	HoliDes **Holi**stic Human Factors **Des**ign of Adaptive Cooperative Human-Machine Systems	

D9.10 Final version of the Automotive AdCoS

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1 Introduction

The objective of this document is to describe the final implementation of the Automotive AdCoS, with feedback to the HF-RTP and related methodology, including the assessment against the Project Baseline. Since there are multiple AdCoS applications for the Automotive (AUT) domain, each chapter covers a separate one. Each chapter starts with a short AdCoS introduction, followed by a description how the MTT's from the HF-RTP have been integrated. Furthermore, details about the HMI implementation are given. Finally, each chapter concludes with next steps, feedbacks and, if relevant, an update of the HF-RTP requirements.

In general terms, we remind here the target-scenario (TS), which is the problem statement for the AdCoS in Automotive (AUT) domain:

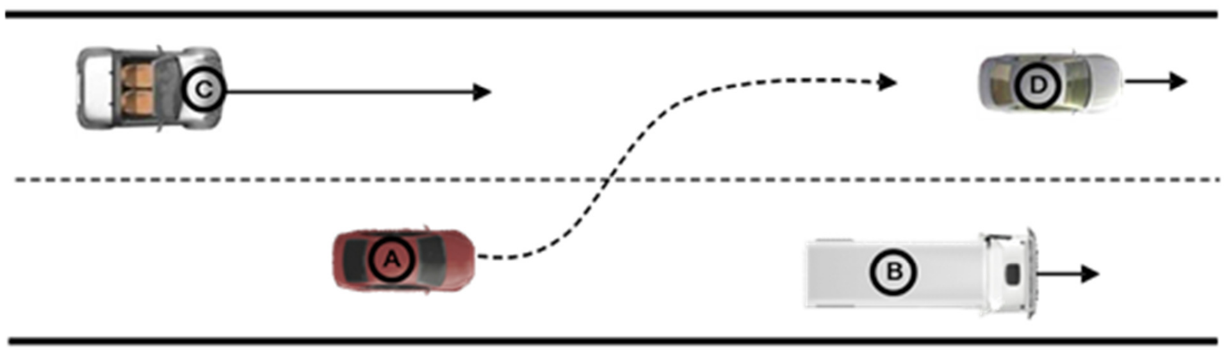


Figure 1: sketch of the target-scenario in AUT domain.

In this case, the Ego-Vehicle (EV), namely the RED car in the figure, is preparing to overtake a slower vehicle ahead (i.e. truck) and entering in collision path with another vehicle on the adjacent lane already overtaking the same EV. Another vehicle can travel ahead on the same adjacent lane. The precondition is that agent A is driving faster and approaching a slower vehicle (B) on a straight road.
The successful end-condition is that the Lane-Change (LC) manoeuvre – and then the overtaking (OV) – is performed without risks and without stop/strong speed reduction of EV (minimum change in traffic flow, namely the function must not disturb traffic "too much"). The trigger event is that the vehicle with lower speed is driving in the same lane as the agent A.

2 Adaptive Assistance AdCoS

This AdCoS has been developed by a specific team, composed by the following partners: CRF, REL, UTO, SNV, INT and OFF.

2.1 AdCoS description

With reference to deliverable D9.7 "Implementation of the Automotive AdCoS and HF-RTP Requirements Definition Update (Feedback)", the AdCoS developed by CRF team is named **Adaptive Assistance**, since it is able to provide assistance to the driver, both in longitudinal and lateral driving task, adapting its strategies to several external and internal conditions.
In particular, the Adaptive Assistance AdCoS consists in two main functionalities, one for lateral support and one for longitudinal, respectively:

- Lane-Change Assistant (LCA) and Overtaking Assistant (OA)
- Forward Collision Warning (FCW).

For what concerning the adaptivity of this AdCoS, it is based on the following aspects:

- *External situations*, that is the traffic conditions, the dynamic and state of the other road users, as well as the related trajectories (e.g. a vehicle braking in front of the host-vehicle, on the same trajectory).
- *Internal situations*, that is the states and desires of the human-agent. In our case, this means the classification of the visual driver's distraction and his/her intention to change the lane (for a possible overtaking).

The core of the system is represented by the co-pilot, which is a module able to put together all these elements, in order to provide the right strategy at the right time. The co-pilot is based on the adoption of a statistical approach: the principle is to model our system as an MDP (Markov Decision Process), in order to construct optimal warning and intervention strategies (WISs). More details can be found in the next paragraph, while the updated version of DVDC and DIR modules are described in the last deliverables of WP2, WP3 and WP5.

2.1.1 Description of the MDP Co-pilot module

The co-pilot module is based on a MDP model, that simulates trajectories of the car based on the environment data, and generates a safety level for each of these trajectories, in order to avoid possible risky situations (i.e. collisions).
A simulated trajectory is called a strategy, which includes:

- **Keep your lane** ⇒ the car continues to follow the current lane, eventually turning if the lane turns.

- **Slowdown to follow next car** ⇒ the car continues to follow the current lane, but needs to decelerate a bit, in order to keep the safety distance from the vehicle ahead.
- **Brake** ⇒ the car needs to perform a hard brake to avoid a collision with the car ahead or with a fixed obstacle.
- **Change to the left** ⇒ the car moves to the left lane, in order to start an overtake manoeuvre.
- **Change to the right** ⇒ the car moves back to the right lane, typically to end an overtake manoeuvre.

Each strategy determines a safety value, based on the TTC (Time To Collision) with the first obstacle encountered in the simulated trajectory.
Figure 2 illustrates how the safety risk values, computed as MDP costs, enters a decision procedure that selects the feasibility of each strategy:

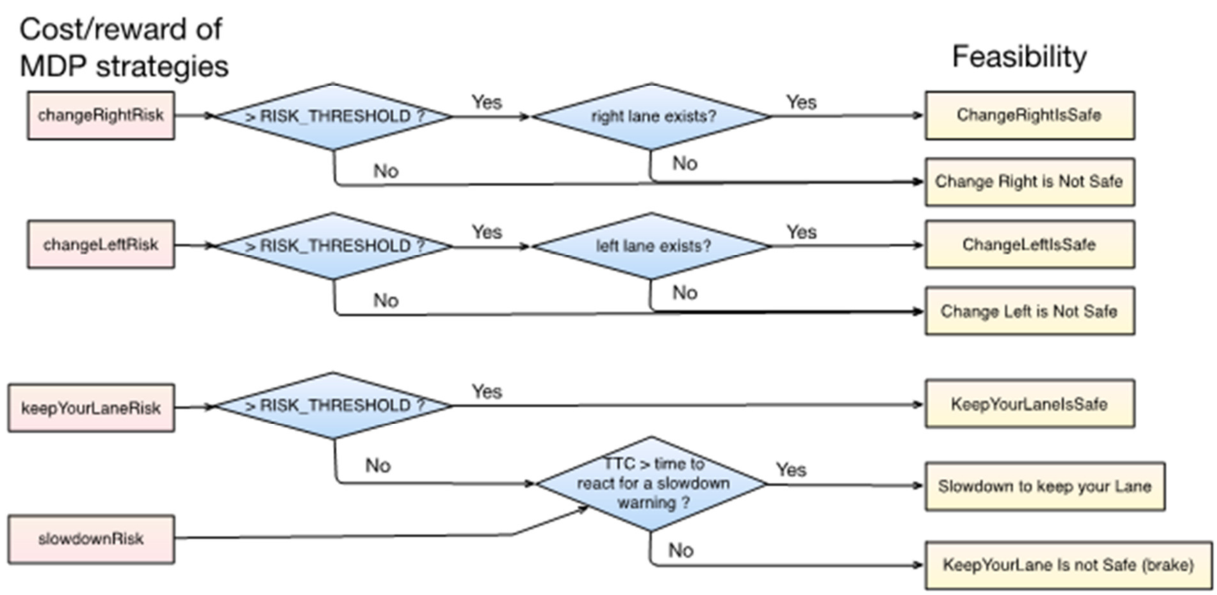


Figure 2: MDP module logic flow.

Feasibility values are Boolean decisions that determine if the strategy is doable under the parametric configuration of the module. Feasibility is decided if the risk value of the simulated strategy is below a threshold value (configured in a linear ramp between 4 and 6 seconds of TTC). The threshold value has been set to 0.5 (determined empirically), i.e. a TTC of least than 5 seconds will trigger the unfeasibility of a strategy.

The Co-pilot takes as inputs both the results of distraction classifier and driver intention estimation modules, which is based on a Bayesian network that makes a prediction of the user intention. Such a prediction is subject to the following post-processing. Since the prediction is continuous, the module ignores a new intention command (like a "change left") if the human driver has just completed a

manoeuvre. Suggestions are suspended for 6 seconds after each manoeuvre has been completed, to avoid annoying the driver.
The intention commands are filtered according to the following schema:

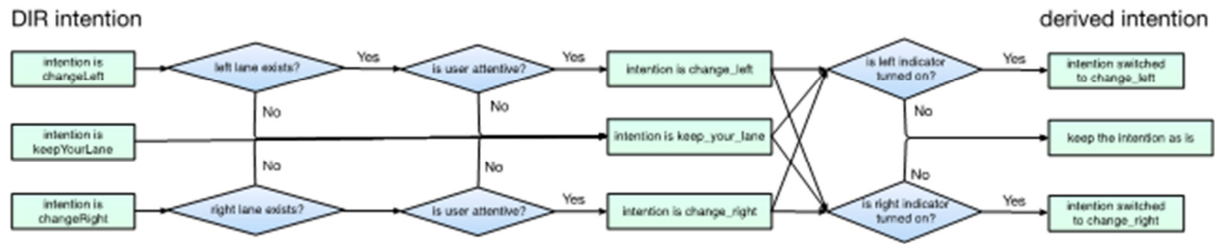


Figure 3: logic-flow how the DIR module outputs are considered inside the Co-pilot.

The intention of a left/right change is first tested for feasibility, ignoring it if it is not doable.
The human driver distraction is also accounted, since the module does not want to suggest complex maneuvers to the human driver that results to be non-attentive. Only safety suggestions (slowdown, brake) are active for distracted drivers.
The left/right indicators of the car are assumed to be a certain intention of turning to the left/right, therefore any predicted intention based on the car dynamic is ignored when the indicators are turned on.

Eventually, given the feasibility of the strategies and the filtered intention of the human driver, the Co-pilot module decided which command has to be sent to the HMI, to communicate with the driver. This task is accomplished as following: when the user intention corresponds to a feasible strategy, the HMI will notify this with a positive command (like change your lane or keep your lane).
When the user intention correspond to a non-feasible strategy, the module will:

- either not perform the maneuver (do not change left!) if the change is not safe, but is still safe to keep going in the current lane; or
- the module will tell that not only the maneuver is unsafe, but the driver needs to slowdown in order to avoid a collision by staying in the current lane ((do not change left & slowdown!); or
- if the maneuver is unsafe and it is also needed an hard brake to avoid an obstacle in the current lane, the module will emit a Brake signal.

The logic is shown in the following schema:

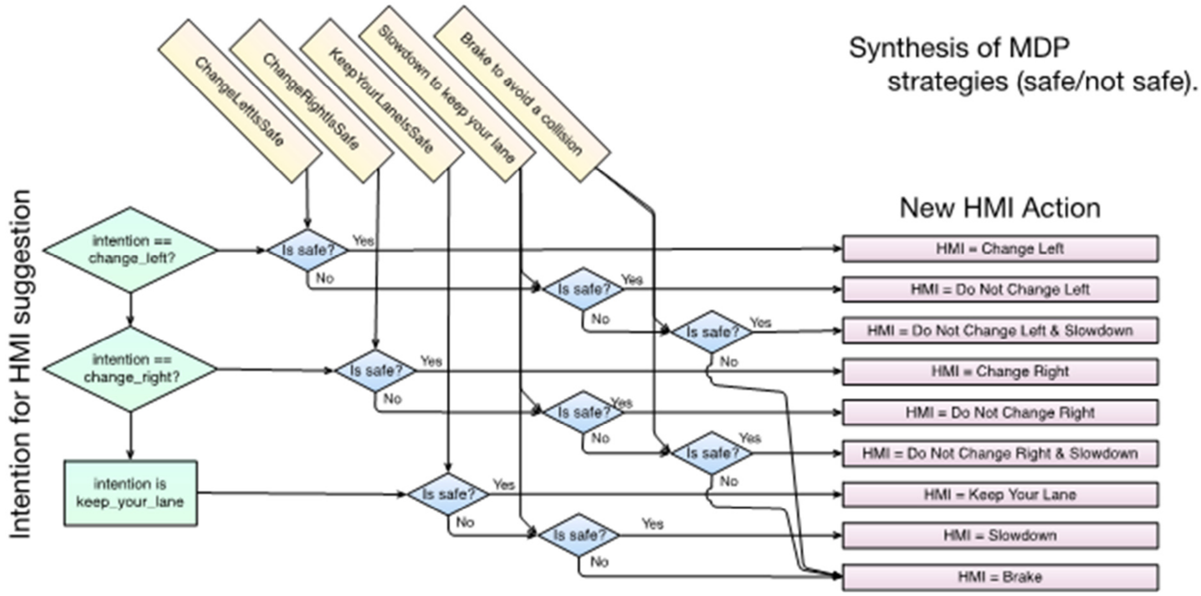


Figure 4: Logic-flow of the message sent by the Co-pilot to the HMI.

After an HMI action has been chosen, it is shown for a minimum amount of time, for hysteresis. If a new action of higher priority is decided, it is shown immediately, again restarting the hysteresis counter. Such counter has been tuned to 0.8 seconds. A "do not" command has priority over positive commands, slowdown commands have a higher priority, and a brake command has even higher priority. Therefore, a low priority command will never hide an high priority one.

The decided HMI action, encoded as an integer value, is sent to the HMI modules, that are responsible for the interaction with the user.

More details about the final implementation of the HMI and its strategies are provided in Section 2.2.

2.1.2 Description of the Driver Intention Recognition Module

The Driver Intention Recognition (DIR) module is a non-lifecycle MTT that provides the AdCoS "Adapted Assistance" with the hidden intentions of the driver in two-lane highway overtaking scenarios, and as such, represents a MTT for context assessment, resp. assessing the user status.

Figure 5 shows a schematic overview of the DIR module as implemented for the AdCoS "Adapted Assistance". The DIR module receives input in form of sensor data and provides output in form of belief states for the current intentions and maneuvers. Internally, the DIR module consists of two components, a component for data pre-processing, and a component for the actual intention recognition. The core of the DIR module is an inference engine that performs probabilistic inferences using a probabilistic model for intention recognition, called the *Driver Intention Recognition* (DIR) *model*. The DIR model itself is defined in a separate XML specification, which allows to simply replacing the underlying DIR model with improved versions. Following Figure 5, we will give a short description of the internal mechanisms of the DIR module:

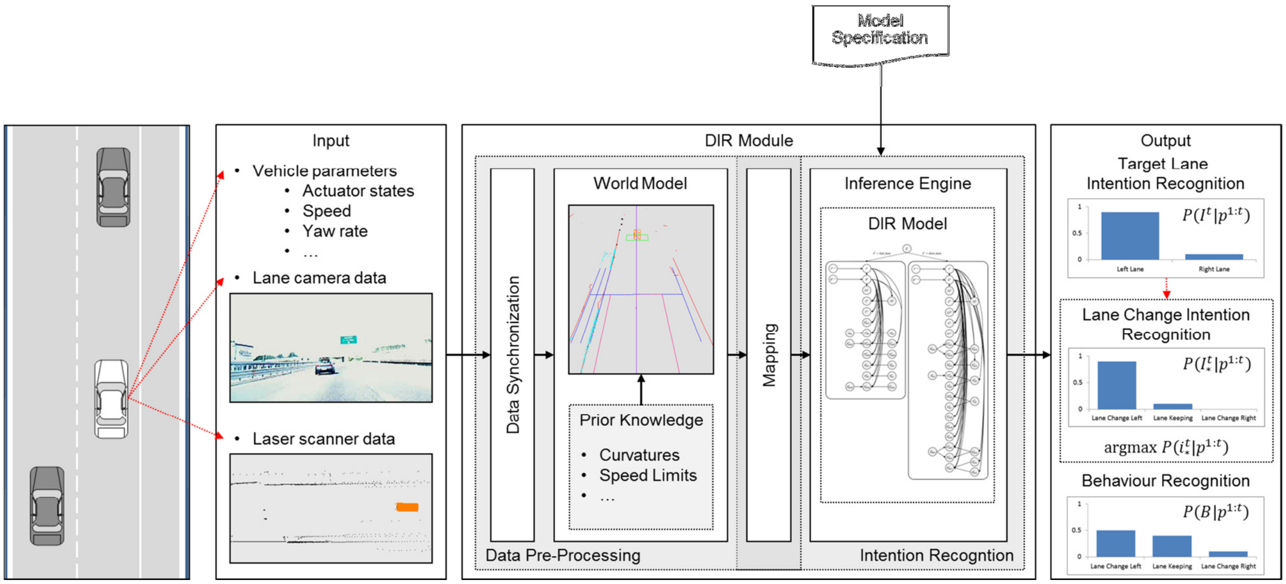


Figure 5: Schematic overview of the DIR module.

- **Input**: The DIR module receives input in form of information collected by a substantial set of sensors available for the CRF demonstrator vehicle. More specifically, the CRF demonstrator vehicle is equipped with:

  - Four IAS laser scanners, placed at the front, back, and sides of the vehicles, able to detect obstacles and track surrounding traffic,
  - an external camera provided by CONTI (as developed during the ARTEMIS EU project DESERVE) that detects lane edges and the relative position of the vehicle in the lane,
  - an internal camera provided by CONTI (as developed by the ARTEMIS EU project DESERVE) to detect the head position and direction of the driver (which however is not used by the DIR module),
  - and a PC, interfacing the CAN bus of the vehicle with the MTT RTMaps used to model the AdCoS "Adapted Assistance".

  Additionally, the CAN bus provides a set of vehicle parameters including e.g., the current velocity, acceleration, and actuator states.

- **Data Synchronization**: The DIR module is triggered by central clock with a frequency of 20Hz. As the different sensor readings are provided asynchronously and in potential different frequencies, it is therefore necessary to gather and combine them in synchronized time slices. For this, at each time step t, internal RTMaps components are used to guarantee that the most complete and up to date sensor values are passed to the world model.

- **World Model**: Conceptually, the DIR module requires input in terms of information about the future path of the road, the state of the driver's vehicle (ego-vehicle), the driver's control behavior, surrounding traffic participants (alter-vehicles), and additional contextual information, like the lane, the ego-vehicle is currently inhabiting and the current speed limit. Concerning the surrounding traffic participants, the DIR module additionally requires a classification of surrounding vehicles based on their position relative to the ego-vehicle (e.g. the lead vehicle, the vehicle behind on the fast lane, etc.). Unfortunately, while such inputs and classifications are readily available in simulator environments, real world scenarios are slightly more complicated. As the classification of the alter-vehicles is not provided directly, it needs to be derived based on the current lateral position and heading angle of the ego-vehicle and the curvature of the road. Although the external camera of the CRF demonstrator vehicle provides the required information, the curvature provided is subject to strong noise, and the lateral distance and heading angles, while very precise in general, sometimes fails during lane changes, making a tracking of the lane, the ego-vehicle inhabits, very challenging.

  As a solution, the data pre-processing component implements a world model that enriches the actual sensor input available by less precise but robust estimates of the lateral distance to the left lane edge, the lane the ego-vehicle is currently inhabiting, the heading angle, the curvature, the current speed limit, and the classification of the alter-vehicles. As no GPS or map information is provided, the world model requires some prior knowledge to achieve this task. More specifically, we used experimental data provided by CRF to derive a hard-coded mapping from the distance travelled to the curvature of the road and the current speed limits for a section of the Italian highway "A55 Torino-Pinerola", beginning at the "SP142" entry and ending at "Via Maestra Riva" exit. Obviously, the dependence on this prior knowledge is a major limitation of the DIR module, rendering the DIR module unusable for any other scenario. We note however that this limitation is not inevitable, as better sensor information would render the reliance on prior knowledge irrelevant.

  The estimation of the lateral distance and the current heading angle is achieved in a two-step process. The first step is based on a basic particle filter. The filter maintains a set of weighted instantiations for the current lateral distance, the heading angle, and the curvature, called particles. At each time step t, a new set of unweighted particles is sampled and slightly modified, simulating random vehicle dynamics. Based on prior information about the highway, the weight of each particle is then updated according to the likelihood of observing static outlines of the left guardrail, provided by the laser scanners. The weighted particles are then used to derive the marginalized expectation and variance for the current relative heading angle, the lateral deviation, and the curvature.

In second step, the expectations of the heading angle and the lateral deviation are passed to a non-dynamic filter, which uses a set of raw IAS laser scan points from the left guardrails to derive a finer estimate of the lateral deviation and the heading angle. As the left lane edge in the vicinity of the ego-vehicle is approximately linear, these scan points provide a good basis for a robust estimation of the heading angle and the lateral deviation. The filter uses the statistics of the first step to define a prior distribution from which a new set of particles is sampled and then weighted by the likelihood of the scan points. In conjunction to the estimate of the curvature, the resulting improved expectation and variance of the heading angle and lateral deviation serve then as basis to derive the "roles" of the vehicles in the vicinity of the ego-vehicle.

- **Mapping**: As a next step, the augmented sensor data must be mapped onto concrete instantiations of random variables in the DIR model. Furthermore, many variables in the DIR model represent functions of the available sensor data, so e.g. rates of changes, time headways, and time to collisions. In the mapping step, the available data is therefore enriched by additional information and then re-arranged in a form that can be processed by the inference engine.

- **Inference engine**: The core of the DIR module is the inference engine that, provided with a DIR model, can be used to estimate belief states over intentions (and other variables of interest) via probabilistic inference. The inference engine implements a standard algorithm for exact inference based on variable-elimination in clique trees. The DIR model is conceptualized as a Dynamic Bayesian Network and has been previously described in D2.7 "Modelling Techniques and Tools Vs2.0".

  Driver Intention Recognition usually deals with the recognition of maneuver intentions, which for the target scenario of the AdCoS "Adapted Assistance" translates to the recognition of *lane change intentions*. As such, the DIR module must be able to recognize the intention to perform a lane change to the fast (resp. left) lane, a lane change to the slow (resp. right), or the absence of such an intention, as early as possible. Internally, the DIR module uses a slightly different concept by trying to recognize *target lane intentions* (e.g., recognizing that the driver intends to drive on the fast lane). Let I denote a binary random variable with the possible values $\mathrm{Val}(I) = \{\mathrm{slow\_lane\_intention}, \mathrm{fast\_lane\_intention}\}$ that represents the behavioural intentions of a driver in respect to the lane he/she intends wants to inhabit and B denote a discrete random variable with the possible values $\mathrm{Val}(B) =$

$\{\text{lane change left, lane change right, lane-following}\}$, representing a set of three potential behaviours/manoeuvres. At each time step t, the DIR model is used to estimate the (conditional) joint probability $P(I^t, B^t | \boldsymbol{P}^{1:t} = \boldsymbol{p}^{1:t})$ of the current target lane intentions I^t and the currently shown behaviors B^t, given all available perceptual evidence collected up to the present $\boldsymbol{P}^{1:t} = \boldsymbol{p}^{1:t}$.

- **Output**: The primary output of the DIR module tailored to the AdCoS "Adapted Assistance" is as follows:
    - A vector of probabilities representing the belief state over the current target lane intentions $P(I^t | \boldsymbol{p}^{1:t})$, i.e. the probability for each target lane intention $i^t \in \mathrm{Val}(I)$, given all available evidence $\boldsymbol{p}^{1:t}$ collected. Via marginalization, this probability can easily be obtained from the (conditional) joint probability $P(I^t, B^t | \boldsymbol{p}^{1:t})$.
    - A vector of probabilities representing the belief state over the current behaviors $P(B^t | \boldsymbol{p}^{1:t})$, i.e. the probability for each driving manoeuvre/behaviour $b^t \in \mathrm{Val}(B)$ given all available evidence collected. Once again, this probability can easily be obtained from the (conditional) joint probability $P(I^t, B^t | \boldsymbol{p}^{1:t})$.

Let I_* denote a binary random variable with the possible values $\mathrm{Val}(I_*) = \{\text{lane\_change\_left, lane\_keeping, lane\_change\_right}\}$ that represents the lane change intentions of the driver. Knowing the lane, the ego-vehicle currently inhabits, the , the belief state over target lane intentions $P(I^t | \boldsymbol{p}^{1:t})$ can easily be mapped onto onto a belief state over lane change intentions $P(I_*^t | \boldsymbol{p}^{1:t})$ (e.g., an intention to drive on the fast lane, while driving on the slow lane implies the intention to change to the fast lane), from which the most probable lane change intention $\operatorname{argmax} P(i_*^t | \boldsymbol{p}^{1:t})$ is provided as input to the co-pilot.

2.1.3 System Architecture of the Adaptive Assistance AdCoS

With reference to the Levels of Automation (LoA) from "SAE International" (Society of Automotive Engineers), the Adaptive Assistance AdCoS is collocated between the levels of "Driver Assisted" and of "Partial Automation. The "trigger" for the adaptation is represented by the state and the intention of the driver (if he/she is distracted or not, which is her/his intention): depending on the cognitive state and on his/her preferences (willing to overtaking, or to follow car ahead), the strategies of the AdCoS are modified by the Co-pilot module.
In particular, the novelty is the advanced cooperation between human-agent and machine-agent, where the system can adapt to the driver capabilities, needs and intentions, as well as to the other road users and the environmental conditions. It is characterized by a decentralized decision making process, between the artificial (represented by the co-pilot) and the human intelligence; the related architecture is represented in the following figure, where the flow of information is illustrated:

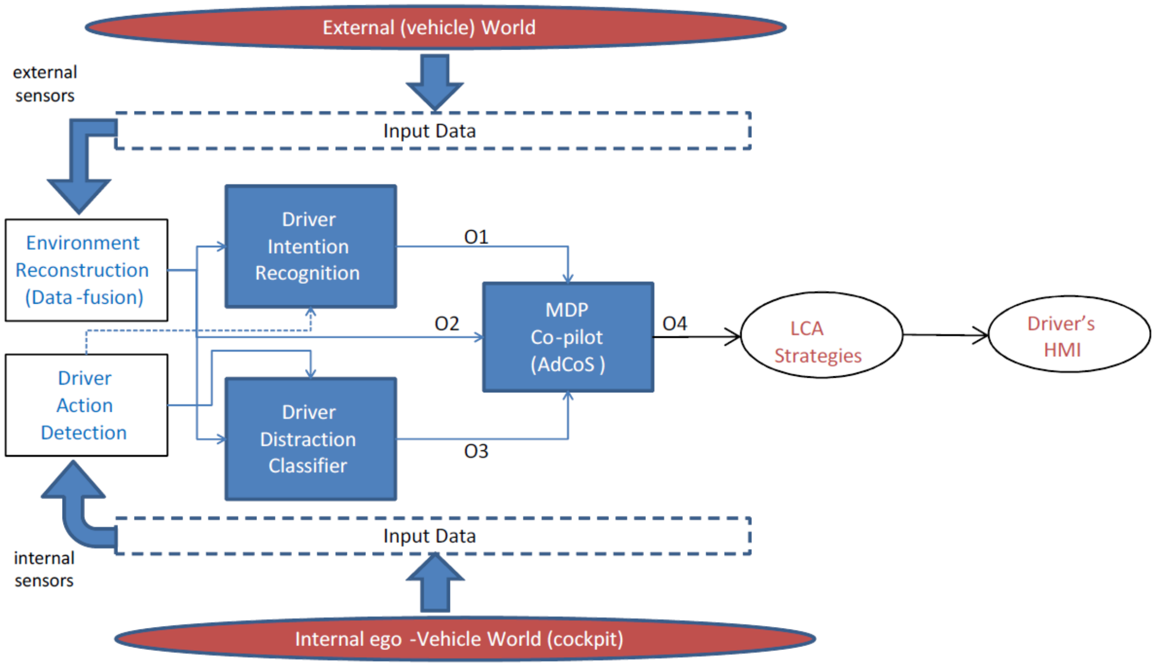


Figure 6: final representation of the information flow from / to the different modules in the Adaptive Assistance AdCoS.

The related (and final) system architecture is represented in Figure 7:

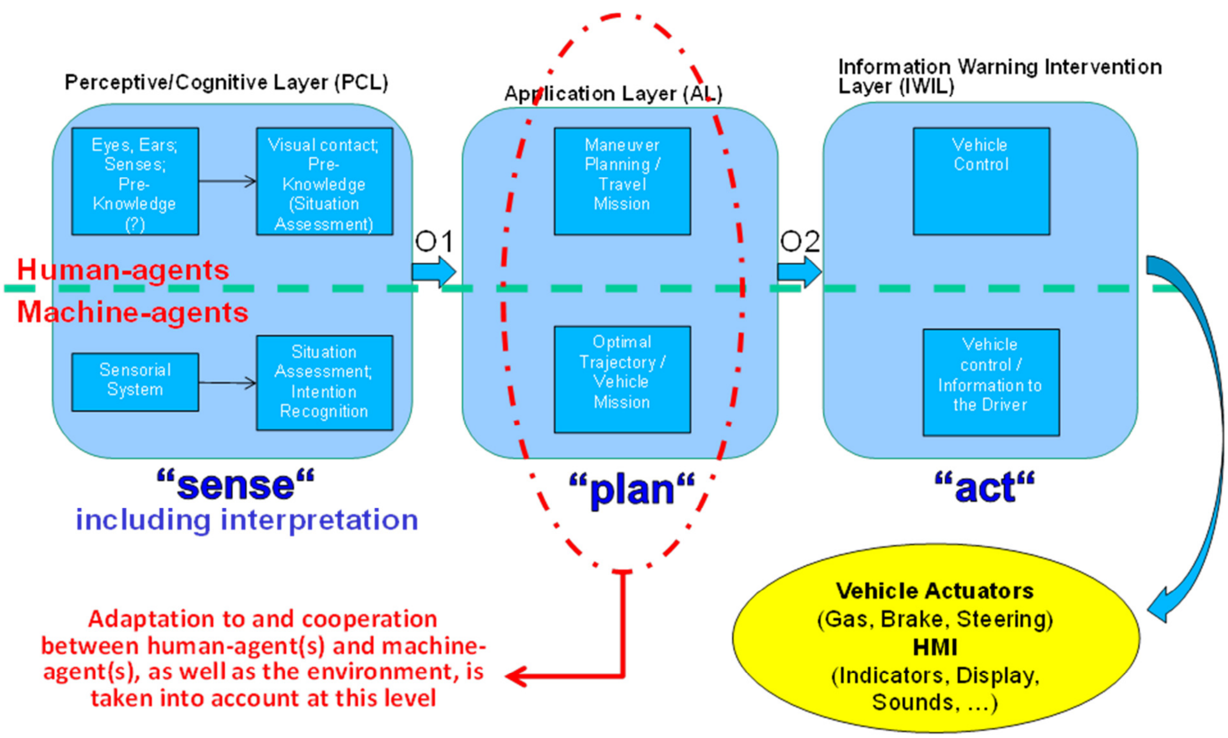


Figure 7: final system architecture of Adaptive Assistance AdCoS, as implemented on CRF prototype vehicle.

This architecture shows how human-agent and machine-agent follow the same process. In the perception and cognitive layer, the external environment is perceived and interpreted, together with the cognitive state of the driver and his/her intentions/needs. The adaptation and cooperation aspects are taken into consideration in the application layer, where the co-pilot is implemented. It analyses the behaviour of the human-agent and tries to "emulate" him/her, providing this information to the machine-agent, which adapts the driving style to the individual human driver. Finally, the goal of the Information Warning and Intervention Layer is to keep the driver informed about the detected traffic situation and the optimal manoeuvre the system will plan and suggest.

2.1.4 Final Use-cases for the Adaptive Assistance AdCoS

For this AdCoS, three main use-cases have been finally considered; they are summarized, as following:

- **UC1 – Normal situation (attention)**. This is the "standard situation", where the driver – completely attentive (the system is monitoring the cognitive state) – intends to perform the lane change and initiates the manoeuvre. Since the lane-change is possible, the system can simply "pay attention" that the manoeuvre is correctly executed.
- **UC2 – Normal situation (obstruction)**. Now, the driver intends to perform the lane change and initiates the manoeuvre, which is now not possible due to lane obstruction (for example, another vehicle is approaching from the rear in the adjacent lane). The AdCoS detects the situation and supports properly the human-agent (the driver) who aborts the lane-change manoeuvre. Also in this case, the driver is attentive (monitored by the system).
- **UC3 – Impaired driver (still responding)**. The driver intends to perform the lane change and initiates the manoeuvre; the driver is impaired, but responding to the HMI. In this situation, the machine-agent is monitoring the driver, who is distracted; therefore, when he/she intends to perform a lane-change (for overtaking), the system requests for a correct behaviour[2] before supporting this manoeuvre. After that, UC1 or UC2 can occur.

How these manoeuvres have been taken into account at HMI level is described in the following paragraph.

2.2 Final HMI

The HMI in the complete version of the AdCoS is based on a multimodal strategy that considers three different channels:

1. **Visual** ⇒ information on the "what" (e.g. "do not change lane on the left")

[2] With "correct behaviour", we mean a behaviour without risky situation. For example, for the longitudinal aspect, this can be related to the Time-To-Collision (TTC) values, which have to be under a given threshold.

2. **Haptic** ⇒ information on the "why" (e.g. "because a car is approaching very fast on the left")
3. **Auditory** ⇒ warning in case of driver distraction

The evaluation studies conducted within the task T9.5 and described in details in D9.9 compared the AdCoS strategy with the baseline one, involving only channel 1 and 3. From a cooperation perspective, the two systems in comparison implements two mutual-control modes realized with different warning strategies (see D2.7, Section 2.3, for more details).

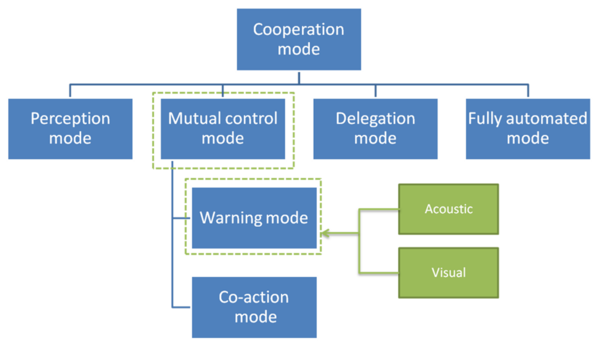


Figure 8. Cooperation model of the baseline AdCoS (acoustic and visual warning)

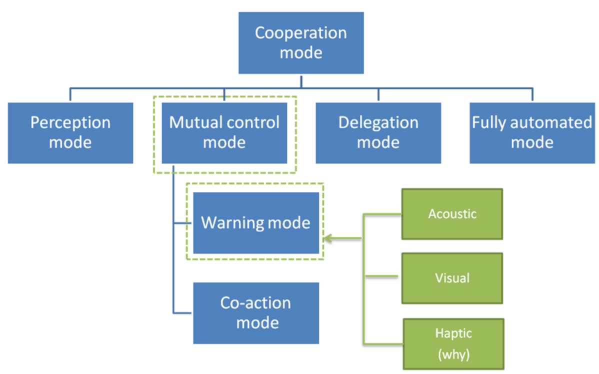


Figure 9. Cooperation model of the complete AdCoS (acoustic, visual and haptic warning explaining the why of the adaptation)

Evaluation results presented in D9.9 highlighted that the AdCoS had a higher cognitive effort compared to the baseline. Participants motivated the responses referring that the novelty of the haptic signal has determined distraction. Interference between driving and the vibration, both involving the motor system processing, could explain, at least in part, the major effort in the complete version of the AdCoS.

Therefore, a second study was designed and conducted to measure the performance of the multimodal strategy with the haptic signal (i.e. complete AdCoS) and without it.
As already described in D9.9, since the messages to be displayed are decided by the co-pilot (while the HMI module applies the multi-modal strategy), a protocol has been defined to allow the communication between the co-pilot and the HMI. Table 1 shows all messages shared between these modules as well as the complete HMI strategy associated to each of them when the driver is distracted.

MsgID	Message name	HMI strategy if the driver is distracted	Visual distribution			Haptic distribution		
			Left	Centre	Right	Left	Steering wheel	Right
0	HMI_COPILOT_DISABLED	visual	x	x	x			
1	HMI_KEEP_YOUR_LANE	visual		x				
2	HMI_CHANGE_LEFT	visual	x					
3	HMI_CHANGE_RIGHT	visual			x			
4	HMI_BRAKE	visual + haptic + auditory		x			x	
5	HMI_DO_NOT_CHANGE_LEFT	visual + haptic + auditory	x			x		
6	HMI_DO_NOT_CHANGE_LEFT_BRAKE	visual + (double) haptic + auditory	x	x		x	x	
7	HMI_DO_NOT_CHANGE_RIGHT	visual + haptic			x			x
8	HMI_DO_NOT_CHANGE_RIGHT_BRAKE	visual + (double) haptic + auditory		x	x		x	x
9	HMI_SLOWDOWN_CAR_FOLLOWING	visual		x				
10	HMI_DO_NOT_CHANGE_LEFT_SLOWDOWN	visual + haptic + auditory	x	x		x		
11	HMI_DO_NOT_CHANGE_RIGHT_SLOWDOWN	visual + haptic + auditory		x	x			x

Table 1: complete HMI strategy for distracted driver, grouped per message.

2.2.1 Design of experiments

The study has been conducted on the driving simulator of REL partner, as showed in the following figure:

Figure 10: picture of the driving simulator and of a participant involved in the study.

2.2.1.1 Participants

Twenty (20) participants have been involved in this study, whose characteristics are summarized as following:

Gender (Men-Women)	10 men – 10 women
Average age	35 years old
Average Km per year in the highway	16.000 km
Average years of driving licence	16 years

Table 2: demographic of participants to the experiment.

The panel included 10 men and 10 women for the main purpose of taking into strict account the gender issue and to guarantee a wider representativeness.

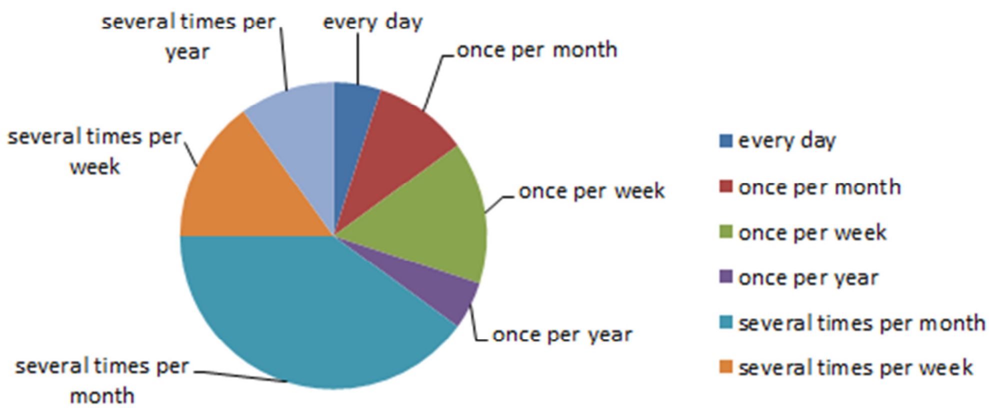


Figure 11: frequency of driving in highway

As shown in Figure 11, most of the participants have been selected because they declared to drive several times per months or per week in highway (thus we could expect them to have a good experience in the scenario and manoeuvres they were required to perform).

2.2.1.2 Procedure

In order to evaluate the performance of the haptic (i.e. the benefits and advance it brings), we have performed some tests with real drivers in 2 conditions:

A) *Baseline* ⇒ AdCoS with only visual and auditory signals.

B) *Complete* ⇒ AdCoS with visual, auditory and haptic signals.

Thus we have considered the HMI based on the visual + auditory signals as the baseline, and the HMI with the visual + auditory + haptic signals as the new system. In some cases, a double haptic signal is used when 2 different messages of risk have to be provided (e.g. "do not change left AND brake").

In both conditions the participants were distracted by the SURT tool that periodically requested the visual attention of the driver. The activation of the SURT was repeated 10 times during each scenario.

The drivers have be asked to drive for 10 minutes in each scenario, and then to fill in a brief questionnaire on the acceptability and usability of the system (mainly focused on the HMI). The scheduling of the scenarios has been randomized in order to avoid any bias (e.g. learning effect), as listed in Table 3:

	Test 1	Test 2
ID01	baseline	AdCoS
ID02	AdCoS	baseline
ID03	baseline	AdCoS
ID04	AdCoS	baseline
ID05	baseline	AdCoS
ID06	AdCoS	baseline
ID07	baseline	AdCoS
ID08	AdCoS	baseline
ID09	baseline	AdCoS
ID10	AdCoS	baseline
ID11	baseline	AdCoS
ID12	AdCoS	baseline
ID13	baseline	AdCoS
ID14	AdCoS	baseline
ID15	baseline	AdCoS
ID16	AdCoS	baseline
ID17	baseline	AdCoS
ID18	AdCoS	baseline
ID19	baseline	AdCoS
ID20	AdCoS	baseline

Table 3: Order of tests for each participant.

Two people of REL managed the experiment:

- A technician, whose role was to start the simulation as well as the RT-Maps modules and check they all worked correctly.
- A psychologist to conduct the experiment (including the questionnaires, designed by SNV in collaboration with REL and CRF).

The study protocol foresees the following steps:

1. Description of the project and the experiment
2. Consent forms
3. Demographics
4. Description and use of the SURT (without driving)
5. Driving warm-up – about 3 minutes
6. Test 1 (driving scenario 1 + driving scenario 2) – about 10 minutes
7. Questionnaire
8. Test 2 (driving scenario 1 + driving scenario 2) – about 10 minutes
9. Questionnaire
10. Conclusion

Each study lasted about 45 minutes.

2.2.1.3 Driving scenarios

Since the aim of the evaluation is to measure the benefits brought by the haptic signal (used for the "why" information) compared to the baseline (i.e. visual + auditory signal), we mainly focused on the messages that include the haptic in the strategy. Therefore, we created driving scenarios (in the simulator) where (at least) all messages with the haptics were included (i.e. # 4, 5, 6, 7, 8, 10, 11):

- HMI_BRAKE
- HMI_DO_NOT_CHANGE_LEFT
- HMI_DO_NOT_CHANGE_LEFT_BRAKE
- HMI_DO_NOT_CHANGE_RIGHT
- HMI_DO_NOT_CHANGE_RIGHT_BRAKE
- HMI_SLOWDOWN_CAR_FOLLOWING
- HMI_DO_NOT_CHANGE_LEFT_SLOWDOWN
- HMI_DO_NOT_CHANGE_RIGHT_SLOWDOWN

Two macro scenario and some sub-scenario have been created to show the selected messages and conditions:

- **Sub-scenario for the message #4 (HMI_BRAKE)** ⇒ driver on the fast lane, queue on the slow lane and sudden stop of the vehicles in the fast lane.
- **Sub-scenario for the message #5 (HMI_DO_NOT_CHANGE_LEFT)** ⇒ driver on the slow lane, slow vehicle in front of it and fast vehicle approaching on the fast lane.
- **Sub-scenario for the message #6 (HMI_DO_NOT_CHANGE_LEFT_BRAKE)** ⇒ driver on the slow lane, slow vehicle in front of it and fast vehicle approaching on the fast lane, and the slow vehicle suddenly brakes.
- **Sub-scenario for the message #7 (HMI_DO_NOT_CHANGE_RIGHT)** ⇒ driver on the fast lane and queue with same spaces on the slow lane after the first part of the overtaking (the driver would like to go back to the original lane, but there is not enough space) OR driver on the fast lane after the first part of the overtaking and the car on the slow lane starts accelerating.
- **Sub-scenario for the message #8 (HMI_DO_NOT_CHANGE_RIGHT_BRAKE)** ⇒ driver on the fast lane and queue with same spaces on the slow lane after the first

part of the overtaking (the driver would like to go back to the original lane, but there is not enough space) AND car suddenly brakes in the fast lane OR driver on the fast lane after the first part of the overtaking and the car on the slow lane starts accelerating AND car suddenly brakes in the fast lane.

- **Sub-scenario for the message #10 (HMI_DO_NOT_CHANGE_LEFT_SLOWDOWN)** ⇒ driver on the slow lane, slow vehicle in front of it and fast vehicle approaching on the fast lane, and the slow vehicle starts braking.
- **Sub-scenario for the message #11 (HMI_DO_NOT_CHANGE_RIGHT_SLOWDOWN)** ⇒ driver on the fast lane and queue with same spaces on the slow lane after the first part of the overtaking (the driver would like to go back to the original lane, but there is not enough space) AND car suddenly starts braking on the fast lane OR driver on the fast lane after the first part of the overtaking and the car on the slow lane starts accelerating AND car suddenly starts braking on the fast lane.

We also use the fog in some sub-scenarios to create a further risk for the driver.

2.2.1.4 Performance Indicators

Differences between the "HMI_Baseline" and the "HMI_Complete" versions of AdCoS HMI have been investigated by means of the same questionnaire used for the subjective evaluation of the Lane Change Assistant System. The definitive version of the questionnaire had the aim to verify five PIs by means of five dedicated sections:

- **cognitive effort** ⇒ this section consists of questions dedicated to the evaluation of the perceived workload determined by the system, in terms of fatigue and distraction;
- **perceived ease of use** ⇒ this dimension has been defined by Chang (2009) as "the degree of which a person believes that using a particular system would be free of effort";
- **usability** ⇒ this section has been elaborated selecting from the SUS questionnaire the questions about the usability of the system and excluding the questions about the learnability since no learning phase has been provided for the use of the driving assistance system;
- **attitudes toward using** (ATU) ⇒ this section has been dedicated to define a measure of the desirability of using the safety system;

- **intention to use** (ITU) ⇒ this section has been dedicated to the evaluation of the likelihood of the participants to use the system.

The questionnaire included 25 questions. For each question participants have been asked to evaluate the degree of accordance on a five-point scale where 1 corresponded to "strongly disagree" and 5 to "totally agree".
In addition, an ad-hoc prepared questionnaire has been elaborated to deeply investigate the "HMI_Complete" version. In particular, the questionnaire has been dedicated to the evaluation of four PIs:

- *comprehensibility of the system* ⇒ the property of the system to be identified by the user as a safety system;
- *distinguishability of the signal* ⇒ the physical property of the vibration signal of being clearly distinguishable;
- *perceptibility of the signal* ⇒ the physical property of the vibration signal of being clearly perceptible;
- *effectiveness of the signal* ⇒ the degree at which the objective of the signal is achieved.

The questionnaire, hereafter called "Final questionnaire", included four questions and has been presented to the participants at the end of the experiment. For each question participants have been asked to evaluate the degree of accordance on a five-point scale where 1 corresponded to "strongly disagree" and 5 to "totally agree".

2.2.2 Final Results of HMI tests

The ANOVA analysis of the results of HMI_Baseline questionnaire and HMI_Complete questionnaire revealed no significant differences between the two HMI, as reported in Table 4:

One-way ANOVA

		Sum of squares	df	Mean of squares	F	Sig.
	Between	94,737	1	94,737	,231	,633
Cognitive effort %	Within	14736,842	36	409,357		
	Total	14831,579	37			
	Between	467,836	1	467,836	1,617	,212
Perceived ease of use %	Within	10416,374	36	289,344		
	Total	10884,211	37			
	Between	17,401	1	17,401	,218	,644
Usability %	Within	2878,625	36	79,962		
	Total	2896,026	37			
	Between	23,684	1	23,684	,159	,692
ATU %	Within	5360,526	36	148,904		
	Total	5384,211	37			
	Between	79,605	1	79,605	,233	,632
ITU %	Within	12297,368	36	341,594		
	Total	12376,974	37			

Table 4: results of the ANOVA analysis on questionnaires results (cognitive effort, perceived ease of use, usability, attitude towards use (ATU), intention to use (ITU).

The analysis of the results of the Final questionnaire have demonstrated a general good performance of the haptic signal in terms of comprehensibility, distinguishability and perceptibility, as showed in the following figures:

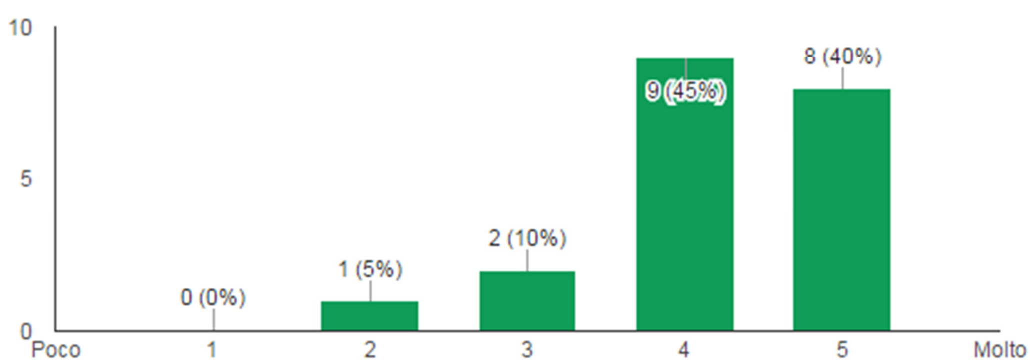


Figure 12: "Comprehensibility" (Is the presented system a safety system?). Percentage of responses on the 5-point scale

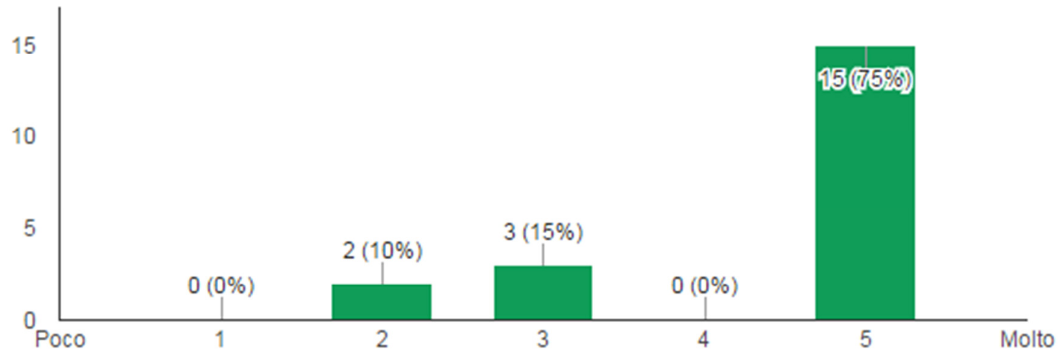


Figure 13: "Distinguishability" (Is the vibration of the steer and of the seat (right and left part) distinguishable?). Percentage of responses on the 5-point scale.

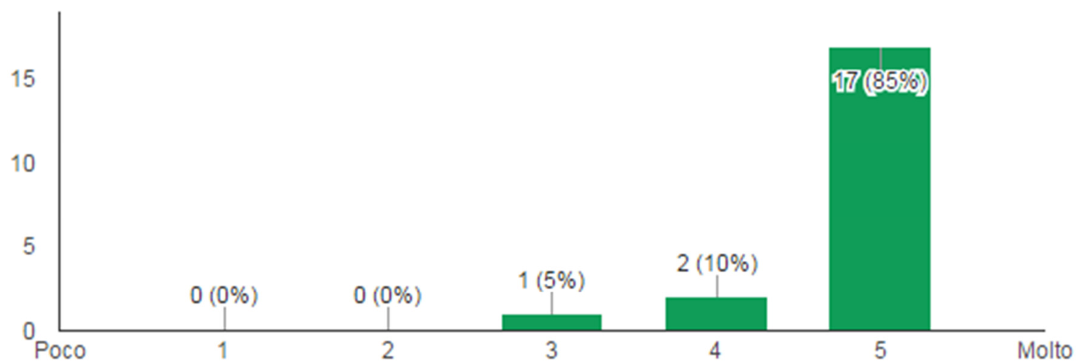


Figure 14: "Perceptibility" (Is the vibration clearly perceptible?). Percentage of responses on the 5-point scale.

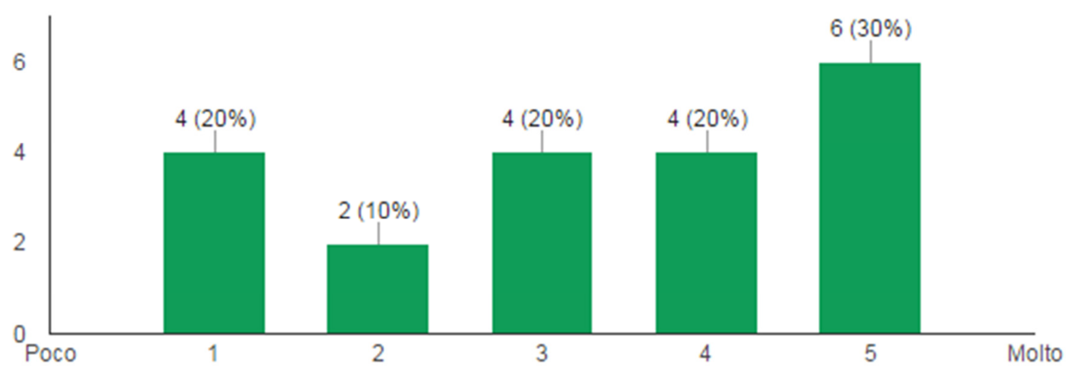


Figure 15: "Effectiveness" (Is the vibration effective to signal the direction of the danger?). Percentage of responses on the 5-point scale

The responses to the question about the effectiveness of the haptic signal (see Figure 15) revealed that the objective of the signal is not completely achieved for half of the participants. They motivated the responses with the novelty of this kind of signal, not usual in a car environment, that in a first time determined confusion.

2.3 HF-RTP assessment and recommendations

For the design and development of the Adaptive Assistance AdCoS, taking into account all the adaptivity elements as mentioned in the previous sections, different MTTs have been implemented and used, such as the following table shows:

Tool name	Tool type	Tool provider	Comments / Status
Driver Visual Distraction Classifier (DVDC)	HF Modeling Techniques and Tools (Machine learning prototype)	UTO, CRF	Used and implemented. Classification of the driver visual distraction, thus adapting the optimal manoeuvre to be suggested.
Probabilistic Driver Intention Recognition (DIR)	HF Modeling Techniques and Tools (Probabilistic model)	OFF	Used and implemented. Recognition of the driver intention, in particular for the lane-change and overtaking manoeuvres, thus adapting the optimal manoeuvre to be suggested.
Great SPN for Co-pilot MDP development	Techniques and Tools for Adaptation (Probabilistic model)	UTO	Used and implemented. Co-pilot module provides the assisting strategies to the driver, based on external and internal conditions.
RT-MAPS	Model based HF techniques & tools (Software framework)	INT	Integrated and used. It represents the SW tool for data collection and the SW framework to make all modules properly running in real-time.
SURT	Empirical based HF techniques & tools	DLR	Used for data collection and for final tests, as distraction source.

Table 5: tools and services used in Adaptive Assistance application.

This table provides a final overview of the tool used in WP9 for the Adaptive Assistant AdCoS; with respect the original list – described in the deliverable D9.7 – only the PRO-CIVIC tool has been not considered at the end, for a matter of time, efforts and for the choice to use the REL driving simulator.
The following table provides some indications about the strong points and possible improvements for the MTTs in use:

Tool Name	Strong Points	Possible Improvements
Driver Visual Distraction Classifier (DVDC)	Very accurate when there is a model for each user. Capacity to classify driver's status in real-time.	Difficult to create a unique model for more users. Not easy to create the appropriate dataset for training.

Probabilistic Driver Intention Recognition (DIR)	Very accurate prediction of driver's intention. Capacity to work in real-time.	More robustness to change is needed (e.g. limited scenarios).
Great SPN for Co-pilot MDP development	Real-time and on-line tool for assisting the driver. Possibility to compute an optimal trajectory.	Possibility to include vehicle control. Possibility to cooperate with other agents. Possibility to make the co-pilot behaviour more "human-like".
RT-MAPS	Unique tool which both for design (data collection and recording) and development (SW framework, where all modules run in real-time).	Deeper integration with other tools (e.g. MATLAB). Possibility to generate C/C++ code for ECU, even at prototype level (such as "dSpace").
SURT	Methods and tool to generate distraction in a flexible and defined way. Integration with RT-MAPS.	Not always easy to program and integrate.

Table 6: strong / weak points, with related suggestions for possible improvement, for the MTTs used in Adaptive Assistance application.

All in all, no strong / hard drawbacks have been highlighted during the use of these MTTs. Possible improvements and "next steps" for their further development are detailed.

For what concerning the conclusions in the AdCoS evaluation, we have to consider both the subjective and objective assessment, in particular for the adaptivity aspects, with respect the defined baseline. It is represented by a Blind Spot System and a Forward Collision Warning system, as separated applications, while the our AdCoS merges the longitudinal and lateral functionalities in a unique supporting system, taking into account the adaptation aspect. In this sense, the adaptivity considered in HoliDes is mainly focused on human factor aspects and, in our specific case, it considers the driver state and intention.

For the technical assessment, the AdCoS has improved all the performance indicators (PIs) related to safety by almost 50% (see D9.9 for all details), in particular for the most relevant ones, that is the PIs related to the total number of accidents in baseline and with AdCoS, as well as the time spent in critical region, with $TTC \leq 2s$.

The subjective evaluation has showed no results against the introduction of a haptic warning in a real car. The "HMI_Complete" version of the HMI with visual, acoustic and haptic warnings has been evaluated compatible with the current standards used for the development of the safety systems, in terms of cognitive effort, perceived ease of use, usability, attitude toward using and intention to use. In addition, comprehensibility, distinguishability and perceptibility of the vibration received a good evaluation from participants, suggesting an appreciation from the end-user point of view. The only remark concerns the effectiveness of the haptic signal, the ability to signal the direction of the danger. The novelty of this functionality, unusual for a driver, has influenced the effectiveness for half of the participants. A suggestion to overcome this aspect could be the prevision of a learning phase highly recommended for a new system.

3 Adaptive Automation AdCoS

This AdCoS has been developed by a specific team, composed by IAS, DLR, TWT.

3.1 AdCoS description

The Adapted Automation AdCoS (see also D9.7) is a cooperative development of the partners IAS, DLR and TWT. The key concept is shown in Figure 16. IAS is responsible for environment sensing, modelling and localisation, whereas DLR is the responsible partner for modelling and classifying human driving styles. Cognitive distraction is measured from modules provided by TWT.

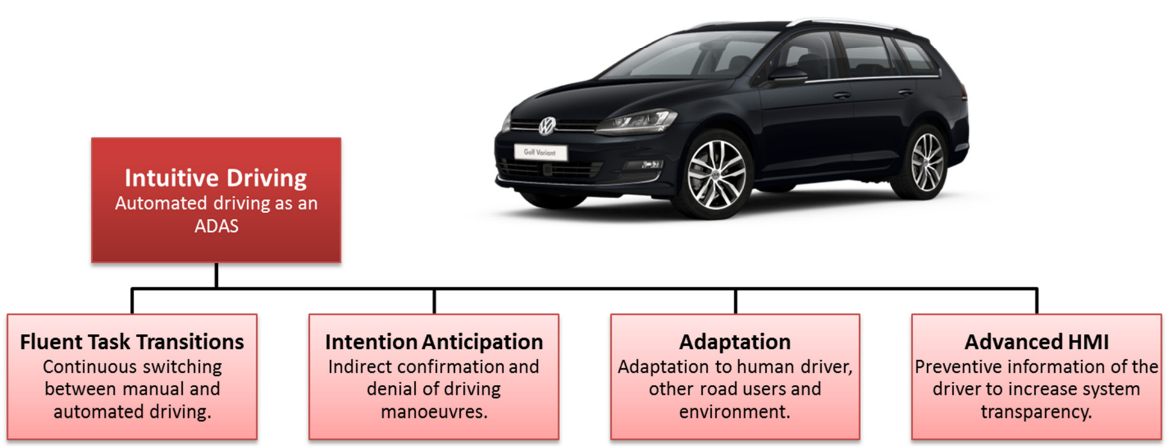


Figure 16: Key features of the Ibeo AdCoS

The highly automated driving (HAD) system is characterised by four main features, as shown in Figure 16:

1. **Fluent Task Transition.**
   The switching between manual and automated driving shall be fluent. This means that the driver can give control to the automated system at any time, while the automated driving function is available. Also the driver can interact with the automated system by operating the standard control inputs (gas, brake, steering wheel, indicators). In case the system detects that it is unable to handle an upcoming traffic situation it will warn the driver early that has to take over control.
2. **Intention Anticipation.**

In case the human driver operates the pedals, the steering wheel or the indicators during automated driving, the system will automatically anticipate the driver's intention, e.g. if the vehicle is following a truck in the outer lane of a highway and the driver sets the indicator to the left, the automated system could anticipate that the driver wants to overtake and go faster.

3. **Adaptation**
   The automated vehicle will be able to determine a range of safe driving manoeuvres at any time. Within this range, the system offers room to adapt the driving style according to the driver's characteristics, intentions and level of distraction.
4. **Advanced HMI**
   To keep the driver informed about the detected traffic situation and planned manoeuvres the system will include an HMI to communicate these information to the driver. The HMI is an important part of the overall system to create transparency for the human driver.

The process of driving can be broken down into four layers that are similar for the human driver as well as the automated system, as illustrated in High Level Architecture of the Ibeo AdCoS:

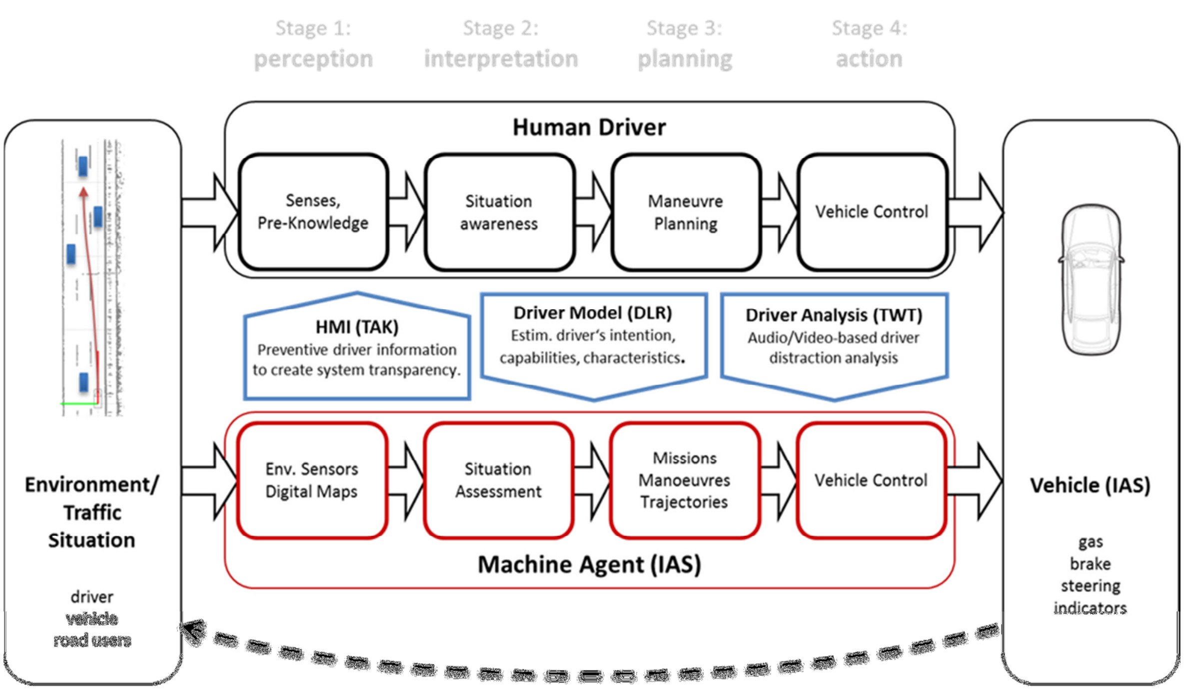


Figure 17: High Level Architecture of the Ibeo AdCoS.

3.1.1 Final MTT integration and test (CONFORM & CDC)

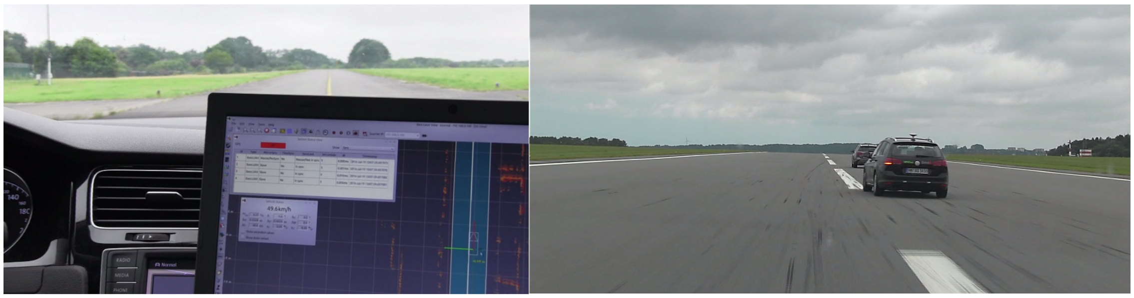


Figure 18: Impressions from the test track: Kiel city airport

The final integration and test took place on a test track (Kiel city airport) for CONFORM and on a highway in Hamburg for the Cognitive Distraction Classifier (CDC). Figure 18 gives some impressions of the test track. The CDC and CONFORM have been integrated into the IAS autonomous driving system in the IAS test vehicle. Both MTTs connect via the RT-Maps framework to the IAS test vehicle to receive the inputs about the current user state, vehicle state and environmental state.

The CDC output (estimated level of distraction and reliability value) and CONFORM output (predicted driving style) are sent from RT-Maps to the vehicle CAN using a USB to CAN adapter and dedicated RT-Maps CAN signal processing packages. A specification of the CAN signals can be found in D9.9.

3.1.2 Description of CONFORM:

Figure 19 and Table 7 summarize the final list of input parameter for the tailoring of the MTT CONFORM. Figure 20 shows the final RT-Maps diagram of the integration of the MTT CONFORM.

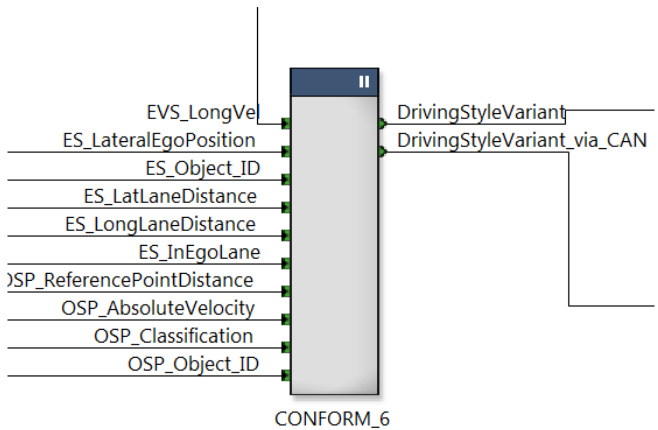


Figure 19: RT-Maps CONFORM inputs

Table 7: CONFORM RTMaps inputs

Parameter	Description
EVS_LongVel	Longtiduinal velocity of the ego vehicle
ES_LateralEgoPosition	Lateral deviation from the current lane
ES_LatLaneDistance	Lateral deviation from the current lane of the detected objects
ES_LongLaneDistance	Long distance between the ego vehicle and the detected objects in the current lane
ES_InEgoLane	Information if the object is in the same lane as the ego vehicle
OSP_ReferencePointDistance	Euclidian Distance to detected objects
OSP_AbsoluteVelocity	Absolute velocities of the detected objects
OSP_Classification	Classification of the objects, i.e. truck, car, person
OSP_Object_ID	ID of the object to track the object

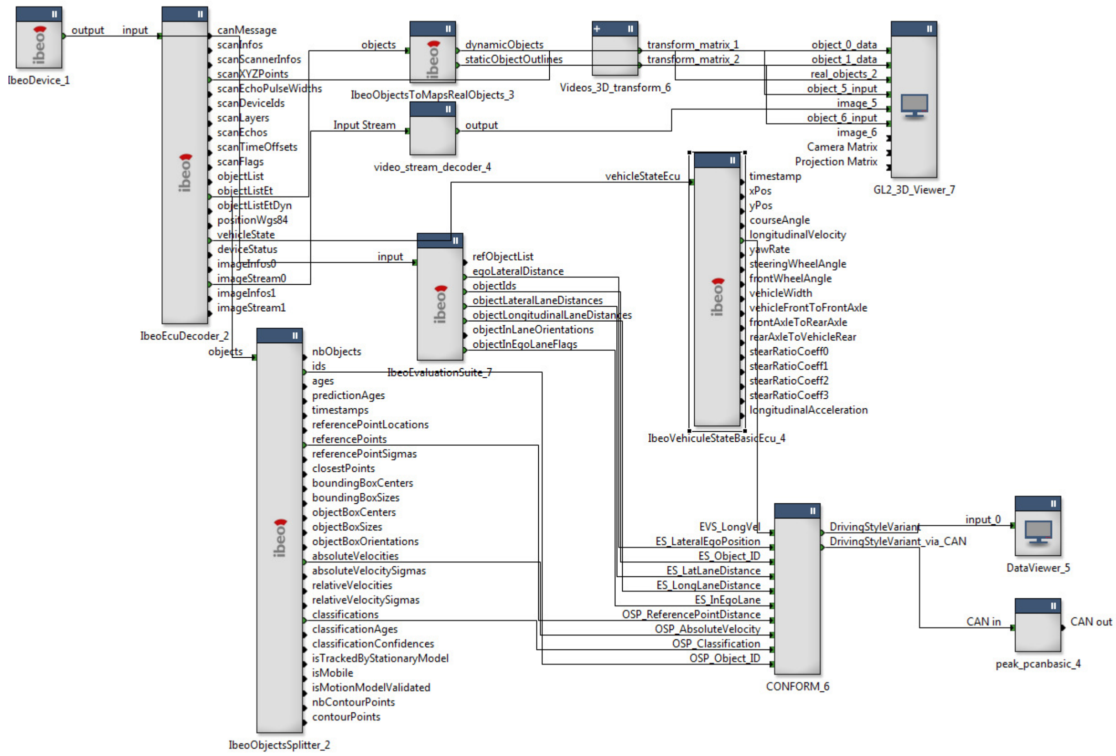


Figure 20: Integration of CONFORM in the RT-Maps framework for the Adapted Automation AdCoS.

3.1.3 Description of COGNITIVE DISTRACTION CLASSIFIER (CDC)

The integration of the CDC is depicted in the final RT-Maps diagram including macro component for the connection via CAN (Figure 21). The integration included two web cameras: one positioned behind the steering wheel, another one next to the rear view mirror that both provide video images of the driver's face. The video stream passes several processing stages. From the video recordings, facial elements (eyebrows, eyes, nose, and mouth) are located and tracked. Besides the video images of the driver's face, vehicle kinematic and control data serve as tool input. Of the vehicle data, velocity, steering wheel angle and accelerator, and brake pedal positions are used.

Video and vehicle data streams are recorded as a series of video and vehicle data frames, respectively. During acquisition, each frame is labelled with a timestamp, allowing for synchronization of the three data streams. Features calculated from a particular video or vehicle data frame are associated to the timestamp of that frame. If a feature is calculated from a series of past frames (such as the eye blink rate), the feature value is associated with the timestamp of the most recent frame in the series. In this way, features are synchronized into a joint stream of feature frames.

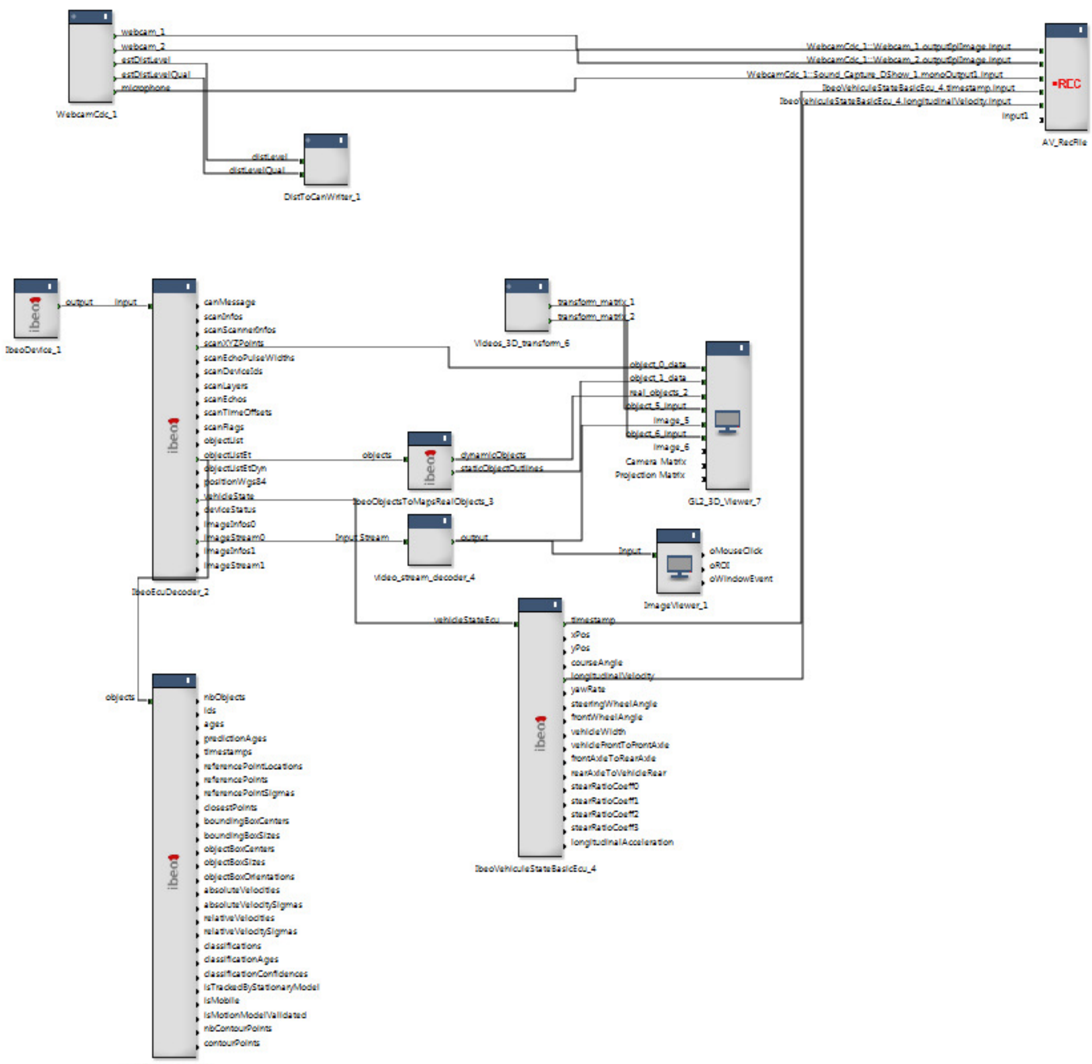


Figure 21: Integration of the CDC in the RT-Maps framework for the Adapted Automation AdCoS.

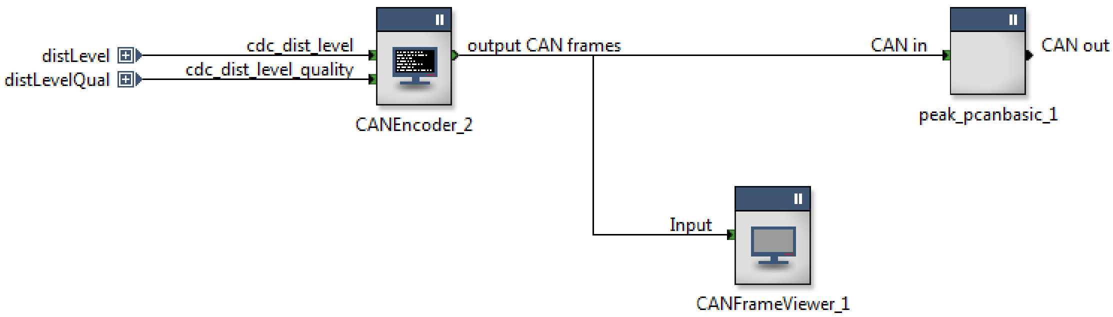


Figure 22: Integration using CAN.

Vehicle data and facial elements are sent to the CDC via Ethernet. Machine learning methods have been developed to classify these data offline. The first online implementation of the CDC, suitable for near-to-real-time use, is developed to use facial video data. The framework allows the other types of data (e.g., eye-tracking) to be included in future developments.

The output is the distraction level classification value, which is an estimate of the driver distraction level (undistracted vs. distracted). It is accompanied by a quality measure, quantifying the estimation reliability between 0 (unreliable) and 1 (most reliable). The CDC output (estimated level of distraction and reliability value) is sent from RTMaps to the vehicle CAN using a USB-to-CAN adapter and dedicated RTMaps CAN signal processing packages. The CDC output can then be used by the Adapted Assistance AdCoS to adapt the driving style of the car to the level of cognitive distraction of the individual.

In a first pilot experiment, the output of the CDC was successfully integrated into the Adapted Automation AdCoS as indicated by the resulting (theoretical) adaption of the driving mode that was displayed in the car. There was, however, a considerable delay between the classification of the distraction level and the (display of the) adaption of the driving mode. This was due to a high number of CAN-signals that arrived at the AdCoS. This problem could be solved by a reduction of the number of incoming signals.

During the final experiment, experimenters from IBEO and TWT compared the output of the CDC with the signal displayed by the AdCoS. The display of the appropriate driving mode demonstrated that the CDC classification was integrated in real-time into the AdCoS. Additionally, the reliability was provided. Taken together, this demonstrated a successful integration of the CDC into the Adapted Automation AdCoS.

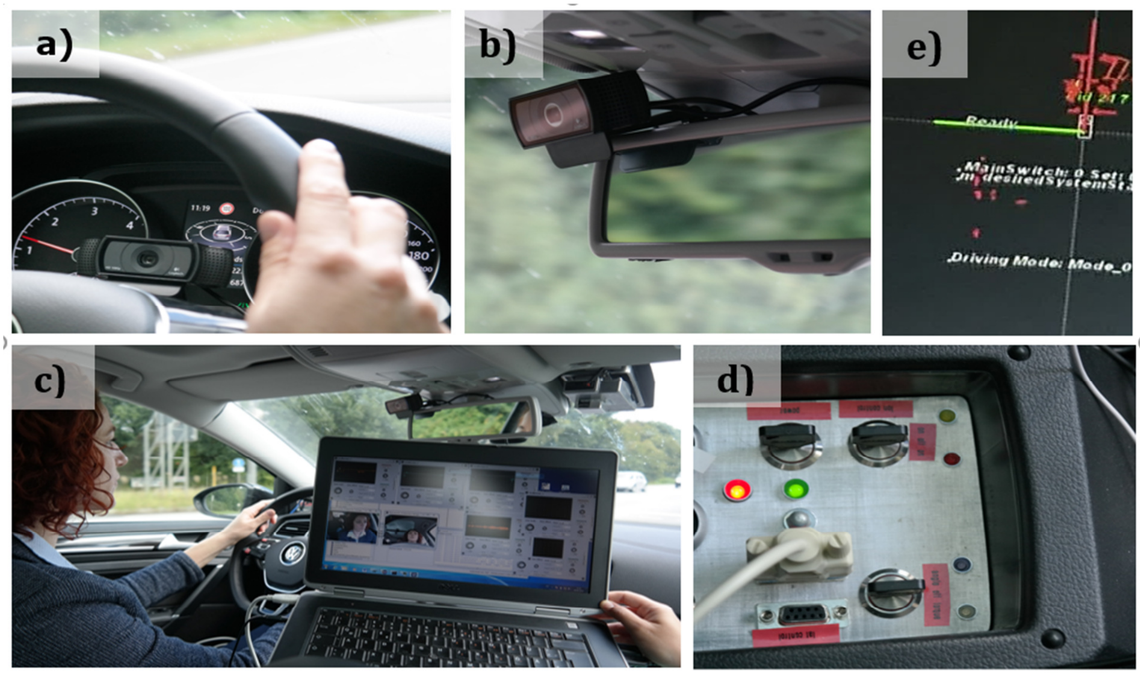


Figure 23: Integration into the IBEO car. a)-b) Camera position in the car; c) RT-Maps showing the CDC; d) CAN-connection; e) CDC-based adaption of the driving mode.

3.2 Final HMI

The focus of the Adapted Automation AdCoS development was the adaptation of the automated driving style rather than the development of a HMI. For that reason the test vehicle has some limitations for a HMI implementation. The test vehicle has for instance no free configurable instrument cluster. Consequently, the final HMI was implemented in the DLR simulator. The final HMI takes the evaluation result from D9.9 into account. The evaluation result highlighted the requirement of an interaction between driver and automation regarding the driving style. 24% of the driver preferred an automated driving style different to their own manual driving style. In addition, the difficulties to design a prediction function and to estimate the preferred driving style were mentioned.

The first aim of the HMI is to give the driver the chance to change the driving style if the driver is unsatisfied with the prediction made by the AdCoS. The second aim of the HMI is to communicate the current driving style to driver. Since the baseline was none adaptive, no different driving styles were available. Thus no different driving styles had to be communicated to the driver. The baseline cluster display (see Figure 24 &

Figure 25) only showed the available automation levels: "Manual driving" and "Chauffeur" (nickname for the automated driving mode). In a usability study with 14 participants in a fix-based simulator four different design variants were evaluated against each other, see Table 8.

Table 8: Description of the four different design variants

Variant	Description
1	• Driving style can be changed after open a driving style menu and pressing a up/down button • Current driving style and alternatives **not** permanently visible • Driving style **not** indicated by colours
2	• Driving style can be changed after open a driving style menu and pressing a up/down button • Current driving style and alternatives **not** permanently visible • Driving style indicated by colours
3	• Driving style can be changed by pressing a up/down button • Current driving style and alternatives permanently visible • Driving style **not** indicated by colours
4	• Driving style can be changed by pressing a up/down button • Current driving style and alternatives permanently visible • Driving style indicated by colours

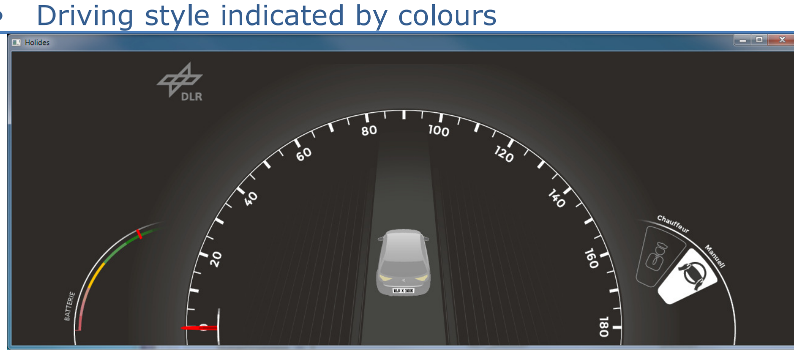


Figure 24: Baseline visualization: Manual driving mode

Figure 25: Baseline visualization: Automated driving mode

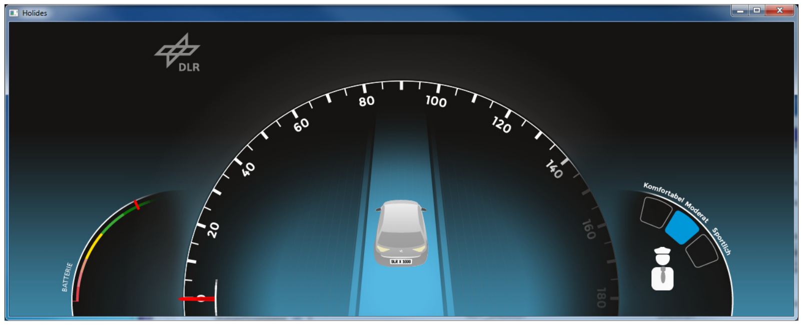


Figure 26: Visualization of driving style menu variant 1

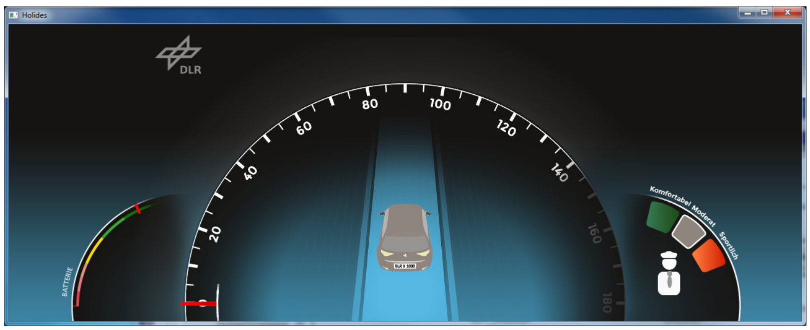


Figure 27: Visualization of driving style menu variant 2

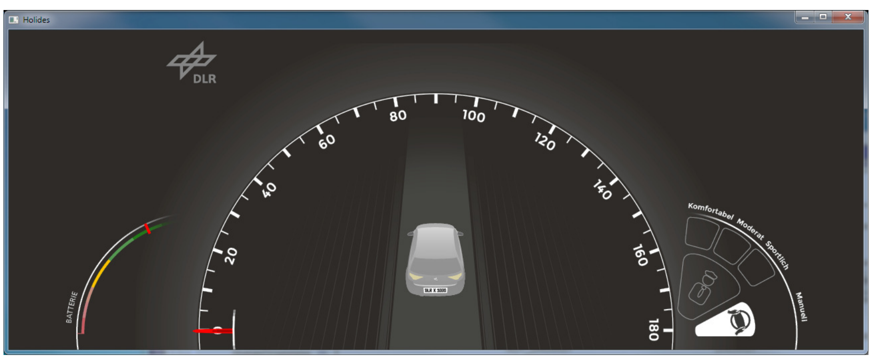


Figure 28: Visualization manual driving mode for design variant 3&4

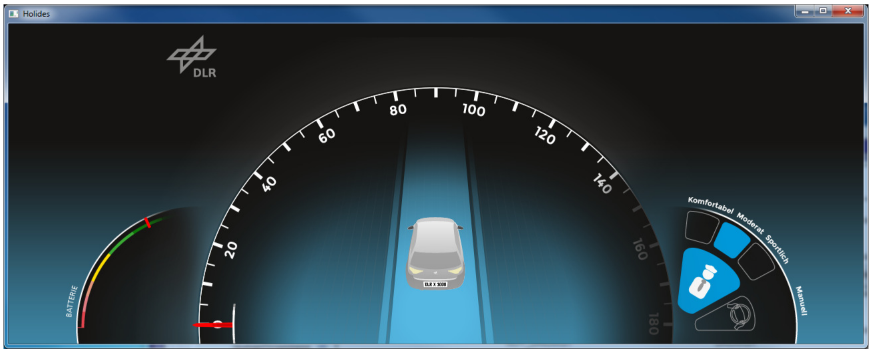


Figure 29: Visualization of automated driving mode and driving style variants for design variant 3

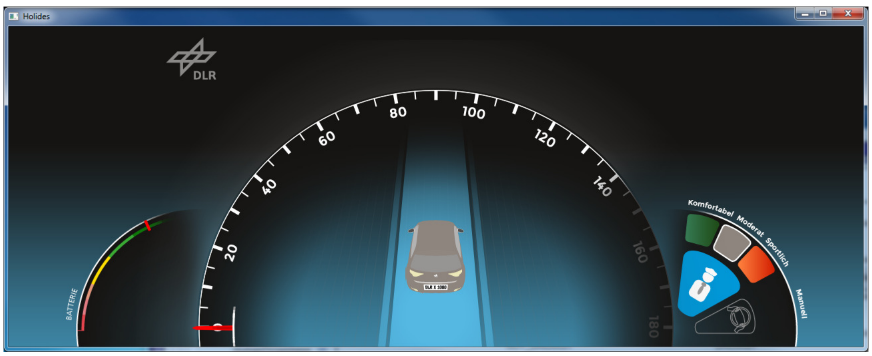
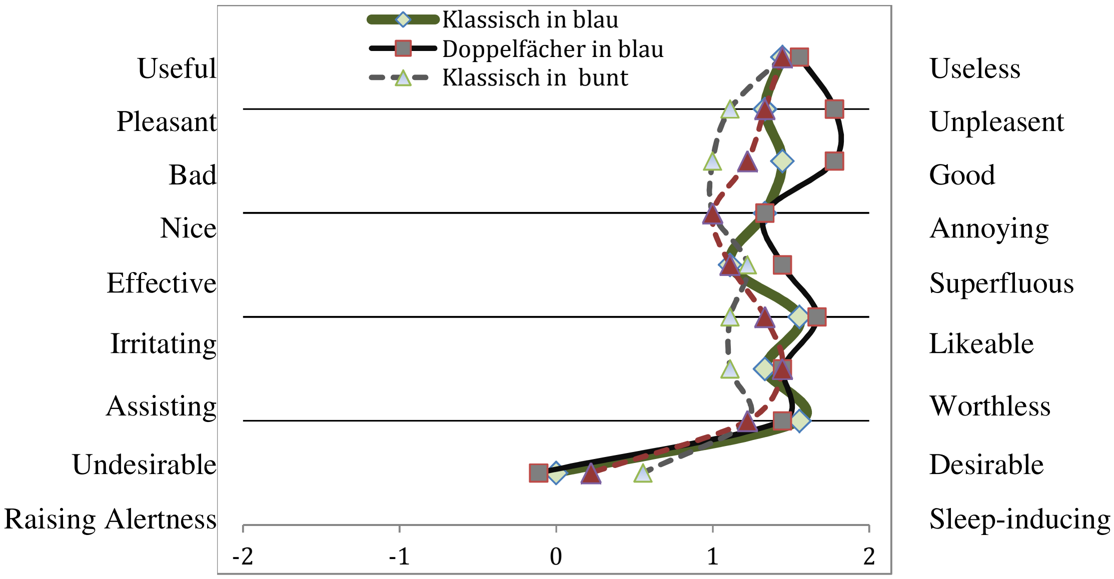


Figure 30: Visualization of automated driving mode and driving style variants for design variant 4

The test scenario was a five-minute highway scenario repeated for each design variant. Within the highway scenario participants had to follow certain audio instructions. The instructions consist of activate/deactivate the highway chauffeur and switch either to driving style comfortable or to moderate or to sportive. After each scenario/design variant the participant had to answer questionaries' including the acceptance scale by Van der Laan[3]. Table 9 illustrates the results of the acceptance scale ratings.

[3] Van der Laan, J.D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research - Part C: Emerging Technologies, 5, 1-10.

Table 9: Acceptance scale of the four design variants



Considering the calculated satisfying and usefulness scale variant 3 is the overall preferred design variant by the participants. A post hoc ranking by the participants after the study confirmed this result. Variant 4 was ranked second, variant 1 ranked third and variant 2 ranked fourth. A comparison to the baseline was not conducted and would be misleading since in the baseline condition such HMI is not necessary. The acceptance of variant 3 is in general very high and positive, and absolute sufficient for the use case. Overall we can conclude the following results:

- Participants prefer to have the possibility to change the driving style directly rather than open an additional driving style menu.

- The identification of the different driving styles via colouring is not necessary. Participant found the colours not always intuitive and recognized no benefit.

With results of the usability study a final HMI (design variant 3) is defined for the visualization of different driving style variants. However it is an open research question how to name the different driving styles and how many driving style shall maybe actually available. The evaluation results from D9.9 give first hints about the number of how many driving styles should be available. As an outcome of the evaluation three fixed driving styles plus the ego driving style lead to an improvement of the appealing of an automated vehicle. For the final implementation we therefore use four driving styles and name than after typical styles available for an automatic transmission: Comfortable, Normal, Sportive and Ego.

In addition a fifth driving style "Individual" is introduced to allow the driver to configure the driving style after its own wishes and to offer maximal transparency to the driver. The "Ego" driving style in comparison is an adaptive driving style using the output of the MTT CONFORM to adjust the driving style based on the context and the manual driving data (see D9.9 for details). For the configuration of the "Individual" driving style an application/GUI was developed. The GUI is placed on the second display in the vehicle, which is the display of the information system. The GUI allows to figure different aspects of the driving task separately (Acceleration, Deceleration, Lat. Position, Vehicle Following, Lane change). For each task predefined parameters can be chosen (Comfortable, Normal, Sportive, Ego) or individual settings can be made.

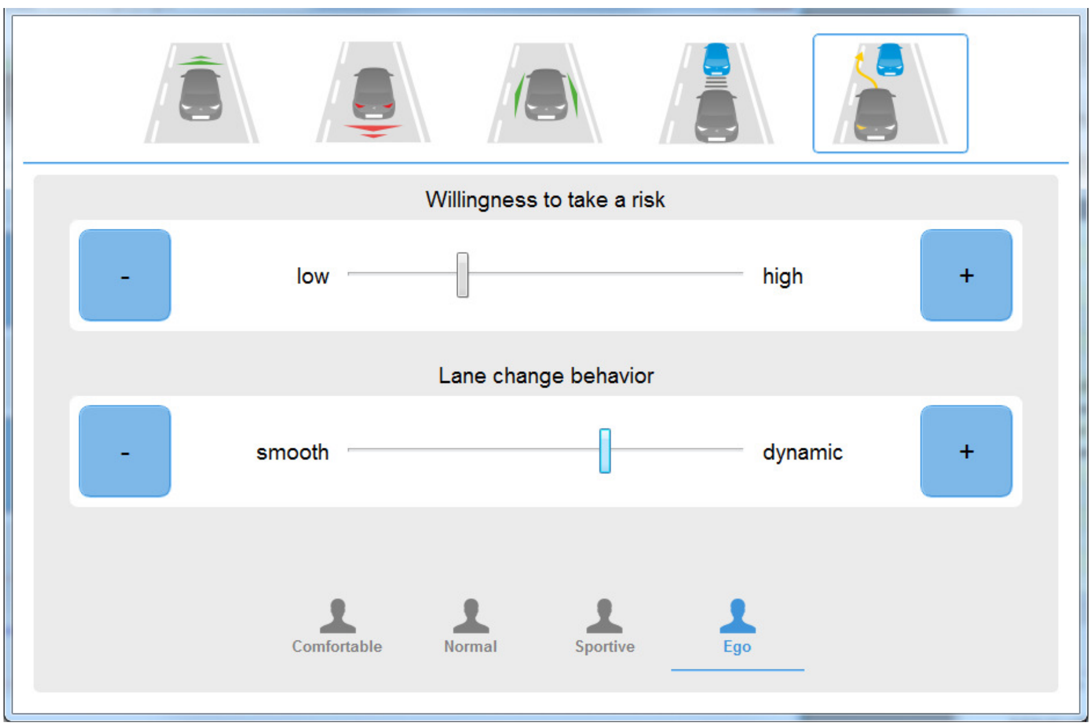


Figure 31: Driving style configuration GUI.

3.3 HF-RTP assessment and recommendations

The finally used MTTs for the development of the Adapted Automation AdCoS are listed in Table 10. The integration into the overall AdCoS is shown in Figure 32.

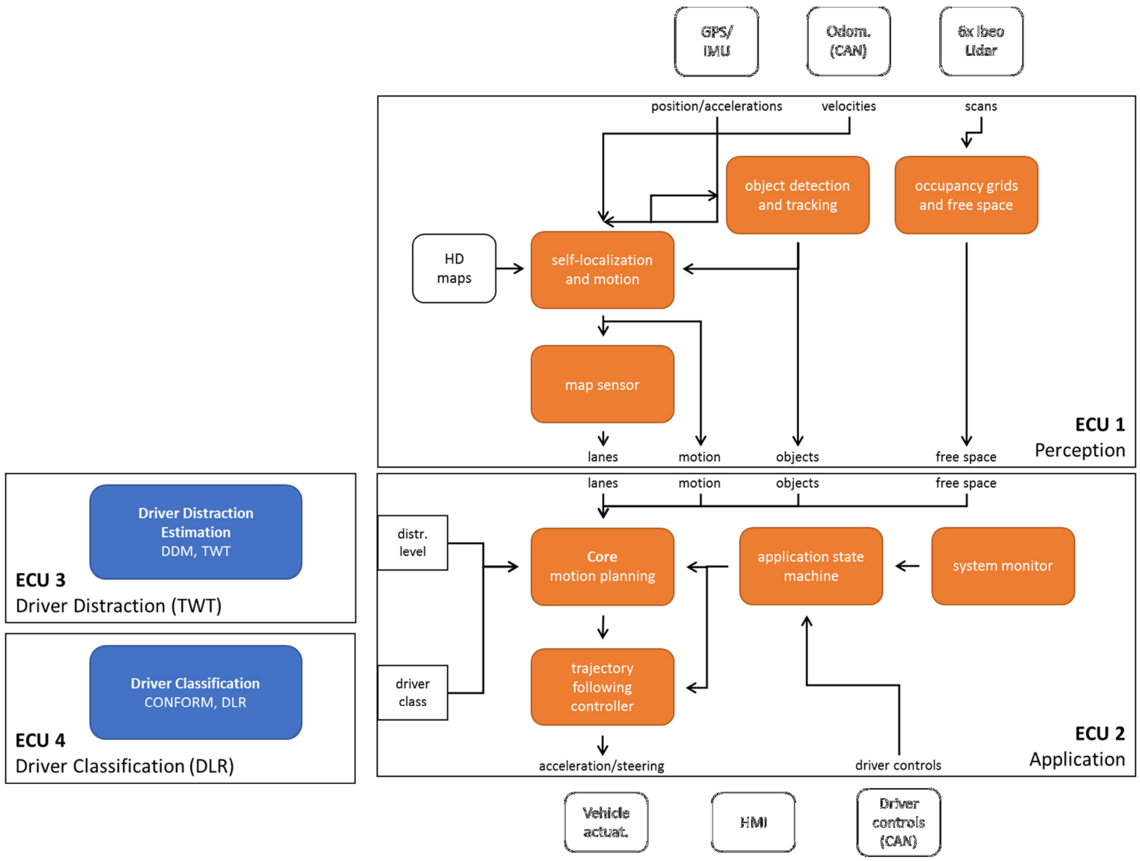


Figure 32: MTT integration into the overall AdCoS

Tool name	Tool type	Tool provider	Comments / Status
CONFORM	Driving style estimation	DLR	Used and implemented. Classification of the driver human driving style and mapping to a preferred autonomous driving style
RT-Maps	Integration Platform	INT	Integrated and used. It represents the SW tool for data collection and the SW framework to make all modules properly running in real-time.
Cognitive distraction classifier (CDC)	Estimation of the drivers cognitive distraction	TWT	Integrated and used. Sends a signal to the automated vehicle if the driver is distracted or not. The automated driving style is adjusted accordingly

Table 10: tools and services used in Adaptive Automation application.

Tool Name	Strong Points	Possible Improvements
CONFORM	• Easy to integrate in system architecture • Inputs can be changes easily • Able to handle all kind of input data, independent from scale/unit • Cluster can be loaded from extern, easy to add cluster and matching to predefined cluster works pretty well • Clustering of driving data works well	• Currently number of cluster is fixed in advance . A flexible number of clusters based on the context and driving data would be an improvement.
RT-Maps		
Cognitive distraction classifier (CDC)		

Table 11: strong / weak points, with related suggestions for possible improvement, for the MTTs used in Adaptive Automation application.

The evaluation procedure and the results have been reported in D9.9.

4 Adaptive HMI AdCoS

This AdCoS has been developed by TAK by applying and adapting MTTs provided by HoliDes partners and with their cooperation. Altogether, TAK cooperated with HMT, OFF, TWT and INT.

4.1 AdCoS description

The adaptive HMI AdCoS development has a twofold background: Firstly, driver distraction is one of the major accident causation factors (Regan et al., 2013) and needs to be counteracted to increase traffic safety. Secondly, with the expected steady increase of driving automation and the different levels of driving automation until full automation (a summary of the BASt, NHTSA and SAE classification can be found in Smith, 2013), driver state is a crucial factor especially in hand over situations between automated and manual driving. Again, it is expected that distraction has a major influence on take-over times. This is expected to be mainly relevant for visual distraction but applies similarly to cognitive distraction.
The adaptive HMI AdCoS developed in HoliDes is based on an overtaking scenario on motorways, which is likely the most relevant basis for use cases of automated driving. This adaptive HMI AdCoS consists of two main components:

- The detection and classification system of environment and driver state that consists of hard- and software.
- The HMI as such with the two components instrument cluster and infotainment system and the content shown or not shown there.

The adaptation is based on a combination of situation criticality and driver distraction. The AdCoS was implemented, tested and evaluated in the TAKATA driving simulator.
Situation criticality is monitored and assessed via the data from the simulator. Criticality is based on selected parameters of position, time and speed of the Ego-vehicle and relevant other vehicles. Relevant other vehicles are the next vehicles in front, behind and next to the Ego. A critical situation is assumed when time-to-collision (TTC) is below 2.8 seconds and time headway (TH) is below 0.6 seconds. The definition of these values was originally based on Breuer (2012) and ISO-15623 (2013) but was adapted to the specific simulation situation.
Visual driver distraction detection was implemented via the head-mounted eye-tracking device Dikablis. Visual distraction was assessed when longer glances away from the road were detected or when the driver touched the SURT within the last two seconds. Driver distraction was defined as gaze being directed to the SURT for at least one second within the last five seconds. Because driver distraction had to assessed almost in real-time,

the data collected by the eye tracker had to be pre-processed. This was done by TAKATA and resulted in the final version of the Driver Distraction Detection. As part of the pre-processing, areas of interest (AOIs) were defined and gaze date was related to these AOIs, was further assessed and was forwarded to the simulator and the HMI. Figure 33 shows an overview of the structure of the Visual Distraction Detection as implemented in HoliDes.

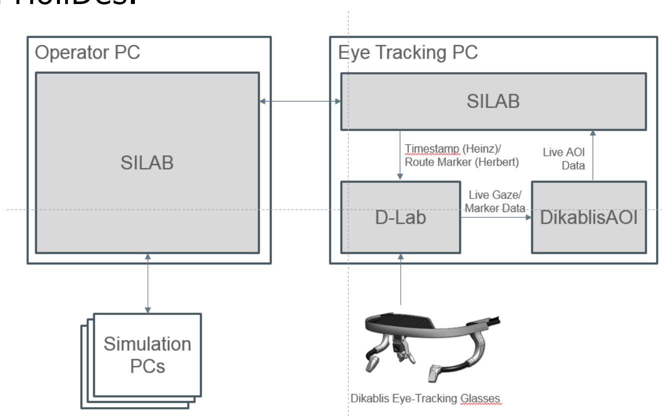


Figure 33: Schematic overview of data exchange between simulation and Visual Distraction Detection based on eye-tracking.

The HMI components received driver and situation state via the driving simulation software SILAB and via RT-MAPS. Figure 34 shows the overall system architecture and Figure 35 the RT-MAPS related architecture of the entire AdCoS.

In Figure 34 the HMI components that are in some way perceived by the driver are represented by the center display (SURT presentation), the cockpit display (situation-HMI) and Automatic Driving. The activation of automated driving depended on the experimental condition and further differed between the two generations of the AdCoS. In the final version, automated driving was only activated when the conditions for the adaptation were fulfilled, that is, the situation was critical and the driver was distracted. If automated driving was activated the HMI in the cockpit display (i.e. the instrument cluster) was adapted (see Figure 39). After the situation was solved, the driver was reminded to take over manual driving and the Ego-vehicle resumed its position on the right lane.

With regard to distraction based adaptation, the changes on the center display (the infotainment display) were most relevant. In case the adaptation criteria were fulfilled, the source of distraction, i.e. the SURT, was supressed and was no longer visible for the driver.

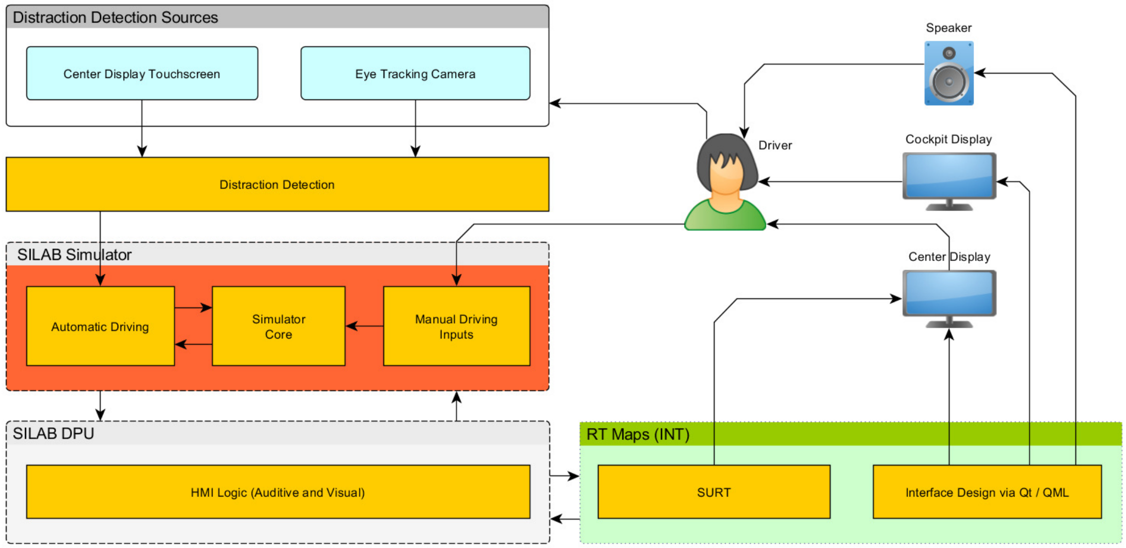


Figure 34: System architecture of the adaptive HMI AdCoS.

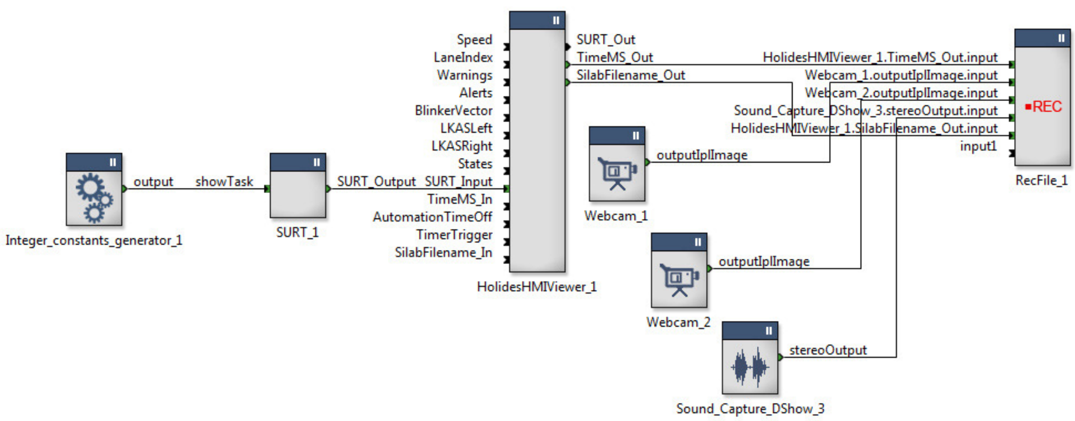


Figure 35: RT-MAPS architecture of the adaptive HMI AdCoS.

Regarding traffic safety, distraction is one of the major accident causation factors. Driver-distraction can be triggered externally by the environmental situation or internally by the driver and its psycho-physiology.

The HMI (human-machine-interface) is the key element to exchange information between the driver and the vehicle and between the driver and the environment.

For a successful interaction sensors are needed that detect the actual state and that can preferably even predict the future state of the system-

elements. At present, a major challenge is the reliable detection of driver state in real time.
The adaptive HMI AdCoS developed by TAKATA in HoliDes focuses on driver distraction and thus requires sensors that are able to detect states of distraction. In order not to annoy the driver with abundant and unnecessary warnings, the system requires that distraction is detected reliably.
With distraction being reliably detected, functions need to be implemented that are effective in solving potential safety-critical situations associated with distraction.
This is achieved by the AdCoS and in two ways:

- The center stack HMI is adapted in a way that deactivates the SURT - and thus the source of distraction - with the intention of redirecting driver attention to the road.
- The AdCoS itself is used to activate automation functions that prevent the situation from becoming more dangerous. After the situation is solved, the driver is requested to take over manual control again.

In the context of HoliDes the MTTs provide several approaches to support the development of the TAKATA adaptive HMI AdCoS:

- MTTs help defining requirements
- MTTs help detecting different forms of distraction, preferably in real-time
- MTTs support the implementation of distraction
- MTTs support the implementation and integration of several components
- MTTs allow the model-based simulation of user distraction.

The benefits associated with these MTTs concern both the expansion of product scope and the reduction of development time and thus costs.
In Deliverable D1.6, this AdCoS outline was already described. The general description of the HMI and its functionality remained unchanged. However, with regard to the implementation and the KPIs three changes must be taken into account:

- Due to organisational changes in HoliDes, the visual distraction detection (VDD) was designed and implemented by TAKATA itself and could not be taken from an external partner as was originally planned.

- The Cognitive Distraction Classifier (CDC) was not yet available and was thus not implemented. To contribute to the CDC development, two experimental conditions with cognitive distraction were added in the simulator study.
- While CASCaS in the general form was available, some adaptations were made to adjust it to the current AdCoS. This will improve its applicability for later HMI designs.

These changes affected the general KPIs and are considered in the assessment (see below). A more detailed description of the AdCoS can be found in Deliverable D9.9.

4.2 Final HMI

The structure of the final adaptive HMI AdCoS is shown in Figure 34 and Figure 35. The Visual Distraction Detection is the central part of the AdCoS on which the adaptation is based. The functionality is described above and the structure is shown in Figure 33.
The experiences made with the first generation AdCoS resulted in several changes that were implemented in the second and final version shown here. First of all, the SURT was presented continuously to increase visual distraction. Further, the Visual Distraction Detection developed by TAKATA was implemented (for details see above). In addition, physiological data was assessed with TAKATA's vital sign steering wheel (VSStW) and an additional standard device. Finally, the experiment itself was adjusted, amongst others to include cognitive distraction conditions. However, the latter were used to support the development of the Cognitive Distraction Detection and Classification (CDC by TWT, see Deliverable D9.9 for details) and are not a genuine part of the AdCoS.
Figure 36 to Figure 39 show different versions of the HMI presented in the instrument cluster as seen from the driver's perspective.

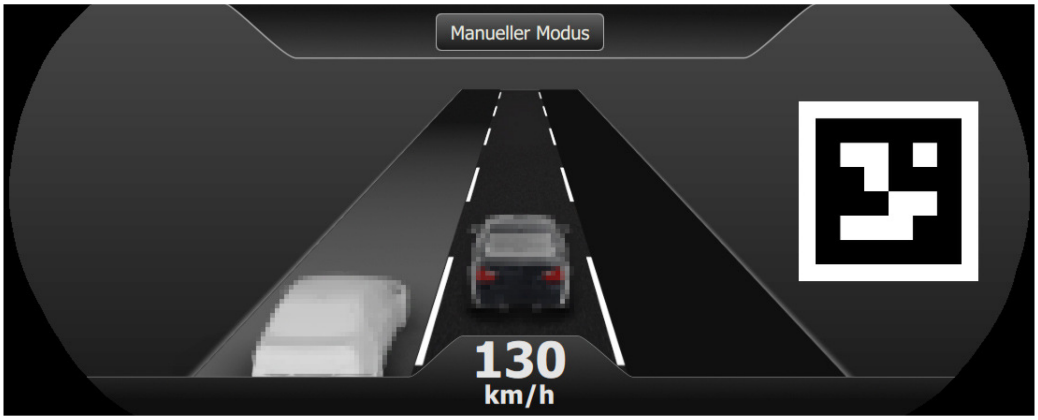


Figure 36: Instrument cluster of the HMI in manual mode with eye-tracking marker with approaching car from behind without driver intention to overtake.

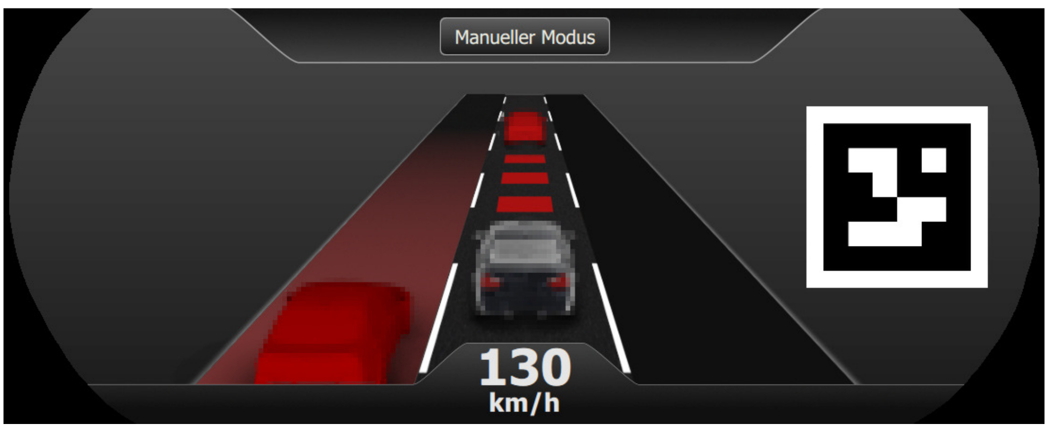


Figure 37: Instrument cluster of the HMI in manual mode with eye-tracking marker and critical distance to car in front and approaching car from behind with overtaking intention of the ego vehicle.

Figure 38: Instrument cluster of the HMI in automatic mode with eye-tracking marker and lane-change information provided to the driver.

Figure 39: Instrument cluster of the HMI in automatic mode with eye-tracking marker and take-over request ("Übernahme in") with remaining seconds.

Both generations of the AdCoS were assessed in experimental studies in TAKATA's driving simulator (see Figure 40).

Figure 40: Prototypical setting for the experimental evaluation of the AdCoS.

For the final version of the AdCoS the results confirmed the general technical functionality of the AdCoS and the Visual Distraction Detection. Although the behavioural effects of the AdCoS were not statistically significant a positive tendency for adaptation was found. An example is shown in Figure 41: although the results shown in Figure 41 indicate a positive effect for adaptation (i.e. less drivers overtaking before the vehicle approaching from behind), these results were not statistically significant, neither for all five conditions ($X^2(4) = 4.94$, $p = 0.29$) nor for the three conditions with visual distraction only ($X^2(2) = 3.60$, $p = 0.16$). Comparable effects were found when the data were separated by situation.

However, for subjective workload, assessed via the NASA-TLX, the statistical tests matched the visualisation of the data (see Figure 42) and resulted in a significant reduction of workload for the adaptive condition (results paired t-test: $t = -12.38$, $df = 40$, p-value $< .001$).

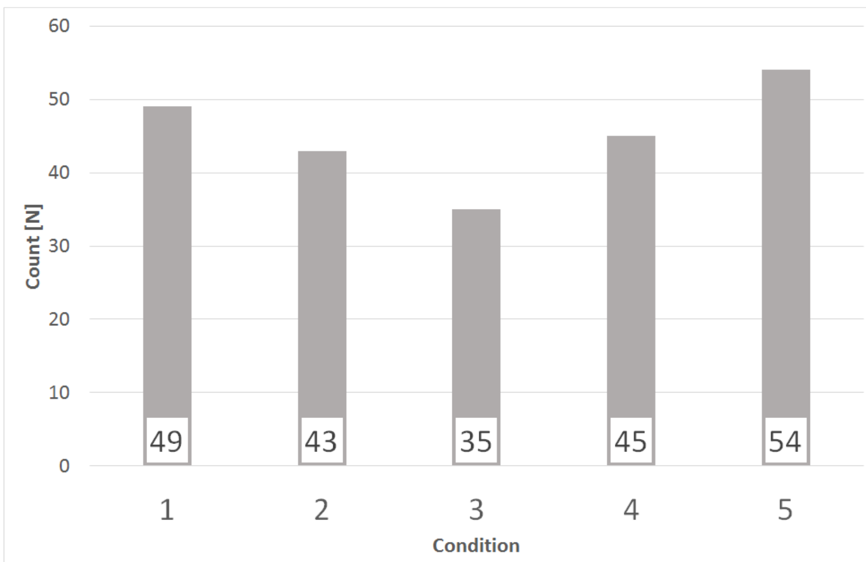


Figure 41: Number of drivers that overtook before the approaching vehicle from behind depending on experimental conditions (see text for details).

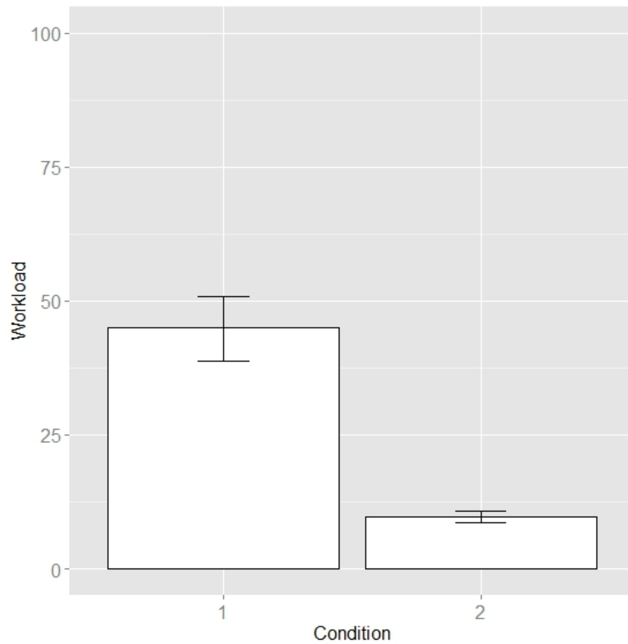


Figure 42: Workload (Sumscore NASA-TLX) for condition 1 (non-adaptive) and 2 (adaptive).

The results shown here (Figure 41 and Figure 42) are a selection of results that are representative for other variables. Whereas the behavioural data indicated some positive effects in favour of adaptation, these were mostly not statistically significant. The reason is likely the large variation participants exhibited during driving, despite experimental instructions were given to prevent such large behavioural variations. However, on the other hand, the results for the NASA-TLX showed a positive and significant effect for adaptation. In order to increase the positive effects for adaptation, it is suggested to start the adaptation earlier. This would diminish visual distraction and would subsequently lead to adapted behaviour. On the other hand, in order not to annoy the driver, the time of adaptation must be as late as possible. Finding the best time to start the adaptation can be a task to be implemented in future experiments.

4.3 HF-RTP assessment and recommendations

In this Section (and its sub-sections) it is described how the MTT's in the HF-RTP have helped to build the Adaptive HMI AdCoS; moreover, feedbacks are provided on strong points or possible improvements.

4.3.1 Used MTTs

For the development, implementation and evaluation of the adaptive HMI AdCoS several MTTs were applied. MTTs used comprised RT-MAPS (Intempora), the Visual Distraction Detection (TAKATA), the HEE (OFFIS) and the SURT (DLR). All MTTs served different purposes and were used at different stages of the development process. The Visual Distraction Detection and the SURT were applied in the design phase, RT-MAPS was used in the implementation phase. All MTTs contributed a great part to the AdCoS.

In addition, the experiments conducted at TAKATA contributed to the development of MTTs itself. This is the case for the Cognitive Distraction Detection and Classification (CDC) for which two experimental conditions were implemented in the experimental studies. Furthermore, data were assessed and exchanged to develop a Driver Risk Awareness Prediction (see next Chapter).

4.3.2 Driver Risk Awareness Prediction (HMT)

The development of the Driver Risk Awareness Prediction is based on the data that were collected during the experiments of the second generation adaptive HMI AdCoS. This development was conducted by Humatects (HMT).

Literature asserts that physiological data such as Heart Rate (HR), Respirational Rate (RR), Non-specific Skin Conductance Fluctations (NSF) are linked to the affect and arousal state (McDuff et al, 2014; Healey & Picard,2005; Drachen et al., 2010). The main assumption behind the model is that arousal and risk awareness are linked together. The goal is to create a model which may detect whether the driver's risk awareness is adequate to the potential danger of a given traffic situation.

The modelling uses Bayesian Belief Networks (BBN) to learn conditional probabilistic distributions from driving experiment data. BBNs (Koller & Friedman, 2009) have a few advantages over other techniques. As graphical models, they are easy to understand for humans; they are white-box mathematically plausible models of uncertainty. They can be used for diagnostic, predictive, and intercausal reasoning and combine weak evidence to strong hypotheses. In the driving domain, they have been used for stress detection (Rigas et al., 2008).

The goal was to create a Dynamic Bayesian Belief Network for online risk awareness inference. An HMM consists of several time slices. Each time slice has a sensor model, which links a state to sensor variables. Sensor variables are physiological measurements such as Heart Rate (HR), Respirational Rate (RR) or Electro-Dermal Activity such as Non-Specific

Skin Conductance Fluctuations (NSF). Other Sensor Variables include the objective traffic situation, which serves as indication for danger. In this case, we used the minimum Time-to-Collision (MinTTC) to any other vehicle during an overtaking episode.

The Risk assessment by the driver, which is available for each overtaking episode during the experiment, is used as state variable in the model. A transitional model between time slices connects the Risk Awareness state variables. Sensor and transitional models are described by conditional probability distributions. The resulting BBN is seen in Figure 43.

Since all variables are observable in the training data, we used the more robust Bayesian Parameter Estimation algorithm for learning the probability distribution of the BBN, as provided by the “bnlearn” package for R (Nagarajan et al., 2013). The numeric observations for HR, RR, NSF, and MinTTC were discretized by quantiles to ensure an equal distribution of observations for each bin. The categorial Risk variable was further simplified from a scale of 0 to 10 to 0 to 4 according to the linguistic variables from Neukum et al. (2008). The experiment data has been gathered from 26 participants in four different conditions.

Condition 3 (Adaptive Automation Condition) has been removed because of two reasons. First of all, a comparison between situations cannot be fully achieved because automation was only activated in some cases when certain preconditions were met. Secondly, the subjective ratings, which are essential for a valid classification might be influenced by the new experience of automation.

The dynamic BBN spreads over four time slices. The data was time-homogenous, and as the latencies for Physiological response is at least 250ms, we sampled the data with a frequency of 4 Hz. Thus a four-slice network such as in Figure 43 covers a full second of driving. MinTTC and risk are steady-state variables during any particular overtaking episode, but vary between episodes.

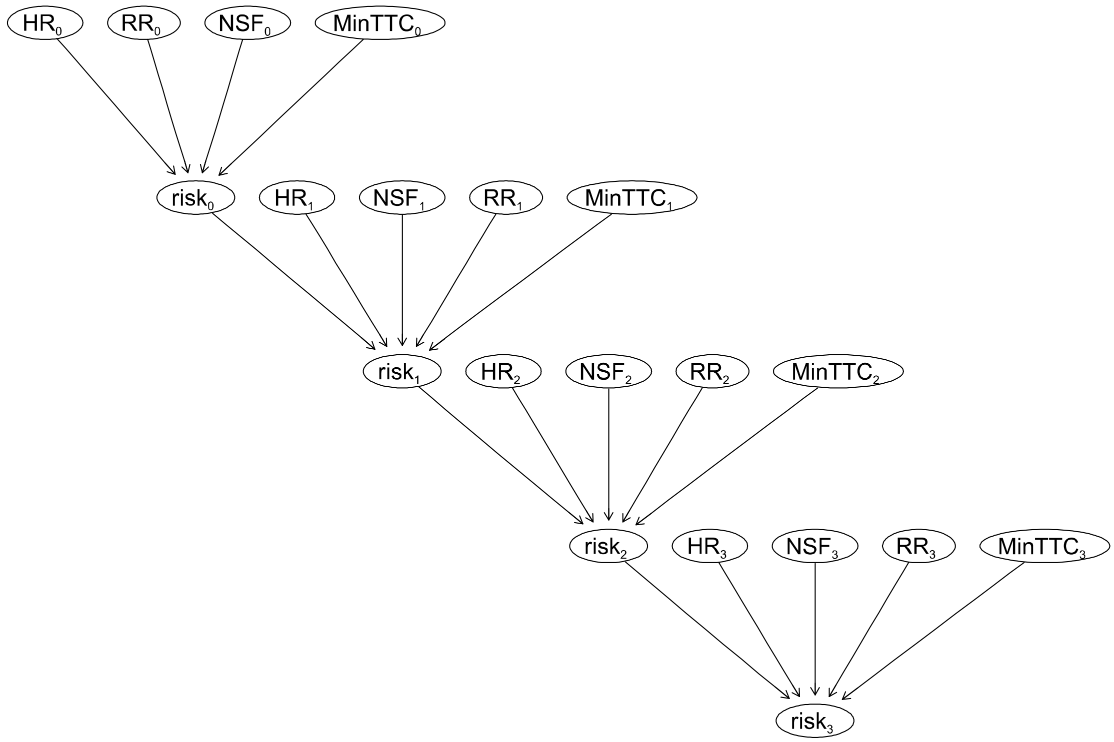


Figure 43: Dynamic Bayesian Belief Network for Risk Awareness prediction for four time slices with traffic situation (MinTTC) and physiological as sensor nodes.

For prediction, the dynamic BBN is, in fact, a hidden Markov model, because it respects the Markov property (a slice is dependent on the previous only) and Risk variable is latent, i.e., not observable. Arcs between sensor node and latent Risk state are anti-causal. This is unfavourable for actual inference performance but greatly increases accuracy.

To validate the dynamic BBN, we performed a 10-fold cross validation of the data (Table 12) and compared the performance with the prediction error rate for the node $Risk_3$, which means that the test set contained physiological data and traffic situation for the last second. For the conditions, the prediction error rate was around 10% or lower, which means that the risk awareness was correctly predicted in 90% of the cases. When all conditions are used for training and validation, the error rate is considerably higher. The root mean square error (RSME) is also given in the table. This is not really a robust measure for ordinal variables, but, in this case, it shows that false predictions were usually one risk level off the actual assessed value.

	Total	Condition 1	Condition 2	Condition 4	Condition 5
Observations	34898	7561	9902	8320	9109
Prediction Error Rate ($risk_3$)	0.24	0.069	0.104	0.077	0.108
RSME	0.722	0.423	0.485	0.357	0.54

Table 12: Results of cross validation for the parameter estimation for the dynamic BBN.

From these results, it can be seen that risk awareness may indeed be predicted by physiological and traffic data. The model can be used in an intelligent driver monitoring system to further assert if the risk awareness is adequate to the traffic situation by comparing $Risk_3$ prediction and MinTTC3 evidence nodes.

4.3.3 Summary

The MTTs used in the different phases of the adaptive HMI AdCoS development showed positive effects with regard to the KPIs. As is shown in different Deliverables (D1.6, D1.7) their application results in a reduction of effort. This reduction will also lead to a reduction in the development cycles, which will increase product availability.

5 Adaptive and Cooperative (MOVIDA) AdCoS

This AdCoS has been developed by a team composed by IFS, INT and CIV, and also with a specific partnership with ENA in WP4. It is an "Adaptive" system, because based on monitoring functions in charge to support real time adaptation of the HMI according to the context, and a "Cooperative" device (Bellet et al, 2011), because able to take the control of the car.

5.1 AdCoS description

The virtual AdCoS based on MOVIDA (for Monitoring of Visual Distraction and risks Assessment) is an integrative co-piloting system supervising several simulated Advanced Driving Aid Systems (ADAS) for Collision Avoidance (like a Frontal Collision Warning system; i.e. FCW), Lane Change assistance (i.e. LCA; including an Over-Taking Assistance, i.e. OTA), and Full Automation devices (i.e. FA) liable to take the lateral and longitudinal control of the car A in case of emergency situations and/or inadequate behaviour of the car driver. All these ADAS are centrally managed by MOVIDA algorithms according (1) to the drivers' visual distraction status and (2) to the criticality of the driving situation, for interacting in an adaptive and cooperative way with the driver, from an Adaptive HMI and a Cooperative Automation support (see Figure 44):

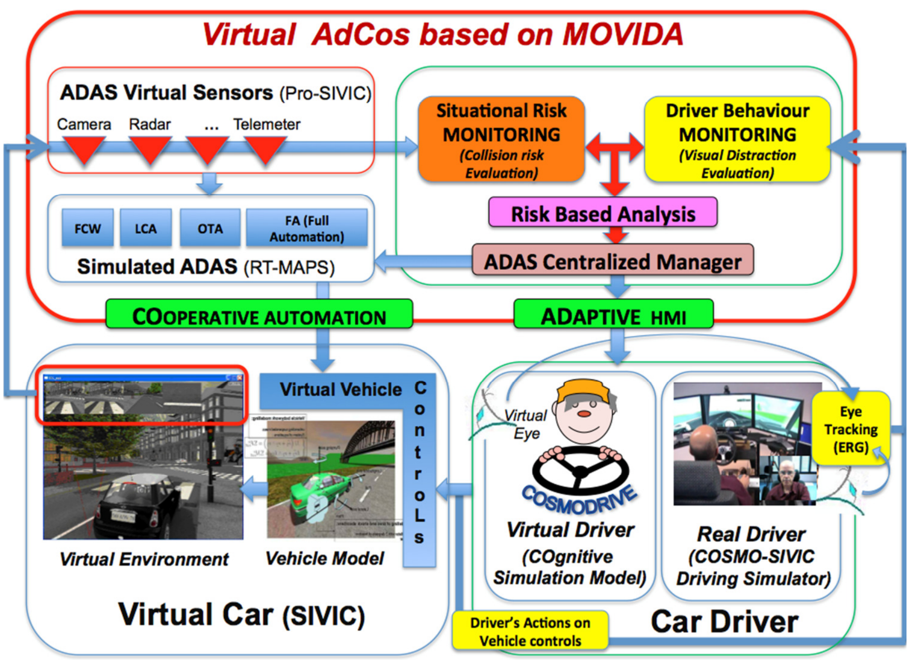


Figure 44: functional architecture of the AdCoS based on MOVIDA.

Figure 45 provides an example of ADAS, as simulated with RTMaps and Pro-SIVIC on the V-HCD platform, to be monitored by MOVIDA:

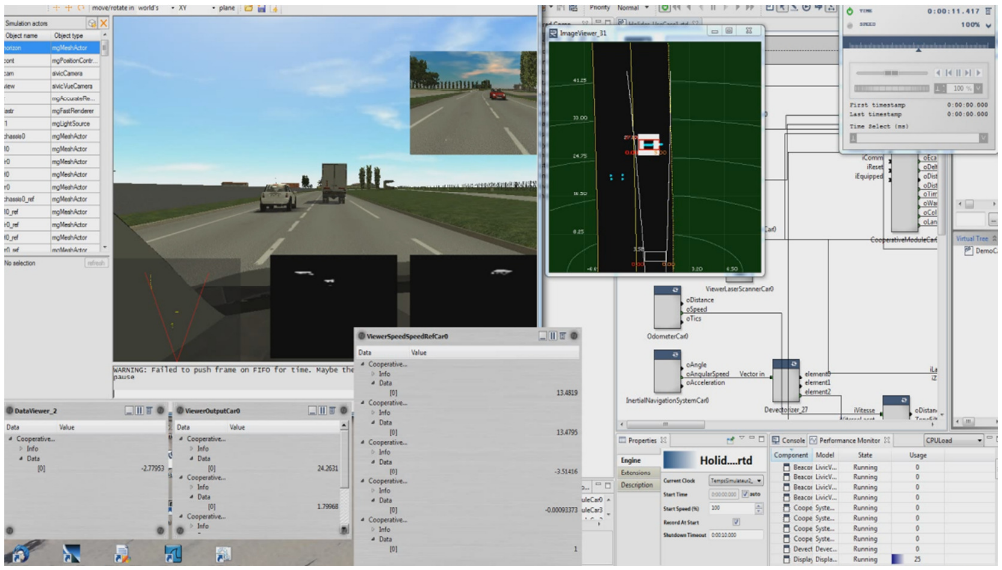


Figure 45: simulated ADAS with Pro-SIVIC and RTMaps, managed by MOVIDA.

In the frame of the target-scenario presented in the first section, in **Figure 1** (as a common use case of reference in WP9), MOVIDA has thus to observe and monitor the car A driver's behaviors. The goal is to diagnose critical visual distraction and/or potential risky maneuvers, regarding the external events and the situational risk (e.g. intention to implement a lane change at a critical time). Then, MOVIDA can adapt the driving aids to support and cooperate with the driver in car A, via information delivery, warning systems to alert the driver, or by activating vehicle automation functions taking partial or the full the control of the car.

MOVIDA-AdCoS inputs are of two main types. On the one side, they are based on the analysis of the external driving situation as perceived by the car sensors (simulated with Pro-SIVIC software). From the other side, Car A driver's activity is also monitored by considering their visual scanning or distraction status (simulated with COMSODRIVE or collected among real drivers by eye tracking systems, cf. detailed description in D2.7), and by analysing their driving behaviours (i.e. the actions currently implemented by the driver/COSMODRIVE on vehicle pedals and steering wheel) collected on the car (simulated on the V-HCD platform by a Pro-SIVIC virtual car).

Then, at the decisional level of MOVIDA, a set of risk-based analysis algorithms are implemented in order to evaluate the distraction risk and to assess the adequacy of the behaviours implemented by the driver according to the external risk of collision with other vehicles (i.e. Truck C regarding frontal collision, and car B regarding Lane Change manoeuvre). Synthetically, these risk-based algorithms consider frontal and lateral Inter-Vehicular Time (IVT) and/or Time To Collision (TTC) values collected from the car sensor of MOVIDA. In case of critical IVT and/or TTC (like low values or high drop of these values during the last seconds, for instance), the current fixation point of COSMODRIVE/driver's eyes is considered.

In case of visual distraction or inadequate visual scanning, meaning a potential unawareness of the critical events (e.g. truck C braking or no-detection of the approaching car B liable to be observed in the left mirror), the car A driver's behaviours are assessed as "inadequate" by MOVIDA algorithms. Thus, a diagnosis value of "critical situation" is provided to the Centralized Manager of ADAS. At this level, another set of decision rules are implemented in order to determine which kind of ADAS integrated in the MOVIDA-AdCoS[4] is able to assist the driver in the current context, and how this driving aids have to interact with the Car A driver, according to his/her visual distraction status and the traffic conditions.

5.2 Final HMI

Concerning MOVIDA-AdCoS HMI, two core sub-modules are in charge to manage interactions with the human driver (in car A):

- the "Adaptive HMI manager", which has to adapt HMI modalities of information delivery and warning signals (Visual and Auditory) in accordance with the driver visual distraction status;
- the "Cooperative Automation" support system, which has to take the control of the car.

The second aspect implements an automatic Braking or Lane Keeping, in case of behavioural errors (e.g. dangerous lane change manoeuvre implemented by the driver), or when the criticality of the situation (i.e. imminent risk of collision with front or lateral vehicles) is assessed by the system as too high for being well-managed by a human driver.

In terms of Human-Machine Interaction (HMI) modalities, MOVIDA-AdCoS is liable to interact with the car driver from 3 modalities:

[4] i.e. Frontal Collision Avoidance system or Lane Change Assistant.

- Visual Information, Visual and Auditory Warnings (both controlled by the "Adaptive HMI manager").
- Vehicle control taking abilities (implemented by the "Cooperative Automation" support system).
- Via partial (i.e. lateral or longitudinal control) or Full Automation (i.e. combining both lateral and longitudinal control of the car).

Visual Pictograms used in the MOVIDA-HMI to assist the driver while changing of lane or to avoid frontal collision are based on HOLIDES partners work (i.e. REL), as presented and discussed in D9.3 (p. 58) and replicated in the following figures.
The first one (Figure 46) is used to inform a non-distracted driver that the Lane Change manoeuvre is required (i.e. due to an emergency braking of truck C, for instance) and possible in the current traffic situation (i.e. No car is approaching on the left lane). This visual information is delivered on a visual display implanted at the centre of the dashboard of the car, as presented in the following figure:

Figure 46: pictogram delivered by MOVIDA (on the in-vehicle display) to inform a non-distracted driver that the Lane Change is possible.

However, when the driver is initially visually distracted, another pictogram is used (delivered in association with an auditory warning, in order to manage the visual distraction risk) for informing the driver that a Lane Change Manoeuvre is required and may be immediately implemented in the current traffic situation (i.e. no car is overtaking or approaching on the left lane). This pictogram is presented in Figure 47:

Figure 47: pictogram delivered by MOVIDA to warn a distracted driver that a Lane Change Manoeuvre is required and possible.

By contrast, when the left lane is not free (i.e. the Car B is currently approaching or overtaking the car A), another pictogram is delivered (in association with an auditory warning) in order to alert the driver about the dangerousness of a Lane Change manoeuvre, and to invite him/her to keep his/her current lane:

Figure 48: pictogram delivered by MOVIDA to warn the driver that that a Lane Change Manoeuvre is not possible.

Regarding the Frontal Collision risk, or to support the driver in maintaining a safe following distance with the truck C, the pictogram presented in Figure 49 is delivered to the driver in case of a collision risk detected by MOVIDA (when the truck is braking hard, for instance). To support a distracted driver, this pictogram is delivered with an auditory warning:

Figure 49: pictogram used by the Collision Warning System of MOVIDA.

Moreover, three additional pictograms were specifically designed to inform the driver about the different modalities of MOVIDA regarding vehicle control taking and automatic manoeuvres (these pictograms are also adapted from previous pictograms initially designed by REL, as presented and discussed in D9.9; from p. 11 to page 16).

In case of a high risk of frontal collision detected (from critical values of TTC and/or IVT with the truck, as collected by car sensors of the AdCoS) and assessed by MOVIDA as not manageable by the human driver (due to his/her distraction or to the high emergency of the situation), an automatic braking is implemented by this AdCoS, and the pictogram presented in Figure 50 is delivered (in association with an auditory warning) to inform the driver about the "active status" of MOVIDA (i.e. the longitudinal control of the car under the responsibility of the AdCoS).

Figure 50: pictogram delivered by MOVIDA to inform the driver about the automatic "Emergency Braking", when implemented by the AdCoS.

Moreover, if the driver starts to implement a lane change manoeuvre (by activating the blinkers or by turning the steering wheel on the left, for instance) while the left lane is not free (i.e. Car B is approaching), the vehicle automation functions of MOVIDA inhibit humans' action and warn him/her about their errors and the dangerousness of a Lane Change. To alert and inform the driver about the automatic control taking of the car by the AdCoS to keep its current lane, the following pictogram is activated, in association with an auditory warning:

Figure 51: pictogram delivered by MOVIDA to inform the driver about the "Lane Keeping" automatic manoeuvre, when implemented by the AdCoS.

Finally, in case of both high risk of Frontal Collision with the truck C and critical risk of Lateral collision with the car B (if a Lane Change is carried out by car A), MOVIDA takes the full control of the car by both (1) keeping the car A in its lane and (2) implementing an automatic braking manoeuvre. In this context, the following pictogram is delivered to the driver, in association with an auditory warning:

Figure 52: pictogram use by MOVIDA to inform the driver about the "Full Automation" status of the AdCoS (i.e. automatic Lane Keeping & Braking).

5.3 HF-RTP assessment and recommendations

In this Section (and its sub-sections) it is described how the MTT's in the HF-RTP have helped to build the Adaptive and Cooperative AdCoS; moreover, feedbacks are provided on strong points or possible improvements.

5.3.1 The V-HCD platform: a tailored HF-RTP to support the Virtual Human Centred design of MOVIDA-AdCoS

To support the virtual design, prototyping and then evaluation of the MOVIDA-AdCoS, a "Virtual Human Centred Design platform" (so-called V-HCD) was jointly developed by IFS, CVT and INT, as a tailored HF-RTP based on RTMaps software (detailed description and discussion in D4.4 and D4.7). All the sub-systems managed by the MOVIDA were interfaced through RTMaps, in order to support the virtual prototyping and dynamic simulations of this AdCoS, when used by a human driver simulated with COSMODRIVE model.

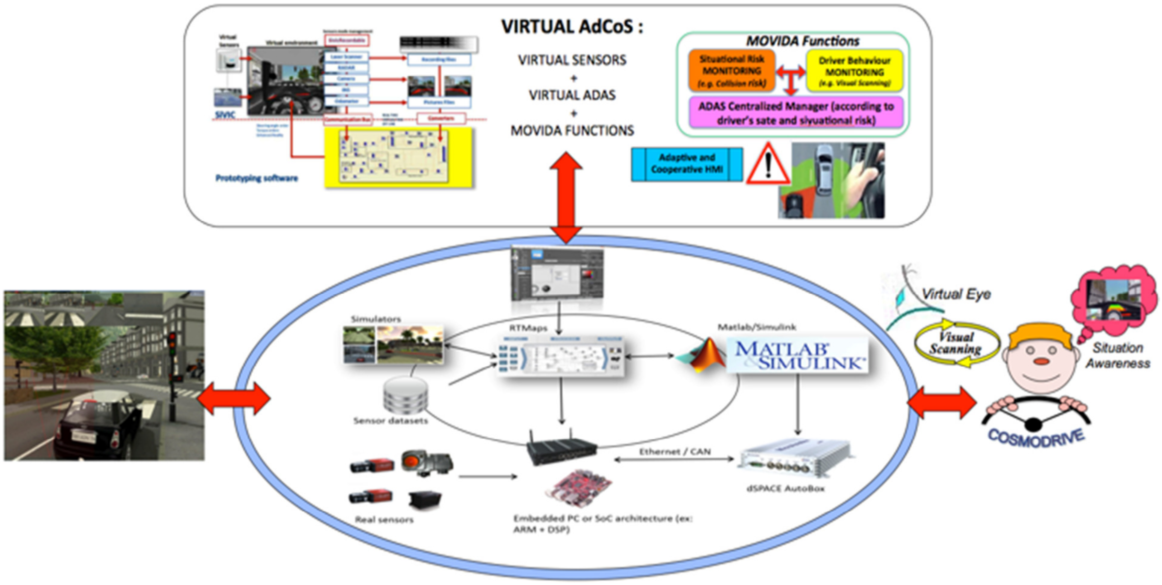


Figure 53: Overview of the V-HCD platform, as an example of a tailored HF-RTP based on RTMaps for automotive application.

In its final status, the V-HCD integrates 4 main HoliDes MTTs: (1) COSMODRIVE model able to visually explore the road environment from a "virtual eye" and to drive (2) a virtual car simulated with Pro-SIVIC (3) equipped with the virtual MOVIDA-AdCoS (simulated with RT-Maps and Pro-SIVIC), for dynamically progressing into (4) a virtual 3-D road environment (simulated with Pro-SIVIC). According to the HoliDes "HF-RTP" logic, COSMODRIVE plays the role the "Human Factor" (HF) component interacting with a virtual AdCoS, also dynamically simulated with this tailored HF-RTP.

Figure 53 gives an overview of the functional architecture of this V-HCD platform. In this platform, RTMaps plays a key role for connecting the different MTTs required for AdCoS simulation, but also to support the interoperability of COSMODRIVE and MOVIDA-AdCoS with all other MTTs developed by HoliDes partners and connected with RTMaps.

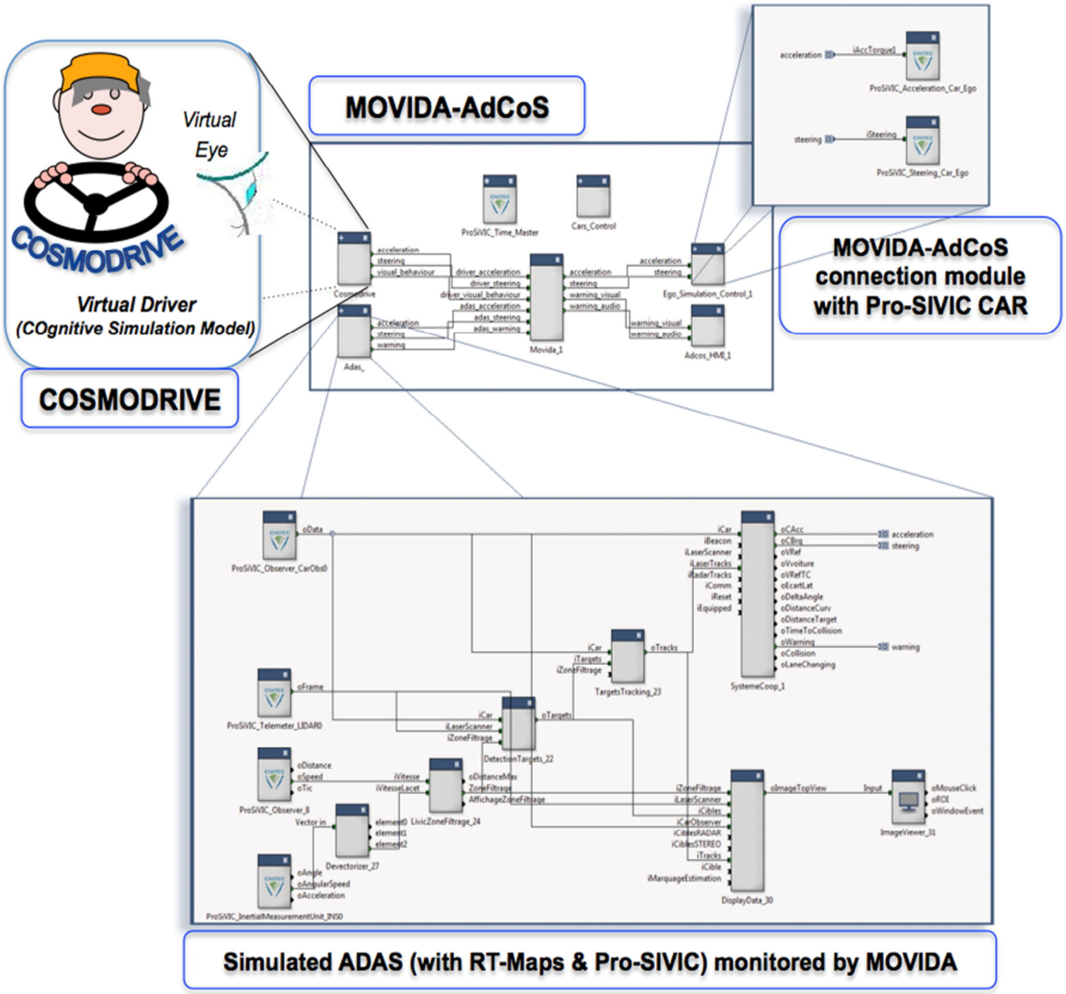


Figure 54: RTMaps diagram for MOVIDA-AdCoS tests with COSMODRIVE.

In addition, the RTMaps diagram presented in Figure 54 provides a more detailed view of COSMODRIVE and MOVIDA integration/interfacing with this software. On the one hand, the MOVIDA-AdCoS sub-diagram receives inputs (1) from COSMODRIVE model regarding drivers' visual scanning (to assess visual distraction status of the driver) and their actions implemented on vehicle commands (for lateral and longitudinal control of a Pro-SIVIC car) and (2) from the car sensors of the virtual ADAS/AdCoS, simulated with Pro-SIVIC and RTMaps. On the other hand, MOVIDA-AdCoS generates outputs towards the Pro-SIVIC virtual car, to implement MOVIDA actions (from warning delivery to partial or full automation by acting on vehicle controls), jointly considered with COSMODRIVE decisions and actions also implemented in parallel by the model for piloting the same vehicle.

In WP4 and WP9, the objective was to use COSMODRIVE-based simulations generated with the V-HCD platform to support MOVIDA-AdCoS design and validation from dynamic simulations, by considering the future use of this AdCoS by human drivers (i.e., the future end-users, as simulated with COSMODRIVE). In this aim, it was necessary to simulate human drivers' perceptive functions in a realistic way. The Figure 55 presents some examples of drivers' visual scanning simulations with COSMODRIVE model (a more detailed presentation is available in D2.7), providing outputs that are similar to data collected among real human drivers from eye tracking systems (as illustrated on the last left view).

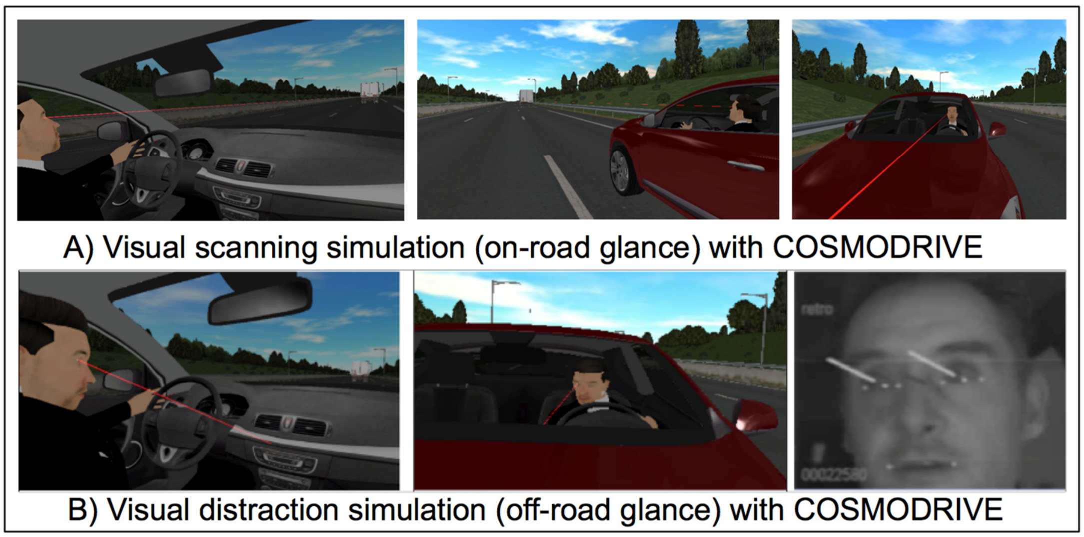


Figure 55: Simulation of Drivers' visual Scanning with COSMODRIVE.

With its virtual eye, COSMODRIVE is able to dynamically explore the road environment like human drivers and then to simulate their visual strategies. Visual strategies take here the form of a set of *fixation points,* which are "outputs" of COSMODRIVE model to be monitored by MOVIDA-AdCoS. By observing COMSODRIVE, MOVIDA analyses drivers' visual scanning and assess their visual distraction status at a given time (like detection of "off-road" glances, for instance).

Perceptive data collected by the virtual eye and processed by the Perception Module of COSMODRIVE are then integrated in the Cognition Module of the model (Figure 56). The key-components of this Cognition module are "Mental Representations" corresponding to the driver's Situation Awareness (Bellet et al., 2009). Mental representations, as mental models of the driving situation, are dynamically formulated in working memory through a matching process between (i) information perceived in the external environment and (ii) pre-existing driving knowledge, that are modelling in COSMODRIVE as "Driving Schemas" and "Envelop Zones" (described in D2.6). These mental representations provide an ego-centred and a goal-oriented understanding of the traffic situation. They take the form of Four-Dimensional mental models of the road environment (i.e. 3D spatial + 1D temporal), liable to be "mentally handled" by the driver in order to support "anticipations" through a "cognitive deployment" process (providing "expectations" about future situational states according, for instance, to the respective effects of alternative actions liable to be implemented at a given time; see D2.7 for a description of this cognitive process of "mental deployment").

External Road Environment	*Fixation point of the Virtual Eye*	*Mental Representation (SA) of COSMODRIVE*

Figure 56: Mental Representation elaborated in the Cognition Module of COSMODRIVE from the data processed by the Perception Module.

In case of a visual distraction, the mental representation updating may be negatively impacted, more particularly if an unexpected event is occurring in the driving environment. Figure 56 presents a typical example of erroneous Situation Awareness of the driver due to visual distraction, as simulated with COSMODRIVE on the V-HCD platform. In this situation, the followed truck C is braking while COSMODRIVE is visually distracted (fixation point of the virtual eye on the car radio; as presented in the central view of the figure). Consequently, the mental model of the driver (right view of the figure) is not correctly updated: the front truck is still far in the mental model, compared to this unexpected but effective change occurred in the road environment (left view of the figure).

Figure 57: Erroneous updating of Driver's SA due to visual distraction

In this context, MOVIDA-AdCoS is in charge to assess the risk due to both the braking of the followed truck and to the visual distraction status of the car driver. Then, it has to alert the driver about this event and to inform him/her, from the warning presented Figure 57 (delivered in association with an auditory warning), that a braking action is required to manage the frontal collision with the followed truck (another possibility of assistance also considered by MOVIDA, and presented later, could be to assist the driver to implement – or not - a Lane Change, according to the traffic conditions in the surroundings).

Figure 58: MOVIDA warning to alert a distracted driver of a Frontal Collision risk (delivered in association with an Auditory warning).

5.3.2 Use of the V-HCD platform (as a tailored HF-RTP) for MOVIDA-AdCoS virtual design and test

The COSMODRIVE/RTMaps/Pro-SiVIC/MOVIDA tool chain, developed in partnership with CVT and INT during the 2 first years of HoliDes, was fully integrated to provide a V-HCD platform, used during the last year of the project (in both WP4/WP9) to design and evaluate the MOVIDA-AdCoS.

Figure 59 presents an overview of the use of this V-HCD platform in WP4/WP9 to support the virtual design, prototyping and evaluation of the MOVIDA-AdCoS. In this "V-Cycle" approach, only the steps presented under the red line were implemented during the HoliDes project, with the aim of demonstrating in WP9 the advantage of using this tailored HF-RTP for the virtual design of AdCoS in automotive domain (i.e. IFS was not in charge in this project to develop a real AdCoS for real cars).

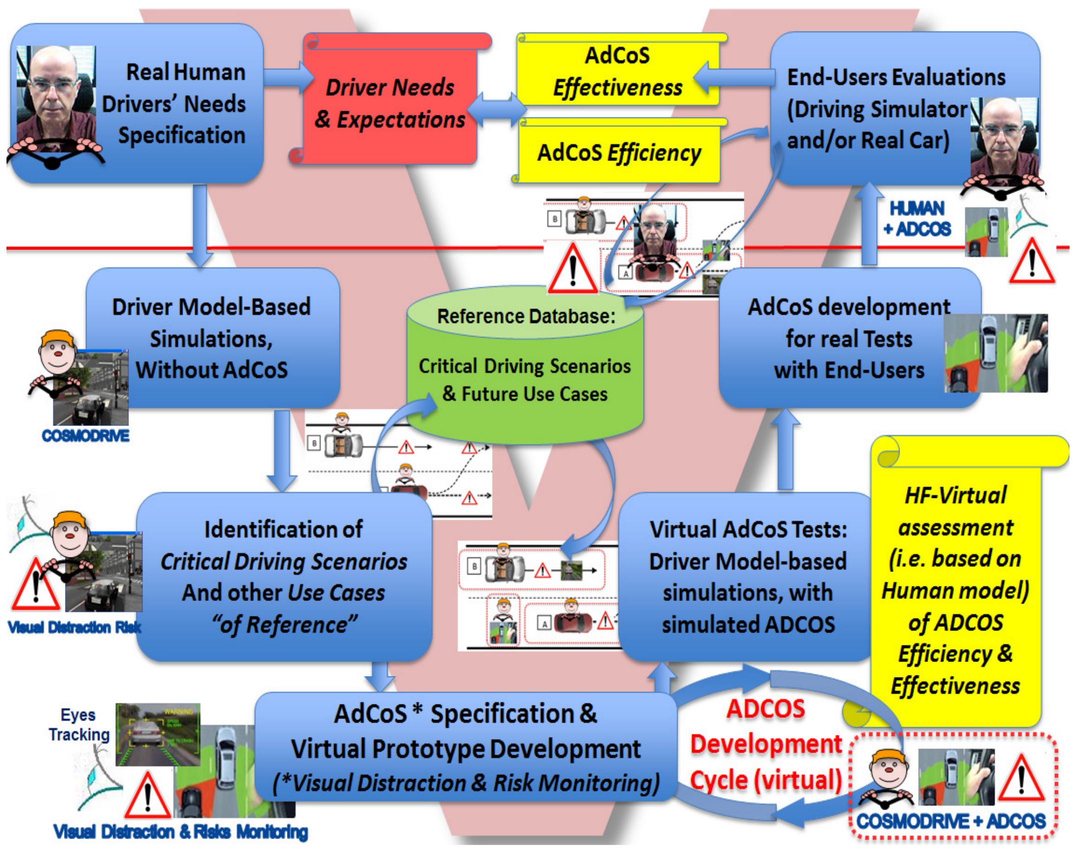


Figure 59: V-Design process of AdCoS with the COSMODRIVE platform

Practically, the V-HCD platform was used to simulate driving performances of human drivers *with* and *without* AdCoS (from "normal" to "critical" situations due to visual distraction of the driver), in order to specify and to virtually design and test MOVIDA functions at two main levels.

At the earliest stages of the design process (i.e. AdCoS specification), COSMODRIVE-based simulations allow the designer to estimate the accident risk due to visual distractions, in case of an unassisted driver. These simulation results provide the "baseline" associated with a set of "Use Cases of Reference" (i.e. the "critical instances" of a generic traffic scenario) to be used, during the second phase of the development process, to virtually evaluate the AdCoS, by comparing the number of accident and/or the criticality of the situations when the driver is assisted – versus - is not assisted by this AdCoS.

5.3.3 AdCoS specification from HF-model based simulations

In the frame of the generic traffic scenario presented in **Figure 1**, it is possible from the V-HCD replaying functions to explore in a systematic way all the critical instances of this scenario, according to the duration of the drivers' visual distractions in Car A.

The following figures provide some examples of these simulation results based-on COSMODRIVE performances when driving the Car A without MOVIDA.

For generating this sets of simulations, COSMODRIVE was calibrated as an experienced driver, with high driving abilities (mean Reaction Time of 0.75 second if not distracted and when confronted to a critical event; Green, 2000), but however liable to be sometime distracted. Simulations based on less efficient groups of drivers could be also implemented in the future on the V-HCD platform by calibrating COSMODRIVE in appropriate ways (by increasing the mean Reaction Time of the model from 0.75 to 1,5 second, for instance).

In the different instances of the generic scenario, we will only present the last seconds of the traffic situation. All of them start at the same initial time, i.e. when the followed Truck C is beginning to implement an emergency braking.

This common "initial state" (with a similar reference time of "T0"), shared by all these simulations, is presented in Figure 60.

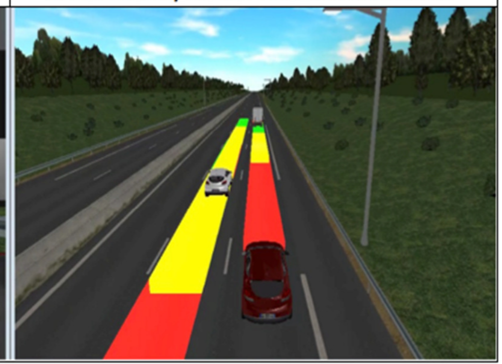
	Road Environment (as seeable by COSMODRIVE)	COSMODRIVE/Drivers' Situation Awareness
Common Initial State (T0): 1) Truck C is starting to implement an emergency braking 2) COSMODRIVE is: - Visually Distracted - Not Distracted (Depending of the simulated use cases)		

Figure 60: Common "initial state" (i.e. T0) of COSMODRIVE-based simulations (distracted or not-distracted)

Then, depending of the duration of their visual distraction status, the Driver / COSMODRIVE had to detect the frontal collision risk with Truck C, to make a decision (to brake or to implement a Lane Change, associated or not with an initial braking), and then to implement the planned behaviour by acting on Car A commands.

The potential "final states" of this scenario may be of three types:

1) The Driver/COSMODRIVE implements an **Emergency Braking** and avoid the frontal collision with the Truck C while keeping its current lane (e.g. if the "Lane Change" solution is not considered by the driver, or is assessed as too dangerous for being implemented)
2) The Driver/COSMODRIVE implements a **Lane Change and overtakes the Truck C,** by adequately managing the lateral collision with Car B (rear car B currently approaching on the left lane to overtake Car A) and the frontal collision risk with Truck C (potentially requiring to brake before the Lane Change),
3) The Driver/COSMODRIVE had an **Accident**: the model/driver **do nothing** (because visually distracted, for instance), **or fails in implementing an efficient driving action** to avoid the frontal collision with the truck C and/or the lateral collision with the Car B.

5.3.4 COSMODRIVE-based simulations to identify the baselines regarding Emergency Braking

The next figures present some examples of simulations results of COSMODRIVE performances if the model decides to implement an emergency braking when confronted to a frontal collision risk with Truck

C. The objective of these simulations was to provide a set of "baselines" for a braking decision when implemented by human drivers, according to the duration of their visual distraction.

As presented in Figure 61, a driver is able to safely manage the Frontal Collision (FC) risk by braking for this traffic scenario, if experienced, not visually distracted, and able to make the emergency braking decision in a limited time of 0.75 seconds. This emergency braking can be assessed as "safe", because at the final state, the truck C is in the Amber Envelop-Zone of the Car A, meaning here a safety margin of 0.8 s. in terms of Inter-Vehicular Time. Regarding this instance of the generic scenario, MOVIDA is not necessary to avoid the FC, but this AdCoS could however provide a relevant assistance by helping the driver in implementing a safe Lane Change manoeuvre, against an emergency braking (this alternative will be explored in the next section).

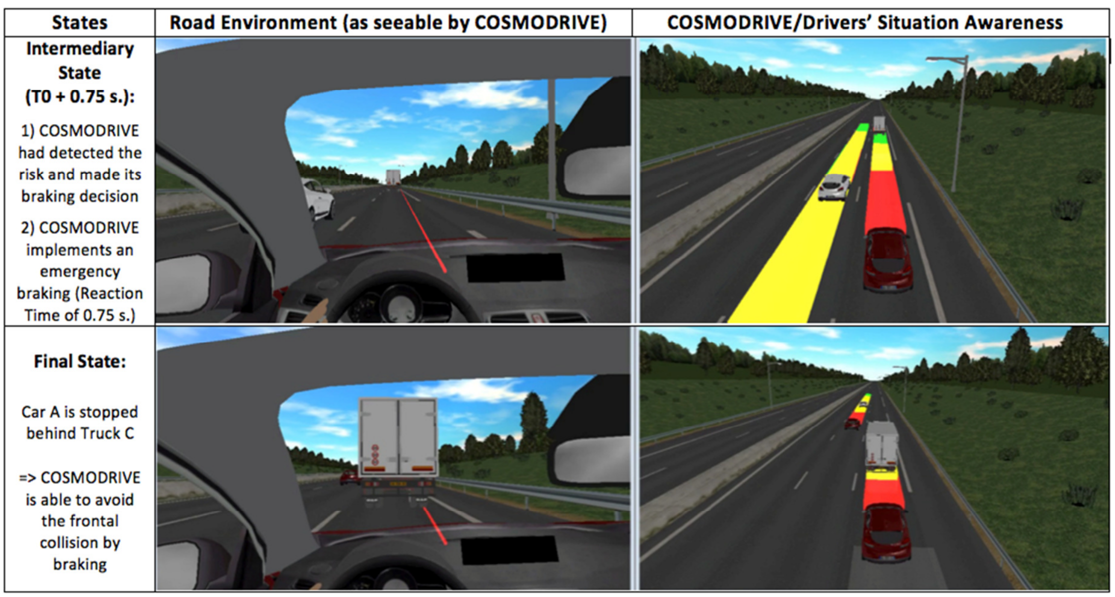


Figure 61: Simulation of an emergency braking implemented by a Not Distracted driver (as simulated with COSMODRIVE)

From the same initial state and the braking decision-making, Figure 62 presents now the results of COSMODRIVE-Based simulations for an initially **distracted driver during 0.5 second** (i.e. from T0, when the Truck is starting to brake, to T0 + 0.5 s.).

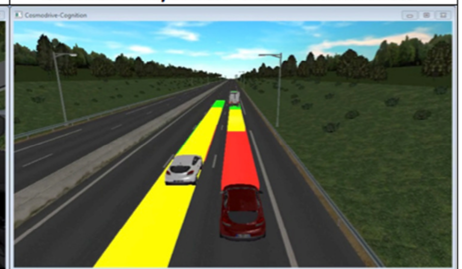
States	Road Environment (as seeable by COSMODRIVE)	COSMODRIVE/Drivers' Situation Awareness
Intermediary State (T0 + 0. 5 s.): End of Distraction		
Intermediary State (T0 + 1.25 s.): 1) COSMODRIVE had detected the risk and made its braking decision 2) COSMODRIVE implements an emergency braking (Reaction Time of 0.75 s.)		
Final State: Car A is stopped behind Truck C => COSMODRIVE is able to avoid the frontal collision by braking		

Figure 62: Simulation of an emergency braking implemented by a Distracted driver (0.5 second of distraction)

Like a Not Distracted driver, this distracted driver (until 0.5 s. after the beginning of the Tuck C braking) is able to avoid the Frontal Collision. However, against the preceding one, the Truck C is in the Red Envelop-Zone at the "final state", meaning a shortest safety margin (0.4 sec. of IVT). This manoeuvre can be consequently assessed as more critical, although also safe for avoiding the frontal collision.

Finally, COSMODRIVE-based simulation with a **Distracted driver during 0.75 second** after T0 (Figure 62) shown that an Emergency Braking does not allow the driver to avoid the Frontal Collision with the Truck C.

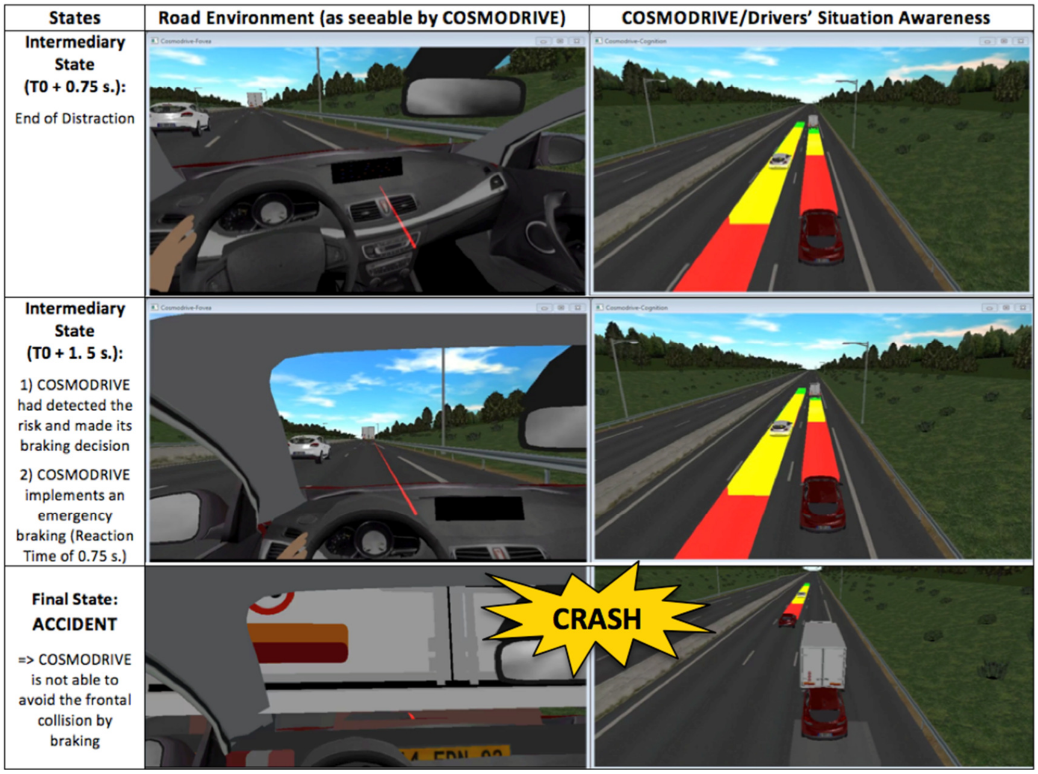


Figure 63: Simulation of an emergency braking implemented by a Distracted driver (0.75 second of distraction)

From this last simulation result, it possible to provide two crucial requirements towards MOVIDA-AdCoS regarding road safety constraints:

- Emergency braking cannot be an appropriate decision to avoid the frontal collision risk with the Truck C for an experienced driver, if distracted during of 0.75 second after the beginning of the truck braking.
- Any drivers with a Reaction Time of 1.5 seconds or more (against 0.75s. for the calibrated version of COSMODRIVE used for the preceding simulations) will be able to avoid the accident with truck C by implementing an emergency braking in the evaluated traffic conditions.

In addition, COSMODRIVE-based simulations may be also used to predict the severity of the accident related to the frontal collision risk, in accordance with the duration of the driver's visual distraction. From the last simulation, it is possible to determine that in case of a distracted driver until 0.75 after T0, the frontal collision of Car A with Truck C will occur with a final velocity of Car A of 4.4 m/s (15.8 km/h), meaning that the consequence of the accident will be limited to material consequences. However, in case of a visual distraction of 1.15 s., the driver will have a more sever accident (Car A velocity at the final state of 10.8 m/s., i.e. 38.9 km/h), and the accident will be probably fatal in case of a visual distraction duration of 1.75 seconds after T0 (collision with a velocity of 16.8m/s, i.e. 61.6 km/h).

5.3.5 COSMODRIVE-based simulations to identify the baselines regarding Lane Change maneuver

The next figures present some examples of simulations results based on COSMODRIVE if the model decides to implement a Lane Change (potentially preceded by an initial braking) when confronted to the similar frontal collision risk with Truck C (i.e. from the common "initial state" previously presented in Figure 60). The objective of these simulations is to provide a set of baselines for a LC decision when implemented by human drivers, according to the duration of their visual distraction.

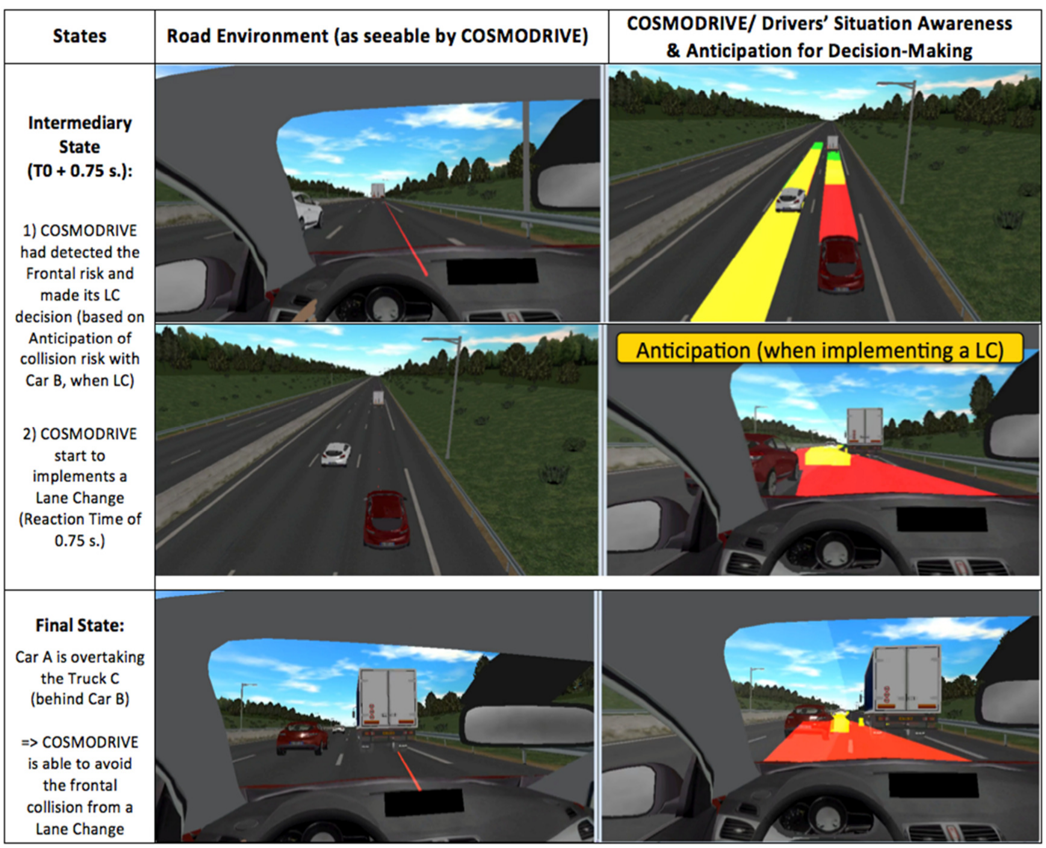


Figure 64: Simulation of Lane Change manoeuvre implemented by a Not Distracted driver (as simulated with COSMODRIVE)

From the simulation result presented in Figure 64, it is shown that a driver is able to implement a safe "Lane Change After Car B" in these traffic conditions, if experienced, not visually distracted, and making its LC decision in a limited time of 0.75 seconds. This LC manoeuvre can be assessed as "safe", because when implemented, Envelop-Zones conflicts occurring between Car A, Car B and Truck C are limited or acceptable (front car B is in the Amber Envelop-zone of the car A when the LC is effectively achieved, and no conflict occur with truck C).

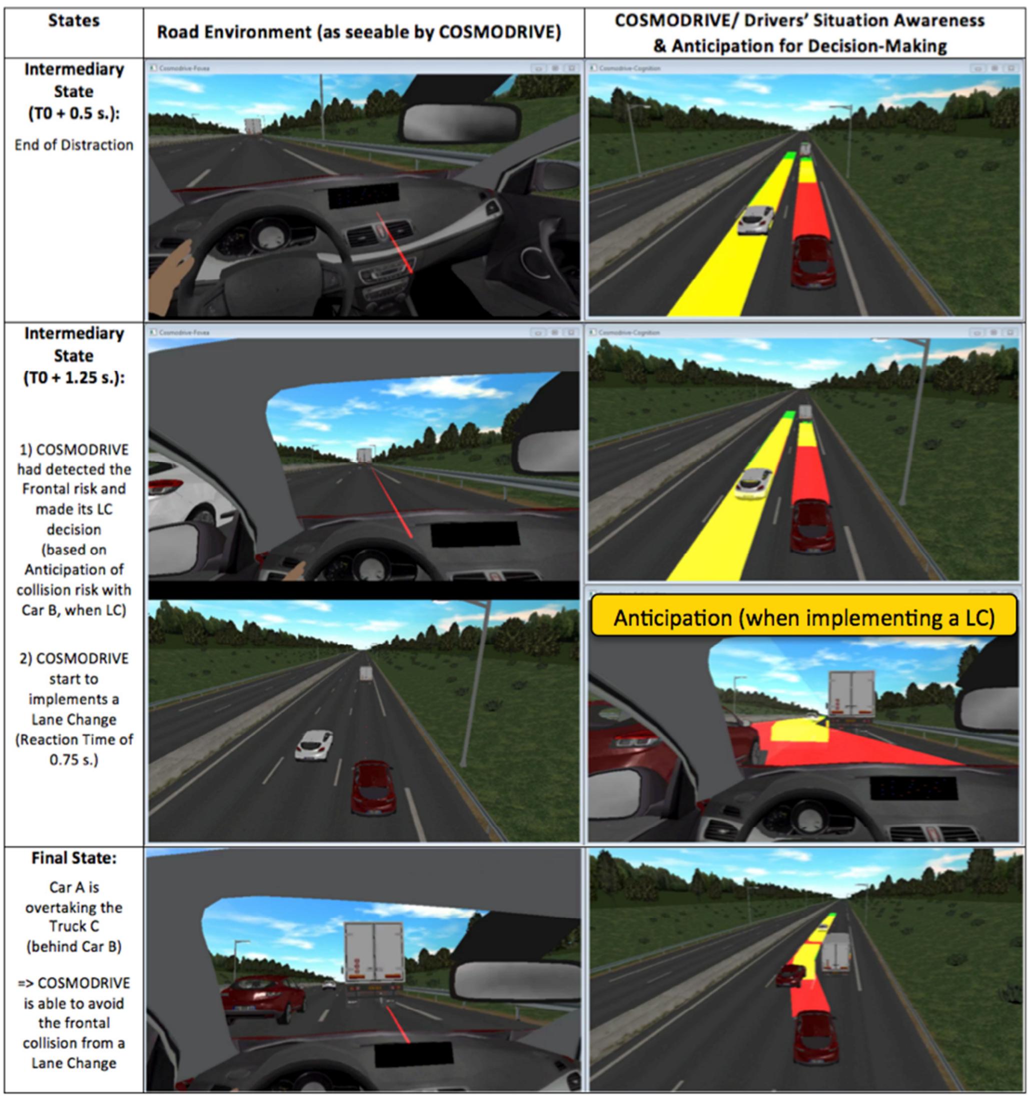


Figure 65: Simulation of Lane Change manoeuvre implemented by a distracted driver (0.5 second of distraction)

In case of a **distracted driver during 0.5 second** (from T0), COSMODRIVE-based simulation presented in Figure 65 indicates that a LC is still possible, although more risky (front car B is and stays in the Red Envelop-zone of the car A when the LC is implemented).

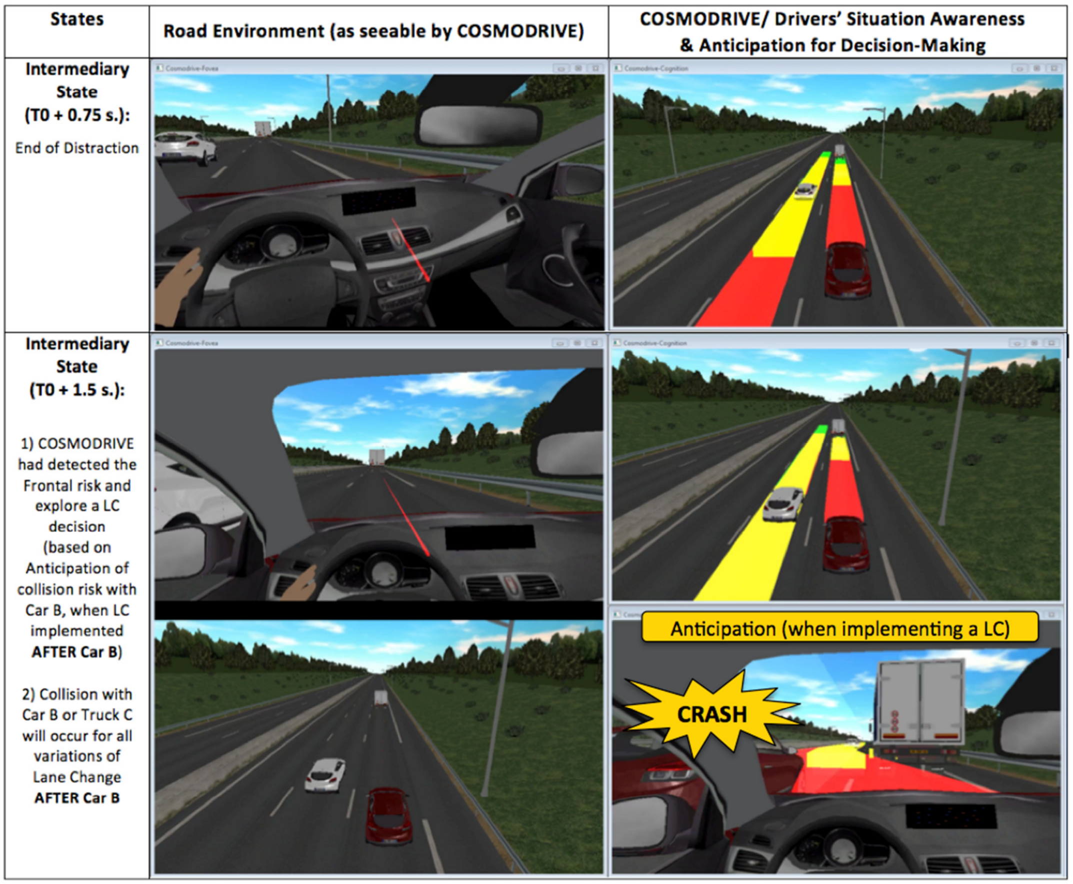


Figure 66: Simulation of Lane Change manoeuvre implemented by a distracted driver (0.75 second of distraction)

By contrast, in case of a **distraction during 0.75s.** (Figure 66), COSMODRIVE is not able to implement a safe Lane Change "After Car B", despite the initial strong braking actions implemented by the model to reduce its initial speed. In fact, the velocity of Car A is too high and the Truck C is too close to allow the driver to implement a safe LC After car B; so, a crash (lateral collision with Car B and/or Frontal collision with Truck C) will systematically occur, if this manoeuvre is implemented. Of course, similar collisions results were obtained for a longer durations of distraction.

During this simulation session, COSMODRIVE never explore spontaneously the LC alternative based-on a "LC Before Car B" (against "After Car B" in the previously cases). This is due to the fact that the simulated scenario was calibrated to reduce this possibility and since COSMODRIVE only explores a limited number of 7 alternative actions[5] based on its current and anticipated Situation Awareness.

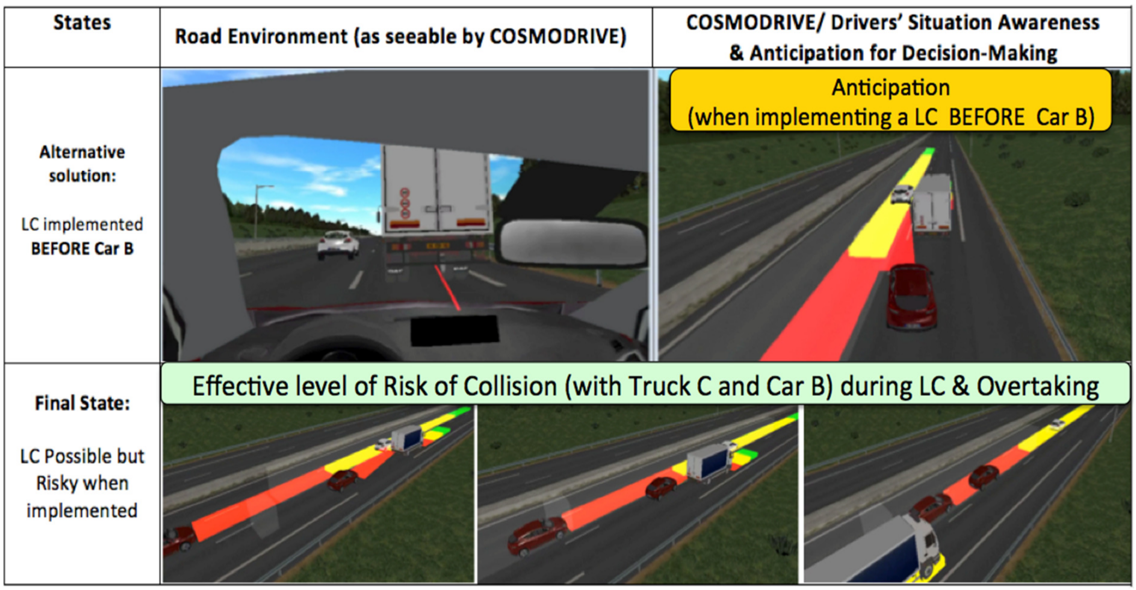


Figure 67: Simulation of Lane Change manoeuvre implemented by a Distracted driver (0.75 second of distraction)

However, by manually allowing COSMODRIVE to implement a highest number of anticipations (i.e. by increasing its abilities in *cognitive deployment*), a LC option "Before car B" is also considered by the model as "acceptable" (after 17 other alternatives), even if assessed as highly risky (because Car A stay in Car B red envelop-zone during all the LC manoeuvre, then during the truck overtaking). If not any other anticipated alternatives cannot avoid the accident, COSMODRIVE will implement this LC option, with an awareness of the high dangerousness of this decision, according to the critical envelop-zones conflicts with car B.

5.3.6 From HF-model based simulations to requirements

From the preceding COSMODRIVE-Based simulations applied to same driving scenario, it was possible to identify a set of baselines about the

[5] in accordance with the limits of human drivers' cognitive resources.

feasibility and the dangerousness of alternative driving actions, according to the duration of the distraction status of the driver. These baselines are summarized in the three following tables.

Regarding the Emergency Braking alternative, it is a safe solution for Car A drivers, only if the duration of their visual distraction is less than 0.75 s. In other words, the MOVIDA-AdCoS must help the drivers to stop their off-road glance before this time. For a longer distraction, the emergency braking - when implemented by a human - does not allow the driver to avoid the frontal collision with truck C:

Duration of visual distraction while the truck is braking (for an experienced Car A driver, with a mean Reaction Time of 0.75 second)	Accident or Level of Criticality (based-on "Envelop-Zones" conflicts with Truck C)
1.75 s	Fatal Accident (at 16.8m/s)
1.15 s	Sever Accident (at 10.8m/s)
0.75 s	Minor Accident (at 4.4 m/s)
0.5 s	Safe
0.25 s	Safe
Not Distracted	Safe

Table 13: Collision risks and accident severity according to the distraction duration, if Braking.

Regarding the Lane Change "AFTER Car B" option, it has been assessed from COSMODRIVE-based simulations (summarized in Table 14) as a safe solution, only if Car A Driver is not visual distracted less than 0.5 s. In case a distracted driver during a longer duration, it becomes a risky manoeuvre to manage the frontal collision risk Truck C, and accident with Car B or Truck C will systematically occur for a visual distraction of 0.75 s. and more. As a conclusion, the future MOVIDA-AdCoS must support future human drivers to respect imperatively this 0.5 deadline before implementing a Lane Change After car B.

Duration of visual distraction while the truck is braking (for an experienced Car A driver, with a mean Reaction Time of 0.75 second)	Level of Criticality (based-on "Envelop-Zones" conflicts with front Car B or front Truck C)
1.15 s	Accident with Car B and/or Truck C
0.75 s	Accident with Car B and/or Truck C
0.5 s	Risky (Red-Red conflicts)
0.25 s	Safe (acceptable Red-Amber conflicts)
0 s	Safe

Table 14: Risks according to distraction duration, if LC After Car B.

Finally, the last possible solution for Car A Drivers, which is to implement the Lane Change "Before Car B", appears as a highly risky manoeuvre (from "critical" to "very dangerous") for this traffic scenario (as calibrated during these simulations), except in the hypothesis of a potential braking of Car B to manage the collision with Car A, during the LC.

Duration of visual distraction while the truck is braking (for an experienced Car A driver, with a mean Reaction Time of 0.75 s.)	Accident or Level of Criticality (based-on "Envelop-Zones" conflicts with rear Car B or Front Truck C during the LC)
1.15 s	Very Dangerous (high probability of accident with Car B and/or Truck C)
0.75 s	Highly Critical (near collision with Car B)
0.5 s	Highly Critical (near collision with Car B)
0.25 s	Critical (Car A in Red zone of Car B)
0 s	Critical (Car A in Red zone of Car B)

Table 15: Risks according to distraction duration, if LC Before Car B.

To complete these baselines, a calibration experiment was also required to further specify MOVIDA, in order to assess the mean Reaction Time of a distracted experienced driver, when supported by MOVIDA warnings as implemented by the HMI of this AdCoS. This experiment was implemented among 21 (12 men and 9 women) middle age (34.9 years old; S.D. 4.7) experienced drivers. Results shown that the mean Reaction Times of drivers of this profile need in mean of 0.9 s. (S.D. of 0.14) to stop their off-road glance, to made their decision and then to implement their action when alerted by our different warnings (related to Braking or to LC).

From the preceding baselines and this additional calibration experiment, it is possible to provide a set of technical specifications and requirements towards MOVIDA-AdCoS, which are summarized in Figure 68. These requirements are more specifically dedicated to the respective timings of the different warnings and /or vehicle automation activation.

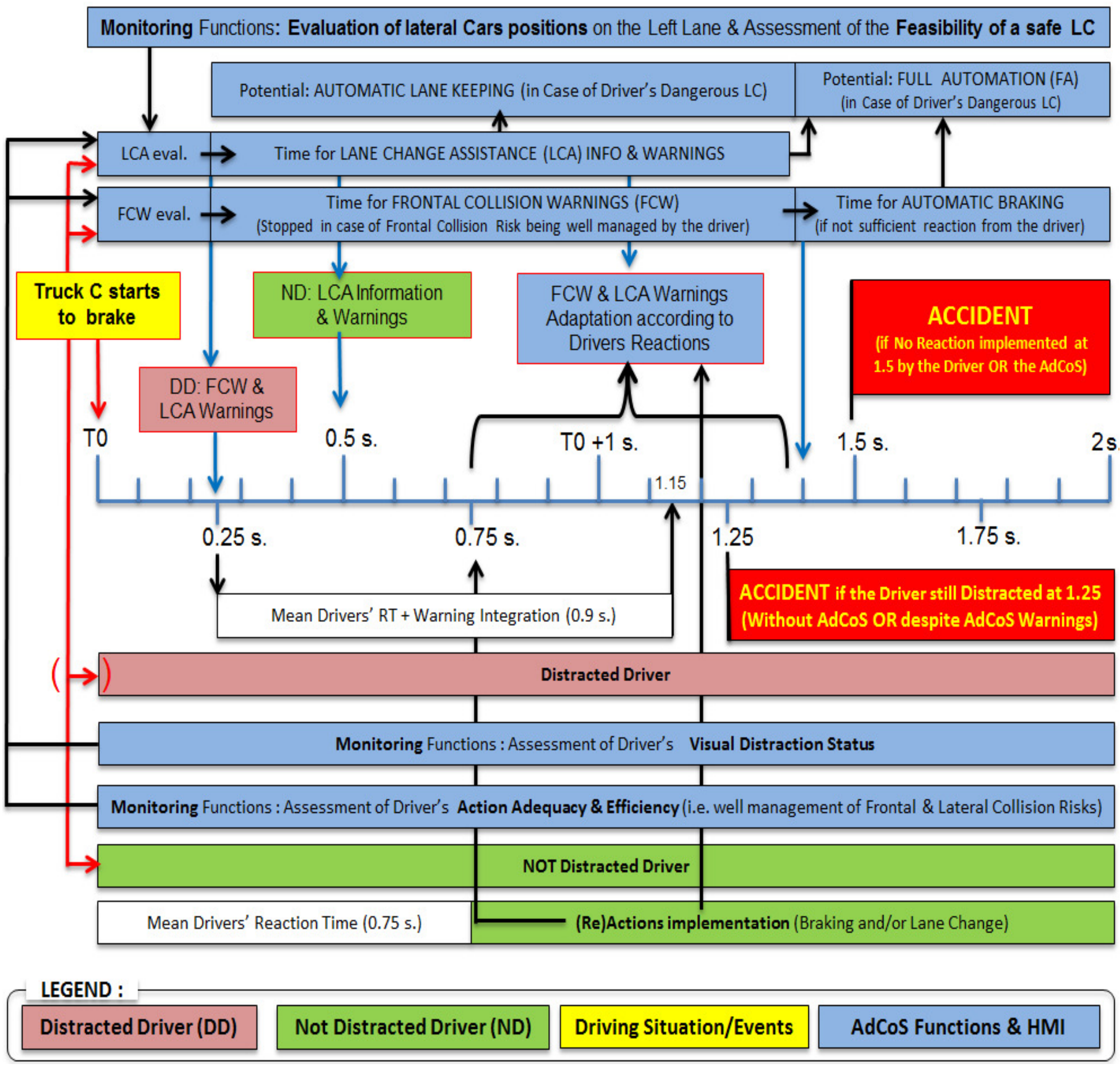


Figure 68: AdCoS Specifications from HF model-based simulation

The most important one is the necessity to alert the drivers about the frontal collision risk with the Truck C in a very short time (less than 0.3 s.), due to (i) their reaction times when visually distracted (mean RT of 0.9 s.) as well as not distracted (0.75 s.) and (ii) to the simulation results showing that a driver has less than 1.5 seconds to react to the truck C emergency braking. After that, it is not possible for a human driver to manually avoid the accident by braking or changing of lane. Of course, the traffic conditions investigated from our virtual simulations are the most critical variations of the initial generic scenario. However, if it occurs, the preceding requirement must be respected. In addition, regarding the time constraint, if MOVIDA is not able to evaluate the collision risks, to make its decision and then to alert the driver in less than 0.75 second, vehicle automation must be systematically implemented (for collision avoidance or for collision mitigation). Alternatively (however not supported by the current version of MOVIDA), an automatic left Lane Change "Before Car B" (potentially requiring to accelerate) or a right Lane Change towards the emergency lane may be also implemented, as alternative emergency solutions based-on vehicle automation.

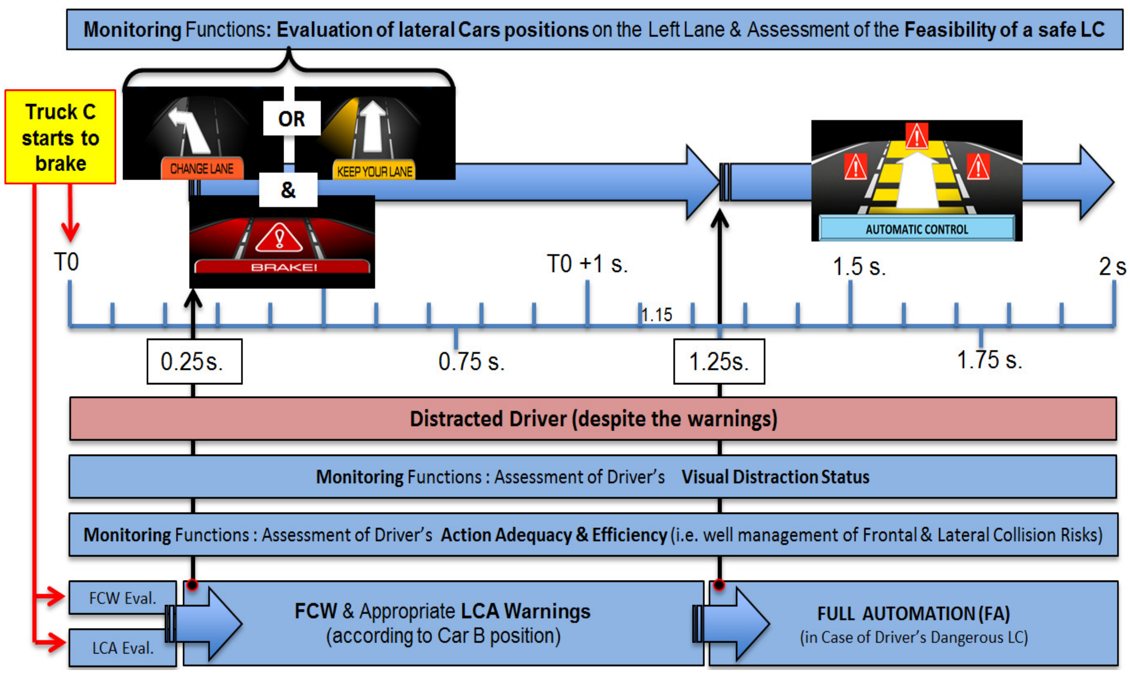


Figure 69: Example of technical specification of HMI from virtual simulations

Figure 69 (which is a simplified version of Figure 68 focused on the specific problem of a persistent distraction) presents a particular example of technical specifications provided from our HF-model based simulations. When the Human driver is still visually distracted after 0.7 second, despite the AdCoS warnings, the "Full Automation" modality (i.e. automatic Emergency Braking and Lane Keeping) must be immediately implemented to avoid the accident.

5.3.7 HF-model based simulations to evaluate the AdCoS

To support the virtual evaluation of the MOVIDA functions, the V-HCD platform was used for implementing simulations of human drivers' performances (simulated with COSMODRIVE) when assisted by this AdCoS (from "normal" to "critical" situations, and according to the duration of the visual distractions of the drivers).

For adequately assisting human drivers in the general "scenario of reference", MOVIDA-AdCoS has firstly to compute (from its virtual radars and cameras) the Inter-Vehicular Time and the Time to Collision with the followed Truck C, and detects in parallel all vehicles on the left lane (like the approaching Car B, for instance). From the other side, MOVIDA functions are also in charge to assess the visual distraction status of the driver (as simulated with COSMODRIVE model or collected from an eye tracking system), in order to interact with him/her in an adaptive and cooperative way. According to the frontal and lateral collision risks, merged with the drivers' distraction status as assessed by MOVIDA, this AdCoS may alternatively generate different warnings (visual and auditory) informing the driver on the necessity to (1) look at the road, (2) to keep or to change of lane, and (3) to brake. In case of dangerous behaviours or critical error of the driver, MOVIDA must take the control of the car (a) for implementing an emergency braking, (b) for avoiding a critical lane change implemented by the driver, or (c) by jointly combining the two preceding actions, if required to avoid the accident.

The following figures present some examples of the different outputs generated by the MOVIDA-AdCoS, as collected from different variations (i.e. replaying) of the initial scenario, by alternatively considering (1) a more or less distracted driver, (2) a more or less hard braking of truck C, and (3) the position and the speed of Car B on the left lane.

In case of a well-managed traffic situation (regarding both frontal and lateral collision risks) by a non-distracted driver, corresponding to an "ideal case of reference", MOVIDA-AdCoS only inform the driver about the possibility to implement the Lane Change manoeuvre (i.e. No car on the left lane). The following figure (Figure 70) provides a typical example of MOVIDA outputs occurring in this driving context, when simulated with the V-HCD platform.

Figure 70: Visualization of MOVIDA outputs for a well-managed situation by a non-distracted driver (as simulated with COSMODRIVE)

By contrast, if the driver is visually distracted while the truck starts to brake, MOVIDA-AdCoS warns the drivers about this event and informs him/her - from the warning presented in Figure 71 - that a lane change is required and currently possible (i.e. not any car is on the left lane and/or is approaching on the rear left lane).

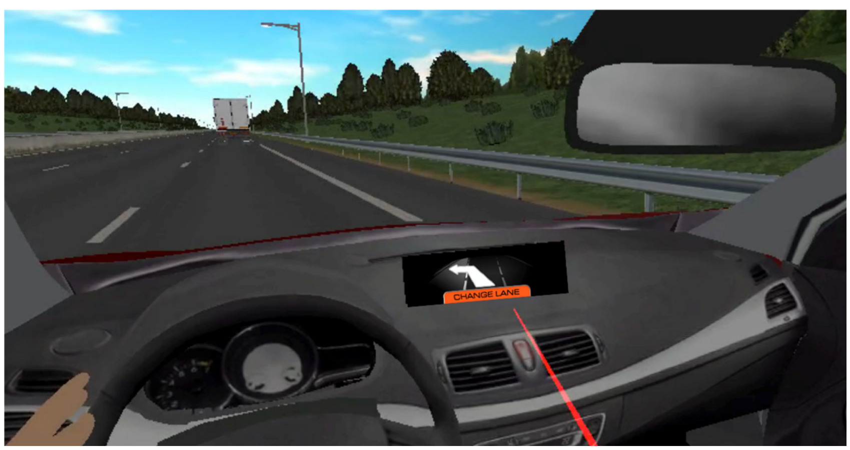


Figure 71: Visualization of MOVIDA outputs delivered to support the Lane Change manoeuvre of a visually distracted driver

In case of an overtaking car occurring on the left lane (more particularly in the blind spot areas) associated with a braking of the followed truck, a warning is sent by MOVIDA to inform the driver about the risk of lateral collisions if a Lane Change manoeuvre is implemented. From this warning (Figure 72), it is expected that the driver will keep his/her lane, until the lane change manoeuvre is possible and safe (i.e. after Car B overtaking).

Figure 72: Visualization of MOVIDA outputs to warn the driver of a dangerous Lane Change manoeuvre

If the driver (distracted or not) starts to implement a dangerous Lane Change[6], while another car is currently overtaking, a warning is sent to the driver and MOVIDA-AdCoS takes the automatic control of the car if required, to avoid the lateral collision by keeping the car in its current lane (Figure 73).

Figure 73: Visualization of MOVIDA outputs when the Automatic Lane Keeping function is activated

Regarding the frontal collision risk management, there are two options in MOVIDA: "Warning" (i.e. Frontal Collision Warning system; FCW) or "Automatic Braking" implemented by the AdCoS (i.e. Frontal Collision

[6] by activating the blinkers, turning the steering wheel, and then by approaching of the left side of the lane, for instance.

Avoidance system; FCA). Figure 74 presents an example of FCW outputs when a distracted driver is assisted by MOVIDA. If this warning is delivered, the driver should immediately brake to avoid a Frontal Collision.

Figure 74: MOVIDA outputs to warn the driver of frontal collision risk

In case of highly critical and very imminent risk of frontal collision (less than 1 second of TTC), or in case of a visually distracted driver assessed by MOVIDA functions, the AdCoS takes the control of the car for implementing an emergency braking. In this context, an auditory warning associated with the pictogram presented in Figure 75 are delivered to the driver, to inform him/her about the automatic braking manoeuvre implemented by the AdCoS.

Figure 75: Visualization of MOVIDA outputs when the Automatic Braking is implemented by the AdCoS

Finally, Automatic Lane Keeping and Braking functions may also be jointly applied in case of both totally impossible Lane Change and imminent

Frontal Collision risk. In this extreme case, the "Full Automation" modality (i.e. Lateral and Longitudinal Control of the car) is implemented by MOVIDA to save the life of the driver, and the different pieces of information presented in Figure 76 are delivered to the driver.

Figure 76: Visualization of MOVIDA outputs when the Automatic Lane Keeping and Braking functions are jointly implemented

When compared to the initial baselines (i.e. the accidents and/or critical behaviours implemented by a non-assisted COSMODRIVE), the global performances obtained from a simulated COSMODRIVE assisted by a virtual MOVIDA clearly validate the final version of this AdCoS. In fact, no accidents were observed, MOVIDA was always able to inform / warn the driver (distracted or not) in less than 0.5 second, and the assisted COSMODRIVE generally reacts to the warning in the right time to implement safe Lane Change and/or Emergency Braking manoeuvres.

The reasons of this high level of efficiency are partially due to the fact that, when the driver does not react in an adequate way in the allocated time of 0.75 s., Automatic Emergency Braking or the Full Automation take immediately the control of the car and implement a safe emergency braking.

During these virtual tests, no failure of the AdCoS was investigated (from embedded sensors to vehicle automation algorithms). However, the advantage in using RTMpas and Pro-Sivic is that it will be possible in the future to also implement validation tests by simulating sensor failures, or by changing the weather conditions for decreasing the environment visibility (for human drivers as well as for the AdCoS cameras), for instance.

5.3.8 Advantages of a tailored HF-RTP as a "V-HCD" to support AdCoS virtual design and evaluation

By considering the traditional method implemented to design Driving Aids without the MTTs provided by HoliDes, as summarized in the Figure 77, 3 main difficulties related to Human Factor issues (i.e. indicated by the 3 red circles) frequently occur (discussed in a more detailed way in D9.8, pp. 38-40). From a "User Centred Design" point of view, it is crucial to take care of end-users' needs since the beginning, and during all the phases of the design process. Unfortunately, it is generally very difficult for HF experts to interact with engineering designers at some steps of the cycle, generally assessed as "purely technical". The only way to proceed is to obtain Mock-Ups and/or simplified prototypes of the AdCoS from the technical designers, to be evaluated with end-users (in order to assess their effectiveness regarding the intermediary versions of the final prototype). However, it is generally very costly in terms of time, effort and money, and in a more general way, very difficult to obtain.

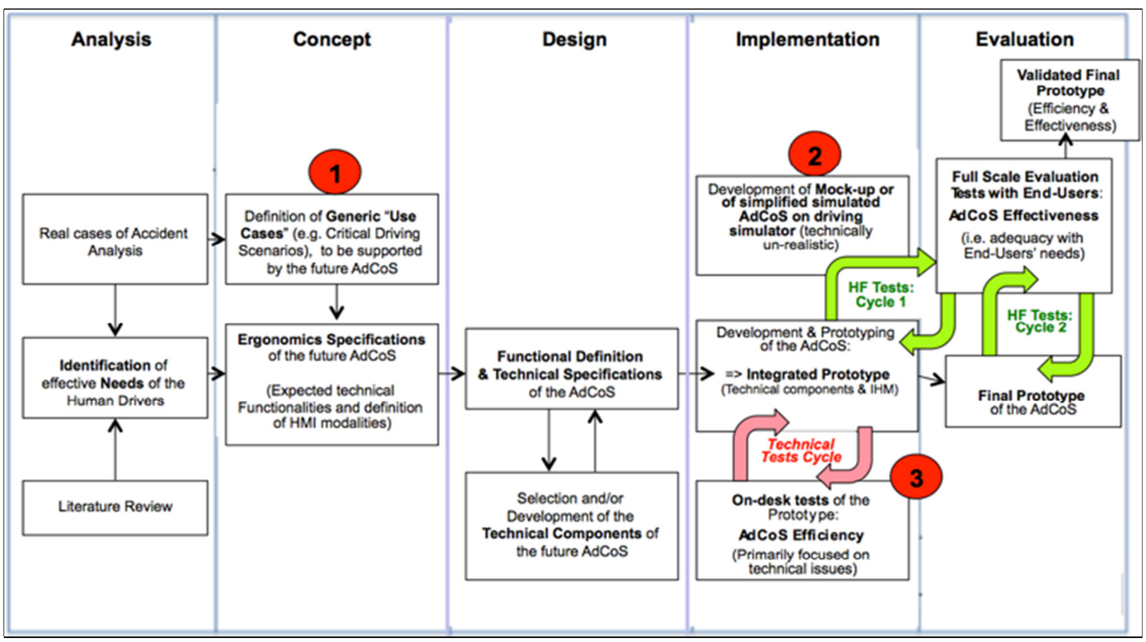


Figure 77: Traditional process and 3 main issues for the development of the AdCoS at IFS before HoliDes (discussed in D9.8, p. 38)

From the MTTs interfaced in WP4 with RT-Maps in the V-HCD platform, it is possible to generate COSMODRIVE-based simulations at the different phases of the AdCoS development process, and to propose a virtual "User-centric" method aiming to better integrate the end-users' needs at all the stages of the development cycle (Figure 78).

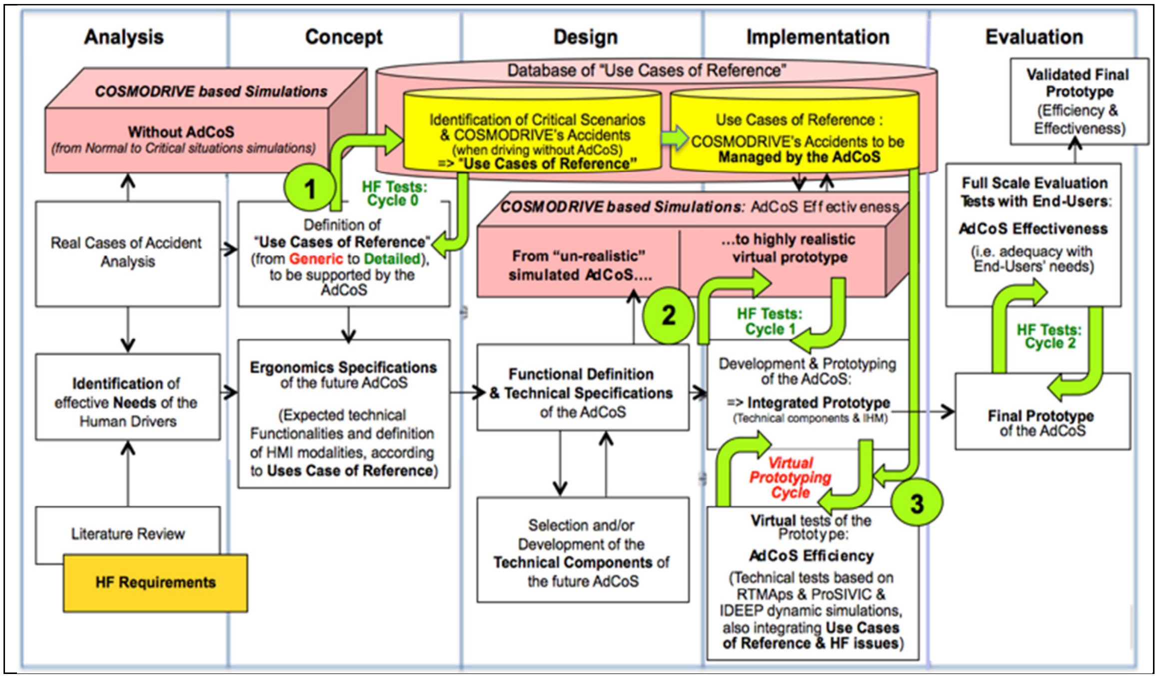


Figure 78: Virtual user-centred design process of MOVIDA-AdCoS, as implemented with the V-HCD platform (discussed in D9.8, p. 41)

The main advantages of this virtual design and prototyping method is the possibility of using COSMODRIVE as a "virtual model of future end-users", in order to improve the traditional design process of driving aids. During the initial phases of the development cycle (from problem analysis to AdCoS specification), COSMODRIVE-based simulations may assist the designer to:

- Simulate human drivers' performances, errors and accidents risks due to visual distraction, in case of unassisted driving,
- Identify particular instances of critical driving scenarios due to visual distraction (against more "generic" scenarios used in the traditional method), liable to be managed by the MOVIDA-AdCoS,
- Select a set of "*Use Cases of Reference*" to be used as Requirements, Functional and Technical Specifications of the future MOVIDA-AdCoS.

At this first stages, the main benefits provided by this HF model-based method it to support the identification of the effective risks of accident due to visual distraction, and then to better integrate end-users' needs since the beginning of the design process. In addition, it is possible to store these initial "Use Cases of references" and to re-use them as "test-scenarios" during all the AdCoS development and evaluation cycle.

Then, during the AdCoS prototyping and evaluation stages, dynamic simulations supported by the virtual model of the driver may be implemented to anticipate the future uses of this AdCoS by real humans and to evaluate its interests from the end-user point of view. From this approach, the objective is to:

- Test and improve AdCoS Effectiveness: by using initial "Use Cases of reference" for evaluating if MOVIDA is able to effectively assist end users by avoiding accidents
- Evaluate AdCoS Efficiency in accordance with end-users' characteristics and limits (by also using "Use Cases of References" as "requirements" at the technical levels)
- Support the evaluation of the "Dual Adaptation principle": of the AdCoS, but also of Humans. RT-Maps and Pro-SIVIC software were specifically designed for the virtual testing of car sensors and ADAS. Combined with I-DEEP functionalities for replaying several times a similar scenario with small variations, it is possible to evaluate ADAS efficiency in a systematic way. Nevertheless, regarding AdCoS, it is not sufficient. For this type of devices, situational changes are not the only one source of variability to be considered. The other one are the Human Drivers themselves, who are also able to adapt (or not) and to cooperate (or not) with the AdCoS. COSMODRIVE-based simulations may support this challenging type of "Dual-Adaptation" evaluation tests.
- Evaluate and validate AdCoS efficiency and effectiveness for highly critical scenarios, ethically impossible to test in real driving conditions among human drivers.

At this implementation and evaluation levels, one of the main benefits of this approach is to better support the virtual Human Centred Design and Prototyping of the AdCoS, more particularly by taking care of HF issues at the "deepest technical" phases" of the development cycle.

Because based-on a Human Driver Model, costly Mock-Ups or specifically designed version of the AdCoS to support tests with end-users are not required: virtual AdCoS developed by the engineering teams from their own virtual prototyping tools may be also used by COSMODRIVE, at all the stages of the V design and development cycle.

Figure 79: COSMODRIVE versus Real Driver piloting the IFSTTAR Driving Simulator (integrating MOVIDA-AdCoS)

In addition, it must be noted that no experiment was implemented by IFS during HoliDes project for testing MOVIDA-AdCoS efficiency among real human drivers (this task was not initially planned, and no resource was dedicated to IFS in WP5).

However, as illustrated in Figure 79, the V-HCD platform has been recently interfaced with the IFSTTAR driving simulator, that is a major progress for our institute in the aim to implement future empirical evaluations of AdCoS among real humans.

6 Conclusions

This deliverable provided an overview of the implementation of the final Automotive AdCoSs: Adaptive Assistance, Adaptive Automation, Adaptive HMI and Adaptive Cooperative applications.
As mentioned in D9.9, the AdCoSs developed in the automotive domain addressed different human factors issues, mainly safety and user acceptance, to improve the baseline systems. The improvement of the baseline was realized throughout the adaptivity of the AdCoS, where the following aspects were considered: Driver state and intention, as well as Driver behaviour and driver preference.

In case of *Adaptive Assistance AdCoS*, the AdCoS considered the driver state and intention to adapt HMI elements and functional strategy, by means of the MDP co-pilot module, developed in the project. The evaluation results for the Adaptive Assistance AdCoS indicated a great benefit compared to the baseline, especially from a technical point of view.
For the user-related assessment the AdCoS showed a good benefit with respect to the baseline, with a significant difference for the "Perceived ease of use". This has determined a positive effect on the attitude toward using the system.
In addition, the analysis of the results of the Final questionnaire have demonstrated a general good performance of the haptic signal in terms of comprehensibility, distinguishability and perceptibility.
For what concerning the MTTs use, the final version of this AdCoS has been created by means of several tools, both for the design and development aspects, in particular to ensure the adaptivity from a HF point of view (e.g. driver's state and intention).

In case of the *Adapted Automation AdCoS*, the AdCoS considered the driver state and driver behavior/driver preference to adapt the driving style of the automated vehicle. The performance indicator compared to the baseline increased and thus the AdCoS was much more appealing than the baseline for the drivers overall situations.
With results of the usability study a final HMI (see Section 3, design variant 3) is defined for the visualization of different driving style variants. However it is an open research question how to name the different driving styles and how many driving style shall maybe actually available. The evaluation results from D9.9 give first hints about the number of how many driving styles should be available. As an outcome of the evaluation three fixed driving styles plus the ego driving style lead to an improvement of the appealing of an automated vehicle. For the final

implementation we therefore use four driving styles and name than after typical styles available for an automatic transmission: Comfortable, Normal, Sportive and Ego.

In case of the *Adaptive HMI AdCoS*, it considered the driver state to adapt the visual HMI. Overall a positive effect of adaptation was found. The positive effect showed that the adaptation of the HMI is a promising strategy to increase the safety of driving and reduce the number of accidents. To achieve these benefits the results highlighted the necessity of high quality visual driver distraction detection in real time and the assessment of the environmental context (criticality of driving situations).
The MTTs used in the different phases of the adaptive HMI AdCoS development showed positive effects with regard to the KPIs. As is shown in different Deliverables (D1.6, D1.7) their application results in a reduction of effort. This reduction will also lead to a reduction in the development cycles which will increase product availability.

In case of the *Adaptive Cooperative AdCoS*, which is based on MOVIDA monitoring functions, developed by IFS in partnership with INT, CVT and ENA, it is an integrative co-piloting system supervising in a centralized way several simulated Advanced Driving Assistance Systems (ADAS) for Collision Avoidance and Lane Change assistance, and liable to take the control of the car in case of emergency situations and/or inadequate behaviour of the driver. This driving aid aims to assist the driver in contextualized way (from an Adaptive HMI and a Cooperative Automation support) according to the drivers' visual distraction status and the external collision risks (Frontal or Lateral) due to the traffic situation. This AdCoS was virtually prototyped and evaluated during the HoliDes project by using a Virtual Human-Centred Design Platform (i.e. the V-HCD) developed by the partners in WP4 (see D4.7), as a tailored HF-RTP based on COSMODRIVE virtual driver. From this platform integrating several HoliDes MTTs, COSMODRIVE-based simulations were used to better integrate end users' needs during all the stages of the development process, from the initial definition of the AdCoS to the virtual evaluation of its efficiency and its effectiveness.

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