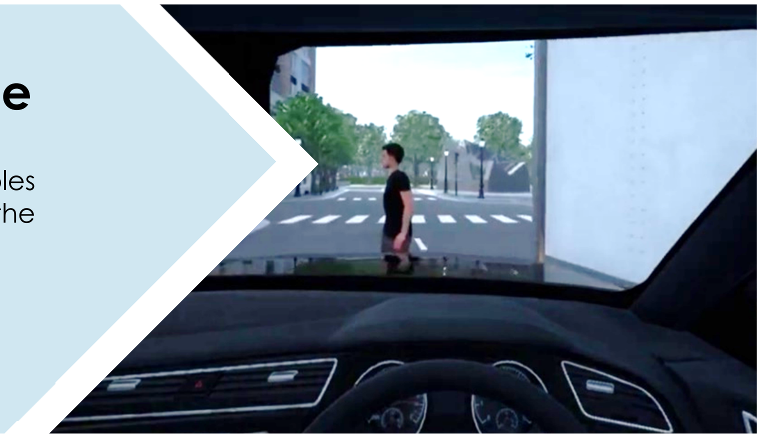
According to recovery and anticipatory strategies the ALFRED modules can understand the passenger's state and act to cope and/or avoid with negatives experiences on board.

Each one of the modules that make up ALFRED has been tested in two loops with an active participation of road users. The following fact sheets summarize ALFRED's assessment, as well as their impact on acceptance.



Ethical module

Ethical module consists of a set of ethical principles formalized by algorithms and is integrated inside the decision making of the CAV.



OUTCOMES

The moral acceptance of several ethics policies that could be integrated in the decision-making algorithm of CAV have been tested with passengers and pedestrians. A **a total of 956 people participated in the study**. These **ethics policies eventually protected the passenger or the pedestrian** and with different strategies in the interests of different parties considering the distribution of risk and harm.

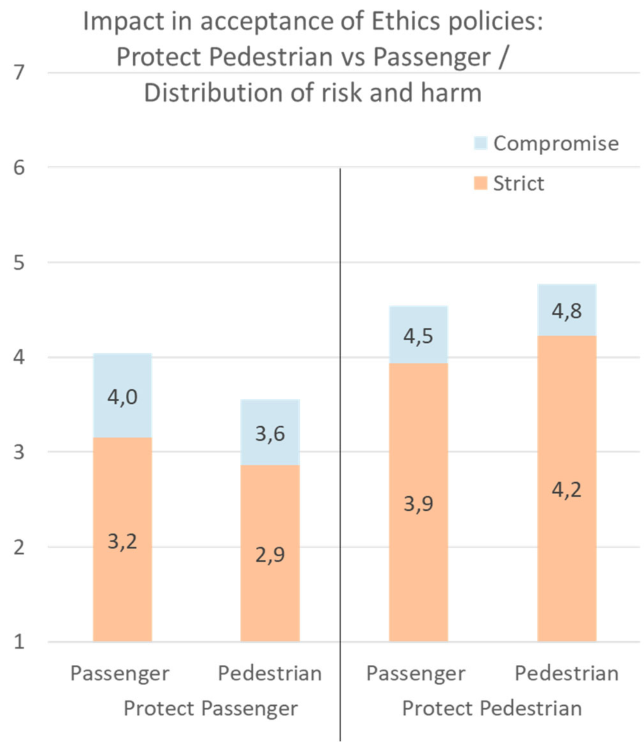
The scenario for assessment was a video depicting an unavoidable accident between a pedestrian and a CAV (both out of each other's visual or the CAV's sensing field). The vehicle can brake immediately, which results in the protection of the passenger at the cost of having an impact with the pedestrian. Alternatively, the vehicle can steer to the left having an impact with the truck and taking risks for the passenger, while protecting the pedestrian.

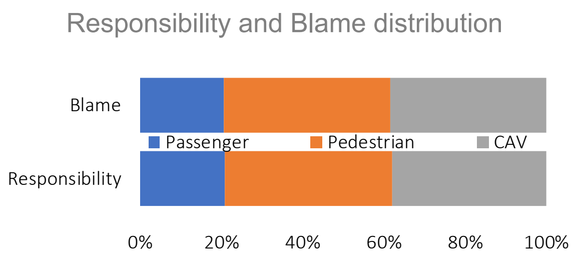
Outcome fairness – Ethics policies that favoured the protection of vulnerable road users (e.g. a pedestrian) were generally evaluated more positively and were associated with more agreeable emotional reactions than the ones that favoured the protection of the passenger.

Procedural fairness – Ethics policies that took the interests of different parties into account in the distribution of risk and harm were evaluated more positively and induced more agreeable emotional reactions compared to those that proposed a strict protection of a particular road user.

Responsibility and Blame – Attributions of responsibility and blame were higher for the driver for a personal CAV and for the vehicle for the robotaxi. The agent's level of control, whether it is a machine or human, influenced the attribution of responsibility and blame.

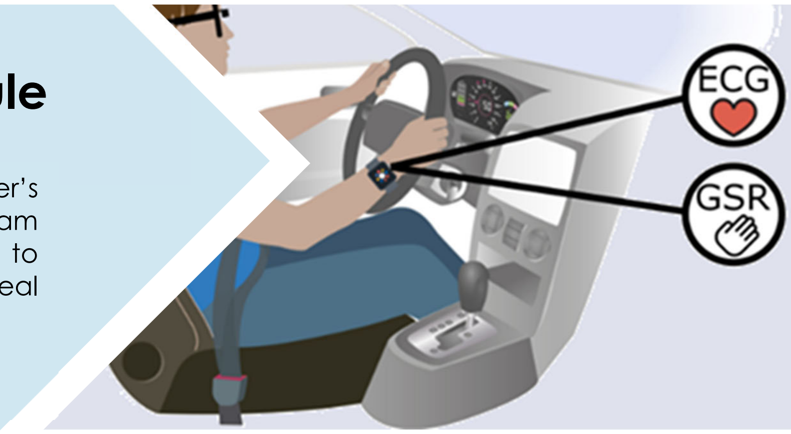
ASSESSMENT





Emotional module

The Emotional module measures the passenger's physiological signals with an Electro Cardiogram (ECG) and the Electro dermal activity (EDA) to monitor the passenger's emotional state in real time.



OUTCOMES

The emotion model is a Bayesian Classifier. The model has been trained through the Continuously Annotated Signals of Emotion (CASE)[6] dataset.

The Emotial model allows the estimation of the emotional state in real time using EDA and ECG signals as imput.

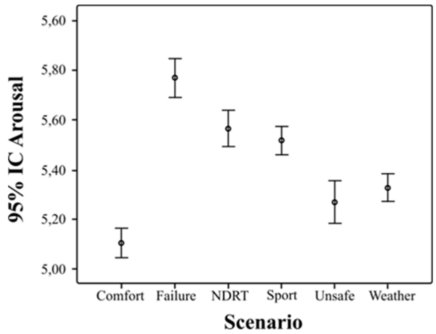
The emotional model pre-processes these signals, calculates their key parameters and **estimates the values of arousal** (activation) and **valence** (pleasantness-unpleasantness) on a scale ranging from 1 to 9, to obtain the estimation of the emotional state.

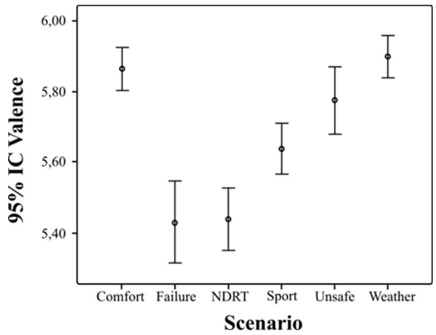
The emotional model works with the Empatica E4 © wristband. This wearable sends the physiological data to a connected device (PC or laptop) through a communication protocol. It updates the data to a server, specifically developed to analyse the data and to estimate the arousal and valence. Finally, the results are sent to the connected device.

[6] Sharma, K., Castellini, C., van den Broek, E.L., Albu-Schaeffer, A., Schwenker, F., 2019. A Dataset of Continuous Affect Annotations and Physiological Signals for Emotion Analysis. Scientific Data 6, 1–13.

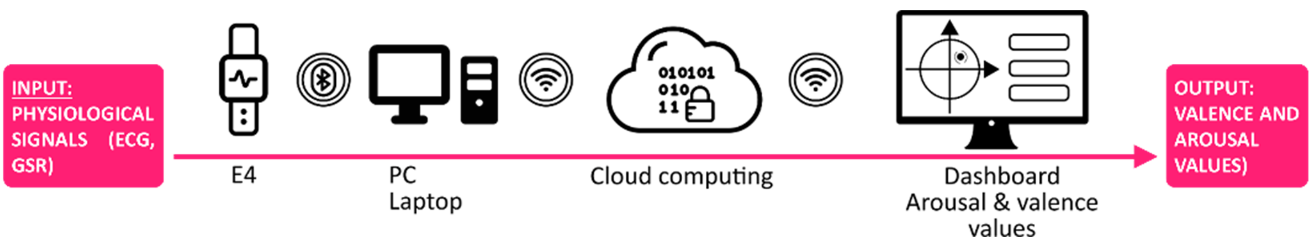
ASSESSMENT

The model was tested with 25 passengers. The use of driving scenarios in the V-HCD simulator permitted to validate the emotional models applied to an automated driving experience and ALFRED strategies. The results indicated that there were significant differences in the arousal and valence values ($p < 0.05$) among different automated driving scenarios, as observed in the Figures.





The Valence and Arousal differences were consistent with self-reported valences and were in line with the hypotheses of the scenario design.



Cognitive model

The Cognitive model characterises "drivers" (adult supervisor in CAV L4) from the perspective of Situational Awareness (SA), which is defined as the way in which the "drivers" perceive events in the environment during the trip.

OUTCOMES

As part of empathic module, a cognitive model is in charge of the monitoring of passengers for **identifing the cognitive state** for an optimal situation awarness for each passenger profile.

The cognitive model we propose is based on different dimensions:

- **Engagement** i.e. interest in the road situation.
- **Hypervigilance**.
- **Fatigue**.

Each dimension is discriminated by specific ocular behaviors, measurable with an eye-tracker: sets of visual metrics computed from the oculometric recording of fixations and saccades.

The cognitive model can be approximated by the following formula : $Y = \beta_i . x_i + \varepsilon$. The explicatives variables x_i correspond to the **visual metrics**. The explained variable Y corresponds to the cognitive state, which is the dependent variable of the model. It is treated in a categorical way according to 3 levels: 1 for engagement, 2 for hypervigilance and 3 for fatigue.

The model is a CARt-type decision tree built on the data set. The set of independent variables of an individual classifies them in a cognitive state.

ASSESSMENT

The cognitive model identifies three cognitive states of the subject (engaged, hypervigilant, fatigued) with an average accuracy of 66%.

The results of the second experimentation loop revealed that the level of expertise of the driver, situational awareness and cognitive status (fatigue, hypervigilance and engagement) were correlated with data from the observation of the experimenter, the webcam, and the eye-tracker.

The categorization of drivers into experts, intermediates, and novices and the use of an adaptive interface in a Wizard of Oz set-up made it possible to observe a relationship between the level of expertise and situational awareness.

If the level of expertise and situational awareness go hand in hand, this can help categorize driver profiles and generate the appropriate levels of interface information to maximize the trust and acceptability of these different driver categories.

We will emphasize the interest of relating cognitive states and categories of expertise for a differentiated reading of cognitive states seen as similar: the engagement of an expert is not the same as of a novice and the hypervigilance of a novice is not the same as of an expert.

5. ALFRED Automation Level Four+ Reliable Empathic Driver

Observation model

The Observation model considers the vehicle parameters, external driving factors, and endogenous characteristics of the passenger as input for predicting different categorical emotional states in real time.

OUTCOMES

The **model is fed** by the effect of different **environmental parameters**, like ambient temperature, weather (whether it is sunny/cloudy/raining), the nature of the road, etc. on the passenger.

Vehicle parameters such as lateral, longitudinal and vertical acceleration and their thresholds are used to determine the comfort level of the passengers.

In addition to this, information about different **relevant events** (like sudden braking, a red traffic light, a near-miss, narrow overtaking, tight cornering, etc.) are also inputs for the observation model.

Baseline questionnaires are used to capture the endogenous characteristics like dependency, autonomy and enterprise scores of the passengers. These questions help form the functions that transform the input features to the scores of familiarity, relevance and context. These internal variables of the model are further transformed into the security, arousal and autonomy of the particular person.

Changes in these internal variables (security, arousal and autonomy) are indicative of different emotions.

ASSESSMENT

The output of the observation model consists of emotional scores of five different emotional states for each timestep normalized between 0-1:

- Anger.
- Fear.
- Happiness.
- Surprise.
- Sadness.

80% of the data obtained in the test were used to fine-tune the observation model whereas the remaining 20% of the data was used for its validation.

The observation model calculates the emotional scores for different emotions (anger, fear, happiness, surprise and sadness) at each timepoint.

The dominant emotion is computed for each timepoint using the observation model and is compared to the dominant emotion computed by AFFDEX SDK[7] , used as the gold standard, in the sample window of 10 seconds.

The average accuracy is computed as 66.8% for the observation model.

[7] McDuff, D., Mahmoud, A., Mavadati, M., Amr, M., Turcot, J., & Kaliouby, R. E. (2016, May). AFFDEX SDK: a cross-platform real-time multi-face expression recognition toolkit. In Proceedings of the 2016 CHI conference extended abstracts on human factors in computing systems (pp. 3723-3726).

Smart Cognitive Assistant

The Smart Cognitive Assistant (SCA) effectively communicates to the passenger information about the current behaviour and future intentions of the CAV in an appropriate and relevant manner. Acceptance of CAV is lower when users do not have a minimum level of trust, which implies a certain level of situation awareness.

OUTCOMES

The SCA can provide automatic adaptation of the amount and the level of complexity of information provided by the vehicle according to the user's preference, activities being performed and the driving context. This adaptation seeks to not overwhelm the user and can evolve over time as the user gains experience with the vehicle.

In this context the SCA was evaluated with two experiments with complementary approaches:

- **30 participants evaluated in depth the usability** of the beta version of the SCA, which was updated following the re-design guidelines derived from the first loop test results alpha version. In this evaluation the SCA was compared with a Baseline HMI.

- **13 participants evaluated the SCA adaptation** through a Wizard of Oz. In this test the SCA offered the user the information they need according to the requirements of the situation, their cognitive state and passenger profile.

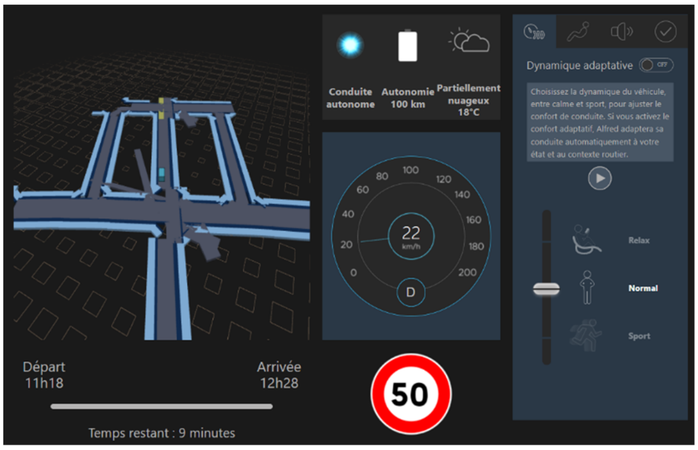


Figure 7: Overview SCA

ASSESSMENT

Regarding the overall usability evaluation, both the SUaaVE SCA and the Baseline HMI were evaluated on average in a positive way, but the SUaaVE SCA evaluation (between positive and very positive) was higher than the baseline one (slightly positive).

The SUaaVE SCA was preferred over the Baseline HMI by 96% of participants. The information was considered more complete compared to the baseline ones.

The presence of the map was considered very important, and the comfort functions were considered necessary too. In fact, the possibility to interact with the SUaaVE SCA and being aware of what is going on around the ego vehicle through the map and being able to activate the comfort functions were appreciated.

In the evaluation of the SCA incorporating the passenger adaptation, participants found the SCA "quite easy to use", and expert drivers found the interface "very easy to use". In the same vein, the users found the interface "relaxing", especially the expert drivers.

Participants are satisfied with the utility of the SCA, which was assessed as quite useful. Expert drivers are more critical about the utility side than intermediate and novice drivers.

The users found the interface "quite pleasant", and the interviews confirm that it was graphically pleasing. The grouping of information in the interface is considered adequate by 92% of participants..

Ride Comfort

ALFRED adapts the Dynamic Driving Mode of the vehicle (Sport, Comfort or Neutral) throughout the trip, taking into account the external context (e.g. traffic conditions, time pressure to reach the destination) while monitoring the user's state to guarantee a positive emotional state. The user can change this suggestion according to your own preference.

OUTCOMES

The **SCA was integrated in the dynamic simulator** platform, allowing participants to choose the dynamic mode they preferred.

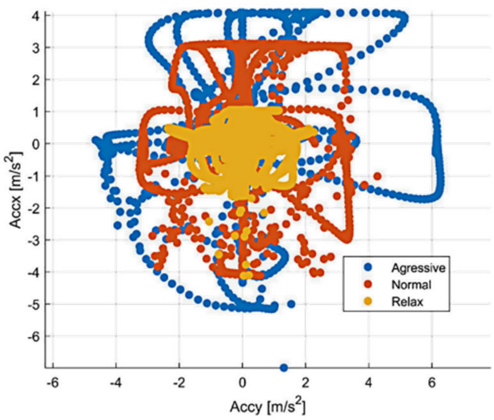


Figure 8: Example of acceleration between modes

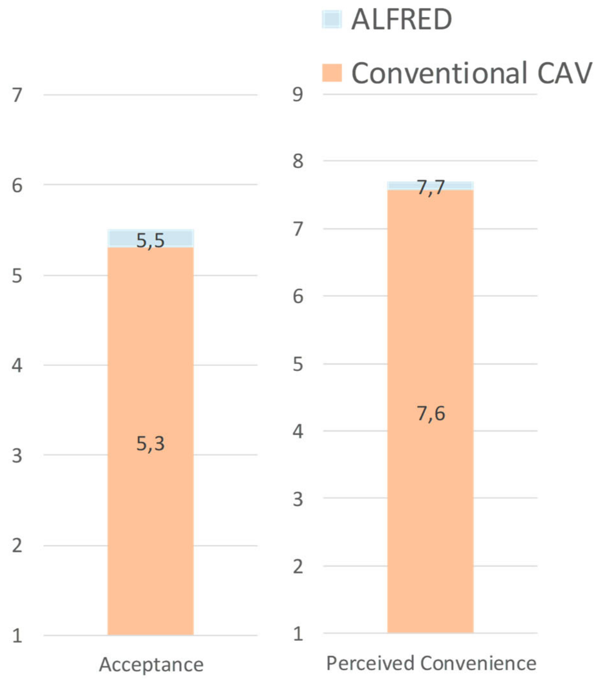
A sample of **30 participants assessed** the level of acceptance after a simulated run with and without the ALFRED dynamic module.

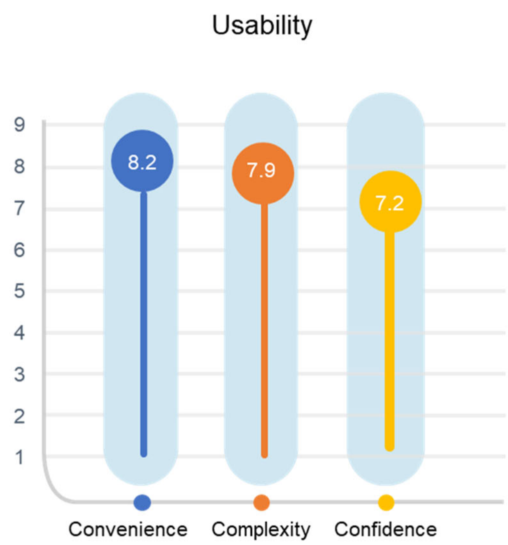
Acceptance was positively influenced by the integration of dynamic comfort module in ALFRED, where initial acceptance increased by 3.6% compared to the acceptance after experiencing ALFRED .

Taking into consideration the participants' acceptance assessment for those who had motion sickness levels lower than 4 (80% of the sample), the acceptance before the ALFRED experience increased by 6.9% compared to after.

These outcomes show how adaptable functions of ALFRED, delivered through the SCA, related to the manipulation of dynamic behaviour according to the user's preferences for their journey, can have a positive impact on acceptability.

ASSESSMENT



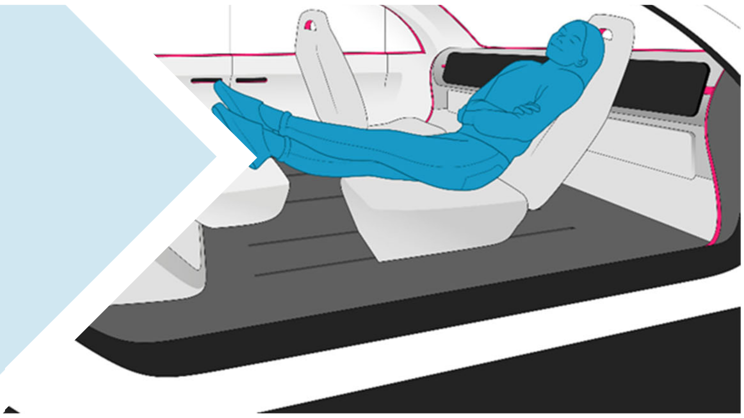


5. ALFRED Automation Level Four+ Reliable Empathic Driver

Comfort module

ALFRED monitors the user's state and the activities they perform to facilitate an automated adaptation of ambient conditions.

The Comfort module concept integrates acoustic, visual, thermal, and postural comfort, which ALFRED will be able to adjust in order to improve the user's travel experience.



OUTCOMES

An autonomous vehicle ride with ALFRED was simulated in virtual reality in the V-HCD, during which **24 participants were able to experience changes in acoustic and visual comfort** through interaction with ALFRED.

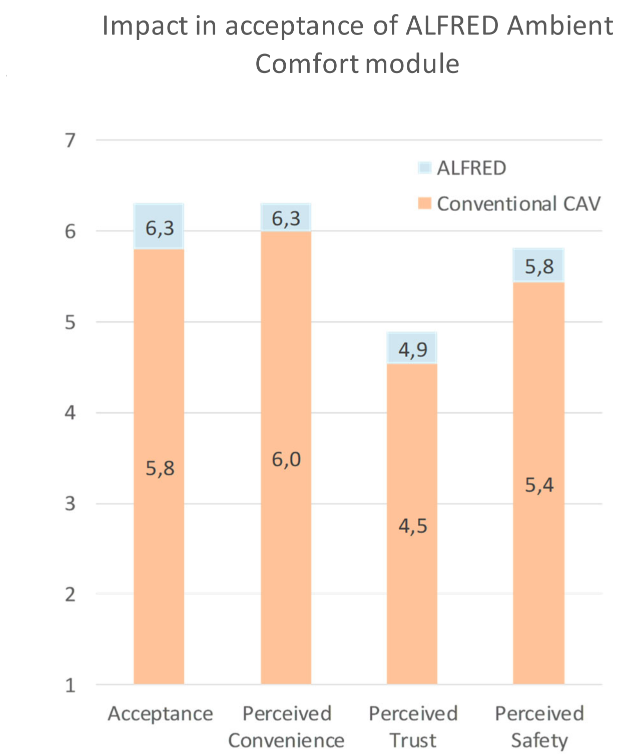
Incorporation of the **ambient comfort functionality in the ALFRED concept was related to positive evaluations of ALFRED's acceptance.**

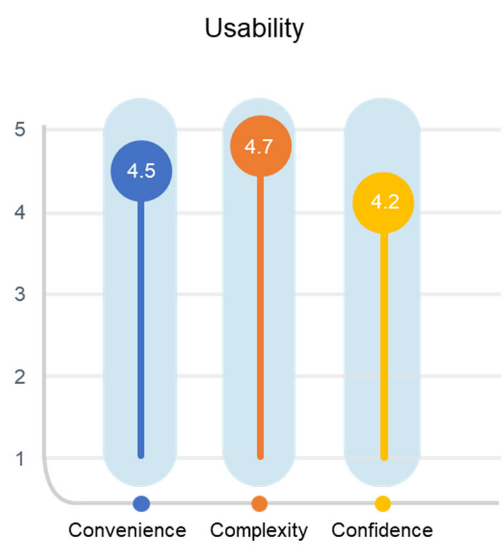
Comments from participants confirmed a positive comparison between the non-adaptive functionality of the standard CAV and the responsive adaptions demonstrated as being part of the ALFRED concept.

Regarding the emotional state, **a general positive feeling was reported by 92% of the sample**. Basic emotions assessment shows a 30% increase in the emotion "delight" and a 33% reduction in "surprise" and a 27% reduction in "fear".

The SCA functions associated with adaptions of ambient comfort components were **positively reviewed on usability by participants**, with 75% of participants rating the overall usability above 4.6 out of 5.

ASSESSMENT





External Human Machine Interface eHMI

The eHMI aims to build an "empathic CAV" in terms of its interactions with other road users, both for the CAV passenger, as well as for the pedestrian.

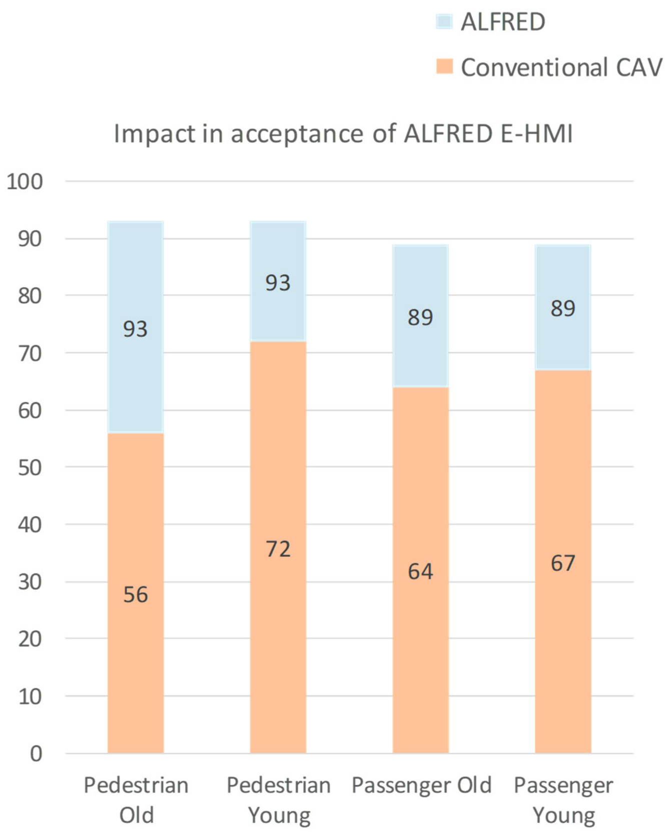
OUTCOMES

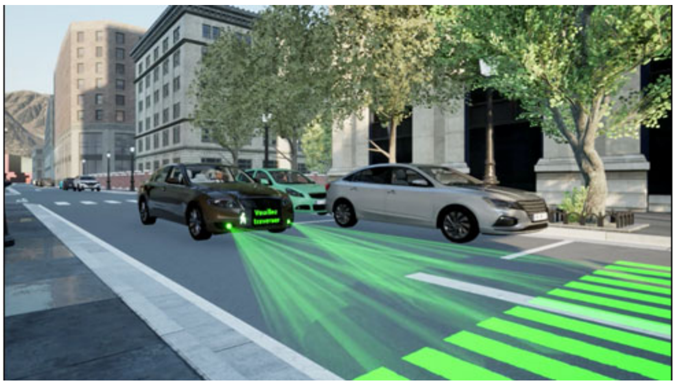
Fourty participants experienced a battery of 32 of immersive interactions in the V-HCD with automated vehicles, a combination of **8 braking behaviours**, with and without the eHMI in a dual-phase experiment of road-crossing situations on-board and outside of the CAV. One phase focused on the pedestrian's perspective (VR grasses), and the second phase focused on the CAV passenger's point of view (driving simulator).

ALFRED's eHMI reduces differences between young and old participants and tends to harmonize their assessments about the safety of CAV's braking behaviours. Thanks to the ALFRED solution, elderly people are more capable to adequately perceive and assess the safety/dangerousness of CAV's braking manoeuvres, and their safety judgments became quite similar to those of young participants.

The use of the eHMI significantly increases participants' CAV acceptability in a general way, and significantly reduces their concerns about their interactions with CAV, as both a CAV passenger and as a pedestrian. These results are found for all the participants, but benefits are particularly high and significant for elderly people.

ASSESSMENT





Alfred strategies: Disengagement

When ALFRED detects that the user has to concentrate on a task (e.g. working with a laptop, teleconferences…) or wants to relax, ALFRED automatically blinds CAV's windows and activates environmental noise cancelling to facilitate the disengagement from the driving context.

OUTCOMES

For **assessing the cabin disengagement functionality 25 participants** experienced a scenario in the V-HCD where they received an arithmetic test (psychometric), simulating part of a job interview. ALFRED adjusts the tinted windscreens and actives noise cancelling when external conditions are noisy (building works).

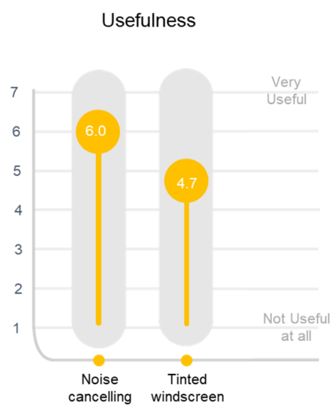
The usefulness of the two functions, namely noise cancelling (6) and tinted windscreens (4,7) was validated. Notably, the cabin noise cancelling function was evaluated very positively, on a scale from 7 (Very useful) to 1 (Not useful at all).

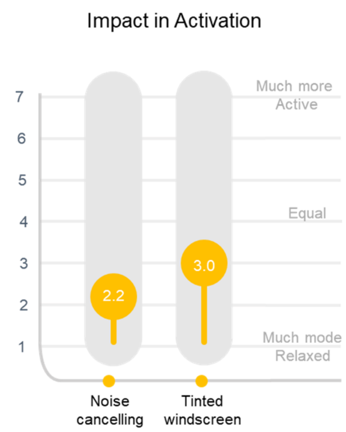
In terms of impact on the emotional state of the passenger, disengagement functions were also assessed in well-being (valence), from "the function makes me feel much better" (7) to "much worse" (1) and their impact on activation (arousal), from "the function makes me feel much more active" (7) to "much more relaxed" (1).

The noise cancelling function had a higher impact on the emotional state of the passenger, with a high impact on well-being (5.8) and it lead to a decrease in activation (2.2).

The tinted windscreens functionality also impacted the emotional state, but in a lesser degree. Participants evaluated the impact in wellbeing with a 5, and the impact in activation with a 3.

ASSESSMENT





5. ALFRED Automation Level Four+ Reliable Empathic Driver

ALFRED strategies: Recovery

ALFRED automatically detects if you have an unwanted emotional state and suggests strategies for your recovery based on previous experiences.

OUTCOMES

For assessing **ALFRED's recovery strategies, two scenarios were tested in the V-HCD with 25 participants**: A monotonous ride leading the passenger to a bored or sleepy state, which ALFRED detects, and suggests to entertain the passenger with a video. The other scenario consisted of heavy rain during the first minute where passengers felt tense or nervous. After this minute, half of participants experienced ALFRED's relaxation strategy with an isolation of the cabin and ambient music.

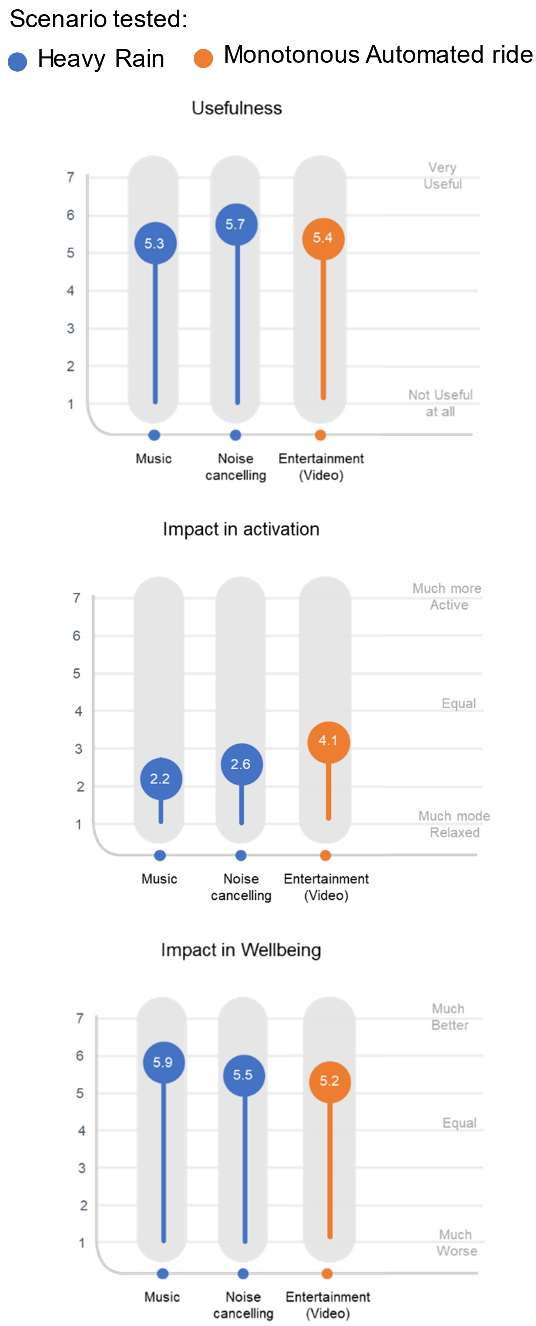
The usefulness of the Noise cancelling (5.7), Entertainment (5.4), and Music (5.3) functions was validated, using a scale from "Very useful" (7) to "Not useful at all" (1).

The functions were also assessed in terms of impact on well-being (valence) and their impact on activation (arousal).

The music function had a stronger impact on the emotional state of the passenger, with a high impact on well-being (5.9) "the function makes me feel better", and it decreased activation, leading to relaxation (2.2) "the function makes me feel slightly more relaxed".

The noise cancelling and entertainment functionality also impacted the emotional state, but in a lesser degree. The noise cancelling was evaluated with a 5.5 by participants on the impact on well-being and with a 2.6 on the impact on activation. For entertainment, participants scored the impact on well-being with a 5.2 and the impact on activation with a 4.1, which was close to neutral.

ASSESSMENT



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6. Guidelines for potential “new drivers”

SUaaVE explored the potential future users of autonomous vehicles with ALFRED with four focus group sessions. We focused on different groups to explore the preferences of potential new users, considering that at present they have driving limitations by their very nature, but these limitations could be overcome by future autonomous driving:

- **The Senior Citizens** group was defined by people older than 65 years, when the retirement period usually begins, which is a vital change that also implies changes in their daily activities and generates changes in their mobility needs.
- **The People with disabilities** group was created to explore the needs and preferences for CAV from the perspective of users who at present have limited access to driving due to their disability, but who could be future users of CAV.
- Exploration of **children’s and teens’** preferences for CAV as potential new drivers was the objective of the 3rd and 4th groups. In this context we divided them in two groups, from 10 to 14 years old and from 14 to 18 years old (teens).

Based on the key results, SUaaVE suggests a set of guidelines that should be considered for the future development of the CAV.

Guidelines for potential new drivers	Potential user group
General acceptance. Several positive emotions were associated with CAV, such as relaxation and tranquillity, but a tendency to **distrust the vehicle** was present, probably based on the **lack of real experience** with CAV.	**All groups**
Autonomy benefits. The main interests of people with disabilities revolved around **saving time, independence** from other people and the possibility of giving it a **medical function** for example for outpatient treatment. During travelling CAV would allow them to rest, be comfortable, to travel during the night and to gain spare time.	**People with disabilities**
Autonomy benefits. Most valued in CAV was to **be calm, and comfortable**, and the possibility to perform leisure activities while travelling. The CAV’s functions could **make up for the limitations** senior citizens currently experience due to age or lack of driving.	**Senior citizens**
Autonomy benefits. Teens were mainly interested in performing different **activities during the ride, so they could be** productive or spend time on leisure.	**Teens**
Autonomy limitation. The idea of **traveling with adults was more prevalent for children and teens** over the idea of traveling alone.	**Children and Teens**
Passenger monitoring. All groups **readily embraced** the passenger monitoring system, although they expressed a **preference for first validating** the system's decision before its execution.	**All groups**
Passenger monitoring. People with disabilities had an interest in the possibility of being **medically monitored**, so that the vehicle could be used for outpatient treatment or could make an emergency call if necessary.	**People with disabilities**
Control. All groups preferred the possibility of **taking control** of the vehicle in specific situations. An in-depth analysis of the factors on which this need for control is based is necessary.	**All groups**
CAV interface. The HMI should integrate the **preferences of different types of users**, by allowing them to select the type of information that the user receives, and by being able to configure the channel according to the type of information and by even deciding the pace and type of interactions that the user wants to have during the trip.	**All groups**
Interior design. The future CAV should have a vehicle interior design that **allows different configurations depending on the needs** of the passengers using the vehicle. This interior should guarantee the **privacy** of its passengers while they carry out other activities than driving.	**All groups**

Consortium Partners

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