Dream-like simulation abilities for automated cars

DREAMS4CARS

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<tr><td rowspan="3">Lead Editors</td><td colspan="3">Andrea Saroldi, CRF</td></tr>
<tr><td colspan="3">Paolo Denti, CRF</td></tr>
<tr><td colspan="3">Mariangela Donato, CRF</td></tr>
<tr><td rowspan="3">Contributors</td><td colspan="3">Mauro Da Lio, UNITN</td></tr>
<tr><td colspan="3">Paolo Bosetti, UNITN</td></tr>
<tr><td colspan="3">Francesco Biral, UNITN</td></tr>
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Executive Summary

This deliverable sets the requirements of the "Co-driver[1] agent". These are derived from the analysis of the application domain of autonomous cars, to guarantee that the project results can be easily applicable to the automotive industry.

The requirements are derived firstly from the examination of the complete "autonomous vehicle system[2]" and, secondly, from the analysis of the role played by the Co-driver agent as part of that system.

The intended application scenarios are described, ordered by priority. The information supplied as input and expected as output from the Co-driver is also defined.

The definition of the levels of automation (which is going to become standard in automotive applications) is introduced. The autonomous vehicle system, and the Co-driver, must be able to act at different automation levels to cover different types of automated driving use cases and to permit the progressive introduction of the technology in the market.

Finally, moving from the previous work done in the AdaptIVe project [6], [8], an initial definition of the interfaces with the Co-driver unit is also presented. This is done in order to allow easy integration and test in currently available test beds and prototype vehicles, as inherited from the AdaptIVe project. This also means the possibility to test the Co-driver agent in different test environments, from simulation (Model in the Loop), to Hardware in the Loop test beds, to real prototype vehicles.

The implicit idea is that Dreams4Cars can maximise its usefulness and contribution to the mainstream research on road automation by considering the aimed levels of automation, the current and future vehicle architectures, and supporting technologies (sensors, communications, maps, control, etc.) and interfaces to enable use both in real vehicles and in test beds.

[1] The agent driving the vehicles in this project is termed "Co-driver agent" or shortly "Co-driver", because it might share the control with the human diver when operating at different levels of automation (see section 2.1). Hence, the terms "Co-driver" and "agent", together or in isolation, will be used in the document to refer to this artificial driving agent (see also Fig.1).

[2] To indicate the entire autonomous vehicle system (Fig.1), which embeds the co-driver, sensor collection and application control, we will use the terms "system" or "vehicle system" or "autonomous vehicle system".

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1 INTRODUCTION

This document describes the main requirements of a Co-driver agent for autonomous driving cars (see section 3). These requirements are derived from running activities on research projects in the intelligent vehicles domain, such as the European Integrated Project AdaptIVe [6], [8], and consider the evolution of technology and constraints for in-vehicle use.

1.1 Document organization

This document is composed by four parts.

- Section 1 introduces the document and explains the document structure.
- Section 2 explains the main system requirements and the functional system architecture. The system should be able to manage a set of selected scenarios.
- Section 3 focuses on the Co-driver functionalities and interfaces.
- Section 4 reports bibliographical references.
- Section 5 gives additional information as appendices.

1.2 Definitions, acronyms and abbreviations

Abbreviation	**Meaning**
AD	Autonomous Driving
ADAS	Advanced Driver Assistance System
DNN	Deep Neural Network
ECU	Electronic Control Unit (a hardware device which allows implementing software in the car)
E/E	Electrical & Electronic
EGO	Autonomous vehicle
EH	Electronic Horizon
GPS	Global Positioning System
GPU	Graphical Processing Unit
HIL	Hardware in the Loop
HMI	Human Machine Interface
HW	Hardware
I/O	Input / Output
MIL	Model in the Loop
NP	Normal Production
OBE	On Board Equipment

RV	Remote Vehicle
RTK	Real Time Kinematic
SAE	SAE International, formerly the Society of Automotive Engineers
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to any (where x equals either vehicle or infrastructure)
VRU	Vulnerable Road User

2 SYSTEM DESCRIPTION

The goal of Dreams4Cars is to develop a simulation-based mechanism –a state comparable to mental imagery and dreams in humans– to improve the abilities of agents for automated driving. Offline simulations that (usefully) re-combine elements recorded in real driving situations will be used to generate hypothetical (yet realistic) situations. These off-line simulations serve to discover potentially critical (and rare) conditions, to develop safer higher-level strategies, and to optimize the lower-level sensorimotor system of the agent. The number of imaginary situations that can be studied in this way outnumbers the situations that can be discovered with only real driving in the same interval of time. Hence Dreams4Cars will speed up both the optimization and the certification of automated driving systems.

This chapter introduces the requirements for the autonomous vehicle system and the role of the Co-driver inside the system based on the definition of automation levels, target abilities, and application scenarios.

2.1 Automation levels

There are a few different definitions of automation levels in road transport. The one which is used in this project, that is also the most followed today, is SAE J3016 (see Table below), which defines 6 discrete levels of automation from level 0 to level 5.

Each level allocates to the human driver or the system the following tasks:

a) execution of steering and acceleration/deceleration;
b) monitoring the driving environment;
c) provide fall-back solution to perform the driving task.

The levels are discrete because each of the above tasks can be performed either by the human or by the system; but they are also discrete because the level at which the system is currently operating must be clear to the driver (to avoid “mode confusion”). Hence, the need for the human driver to have a clear mental model of the different system capabilities at the different levels is considered.

The definition of the automation levels according to SAE is summarised in the following table. The term “driving mode” means a type of driving scenario with corresponding requirements (e.g. driving on roads with digital infrastructure), while “dynamic driving task” means the operational and tactical aspects of the driving task (e.g. how to behave in a given driving mode).

Table 1: Automation levels as defined by SAE (J3016)

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

As described in the table, automated driving begins with level 2, in the sense that the system controls both the longitudinal and the lateral dynamics of the vehicle. However, the driver *must* monitor the environment and supervise the system in order to be prepared to take immediately over when the situation requests it.

At level 3, the human driver is no longer required to monitor the system, but might be called to control the vehicle with sufficient anticipation when approaching conditions that exceed system capabilities (e.g., a system may be capable of driving autonomously in a motorway and asks the driver to control the vehicle before leaving the motorway).

At level 4, the system must be able to reach a safe state even without human fall-back. However, there may still be limitations in the scenarios that the system covers (e.g., only particular types of roads).

The main goal of Dreams4Cars is to develop methods to fill gaps in the co-driver autonomy –both for its ability of understanding and acting in the driving environment and for its ability to produce valid fall-back– in order to safely achieve automation levels 3 and 4[3].

[3] Automation level 5 would mean that the system is capable of driving in *any driving mode*; in particular, without digital infrastructures and relying only on its own sensory system. However, digital infrastructures will in any case be developed in parallel to autonomous driving for many reasons, among which the fact that perception can be extended beyond the line of sight of one single vehicle and that detailed intentions can be communicated and traffic coordinated. Hence, au-

Moreover, the approach suggested for the project is to develop an autonomous vehicle system that, depending on the situation and driver wishes, can support the driver at different automation levels and also negotiate with the driver transitions between automation levels. The human factors elements and how to inform the driver about the current automation level is not in the scope of this project (it has been addressed in other projects, including the cited AdaptIVe), but the possibility to adapt the support given by the system at different automation levels is an important requirement for the autonomous system to be.

To sum up, the aimed levels of automation for the Dreams4Cars project are level 3 (Conditional Automation), and possibly level 4 (High Automation). Accordingly, the system is capable of some autonomous driving modes (in particular, the system's ability to operate in different conditions is dependent on the available digital infrastructure, which in particular means digital maps and infrastructure to vehicle communication) and, when requested, can rely on the human as fall-back (level 3). The system may also be required to operate at lower levels of automation such, e.g., level 0, hence with the co-driver assisting the human driver as like an ADAS system.

The road application scenarios described in section 2.3 define the areas where automation levels from 2 to 4 can be obtained. At automation levels 0 or 1, the system can still be used to understand driver goal and partially control the vehicle (at level 1).

2.2 Target abilities

2.2.1 Current accident rate of automated systems

The **Tesla Autopilot** is a system with **automaton level 2**, with high market penetration. On May 7th 2016, a Tesla Model S operated with the Autopilot crashed on a tractor trailer, causing fatal injury to the driver. The following investigation [1] carried out by the U.S. Department of Transport, National Highway Traffic Safety Administration concluded that the system was improperly operated by the owner. At automation level 2 (which was clearly stated in the owner's manual and whenever the system was turned on) the responsibility of monitoring the driving environment is ultimately of the human driver.

Tesla's system is made of two main components: a "Traffic-Aware Cruise Control System", which automates the control of speed of the vehicle (automation level 1) and an "Autosteer" system that provides automated "lane-centring". The systems are intended for "driving on dry, straight roads, such as highways and freeways" and "should not be used on city streets". The Autosteer, in particular, requires the driver to be "fully attentive" and "always prepared to take immediate actions". "Many unforeseen circumstances can impair the operation of Autosteer", which "may not steer Model S appropriately".

According to a Communication by Tesla [2], the accident happened after 130 million miles of cumulative driving, whereas human driven vehicles have 1 fatality every 94 million miles in the US and 1 every 60 million miles worldwide.

However, the comparison is inconclusive because: a) Tesla's autopilot should be operated in restricted scenarios (highways and dry roads); b) Tesla's system requires human supervising (with correct supervision accident may be prevented by human intervention); c) the figure for human driver accident rate is a gross average of all types of roads, weather conditions, and driver risk-taking attitudes.

Google's car is a system aiming at **automation levels 4-5** (driverless vehicles, operating in digitally mapped roads). According to Google's report [3], over the course of one year the human pilot that was supervising and testing the vehicle had to take control from the autonomous vehicle 341 times. Of these, 69 were safety criti-

tomation levels 3 and 4 can be obtained on properly infrastructured roads at a fraction of the sensors cost that would be required for level 5, and is a more realistic target for the initial market introduction.

cal and 13 might have led to a crash. At the time of this project proposal, Google reported having collected about 3 million miles of driving logs (which are used for Quality Assurance of new software releases).

Other vehicle prototypes are continuously presented, such as for example, NVIDIA's announcement at CES 2017 [4], but no figure for long-term reliability exists. EU funded projects, such as e.g., HAVEit and AdaptIVe, so far have developed prototypes for level 3-4 automation that were however tested for limited time. The German funded Pegasus project [5] aims at the development of methods for the validation of highly automated car functions and lays the foundation for the market introduction.

2.2.2 Target accident rate

To our knowledge, there is no consensus yet about what may be an acceptable fatality rate for automated vehicles (absolute zero accident rate cannot be achieved). Many research activities have been carried out addressing legal aspects such as: product liability, road traffic law, regulatory law, data privacy and data security (e.g., within subproject 2 of the EU FP/ AdaptIVe project). Concerning the accident rate, an emerging opinion is that *favourable cost-benefit ratio must be demonstrated*. It is likely that automation will introduced new kind of accidents, while reducing others (not to mention ethics impacts such as possible misuse, data privacy, etc. which will be addressed in another deliverable).

An automated driving system must be *significantly* more reliable than humans, *in same driving conditions* (e.g, motorways vs motorways) and *compared to best human drivers* (being better than simply the "average" driver might mean that the most cautious drivers would incur greater risks with automation than driving themselves, which is not acceptable).

An indicative target figure of **1 fatality every 1 billion miles** (1/10 the average human driver fatality rate) in sufficiently ample driving conditions (automation levels 3-4) may thus be not far from what will have to be achieved. Dreams4Cars, is a technology that allows to expand the design and test scenario, and optimize the agent for these discovered cases. Hence it is expected to significantly contribute to the effort towards achieving such highly reliable driving agents.

2.3 Application scenarios

In the following paragraphs the scenarios characteristics for the automated driving will be analysed starting from the simplest (Motorway) up to the more complex (Urban).

For the prioritization of application scenarios, a preliminary step consists in the analysis of the environmental and traffic situations where automated driving will be applied first. Therefore, the system should be able to face different driving scenarios with the following priority order:

1. Motorway scenarios;
2. Extra urban scenarios;
3. Urban scenarios.

This means that autonomous driving will be introduced first in Motorways and then in the other scenarios. In each case, the system will have to be able to determine which automation level is chosen and allowed. This can be achieved by using information derived from maps or other sources (e.g., infrastructure communications). The idea is that higher automation levels will be allowed only where the road infrastructure can support it.

The system should be able to manage environmental conditions with low variability rate (the frequency with which conditions could vary) as:

- visibility (day, night, sunset, sunrise, fog or rain);
- road friction (snow, ice or water).

And conditions with high variability rate like:

- traffic density.

2.3.1 Motorway scenarios

Motorway scenarios are characterized by velocities greater than 100 km/h[4]; driving directions are structurally separated by e.g. guard rails; carriageways consist at least of two lanes per driving direction and of a breakdown lane for unexpected stops (or at least sufficiently close safe-stop spots); lanes are exclusively for rapid transit; speed limits and other traffic regulations are specified by traffic signs. In this application scenario, the traffic density has low variability rate.

In Motorway scenarios, the autonomous vehicle should be able to manage the maneuvers listed below:

- free flow and speed adaptation to speed limits;
- lane following with speed adaptation on bends;
- front vehicle speed and distance adaptation (car following);
- obstacle on the road;
- lane changing and overtaking;
- enter and exit of Motorway.

2.3.2 Extra urban scenarios

Extra urban scenarios are characterized by velocities range 80-110 km/h; driving directions are separated by double or single continuous lines when overtaking is forbidden, or a dashed line; roads consist of one or two lanes per driving direction; speed limits and other traffic regulations are specified by traffic signs. Intersection roads are regulated by traffic lights, roundabouts or traffic signs. In this application scenario, the traffic density has medium variability rate.

In Extra Urban scenarios, the autonomous vehicle will be able to manage maneuvers listed below:

- free flow and speed adaptation to speed limits;
- lane following with speed adaptation on bend;
- front vehicle speed and distance adaptation;
- obstacle on the road;
- lane changing and overtaking;
- crossings with traffic lights;
- roundabouts.

2.3.3 Urban scenarios

Urban environments are characterized by an average speed between 0 and 70 km/h; driving directions aren't structurally separated; the lanes are separated by markings; roads consist at least of one lane per driving direction; intersections may be with or without traffic lights; there can be roundabouts and pedestrian crossings with or without traffic lights. Urban environments are characterized by the presence of pedestrians and cyclists (VRU), public transport and vehicles for delivery of goods.

In this application scenario, the traffic density has high variability rate.

In urban scenarios, the autonomous vehicle will be able to manage the maneuvers listed below:

- free flow and speed adaptation to speed limits;
- lane following with speed adaptation on bend;
- vehicle following in lane;
- emergency brake due to obstacle or VRU on the road;
- lane change;

[4] In Germany, there is no speed limit in most motorways. This has an impact on the design of the system, that will have to operate with possible fast rear-approaching vehicles.

- intersection handling with or without traffic lights with vehicle and VRU;
- pedestrian crossing with or without traffic lights;
- roundabouts.

The speed limit table for different European countries is reported here below.

COUNTRY	URBAN	EXTRA-URBAN	MOTORWAY
Austria	50	100	130
Belgium	50	90	120
Bulgaria	50	80	90 100
Croatia	50	90	130
Cyprus	50	80	100
Czech Republic	50	90	110 130
Denmark	50	80	130
Estonia	50	90	90
Finland	50	80	80 100 120
France	50	90	110 130
Germany	50	100	No limits
Greece	50	90	110 130
Hungary	50	90	110 130
Ireland	50	80 100	120
Italy	50	90	110 130
Latvia	50	90	No motorway
Liechtenstein	50	80	No motorway
Lithuania	50	70 90	100 130
Luxembourg	50	90	130
Malta	50	80	80
Netherlands	50	80	100 120 130
Norway	50	80	100
Poland	50 60	100	120 140
Portugal	50	90	100 120
Romania	50	80 90	120
Slovakia	50	90	130
Slovenia	50	90	110 130
Spain	50	70 80 100	90 120
Sweden	50	70	110
Switzerland	50	80	100 120
United Kingdom	48	96	112

Table 2: European speed limits for passenger cars

2.4 System requirements

The autonomous vehicle system must be designed to improve the vehicle safety, driving comfort (the degree of smoothness and steadiness of acceleration of the vehicle), and to reduce the fuel consumption during the trip, without any impact on the functionality of the vehicle systems.

Therefore, we set the requirements listed below.

1. The autonomous vehicle system shall drive optimally in accordance with the following criteria (ordered by priority).
    a. Safety
    b. Traffic rules
    c. Driving comfort (smoothness, avoiding fast accelerations)
    d. Energy and time efficiency

    Since energy and time efficiency are conflicting (mainly time efficiency versus energy efficiency), the optimisation of these criteria means that a solution that optimises a combination of energy and time has to be found through the trade-off between time and energy consumption.

    These criteria will be associated in the lifetime of the project to indicators computed in simulation to evaluate and optimise system performances.

    With respect to safety criteria, besides accident avoidance, also scoring tests and rules as defined by Euro NCAP [9] will be used as evaluation criteria (see "For Engineers / Protocols / Safety Assist").
2. The autonomous vehicle system shall cope with different traffic scenarios described in the previous paragraph with the following priority list.
    a. Motorway Scenarios
    b. Extra urban scenarios
    c. Urban scenarios
3. The autonomous vehicle system will support the driver at different automation levels, adapting both to the current situation and the driver wishes. The system should allow only the automation levels that can be supported in the specific situation.
4. The autonomous vehicle system will be able to handle the following manoeuvers according to order of difficulty from the easiest to the most complex maneuvers.
    a. First group
        - Free flow
        - Adapt speed to speed limits
        - Lane following
        - Adapt speed on bends
        - Follow vehicles at safety distance
        - Stop at stationary obstacles
    b. Second group
        - Lane change
        - Overtake
    c. Third group
        - Enter and exit of Motorway
        - Lane merging
        - Crossings with or without traffic lights
    d. Fourth group
        - Roundabouts
    e. Fifth group
        - Pedestrian crossings with or without traffic lights
        - VRU crossing the road
5. With respect to the criteria listed in the first requirement, the autonomous vehicle system should allow some personalisation option to trade-off speed, energy and comfort, resulting in different driving styles.

2.5 System block diagram

In order to derive the requirements for the Co-driver subsystem, we need to identify the role of the Co-driver module inside the overall autonomous vehicle system.

In general, the driving task can be seen as a loop between driver, vehicle, and the environment. During normal manual driving, the vehicle motion actuators (engine, brakes, transmission, and steering wheel) are directly controlled by the human driver with actions on the pedals, steering wheel and gearshift.

In automated driving, an *autonomous vehicle system* intervenes between the driver, the environment and the vehicle, as represented in Figure 1. Note that this figure is a practical implementation due to: a) the need of collecting data from different sensors (some of which produce pre-processed data) and other information sources (such as maps or V2X) to be forwarded to one ECU for data fusion, b) using one physical ECU to implement the sensorimotor system (the Co-driver block), c) using peripheral ECU already existing in the car for the control of actuators, HMI and vehicle information to be communicated via V2X.

When automation is active, the actuators are driven by a combination of driver commands and system commands. This combination depends on automation level, and is a core aspect for autonomous driving.

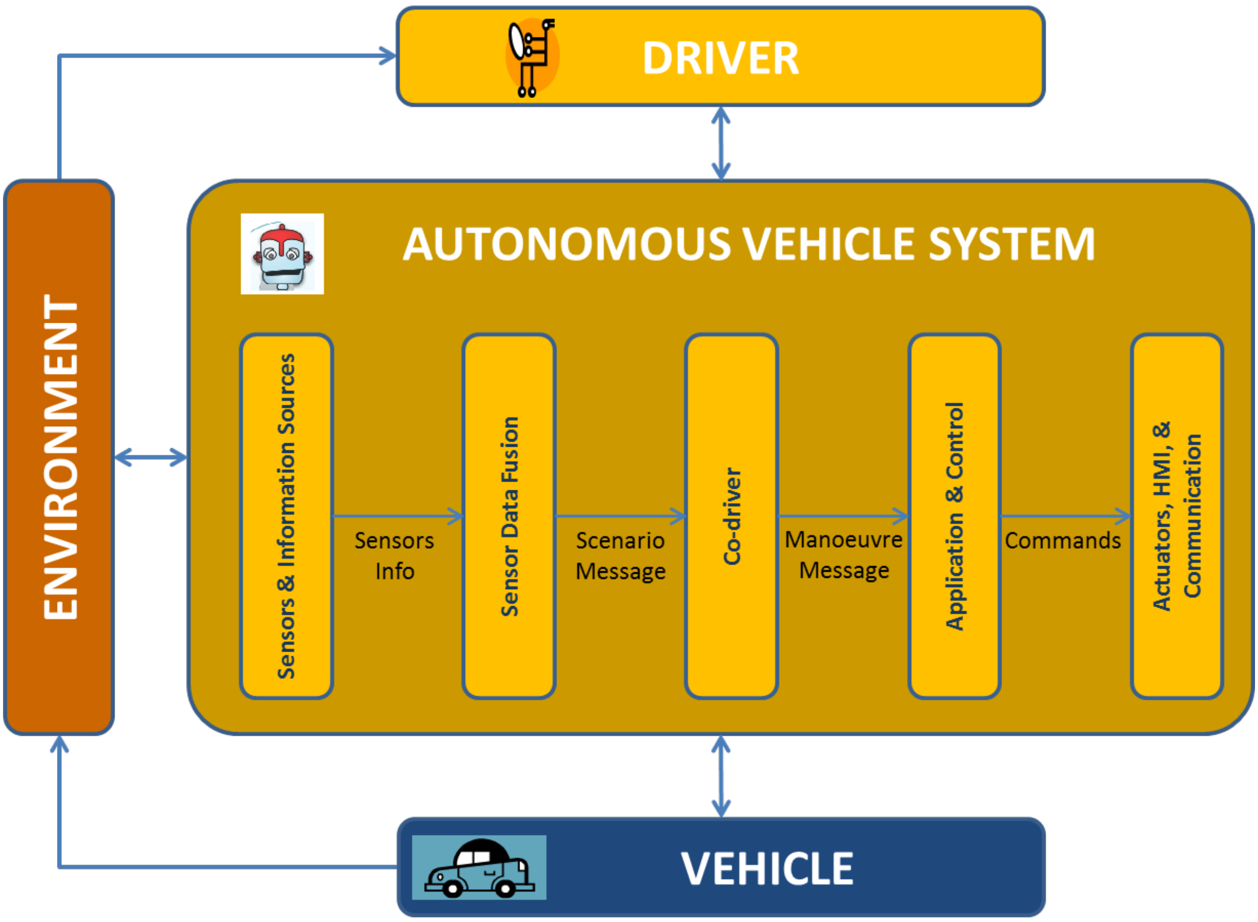

Figure 1: Main functional blocks for autonomous vehicle system.

- The ***Sensors & Information sources* block** stands for all sensors detecting: vehicle position, vehicle dynamics, the environment (composed of obstacles, lanes, road, and weather conditions), driver input, infrastructures and remote vehicles information (V2X) and digital road maps. Some pre-processing of the sensor data, filtering and fusion may be used at this stage; and, in fact, most of the off-the-shelf sensors in the automotive industry have software layers that produce symbolic representations (for example LIDAR sensors produce lists of tracked objects in addition to raw readouts). Dreams4Cars will use off-the-shelf sensor technology.

- The ***Sensor Data Fusion*** **block** processes sensor information from different sources in order to produce a coherent description of the context. This includes road, obstacle, traffic, infrastructure and environmental conditions.
- The ***Co-driver*** **block** is the agent driving the vehicle (at the different levels of automation), which is the main focus of the Dreams4Cars project (note the layout of Figure 1 is the same of the AdaptIVe project, with the only difference being the way the Co-driver agent is developed, which is manual hard-coding for AdaptIVe).
- The ***Application & Control*** **block** is used for the controls of the actuators to follow the trajectory suggested by the Co-driver. It also identifies the HMI outputs to inform the driver and vehicle information to broadcast. This block also manages the transition between automation levels, failure conditions, and recovery actions.
- The ***Actuators, HMI, & Communication*** **block** represents the active devices that send information to the driver (HMI), to other users (V2X), and control the vehicle (engine, brakes, gears, and steering actuators).

3 CO-DRIVER

3.1 Technical requirements

From the previous system functional block decomposition, a set of technical requirements for the Co-driver module can be derived, as listed here below.

1. It should be possible to test the Co-driver in different test environments.
    a. Simulation – model in the loop - environment (MIL)
    b. Hardware in the loop environment (HIL)
    c. Prototype vehicle
2. In order to support in-vehicle applications for different stages of market introduction, the Co-driver should be organised in a modular way, so that simplified versions can be used to implement limited functionalities or scenarios for early markets.
3. The Co-driver should be applicable at different automation levels, defining the best trajectory from its point of view, but also identifying the manoeuver followed by the driver (in manual or semi-autonomous driving mode) in terms of driving goals.
4. The Co-driver should allow for some configuration parameters that affect its driving style.
5. The Co-driver should be implemented in a way that allows execution in an embedded processing unit that will be available for production in the next 5 years.
6. Depending on the available information, the Co-driver should be able to cope with different driving scenarios.

Currently, the last technical requirement is addressed as described in the following table, indicating the main expected functionality for each automation level.

Table 3: Main expected functionality for each automation level

Automation level		Main functionalities	Enabling/activating conditions
0	No automation	Manual driving	
1	Assisted	System takes longitudinal control. Driver takes lateral control. Confirmation request to start after stop.	Map available for the road travelled by the vehicle.
2	Partial Automation	System takes longitudinal and lateral control. The vehicle follows the lane. Crossings, roundabouts, and traffic lights are not supported.	Map available. Lane borders visible.
3	Conditional Automation	System takes full control. Overtaking and crossings are supported. Specific infrastructure is required.	The area is known to support AD. Map available. Lane borders can be absent for limited length. Crossings, traffic lights, and roundabouts are supported by V2X.
4	High Automation	Safe stop manoeuver.	The driver is not reacting as requested.
5	Full Automation	Not addressed.	

3.2 Test environments

Test environments are necessary to assure the quality of updated agents. These have not to be confused with the environment where simulations ("dreams") are carried out. While the latter serve the purpose of discovering and improving the agent sensorimotor system, the former (test environments) serve the purpose of *independently* certify the quality of the newly updated agent.

A test environment is foreseen in Dreams4Cars under WP1.4, which deals with Quality Assurance and evaluation of the agent that was produced with the "dream" mechanism. In future application, such Quality Assurance phase will become a fundamental step for the certification of updated agents before they are installed in the vehicles. In Dreams4Cars WP1.4 the agent is tested in a software system (CarMaker) with the Model in the Loop approach (MIL). Hardware in the loop and real tests must also be possible.

The work done in Dreams4Cars starts from previous developments in the AdaptIVe project. For this reason, a suggested starting point is the definition of test environments and interfaces as developed in AdaptIVe by CRF and UNITN. Hence the main test environments addressed in Dreams4Cars project are described here below (these are specific of the Dreams4Cars project and could vary in other/future developments).

1) In first step, illustrated in figure 2, the Co-driver module should be integrated into a Simulink environment for MIL simulation, as described in the following picture. The CarMaker simulation tool developed by IPG is intended to be used for testing of the Co-driver.

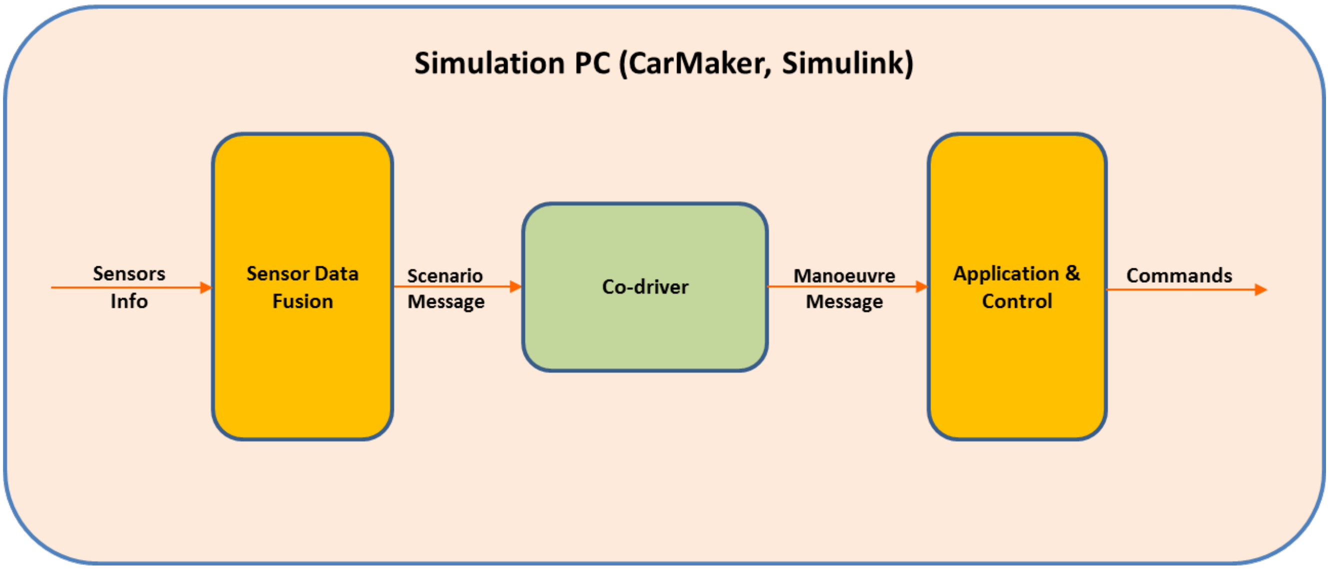

Figure 2: MIL test environment.

The possibility to implement this first test environment depends on the fact that the SW module developed for the Co-driver will have the possibility to be integrated with Simulink in the same computer used to run the simulation of the test scenario.

2) In a second step, illustrated in figure 3, the Co-driver is integrated into a stand-alone unit (i.e. implemented in the exact hardware ECU used in vehicles), and it communicates via UDP with other blocks, developed in Simulink environment (light HIL simulation).

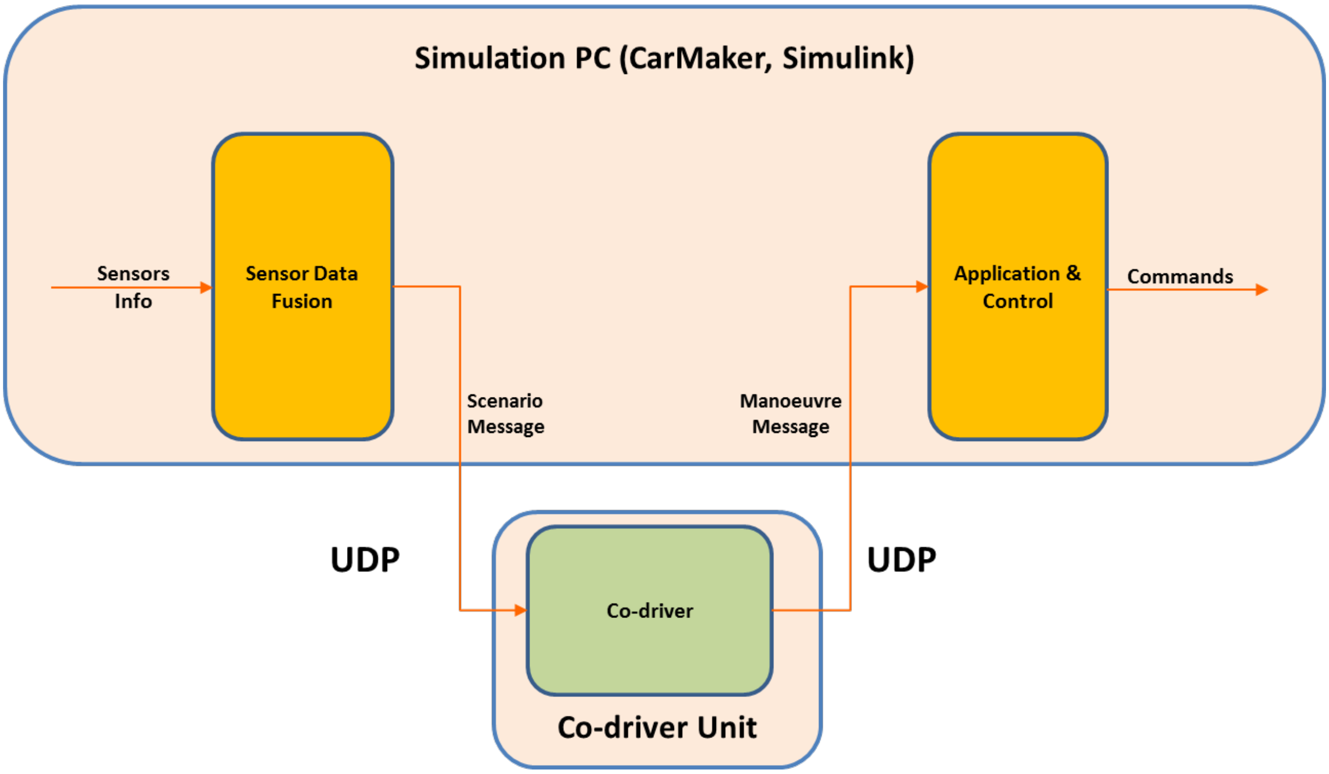

Figure 3: Light HIL test environment.

3) In a subsequent step, illustrated in figure 4, the environment, the vehicle, the sensors and the actuators are simulated with CarMaker and executed on a real-time target (HIL Unit), meanwhile the other modules are integrated in processing units (Co-driver Unit, Control Unit). Both the Co-driver and the Control units are integrated into an HIL test environment reproducing vehicle data as they are on the real vehicle. This test environment is used to test the HW and SW for the Sensor Data Fusion, Co-driver, and Application & Control modules before going to the real demonstrator vehicle.

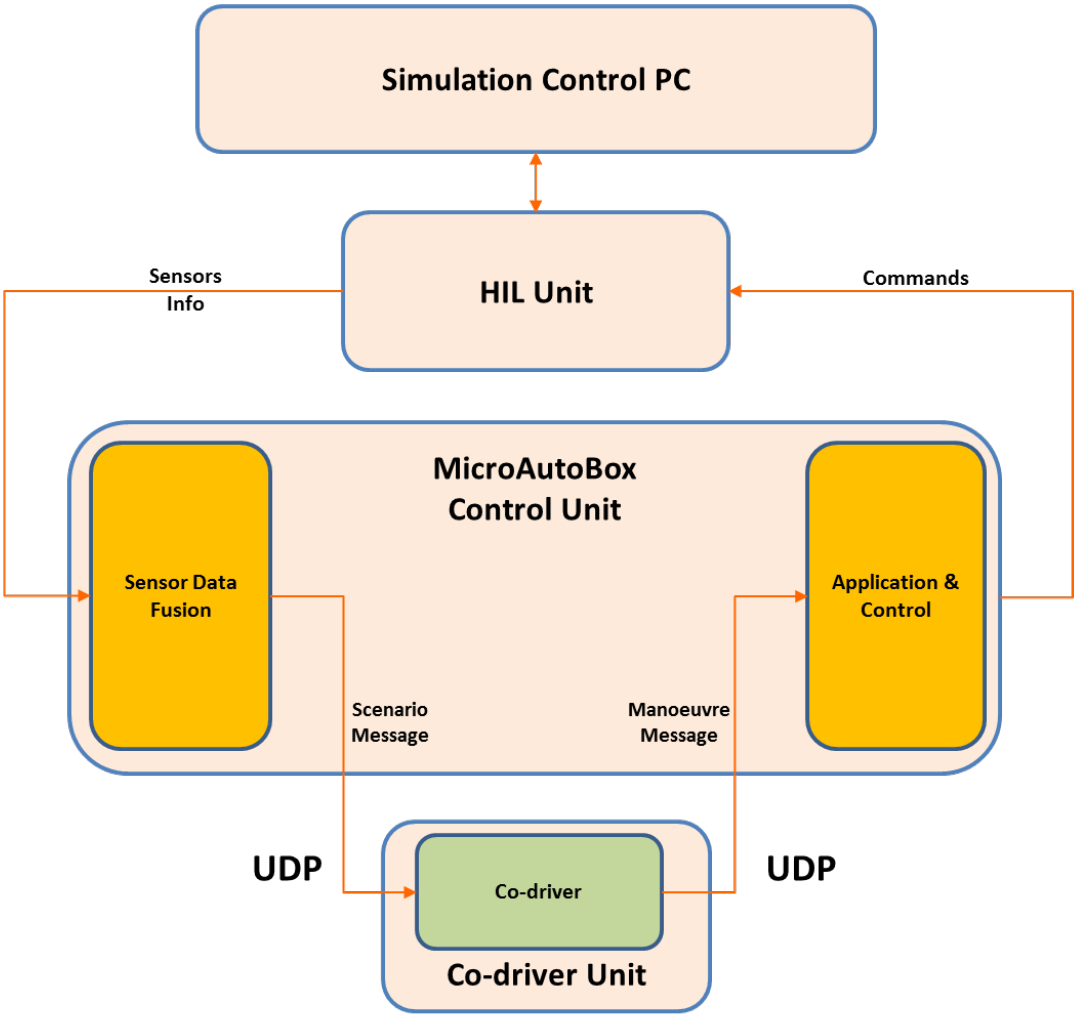

Figure 4: HIL test environment.

4) In the last step, illustrated in figure 5, the Co-driver is integrated into a stand-alone unit and it communicates via UDP to a rapid control prototyping unit (dSPACE MicroAutoBox). Both units are integrated into the demonstrator vehicle.

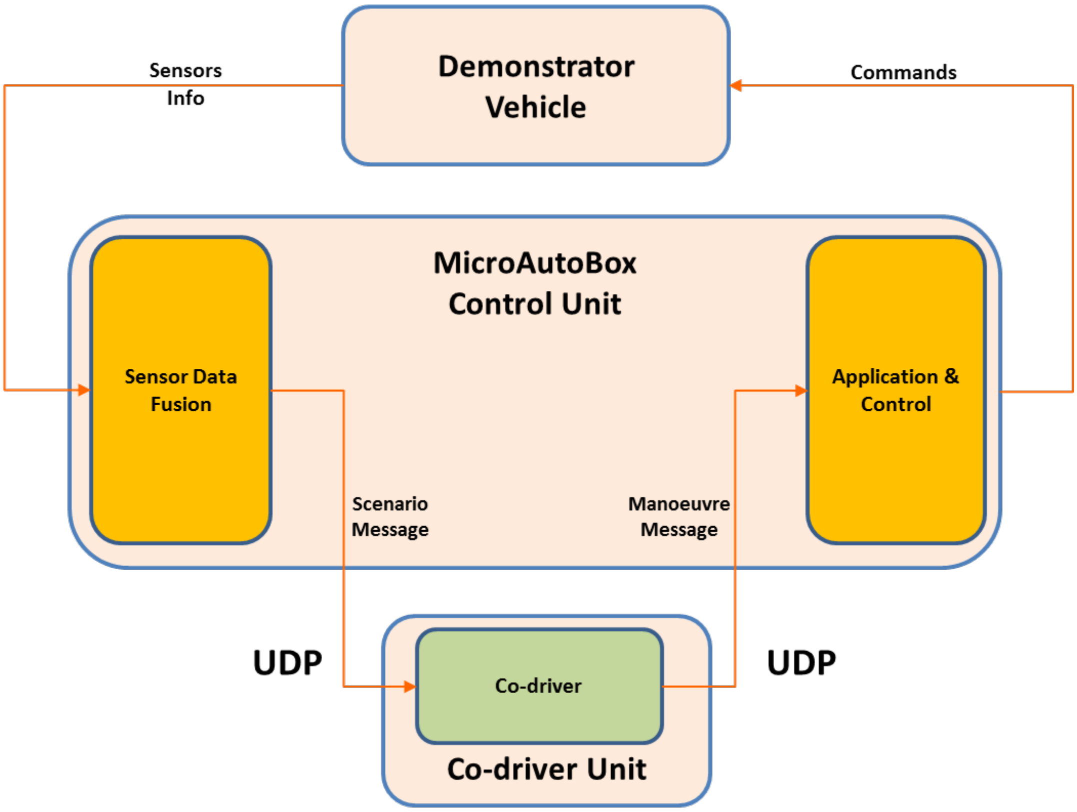

Figure 5: Demonstrator vehicle test environment.

The AdaptIVe demonstrator vehicle will be adapted and used by CRF inside the Dreams4Cars project, mainly to verify the coherence of the simulation environment with the real world. It is depicted in the following picture.

Figure 6: CRF AdaptIVe demonstrator vehicle on Jeep Renegade

3.3 Co-driver interfaces

This section describes the starting point in the definition of the interfaces between the Co-driver module and the ***Sensor Data Fusion*** and ***Application and Control*** modules.

The ***Sensor Data Fusion*** block combines all available information in a scenario description that is sent to the Co-driver Unit in a UDP message called *Scenario Message*.

The Co-driver Unit, after processing of the scenario, sends a UDP message to the ***Application & Control*** block. This message is called *Manoeuvre Message*.

The scenario message with the output of the Co-driver is generated at least every 50 ms (20 Hz update rate).

3.3.1 Input data: Scenario Message

The *Scenario Message* is composed of a set of main categories of data:

- Vehicle data
- Localisation data
- Automation level
- Fused object data
- Road description data
- V2X data
- Requested driving style data

Data categories are described in the table below.

Table 4: Scenario Message

Categories	Description
Vehicle Data	List of information derived from vehicle sensors: speed, lateral and longitudinal acceleration, yaw rate, steering wheel angle, steering wheel speed, etc.
Localisation	Localisation of the vehicle, as resulting from combination of data about absolute position of the vehicle based on the global positioning system and vehicle motion sensor information (yaw rate, acceleration and vehicle speed).
Automation level	The current automation level is used by Co-driver to estimate the best trajectory according to automation level.
Fused object data	List of objects with their relative position and velocity in front of, behind, at the left and right side of the ego-vehicle.
Road Description data	Road path described as resulting from Electronic Horizon, includes road geometry and other information about the road.
V2X data	V2X data are all messages received from communication with other road users, infrastructure or cloud.
Requested driving style	Some parameters about the driving style selected by the driver. These parameters include the selected target speed.

With respect to road description, in order to be easily applicable in vehicles, it should be as much as possible similar to the description used in ADASIS, considering ADASIS v2 as starting point and foreseen evolution towards ADASIS v3 that is specifically conceived for autonomous driving, as defined by the ADASIS Forum [7].

3.3.2 Output data: Manoeuvre Message

The *Manoeuvre Message* is composed of two different trajectories, called first trajectory and second trajectory. Each trajectory is defined by set of parameters that describe the position and speed of the vehicle over time.

The first trajectory indicates the trajectory currently followed by the vehicle; the second trajectory is used only for test, and defines the best trajectory as defined by the Co-driver. In some situations, the two trajectories will be different; to give an example, in manual driving (automation level 0), the first manoeuvre indicates the identified trajectory currently followed by the driver, while the second trajectory indicates the best manoeuvre as selected by the Co-driver.

Also other internal parameters can be sent as output for test purposes; these internal parameters are used to understand the results of the Co-driver processing. To give an example, the information about which obstacle has been identified by the Co-driver as a threat is not a piece of information that is used for HMI nor for vehicle control, but is useful in testing phase to understand the evaluation of the scenario performed by the Co-driver. This information can be given in output as internal parameter.

Table 5: Manoeuvre Message

Categories	Description
First Trajectory	Set of parameters defining the first trajectory.
Second Trajectory	Set of parameters defining the first trajectory.
Internal parameters	Extra parameters used for testing

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5 APPENDIX

5.1 GPU Computing

Processing units based on Graphical Processing Units (GPUs) have been recently made available by NVIDIA (http://www.nvidia.com/object/drive-px.html). They were specifically aimed to Deep Neural Networks and in particular image processing. However, topographical representations of actions, which are already used in the AdaptIVe Co-driver and will be used in Dreams4Cars, may benefit of parallel tensorial computation as well. A couple of these units may deliver 24 trillion operations per second.

The NVIDIA Drive PX2 processing unit is made of 2 Tegra SoC (mobile CPU with a GPU) and 2 separate Pascal GPU on the board (for a total of 12 CPU cores and 2014 CUDA cores). They form 2 computers on a board with different interfaces. Today this is not yet a commercial product (requiring an agreement with NVIDIA for early prototypal uses).

5.2 Automotive sensor technologies

As stated in the Description of Work, Dreams4Cars aims at using the existing automotive sensor technology (hence focusing efforts on discovery and optimization of sensorimotor strategies).

A brief overview of the various types of sensors on the market is given here. It is important to note that advanced types of sensors are available, such as combinations of cameras and RADAR or multi-beam LIDAR sensors. Most of these sensors, after signal processing in the sensor unit ECU, provide high-level symbolic output, such as, e.g., a list of tracked and classified objects.

The automotive sensors used to detect obstacles are commonly based on RADAR, LIDAR, and camera technologies, with proper signal processing to produce associated features such as type, size, position and speed. In some cases, obstacles are also classified considering the power of the reflected signal and shape.

Cameras, and in some cases also LIDAR sensors, are also used to detect road lines such as lane borders, stop lines and pedestrian crossings.

These sensors and associated processing techniques play a fundamental role for autonomous driving in the detection of the traffic situation and also for redundancy reasons.

The output of these single smart sensors are often further combined with data-fusion techniques, also using information coming from other sources such as digital maps (through Electronic Horizon) and V2X communication.

5.3 Digital maps and Electronic Horizon

The Electronic Horizon provider unit is like a virtual sensor, ‘potentially’ connected to many applications, able to compute and provide EH information.

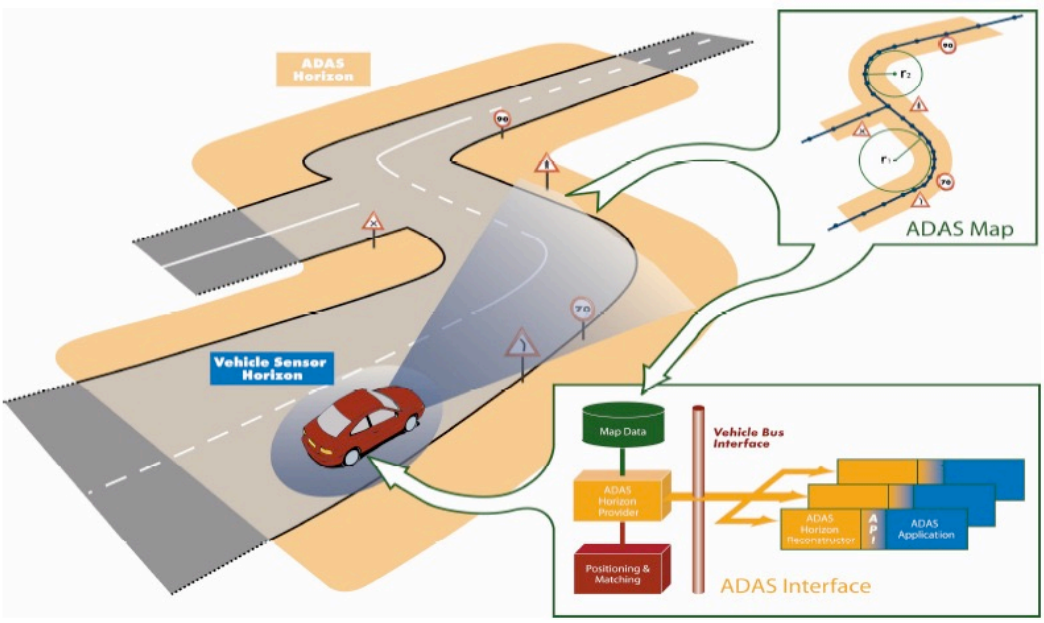

Figure 7: Electronic Horizon concept

Electronic Horizon contains accurate digital maps data; by means of GPS positioning (possibly enhanced with RTK correction) and map matching algorithms, EH Provider Unit sends to driver assistance applications (and potentially to all vehicle subsystems) data about ego-position and attributes of the road in front of the vehicle.

The use of an electronic horizon significantly reduces the need for interpreting t he3 scene in front of the vehicle (either collected by LIDARS or cameras). In addition, EH provide information about road geometry extending their horizon beyond what is immediately visible and thereby contributing to safer, smarter and cleaner mobility. A standardized interface to access to the electronic horizon data has been designed, called the ADASIS v2 (evolution towards ADASIS v3) standard [7].

5.4 V2X

V2X is a form of technology that allows vehicles to communicate with various agents of traffic system around them.

V2V, or vehicle to vehicle, allows vehicles to communicate with other vehicles. V2I, or vehicle to infrastructure, allows vehicles to communicate with external systems such as traffic lights, smart signs, streetlights, buildings, and even cyclists or pedestrians.

The technology uses a short-range wireless signal to communicate with compatible systems, and this signal is resistant to interference and inclement weather.

Similar to the EH technology, V2X technology allows collecting information of the variable parts of the road environment (e.g., reading the status of a traffic light) without needing complex scene scanning, interpretation and classification of the visual field. Moreover, smart infrastructure can communicate information concerning future states (e.g., when and which will be the next traffic light phase). V2V can also communicate the intentions of one vehicle (e.g., like an indicator light but in much richer form).

V2V communications hence enable improved safety system effectiveness by complementing or providing an alternative to self-contained sensors such as RADAR, LIDAR, or camera systems. V2V communications provide the vehicle and driver with 360-degree awareness and can detect potential threats at a greater distance than other types of sensors, as well as detecting potential threats to some degree even out-of-sight or in poor visibility conditions. This enables the driver to receive alerts earlier and have more time to take action to avoid crashes [10].

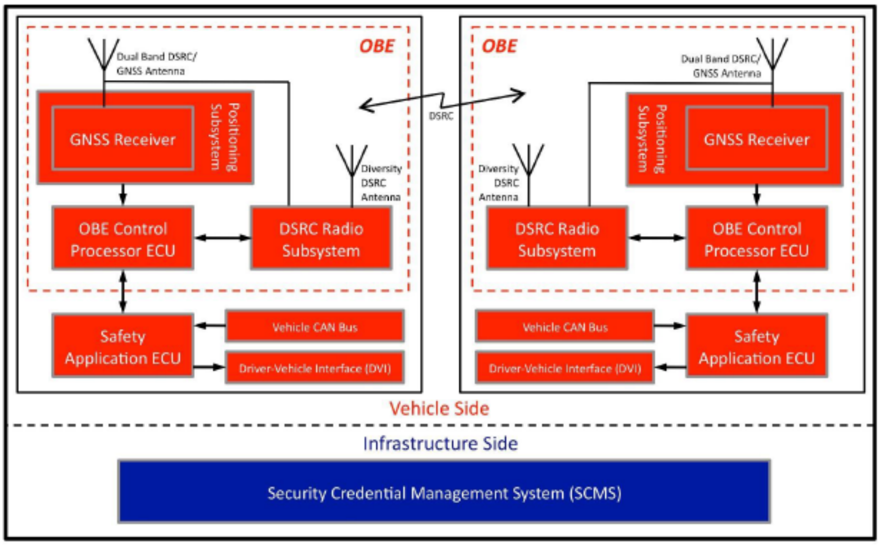

Figure 8: Onboard V2V system [10]

The communication channel uses the DSRC Radio Subsystem as an interface. The System (OBE) can interface to a Safety Application ECU that detects threats and issues alerts through a driver-vehicle interface (DVI). The DVI can provide visual, audio, and/or haptic alerts. The OBE can also interface with the vehicle Controller Area Network (CAN) bus to obtain vehicle status information [10].