interactIVe
Accident avoidance by active intervention for Intelligent Vehicles

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SEVENTH FRAMEWORK PROGRAMME

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The very effective contribution of all the interactIVe subprojects to this final report is greatly appreciated.

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This deliverable has been compiled by the above authors, but it is a summary of individual contributions from many other authors as indicated in the relevant cited references. All results are scientific findings which are only valid inside the statistical assumptions and other limits of application. All findings have to be considered with the associated range of significance. The affiliation of the authors with any organization involved in this project does not indicate that those organizations endorse all the findings contained within this report.

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Executive Summary

After four years of work, the large scale integrated project *interactIVe* has reached its completion, marking major progress towards the realisation of advanced safety systems for Intelligent Vehicles. This report contains an overview of the results obtained in the project and some directions for the future.

Objectives

The general goal of interactIVe was to bring the implementation of Advanced Driver Assistance Systems (ADAS) on cars and trucks a major step forward. An analysis of the status quo before the start of the project showed a very good potential of these systems for safe and efficient road transport, but also a number of limitations in current solutions, and in particular: inadequate functional integration, insufficient reliability of the environment perception, and still high cost for the users, thus preventing the diffusion in all vehicle segments.

In this context, the interactIVe consortium decided to address the key challenges for deployment, with a focus on: (i) overcoming the obstacle of independent functions and high system costs by integrated solutions and affordable technologies, and (ii) considering all vehicle classes in order to extend the market penetration.

The general objective was defined more specifically as: To develop and evaluate safety functions addressing all the different degrees of hazard, from normal driving all the way to crash scenarios. The functions should rely on data elaborated by a perception sub-system and embed strategies to support drivers by information, warning, active interventions whenever necessary, providing responses always aligned with their expectations.

Starting from this concept, the following technical objectives were identified:

- *The coherent integration of multiple functions:* this was especially aimed at extending the range of driving scenarios covered by ADAS and providing a constant support to the driver.
- *A new concept for perception* (a Perception Platform), implementing standard interfaces to the different sensors, data fusion, intelligence, and producing a unified output to the applications (Perception Horizon). The goals here were to improve reliability in capturing the situation and to provide a great flexibility in the use of multiple data.
- *Decision strategies* assuring a good balance of driver and system interventions in all circumstances. The focus was on optimising type, modes and timing of driver-vehicle interactions based on Human Factors, so to reach the intended effect from the safety functions and increase user acceptance.
- *New approaches for active interventions* where steering and braking are merged, thus enhancing the support in dangerous situations.
- *Architectures and low-cost sensor schemes* fitted to passenger cars in the lower segments, specifically for Collision Mitigation

Project components

The above objectives and decisions finally led to the following project components:

Perception, dealing with sensing and interpretation of the environment, on the basis of a general framework and advanced techniques for sensor data fusion.

Information, Warning and Intervention Strategies, addressing the global management of multiple applications with the driver needs in mind.

Applications, with the development of three groups of functions. (i) Continuous Driver Support (ii) Collision Avoidance and (iii) Collision Mitigation. These three domains were expected to provide support in all the phases of the driving task.

Evaluation and legal aspects, addressing the questions whether or not the project requirements are met and whether or not the functions can contribute to improving overall road safety in Europe.

The project consortium consisted of 29 partners from a variety of European organisations: car and truck manufacturers, automotive suppliers, research institutes and small companies. This wide spread of interests has guaranteed a targeted approach responding to all the needs of potential users and capabilities for offering low-cost technologies such as: vision systems, sensors for obstacle detection, digital maps, vehicle controls, and integration with the infrastructure.

The results of the project are described in the Sections 2, 3 and 4 of this document. Detailed results are presented in a large number of project reports and deliverables. Several major deliverables are public, and can be found on the interactIVe website, www.interactive-ip.eu.

Perception

The work on perception was centred on fusing information from heterogeneous sources to provide a holistic environment perception in an integrated, adjustable platform. The basic input sources considered were: perception sensors (radars, cameras, laser scanners etc.), digital maps and wireless communication (V2X). After defining a suitable architecture, a reference implementation was realized using ADTF (Automotive Data and Time Triggered Framework). Several perception modules were implemented, addressing the most important challenges for the project, such as time critical situations, road edge detection, object classification and tracking in frontal, side, and rear areas. Most of the modules were directly used in the demonstrator vehicles, while some others involved advanced research work, paving the way for an extended use of sensor data fusion in future applications. The Perception Horizon, with its unified output, proved to be a very useful approach to simplify the functional development. In parallel, the standard interfaces for each type of information source demonstrated the feasibility of a 'plug-in' concept, which can significantly help system integrators in the choice, personalization and possible update of sensors.

Information, Warning and Intervention (IWI) strategies

During the project developments, it soon became clear that it was crucial to consider the interplay between the vehicle, the automation and the driver starting from the design process. Therefore efforts were dedicated to first define the actual functions from a driver's perspective, and then indicate how, when and where information, warnings and interventions should be activated. This work also covered the input/output components and the interaction with the driver through visual, auditory and haptic channels, including steering, braking, and acceleration.

As a starting point, use-cases were defined in detail, showing how the functions in the different demonstrator vehicles should resolve the so called target scenarios (based on accident patterns). The main focus for this analysis was accident prevention and mitigation, with an emphasis on the events leading up to the crash. This work led to IWI strategies, which can be seen as Human Factors guidelines or general functional requirements for ADAS, covering areas such as scheduling and prioritisation, level of automation, arbitration etc. Several concepts based on IWI requirements were extensively tested with subjects to refine the solutions, using test tracks or driving simulators when reproducing critical scenarios. Examples of topics covered by these experiments are: integrated visual and audio interfaces, haptic feedback on the steering wheel, type of elusive manoeuvre, definition of intervention sequences.

The IWI strategies were finally applied to several cases in the demonstrator vehicles, but are also seen as important guidelines for ADAS deployment beyond the project. Moreover, given the general perspective, they represent a sound basis for further steps towards the introduction of more automation on-board vehicles.

Applications

All the interactIVe applications were developed following the standard process of system engineering. This started from an analysis of accidents and a description of scenarios; the next steps involved the definition of requirements, specifications and system architecture; then the applications were integrated in demonstrator vehicles and further improved by iterative testing, resulting in HW and SW solutions ready for the final evaluation.

As an integral part of the project, interactIVe developed and tested seven demonstrator vehicles: six passenger cars of different classes and one truck for long deliveries. These vehicles were fundamental to tackle architectural, technical and HMI issues; in addition they allowed the fulfilment of the evaluation targets. A well-illustrative experience was the demonstration of these vehicles during the project Final Event in the Ford test track at Lommel (Belgium). These live demonstrations included specific avoidance manoeuvres even in hazardous situations by reconstructing reference scenarios with other cars or dummy obstacles.

The sub-project SECONDS addressed Continuous Driver Support, including therefore normal driving conditions. The focus was on dynamically adapting the share of control between the driver and the system, generating the concept of a skilled co-driver: this co-driver is usually silent but can give advice or, in the most dangerous cases, even take control of the car. When danger is over, the control is handed back to the human driver. The developments were characterised by a deep integration of lateral and longitudinal functions, leading to four demonstrator cars within this sub-project.

The sub-project INCA was centred on Collision Avoidance and vehicle Path Control when an accident becomes imminent, but prevention remains possible. These functions were implemented in two cars (one in common with Seconds) and one heavy truck. Deciding on the best avoidance manoeuvres posed several challenges like possible lateral threats, long-range detection of oncoming traffic, and especially the optimum use of steering vs. braking. For the truck-specific application, different configurations and load conditions had to be considered by thorough simulation and testing.

The sub-project EMIC was dedicated to cost-efficient emergency interventions for Collision Mitigation, targeting vehicle architectures in the low and medium segment. The functionalities were developed as add-on to existing ADAS systems, using sensors and actuators already available on the vehicle, coupled to low-cost vision systems. In a defined set of target scenarios for the frontal direction, the accident severity was reduced significantly by means of emergency driver support and automated intervention systems. The work was completed by working out a driver model allowing adaptive parameterisation of the system interventions, and by a series of sensor tests to benchmark various technologies. The sub-project realised two demonstrator vehicles based on passenger cars.

Evaluation

The evaluation within interactIVe was managed by first defining a common framework and a detailed plan with specific procedures and tools. Then the work addressed three major areas: technical evaluation, user-related evaluation and safety impact assessment. A further important topic was the analysis of legal aspects for the practical exploitation of the interactIVe applications.

The experimental phase collected a large amount of data in hundreds of tests on the basis of the defined use cases. A description of the specific results is reported in chapter 4 and can be found in more detail in the project deliverables. In this summary, we only present some general outcomes.

With respect to the technical evaluation, it can be concluded that all the eleven functions under test behaved as intended. This means the developed functions covered the defined use cases, acting in the expected way. With respect to the false warning behaviour, differences between the interactIVe functions were observed, with some of them delivering false warnings. For a research project the rate of these occurrences was acceptable, but further improvements are needed if these functions are introduced to the market. For other functions no false alarms were observed during the tests.

For the user-related evaluation, nine studies with over 250 participants were performed in driving simulators, on test tracks and in real traffic. Specific tools like focus groups and questionnaires were also applied. The subjects normally judged the systems useful and appreciated not receiving information all the time. Behavioural effects like reaction to the warnings or speed adaptation were normally positive. A few negative compensatory effects were observed, in particular delayed speed adaptation and counter-reactions from some drivers. The tests provided several recommendations for improvements from users.

The safety impact assessment showed that all functions developed in interactIVe would provide a potential safety benefit in the analysed accidents. The amount of the safety effect depends on the function as well as the specific use cases. In the rear-end case some functions show the potential to avoid nearly all accidents. However, the considered number of road fatalities in this scenario is lower compared to other scenarios. Hence, the achieved safety benefit with respect to the total number of road fatalities is also limited. For all results of the safety impact assessment, it must be taken into account that they are only valid given the assumptions of the analysis, the main issue being the lack of input data from accident data bases and data on side effects from the functions.

Lessons learnt and outlook

After four years of collaborative work in a large scale project like interactIVe, it is natural to expect that a large number of lessons learnt can be derived. Considerations are reported in chapter 6 on particular results, problems encountered, and future research needs. Some of these considerations are unexpected and were not known before the project; some others are more obvious, but it was important to have them confirmed by experiments. The partners hope that these comments will be useful for all those who are planning to deploy advanced active systems on vehicles.

The lessons learnt can be framed by considering interactIVe as a part of a general step-wise development on ADAS, characterised by several R&D cycles which started in the 1980s and took advantage until now from the constant commitment of industries, the European Commission and all stakeholders. A major consolidated trend during these years was the progress towards an increased control by the system, gaining more and more authority over the driver. This is also the case for interactIVe, which opens the way to further steps in the direction of automated vehicles. An inevitable lesson (easily learned and unlearned) is that the S-curve of development is a non-negotiable fact. Automatisation comprises many of these curves.

A digest of the main lessons learnt is summarized as follows.

The work on perception showed that vision based object/scene recognition is a promising technique, with the additional advantage of low-cost sensor set-ups. Generic sensor interfaces proved a very good approach for the system design, following a flexible plug-in concept. Overall, further work is needed to obtain reliable real-time perception performance in complex urban environment. Another particular topic where improvements are needed is road edge detection, which was a new subject for the project, with limited prior experience. Also, it will be very useful to extend the availability of precise ground-truth data in order to qualify testing and speed-up the developments.

In the field of IWI strategies, it was found appropriate to create clusters of functions (e.g.: increasing degree of automation, longitudinal vs. lateral support, etc.). The strategies should ensure a smooth transition with regard to the different levels of human and system control. The haptic channel providing interactions via the primary controls gave good results when it was well designed, but certainly additional studies are needed on this topic. The same can be said for investigations regarding driver reactions on active avoidance interventions like steering and braking.

The lessons learnt in the application domain are often function specific. In general, a deep integration of driver assistance systems was not an easy task, due to several aspects like complex architectures, asynchronous data flows, and different kinds of data. This also generated difficulties when tracking the fulfilment of requirements along project life. Continuous driver support showed interesting capabilities for warning and for elaborating a correct escape manoeuvre, with limitations in difficult scenarios. Collision avoidance could conveniently integrate obstacle evasion and path control, both for cars and for trucks. However new efforts are required in the perception domain all-around the vehicle, and (for some use cases) in the precise estimate of the vehicle position. Collision mitigation showed a high potential to reduce the consequences of a crash for the occupants. It was sometimes difficult to find a good trade-off between sensor capabilities and benefits, while meeting the cost targets, so that compromises in the range of covered scenarios were finally necessary. As a final comment on applications, if the path of enhanced automation is pursued for future vehicles, then a deep analysis will be needed in the following directions: (i) Improve shared control strategies, (ii) Consider how to engage the driver back in the loop, (iii) Regard arbitration as a continuous process (not one negotiation only), (iv) Explore if shared control can lead to new types of human error.

The work on evaluation was a fundamental complement in the research. Preparing a test and evaluation plan in the early phase was a good approach; however, the plan must incorporate some flexibility to cope with possible restrictions, delays and new findings, often occurring in a large project. Consolidated test methodologies were lacking for heavy vehicles. For future developments, an additional focus is recommended on scenarios with VRUs. Regarding the impact assessment, the extrapolation of results remains a critical aspect much depending on the assumptions; therefore the presentation of impact data should clearly specify all the underlying hypotheses. A related issue is the need for improving existing accident data bases in order to obtain precise standardized information, especially for the pre-crash phase.

Finally, on the basis of interactIVe results, it is possible to indicate some directions for future developments.

The tangible project results exist as demonstrators, which prove the technology and as deliverables, which report on the architecture, the advances in perception, HMI-expertise and test methodologies. The demonstrators will be probably dismantled; but the experience gained on sensors, actuators, and algorithms will be used in follow-up vehicles. The deliverables will remain, as well as the networking put in place between industry and research.

Even in a short time perspective, some of the interactIVe technologies can be deployed to work as stand-alone applications in every day driving. The industry development process is in place to fulfil the required standards of safety, robustness and usability in developing mature functions.

For other cases, especially where automation is deeply involved, barriers exist which hinder the technology to be exploited in a vehicle on public roads - even if the technology could be proven to work in all scenarios. These barriers are (in 2013) missing legislative measures for type approval, related to legal aspects of partly automated driving. To solve them, a consolidated effort by all the stakeholders is needed.

If we consider more specifically the research agenda, efforts will continue on several topics covered by the project, with a focus on solutions offering high automation.

Perception, which delivers the environment view, is clearly in need of so called ground-truth data to improve existing algorithms and sensors. Benchmarking will add the much needed trust in robustness of the systems (true positive and no false positive detection) for activation of avoidance manoeuvres. The intended result (a particular system working in all tests as required) is a much needed input for the discussion on legal aspects. Complementary information coming from cooperative systems is a necessary functionality (considered in this report for two demonstrators) which increases the sensor range and helps to deal with difficult scenarios.

The increased application of electronics and informatics, which will be the telling sign of automation, requires more research in reliability of control units and software. Supervisory units, smaller systems and increased resilience need lifecycle and robustness analysis with a detailed consideration of failure risks in case of malfunction.

Driver and vehicle need to share intents and control of the selected actions. In this context, driver state monitoring is a crucial factor to be effectively integrated into the applications. Further research is needed on how to deal with control strategies, especially on arbitration between the system and the driver.

Evaluation of automated functions is a topic which breaches the distance between technology and legislation in providing clear facts on the range of applicability. All serious development projects put great emphasis on this topic – but a wider scope is necessary to produce sufficient data for statistical analysis and a sound impact assessment. Moreover, unprecedented methods for evaluating automated functions will be needed, considering the new vehicle missions and types of accident.

The diversity of available functions in the vehicles creates a need for harmonisation between brands on the system design (e.g. range of operability, type of information, warnings or interventions). This will increase the possibility that the driver can build a correct mental model of these functions and build up trust in the automated functions.

In summary, the best way to find more automation in our vehicles is a lively communication between all stakeholders and between research projects. A sine-qua-non is a public understanding that automation is not rocket science but is a sound basis for improved safety and efficiency in road transport.

1 interactIVe vision and objectives

1.1 Introduction

After almost four years of work, the integrated project interactIVe has come to its completion, marking major progress towards the realisation of advanced safety systems for Intelligent Vehicles.

The main achievement has been the creation and evaluation of integrated Advanced Driver Assistance Systems (ADAS), characterised by outstanding capabilities for supporting the driver in varied traffic scenarios, and specifically avoiding hazardous situations. Several new intelligent functions have been implemented in six passenger cars and one truck, based on the following pillar concepts: (i) continuous driver support (ii) collision avoidance and (iii) collision mitigation. These vehicles have granted a comprehensive validation in a large set of field trials, in some cases combined with driving simulator experiments. Special attention has been given to low-cost solutions for all the vehicle segments.

Besides a strong focus on extending the capabilities of Intelligent Vehicles for accident avoidance, interactIVe has provided original results on key enabling concepts, as shown by the following two examples.

A first significant activity has been the build-up of a common Perception Platform for multiple applications. This platform, by using new approaches for sensor data fusion, provides a robust interpretation of the environment and eventually sends a structured output to all the applications by means of a specifically developed standard interface. This is a major step to simplify the perception process, and to facilitate the integration of functions in terms of improved performance, design flexibility and cost-effectiveness.

A second line of research which produced results of general applicability is the investigation of solutions for an effective driver-vehicle-interaction. This work has delivered a set of strategies and specific guidelines aiming to assure a full coherence between driver and system actions, while taking into account information, warnings and interventions in a holistic way. The guidelines are expected to facilitate good design and acceptability in the market for next-generation integrated safety systems.

Having these outcomes in mind, and looking back to the starting point of interactIVe, the results obtained confirm the correct choice done for the key challenges to be addressed:

- Overcoming the obstacle of independent functions and high system costs by integrated solutions and affordable technologies.
- Considering all vehicle classes in order to extend the market penetration.

In this final report the interactIVe achievements are summarised regarding design, technical and scientific development as well as the implementation and validation activities. Furthermore, a final outlook is presented, with the purpose of showing how these project outcomes are already helping to shape intelligent and safe mobility for the future.

1.2 Vision

Numerous accident statistics and in-depth studies carried out over the years yield a very uniform picture of road traffic accident causation. Human error as almost a sole principal causative factor in traffic accidents has been quoted repeatedly for decades. The limitations of road users are well known and recognized.

interactIVe is addressing this problem by developing next-generation safety systems able to compensate driver errors and avoid accidents, or mitigate the consequences of a collision, with a focus on active intervention. Therefore, the project belongs to the family of Intelligent Vehicle projects, aiming to deploy advanced technologies for a safer and cleaner traffic. These goals have been set by the EC, numerous member states and different stakeholders separately.

Despite their capabilities, currently available systems are typically implemented as independent functions. This results in multiple expensive sensors and unnecessary redundancy, limiting their scope to premium-class vehicles. The project was based on the idea that by integrating applications together, drivers can be supported more effectively in a larger range of scenarios, and moreover, vehicle components may be shared among the various safety systems. This approach, allowing an affordable and robust perception complemented by intelligent intervention strategies, is a key enabler for multiple applications and ultimately can lead to a single safety system well adapted to market introduction at acceptable costs.

Consequently, the project vision was as follows:

interactIVe vision is accident-free traffic realised by means of affordable integrated safety systems penetrating all vehicle classes, and thus increasing the safety of road transport.

1.3 Objectives

The general objective of interactIVe was to develop new high performance and integrated ADAS applications, enhancing the intelligence of vehicles and promoting safer and more efficient driving.

More specifically, the project aimed to design, develop, and evaluate three groups of functions: (i) Continuous Driver Support (ii) Collision Avoidance and (iii) Collision Mitigation to be introduced in dedicated demonstrator vehicles as shown in Figure 1. These vehicles are six passenger cars of different classes and one truck for long-distance delivery. The detailed deployment of each group of functions is described in the following chapter on applications.

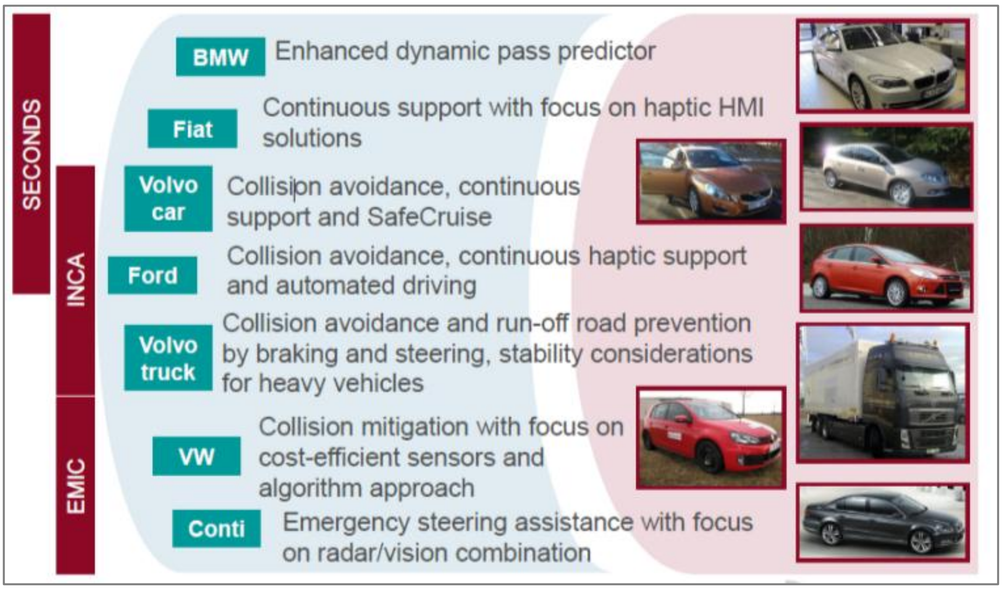


Figure 1: interactIVe objectives condensed

All these developments rely on the attaining a set of more specific objectives at scientific and technological level, which are outlined in Figure 2, together with some major areas focused by the project. These specific objectives are summarized as follows:

a. ***Extend the range of possible scenarios and the usability of ADAS by multiple integrated functions and active interventions.***

This objective implies the coupling of longitudinal and lateral vehicle controls, with a focus on joint steering and braking actuations. Two specific areas are investigated, namely continuous driving support and emergency interventions. In the first case, the system constitutes a natural and well accepted part during ordinary driving, while in hazardous situations, the effectiveness of system interventions for collision avoidance is increased.

b. ***Improve decision strategies for Active Safety and Driver-Vehicle-Interaction.***

One goal in interactIVe was to use new techniques for the dynamic prediction of a safe trajectory ahead. Whereas the final control will be left to the driver, decision strategies, able to balance human and system interventions, are developed. This requires a major breakthrough in the system intelligence and advanced HMI concepts integrated with primary driving controls.

c. ***Develop solutions for collision mitigation that are able to improve the market potential towards low segments.***

ADAS concepts for reducing accident severity, which have been introduced to the market, were further developed with special attention to vehicle architectures in the low to medium segment passenger cars. This implies focusing on cost-effective sensors in combination with relevant accident scenarios.

d. ***Create an innovative model and platform for enhancing the perception of the driving situation.***

This objective involved the enhancement and integration of the perception layer. One main target was to integrate the environment sensing information as a part of the perception layer. This includes inertial sensors, digital maps, and communication.

The Perception Platform aimed to increase the intelligence of interactIVe applications by providing a complete view of the environment, i.e. not only detecting the surrounding objects but also understanding the situation.

e. ***Further encourage the application of standard methodologies for the evaluation of ADAS.***

interactIVe continued in the direction set out by PReVENT and other European projects, in the use of structured methods for the evaluation of safety functions. A specific goal is to define a modular framework, together with test procedures and tools, for coordinating the evaluation of all the developed systems. In addition, interactIVe aimed to analyse current existing legal aspects, in order to identify prospective barriers that might hinder a broader exploitation of the applications. This part of the project contributed to the needs of legislative measures for type approval, as was the case for ESP.

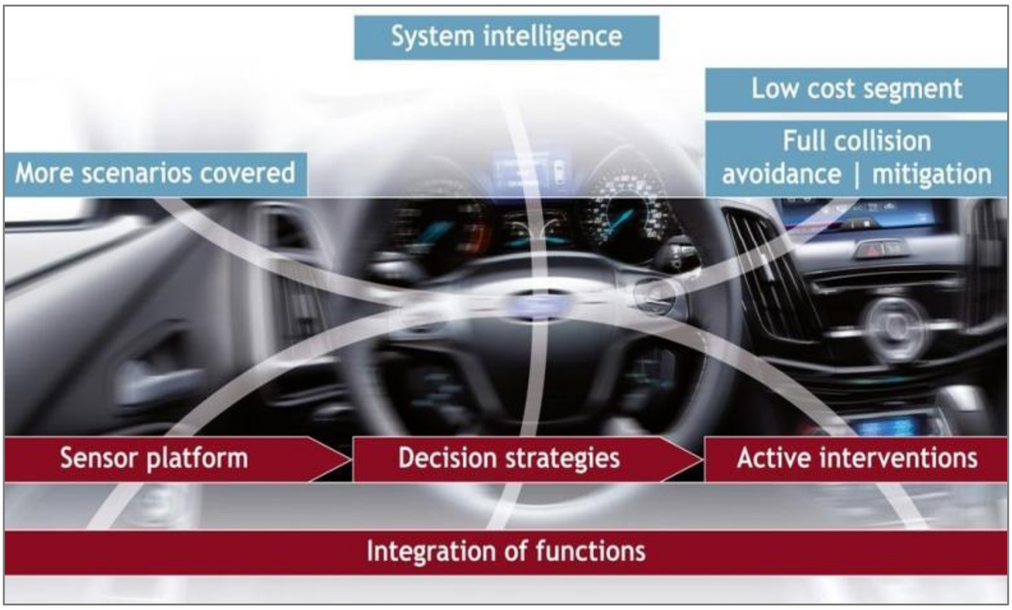


Figure 2: Schematic figure of scientific and technical objectives

2 Concept development

2.1 Concept

2.1.1 Supporting sustainable safety

This chapter provides a synthetic view of the areas addressed by interactIVe in the development of the safety applications, and consequently of the project structure composed of different sub-projects. It also outlines the timeline for all the activities which led to the final results. Therefore, this chapter is an introduction to the following more detailed descriptions of activities and achievements for each area described especially in Chapter 3, Applications and functions development, and later validated and highlighted in Chapter 4, Evaluation.

The interactIVe project - which stands *for Accident avoidance by active intervention for Intelligent Vehicles*, - built on the convergence of recent trends in the European automotive industries. It is composed of a group of collaborative research projects aiming at improving Intelligent Vehicle Systems (IVS) for road safety:

- Automotive manufacturers are striving to increase their competitive position through the integration of advanced safety functions. This is done in response to customer needs and to the challenges for sustainable mobility posed by the high number of accidents on European roads.

- System suppliers benefit from the progress of information and communications technologies. This allows them to offer lower cost sensing and processing technologies, including vision systems, novel sensors for obstacle detection, digital maps, and vehicle-to-infrastructure integration.

If we consider the high potential Active Safety systems, the cost of embedding sensors and intelligence represents a negligible investment when applied to products with a large penetration such as passenger cars and commercial vehicles. The potential number of lives saved, impact on the transport system, and overall socio-economic benefits more than overcome its associated costs. In the field of Preventive and Active Safety this has been demonstrated by several systems introduced in the market over the few past years starting with Collision Warning, Lane Departure Warning, and Assisted Braking.

However, further improvement of these applications towards the *zero-accident vision* is still posing technical and implementation challenges that the interactIVe project tackled. These include:

- Offering a continuous support to the driver, integrated as a natural and well accepted part during ordinary driving.
- Implementing the full capability of collision avoidance.
- Improving performances in the interpretation of the environment, so that the typology of situations covered can be extended.
- Optimising the integration of multiple functions in terms of communication, data processing, and driver interaction, with a good trade-off between cost, redundancy and usability.
- Extending active safety systems towards lower vehicle segments.

interactIVe addressed these issues through a coordinated effort by leading automotive industries, suppliers, and research institutes. The project, therefore, developed high performance ADAS applications, based on:

- The *Integration* of previously independent functions.
- New concepts for the *sensor data fusion* platform.

- *Decision strategies* and novel techniques for the driver-vehicle interaction.
- *Active interventions* performed in specific dangerous situations.
- *Low-cost* sensors and architectures fitted with passenger cars in lower segments.

Considering the overall technological developments, these action areas confirm the role of Advanced Driver Assistance Systems (ADAS) as one of the key priorities in the strategic research agenda within the automotive industry. In fact, a first recognized trend is the exploitation of all information sources for high situational awareness including multiple sensors, maps, and communication to the outside world. A second key point was the progressive transition from existing information and warning systems to new systems that are able to intervene on the vehicle controls in well-defined conditions.

Another major point considered by this integrated project: in the present energy scenario, vehicle technologies should be developed in the frame of an overall picture addressing environmental, weight and cost issues. Therefore, a clear need is emerging to make vehicles safer in a sustainable way compatible with the environmental and cost/market perspectives.

In this context, project results are expected to make the driving task in hazardous situations much easier, thus significantly improving transportation safety and comfort. By doing so, prerequisite steps were taken for enabling fundamental improvements in active safety, and for strengthening the European automotive industry in the areas of Intelligent Vehicle Systems. The domain covered by interactIVe inside the “Sustainable Safety” system for road transport is shown schematically in Figure 3.

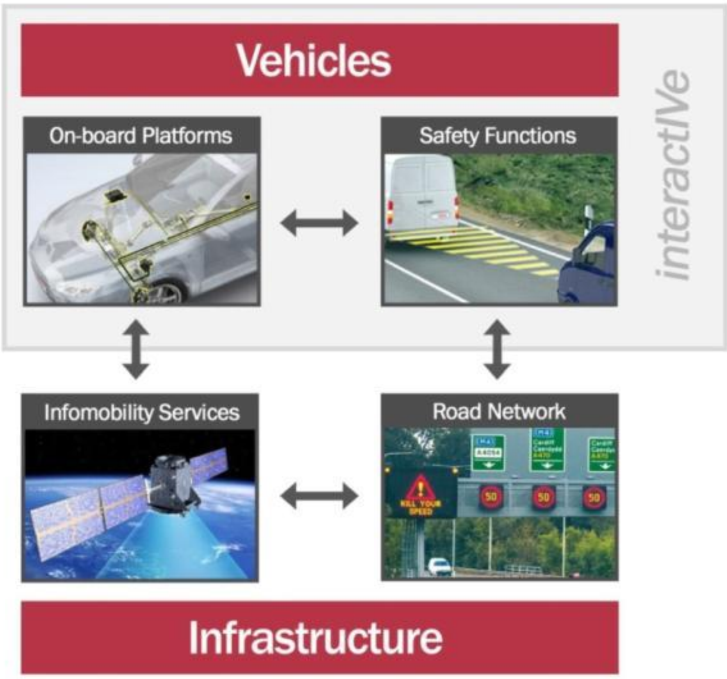


Figure 3: Focus of interactIVe inside the ´Sustainable Safety´ system for road transport

2.1.2 interactIVe structure and concept

The overall concept of interactIVe includes safety functions addressing all the different degrees of hazard from normal driving to accidents. The functions use the data elaborated by the perception layer, and embed IWI strategies to support drivers by warning, active braking, steering and whenever necessary, providing responses always aligned with their expectations. The concept includes the evaluation of both technical performance and user-related aspects to be completed by an assessment of potential benefits deriving from a large-scale exploitation. An analysis of legal aspects completed this part of the work.

Reaching the ambitious goals of interactIVe required the work to be split into separate but interacting sub-projects (Figure 4). Three sub-projects (SP4-SECONDS, SP5-INCA, and SP6-EMIC) constituted application-oriented developments. These aimed at developing and validating the integrated functionalities in the three areas addressed by the project.

These activities were supported by cross-functional activities which dealt with technical and methodological aspects common to all the applications. The three sub-projects of this type were: SP2-Perception, SP3-IWI Strategies, and SP7-Evaluation.

This structure facilitated the integration and the use of uniform methods leading to a common frame in terms of vehicle architecture and specific sub-systems, in particular for the perception layer and the actuation layer. At the same time, different platforms could be developed - and compared - in relation to specific industrial constraints, pre-existing HW, or approaches preferred by a manufacturer.

An additional sub-project, SP1-IP Management, was included for handling the project coordination, links to external activities, dissemination, and general administration.

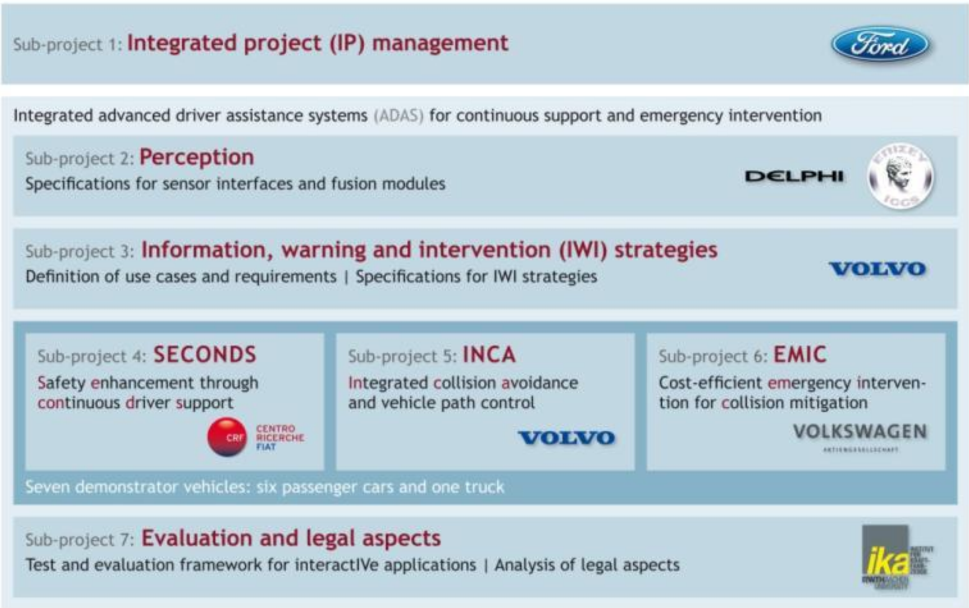


Figure 4: Project structure comprising of seven sub-projects

The development path throughout the project followed a consolidated approach (Figure 5). The first step was to identify target scenarios, develop detailed use cases and define functional and non-functional requirements. This was followed by the definition of systems' specifications and a generic architecture for interactIVe, to be further specialised for the various demonstrators. Meanwhile, a method for the evaluation was elaborated.

The subsequent development work involved parallel and linked activities for the application sub-projects and for the cross-functional sub-projects. In the first case, it led to the realisation of the demonstrator vehicles, equipped with sensors and other specific components, electronics and HMI. The activities on perception were mainly focused on the development of a reference Perception Platform, but also on new fusion modules advancing the scientific state-of-the-art. In parallel, the sub-project provided support for the implementation of the perception sub-systems to be used in the demonstrators. At the same time, research on IWI strategies was centred on defining Human Factors guidelines or general functional requirements for ADAS, after having developed a rationale methodology. These results were obtained by a comprehensive analysis of previous studies through dedicated experiments with subjects and a close collaboration for several interactIVe applications.

The final phase of the project involved testing and evaluation of all the developed applications according to the methodology defined. Test data were obtained by reconstructing the required scenarios in test tracks, or whenever possible, on public roads. Specific tools (for example dummy obstacles representing a pedestrian or a car) were set-up for the purpose. The analysis was completed by an assessment of potential safety impacts, first for the individual functions, and then for all applications.

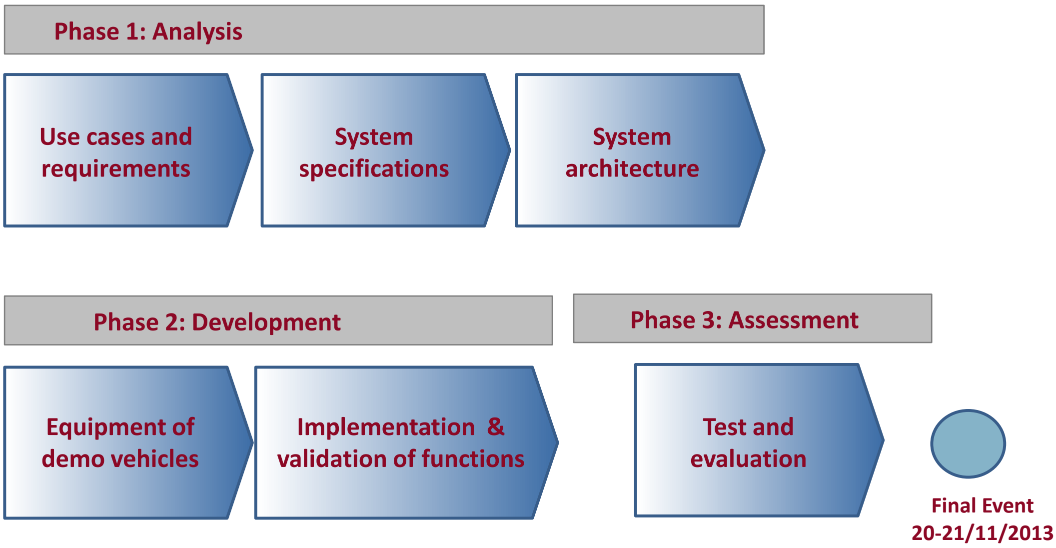


Figure 5: Project timeline

The number of ADAS applications is growing rapidly on the market today. It is obvious that the number of sensors cannot be increased in the same way as the number of applications is increasing. Instead, sensors of different technologies have to be combined by using *sensor data fusion algorithms*. There is still a significant work to be done in sensor technologies to have a fully reliable representation of the environment for various safety applications. The ideal situation would be to use only two to three different types of sensors in vehicles, while using robust sensor fusion algorithms for safety applications. interactIVe addressed these issues in agreement with the general vision and interest of all stakeholders.

A strong paradigm in the development of IVS was sensor data fusion. Another trend was to use information given by maps and communication systems, aimed at providing drivers with more time to respond to sudden changes in the travel environment – so called foresighted driving. Both approaches assumed extensive environment monitoring, data collection and a perceptual model of the environment – but also of the driver - to be further used for various safety functions. The project was also based on the concept that by integrating applications together, vehicle components may be shared among the various safety systems. This was accomplished in interactIVe by discrete architectural layers that are common to all applications. The objective was also to use existing and up-coming sensors - not to develop new ones. A cost-effective solution was sought for.

Although application and sensor fusion was a major activity area, substantial amount of research is still required before applications are market-ready. By building upon current state-of-the-art technologies, interactIVe developed next-generation safety systems based on three pillar concepts:

1. Continuous driver support.
2. Collision avoidance and
3. Collision mitigation.

The core activities of the project addressed the design and development of the Intelligent Vehicle Safety Systems, the capabilities of which were shown by dedicated demonstrator vehicles. The project was conducted through a coordinated effort from leading automotive industries, suppliers, and research institutes. By demonstrating these results, interactIVe will significantly enhance the feasibility and attractiveness of next-generation safety systems, strengthening the position of European industries in the area of Intelligent Vehicles and eSafety

The general idea behind the project concept and the development methodology adopted was to start from the key problems that the interactIVe functions should address, that is, the *target scenarios*. Based on the target scenarios, as well as user needs assessment, *use cases* were developed which defined, in general terms, how the problems defined by the target scenarios should be solved by the intended interactIVe functions. As a last step before the architecture and specifications, the use cases made the basis for defining the *functional requirements* (Figure 6). In interactIVe the target scenarios and functional requirements were defined by the vertical sub-projects from SP4 to SP6 while the use case definition was under the responsibility of SP3.

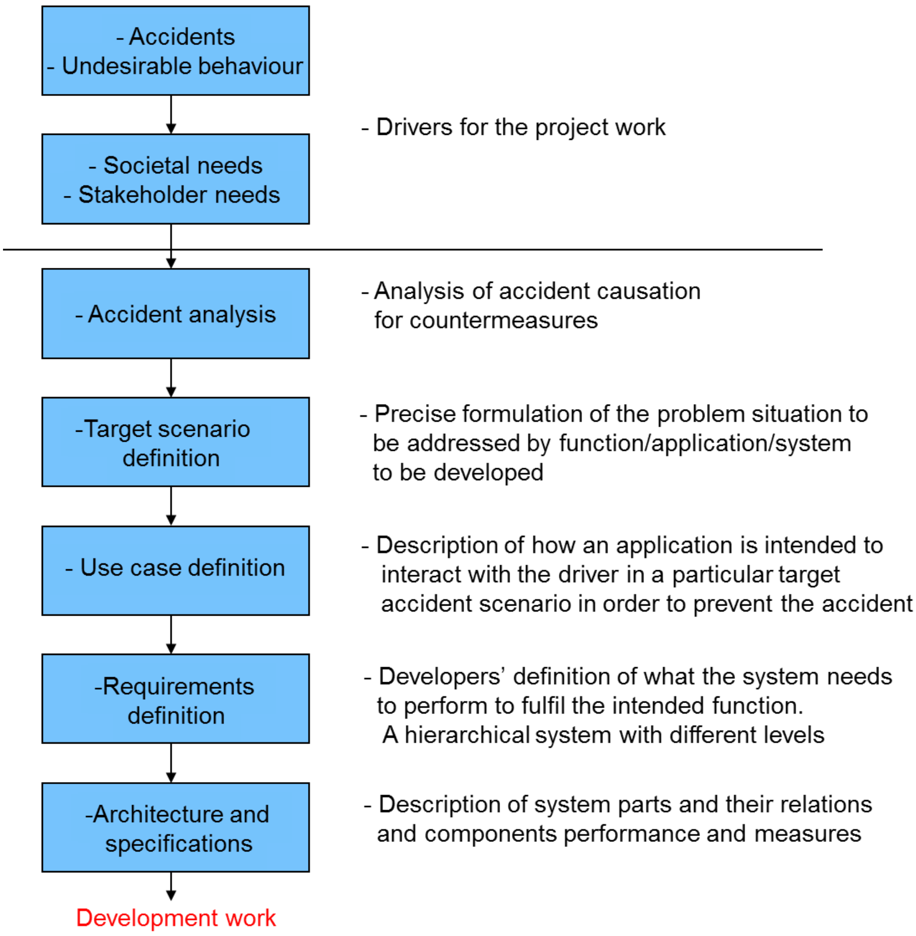


Figure 6: interactIVe methodology process

The term "target scenario" refers to the "problem scenario" that a function is intended to address. In most cases, this relates to road accidents although target scenarios may also describe other undesired outcomes such as, for example, traffic rule violations. The target scenario thus describes a flow of events leading to an undesired outcome which may be prevented, or mitigated, by the envisioned interactIVe function.

Since interactIVe focused on safety functions, the great majority of the target scenarios were derived from road accident data. This involved both high-level statistics (frequency and injury distributions) on the general targeted accident types as well as more detailed descriptions, based on in-depth accident analysis, on the flow of events (including driver- and vehicle kinematic states) leading to the accident.

For the fulfilment of all the target scenarios inside interactIVe project, a common set of high-level building blocks were considered as depicted in Figure 7. This provided a harmonised approach and supported the identification of commonalities for the subsequent development phase. The building blocks of the system lie on four discrete layers which are:

- The Sensor layer.
- The Perception layer.
- The Applications layer and
- The Information, Warning, and Intervention (IWI) layer.

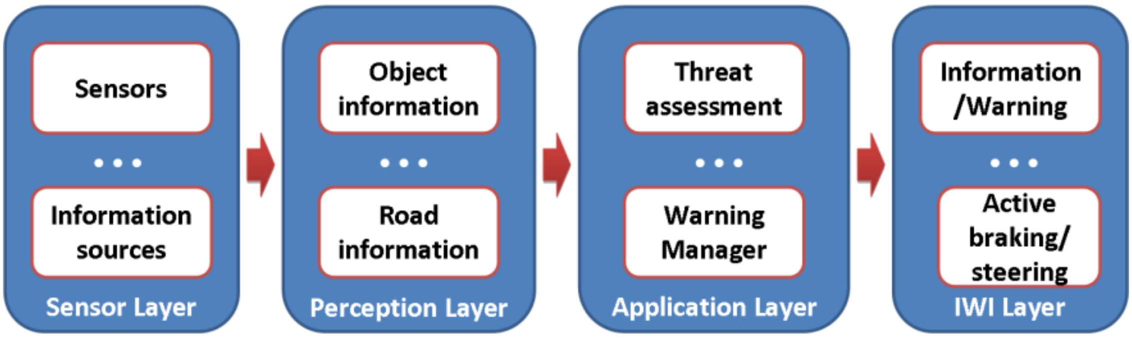


Figure 7: Building blocks of the interactIVe system

A systematic approach was applied to the project planning. On one hand, the work built on what was achieved in previous active safety systems projects, especially in PReVENT by going more to the actuation now. Then the idea was further to enhance sensor data fusion approach and introduce a cost-conscious approach to the system design so that the maximum benefit would be obtained with as few sensors as possible. This was to decrease the system manufacturing costs and speed up the market development, and introduce active safety systems in lower segment cars as well.

Furthermore, the idea in the project concept and applications development was strongly anchored to the analysis of accidents and target scenarios derived from them. Target scenarios helped to describe the problem situations drivers meet with on the road. This again led the project to the use case definition when ideas about the way the system needs to interact with the driver and vehicle to clear the hazardous situation. So, the procedure was stepwise as described in Figure 6 above, and eventually led the system designers to the point of actual technical development work highlighted in vehicle integration and validation tests.

2.2 Perception

2.2.1 Objectives

The technical goal of the project was to build a common perception framework, where general perception modules would not be implemented individually for a dedicated application, but instead, the common framework would be able to serve multiple applications together. Here the following topics of the Perception Platform are covered:

- Objectives
- General sensor interfaces
- Perception Horizon requirements
- Functional architecture
- Perception modules and research activity
- Reference platform.
- Perception Modules evaluation

The challenge to derive the requirements of a common framework is manifold: First, different kinds of applications for safety and continuous driving support have to be served, which results in an increased number of internal perception framework modules. Additionally, the dependencies between the modules increase the links and interactions between the modules. It has to be ensured that the communication between the modules is strongly harmonised. Third, the general sensor and sensor interface requirements for the various sensor types such as radar, lidar, camera, ultrasonic and then the map and communication have to be coordinated with the modules requesting their input. And last, the output of the Perception Platform, the Perception Horizon, will present the vehicle surroundings in a unified manner despite the fact that the information originates from different sensors and from different modules.

2.2.2 Perception sub-system

In interactIVe multiple integrated functions were developed for continuous driver support, but also for executing active interventions for collision avoidance and collision mitigation purposes, all served by an integrated perception layer. The primary objective was to extend the ADAS scenarios in range and usability by introducing a unique access point, the so-called *perception layer*, where not only different fusion approaches will fit into the same concept, (see [Luo 2007] for a definition of sensor, object and situation fusion) but also all applications have an access to a sensor, digital map and communication data through a common interface: *the Perception Horizon.*

The role of sensing and interpreting the environment is performed by the Perception sub-system. The perception sub-system consists of:

- The sensor interfaces.
- The perception modules and
- The output interface (Perception Horizon).

Different types of sensors were used ranging from radars, cameras and lidars to GPS-receivers for the extraction of the electronic horizon (based on ADASISv2). Each perception module can receive input directly from the sensors or output from the other modules. The aim is to provide necessary information about vehicle environment for applications to be developed by other vertical sub-projects. Inside the perception layer different fusion approaches were examined. Apart from the Perception sub-system implementation for interactIVe demonstrators described in D1.0-Reference Perception Platform, an important parallel task assigned to SP2 was to study and present advances and innovations in the area of information data fusion and processing while supporting applications' situation-specific assessment. This latter research work has been presented in the dedicated deliverable D2.2.

2.2.3 Requirements

High level requirements for all elements of the Perception Platform were derived during the requirements phase of the project:

- A unified output interface to all applications, the Perception Horizon.
- Common modules inside the framework.

- A common internal architecture.
- Common sensor interfaces to enable attachment of various sensors.
- A software framework and a hardware platform.

Two key sources of information were used: the applications' requirements delivered by the interactIVe vertical sub-projects (VSPs), and the expertise of various specialists familiar with sensors, methods and applications.

The result was a list of perception framework modules which not only cover sensor data fusion, but also enhance information about e.g. the ego vehicle position and the surrounding. Some modules are only internal to the perception framework and do not have a direct output to the Perception Horizon.

Next to the modules, the requirements on the general sensor interfaces and on the perception horizon interface were derived. The functional architecture was designed to reflect the links between the modules, the sensors and the perception horizon.

As a horizontal sub-project Perception was working on the development of a Perception Platform that is able to deliver a description of the environment around the vehicle. The output of this platform was delivered in form of an interface called Perception Horizon interface. The Perception Horizon is the joint output of the perception layer (including inputs from maps, sensors and communication) and is a superset of the ADASIS v2 interface. Figure 8 depicts the principal structure of the perception layer to be realized by the sub-project.

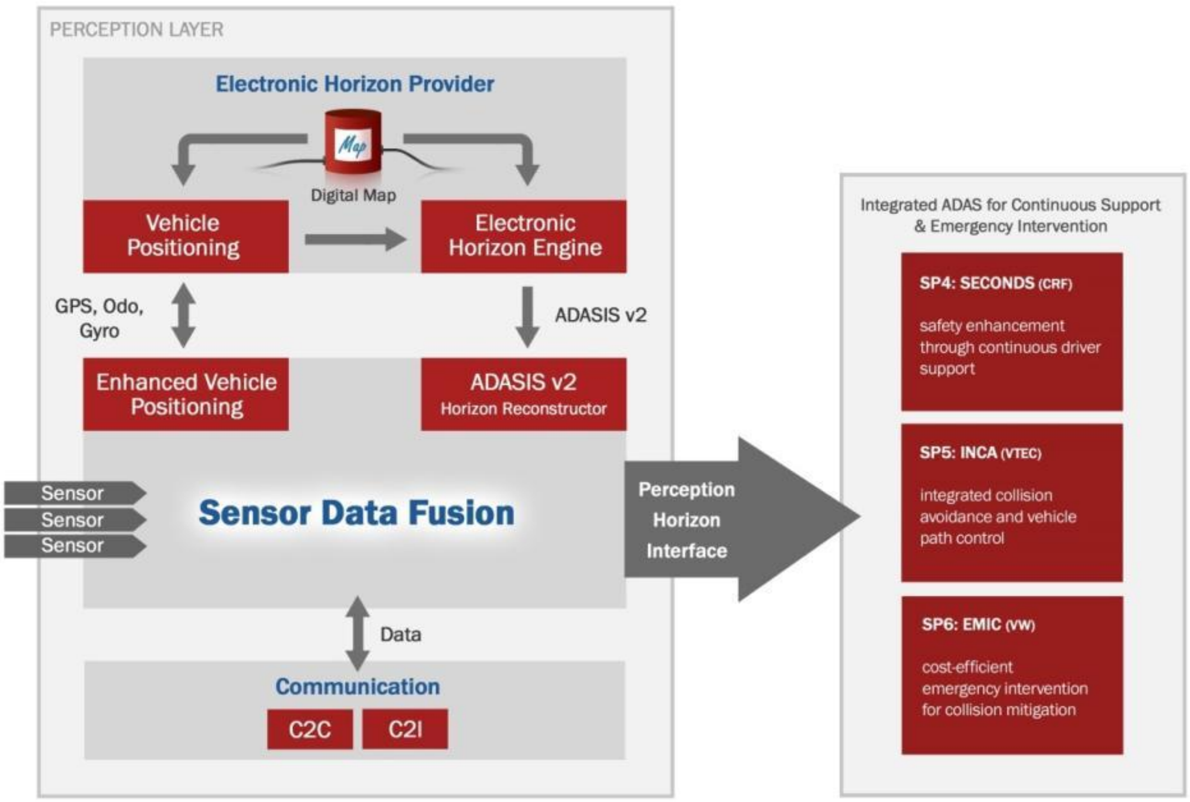


Figure 8: Description of the perception layer

In SP2 WP23 was defined to work on the perception requirements of the Perception Layer, and the following tasks were concluded during the runtime of this work package:

- Analyse requirements from the sub-project applications and define sensor interface requirements to achieve highest performance.

- Define requirements for the Perception Horizon, which includes the ADAS horizon interface, vehicle positioning and communication interface.
- Describe and analyse the Perception use cases that will be considered in this SP. The use cases refer to the situation specific fusion modules.

To fulfil those tasks as a first initial step a complex analysis of different sources of information was necessary including:

- I-2: Internal report that summarizes all perception requirements in terms of software, hardware, perception input, perception and communication from the sub-projects SP4, SP5 and SP6.
- Target scenario descriptions of each sub-project.
- Functional descriptions of the applications targeted by each demonstrator vehicle.

Taking all the collected information into account, perception use cases were derived which are aimed to fulfil the requirements and provide the necessary information about the current vehicle environment for the applications to be developed by the vertical sub-projects.

As a result of this analysis currently eleven general SP2 and eight VSP specific perception modules were identified. Table 1 provides example of such perception module use cases.

Table 1: Examples of perception use cases.

Example	Perception characteristics
Road data fusion	Extend road geometry reconstruction based on vision-based lane and road boundary recognition by fusing these data with the electronic horizon digital map data.
Calculation of vehicle trajectory	List of future position points (X,Y) in fixed time steps
Assignment of objects to lanes	Extend object tracking information by classifying the detected objects to lanes in order to know if there are objects in the ego lane or the adjacent lanes.

As a subsequent step for each perception use case a working group of experts including developers of the module, sensor suppliers and ‘consumers’ defined the respective requirements starting with the assignment of relevant requirements coming from the VSP. In this process also general requirements on the output and input interfaces of the use cases were derived.

Overlapping with these activities working groups of sensor experts from suppliers and OEM companies defined necessary general sensor types and interfaces as input sources to the use case modules. Working groups for long range radar, lidar, camera, digital map, C2X and other types of sensors were activated. The results of these groups were individual requirements on type-specific sensors and sensor interfaces. These interfaces were later on specified during WP24 in a way that a plug-in concept for different sensors of the same type could be implemented on the basis of a SW-Framework supporting such kind of concept.

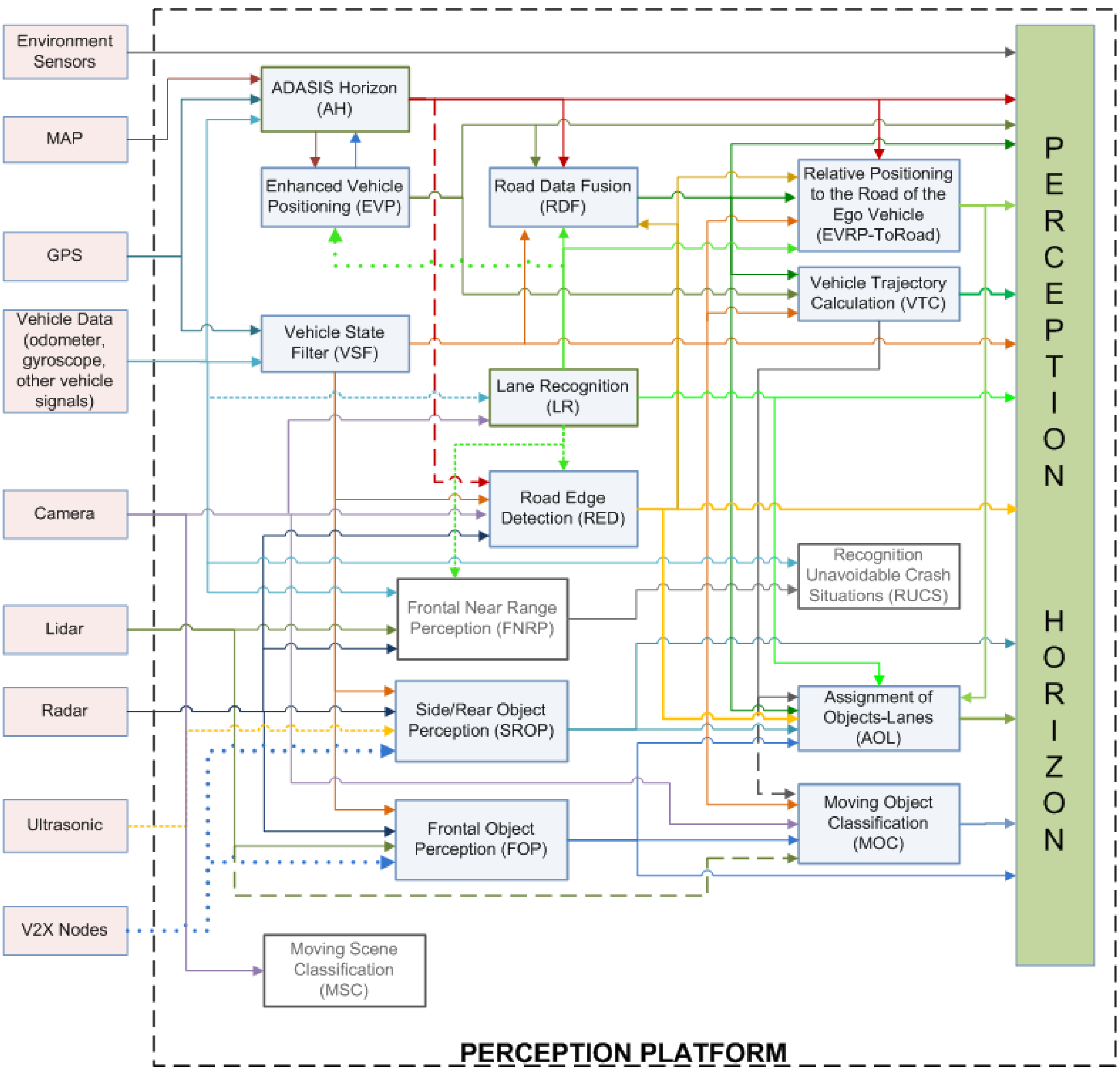
On the other hand, a dedicated working group worked on the integration of a single perception use case output interfaces to the Perception Horizon interface with the result that top level requirements were derived.

A task group working in parallel defined the requirements of the hardware and software for a reference implementation (called reference platform) of the perception framework. This task supported the necessary selection process of hardware and software components in a later phase of the project.

As a preparation of the specification phase of the sub-project Perception (WP 24), a first system architecture based on the perception use cases and identified interfaces were sketched to round up the description of the targeted Perception Platform.

2.2.4 Specifications and architecture

During the specification phase of the project, the SP2 teams were involved in intense discussions with the interactIVe demonstrator research teams in order to collaboratively derive the Perception Platform requirements and specifications that would enable the applications' envisioned functionality. This work included interface, components and high-level/low-level functional as well as non-functional specification for the Perception Platform and Modules (Figure 9).



Components in blue: Reference Perception Modules developed for demonstrator vehicles.

Components in grey: Research Perception Modules developed for SP2 purposes.

Figure 9: Architecture of the Perception Platform

Major outcomes of the specification phase included:

- Generic input interfaces for the considered types of input sources were compiled (see D1.7 Annex).
- SW/HW RPP specifications for efficient implementation of the reference framework.
- Perception Horizon non-functional specifications covering all possible applications were foreseen in interactIVe.
- Perception Modules functional and non-functional specification based on the targeted functionality and level of object and situation awareness required.

Each perception module could take input directly from sensors or output from other modules, and it was aimed to provide necessary information about the vehicle environment for the applications to be developed by other vertical sub-projects. Two examples of Perception Modules definition as these were specified in [INT D1.7] are provided in Table 2 (for complete module specifications see the Annex of [INT D1.7]).

Table 2: Two examples of perception module functional specification

<table>
<tr><th>Name</th><th>Purpose</th></tr>
<tr><td>Frontal Object Perception</td><td>The objective of the module is to detect every relevant obstacle in the front area of the ego vehicle including stationary and moving objects and provide information about these objects (e.g. detection confidence value, ID, position, static/moving flag, moving direction, velocity, acceleration and estimated object size).Sensor data fusion and advanced filtering techniques should be taken into account in order to obtain a more reliable perception result and provide additional information not directly observed from sensor (e.g. estimation of object velocity from lidar data). In contrast to the "frontal near range perception" module this module is more general taking into account also the far range which is closer to Continuous Support and Safe Cruise functions.</td></tr>
<tr><th>Required Input Sensors</th><th>Required Input Perception Modules</th></tr>
<tr><td>Camera (tracked data)</td><td rowspan="4">Vehicle State Filter</td></tr>
<tr><td>Radar (tracked/untracked data)</td></tr>
<tr><td>Lidar (tracked/untracked data)</td></tr>
<tr><td>V2X data (optional)</td></tr>
</table>

Name	Purpose
Road Data Fusion	Road Data Fusion module aims at increasing the accuracy of the road attributes provided by the individual sources of information as the vision lane tracker and map data. Road features are extracted from the image processing units (LR and RED modules) and are fused (first segment) and extended (remaining segments) using the map road geometry. Additionally it increases the availability and robustness of the system i.e. lane information should be always available even if they are artificially reconstructed in absence of visible lane markings using only map data. The output of the module will be a list of road segments. Every segment will be described from the following attributes: Equation describing the geometry of the segment; Alternatively, attributes: segment initial point coordinates, segment length, curvature, curvature rate Road width (fused) Lane width (fused) Quality flag Road geometry is delivered with respect to the ego-vehicle local coordinates system.
Required Input Sensors	**Required Input Perception Modules**
-	ADASIS Horizon
	Enhanced Vehicle Positioning
	Lane Recognition
	Road Edge Detection

2.2.5 Sensor data fusion

Based on the collaboration and interaction with the demonstrator development teams, the orientation of the SP2 sensor data fusion activity was directed towards modules that were considered essential for the interactIVe applications or were missing from previous related European projects (e.g. PReVENT and HAVEit).

The sensor data fusion and processing work in interactIVe as a whole investigated the relationship between the ego-vehicle and the surroundings providing a unified look of the driving environment spanned by different sensor sets at regular and in principle very fast updates. Four general sensor data fusion directions were derived:

1. The estimation of road width and the position within the road; (please note at this point that run-off road prevention is an application objective that has appeared quite recently in the ITS community and its application in the interactIVe truck demonstrator implies additional stability constraints to the project application development).

2. Robust tracking of vehicles, motorbikes and pedestrians in the vicinity of the host vehicle in very dynamic environments. This may include highly cluttered urban environment or may include overtaking scenarios by other vehicles coming with high

speed or temporarily hidden from driver's field of view (blind spot position); In line with this latter requirement, track ID maintenance during targets' transitions through the frontal and side-rear areas of the host vehicle was considered very useful.

3. Understanding contextual and environmental conditions of the host vehicle surroundings in order to assist the situation awareness task involved in all applications.

4. Developing a robust and accurate object detection system by also considering the use of a cost-efficient set-up (e.g. camera based system).

In accordance with the available SP2 and VSPs test vehicles available for this purpose, the above directions were particularized into a set of perception modules to be developed and evaluated in this work. They were outlined as follows (note, that Lane Recognition is not included below as it is provided by the camera sensor):

- *Vehicle State Filter (VSF)*

The vehicle state filter filters the state representation of the vehicle derived by the production vehicle sensors and additional gyroscope and GPS-sensors. An Extended Kalman Filter (EKF) filter with appropriate model has been used to filter the signals and derive associated uncertainties. Furthermore, additional parameters such as yaw rate offset and velocity scale compensation factors are derived. Velocity signals can be provided even when wheel slip occurs, and similarly, vehicle heading can still be provided when the GPS is temporarily unavailable.

- *Adasis Horizon Module (AH)*

A customization of the well-known ADASIS v2 Horizon Provider for the project's objective. Perception platform modules that use digital map data, they can retrieve required data using ADASIS v2 API.

- *Enhanced Vehicle Positioning (EVP)*

This module provides a more accurate absolute vehicle position message by the information about the current lane on which the ego vehicle is actual driving. The current lane information is coming from the lane recognition camera sensor.

- *Road Data Fusion (RDF)*

Road features are extracted from the image processing units (LR and RED modules) and are fused (first segment) and extended (remaining segments) using the map road geometry. Additionally it increases the availability and robustness of the system since lane information can be always available even if they are artificially reconstructed in absence of visible lane markings using only the map data.

- *Assignment of Objects to Lanes (AOL)*

This module uses the positions of the detected objects and the available lane geometry and assigns a lane index to each one of them. The lane index is extracted using the relative distance of the detected objects from the lane markings.

- *Ego vehicle lateral position to the Road (EVRP-ToRoad)*

This module aims at providing the relative positioning of the EV with respect to the road combining information from road geometry and from vehicle motion vector. A more accurate position of the EV is given, assigning a lane index and a lateral offset along with a heading to the lane marking.

- *Short Vehicle Trajectory Calculation (VTC)*

This module provides the future trajectory of the ego vehicle as a list of points in the local ego-vehicle coordinates. Estimation of the ego-vehicle future path is based on the fused road geometry provided by the RDF module and the vehicle dynamics provided by the VSF module.

- *Frontal Object Perception with Moving Object Classification (FOP-MOC).*

An advanced frontal object perception module based on *occupancy grids* fusion and *attention-focused data fusion* approaches for laser, radar and camera for high dynamic situations, such as urban scenarios where pedestrians are included in the objects of interest. The approach included identification of static and dynamic parts of the environment, tracking of moving objects and classification of moving objects in almost real-time.

- *Pedestrian Detection (PD)* - only for research purposes (sub-case of moving object classification).

Complementary to pedestrian classification offered by the previous more general object perception module, a vision-based approach to pedestrian detection and tracking was offered. The target was to create a real-time pedestrian recognition system based on a monocular camera, which would not require special hardware acceleration.

- *All-around Object Perception (OP)* - only for research purposes.

An advanced all-around (360 degrees) id-maintenance object perception module for fast/slow scene changes including all surrounding moving and stationary objects. All-around Track-ID maintenance was addressed for the VTEC research truck in this research module implementation. Id maintenance objective mainly referred but not limited to the tracked vehicles approaching from the rear-side area moving to the side-front area and the track-ID assigned to these vehicles were kept the same during this transition. The approach could be built upon the discrete Frontal Object Perception and Side-Rear Object Perception modules of the RPP (see [INT D1.7]).The application of the approach to a 360 degrees area around the host vehicle is novel.

- *Road Edge (or Boundary) detection (RED and BD modules).*

Here, the fusion “object” is the natural or infrastructure imposed road boundary. The *road boundary* was defined as the border of a *drivable area.* This is considered to be the change between the homogeneous road surface and the off-road area such as gravel, grass, pavements etc. - the *road edge* - or a solid *road barrier* like a guardrail. The research module had to be able to recognize road boundaries without lane markings. Two versions of this research module were implemented: one is multi-sensor based (RED) and one is only camera based (RB).

- *Frontal Near Range Perception (FNRP) and Recognition of Unavoidable crash Situation (RUCS) - only for research purposes.*

Robust, accurate and dynamic perception of all relevant obstacles in front of the ego vehicle for identifying pre-crash situations (including cases of high dynamic traffic scenarios). One level higher (situation fusion), a Recognition of Unavoidable Crash Situations (RUCS) module has been developed based on the object fusion output of the FNRP. The approach utilized *attention-focused* data fusion for emergency situations. This was accomplished by controlling the fusion system based on areas of interest provided by the situation refinement level.

As a basis for this perception module development, raw detection data from laser scanners and targets from long range radar including a mid-range mode was used. For data collection and evaluation of these two modules a SP2 dedicated test vehicle was equipped with two Sick laser scanners and Delphi ESR long range radar together with comprehensive ground truth measurement equipment.

- *Moving Scene classification (MSC) - only for research purposes.*

This was a vision-based scene classification approach from a camera mounted on a moving vehicle. It provided conceptual understanding of the scene surrounding the host vehicle by assigning a semantic class label (e.g. “inside tunnel”, “rural road”) to the scene scanned by the camera sensor. Novel image and video representation and fusion techniques were investigated. Although most of the video scenes recognized by the approach include static categories of a scene like rural, highway and urban (categories that can be easily provided by a static map information provider), we included also a differentiation between highway with traffic and highway with no traffic class: these two classes show the applicability and usefulness of the method to recognize dynamic semantic characteristics of the scene that cannot be provided by a GPS-based system.

Modules with advanced research objectives

Inside the perception layer different fusion approaches were examined while SP2 dedicated research module development -independent from the reference platform and the interactIVe demonstrators- was performed in parallel with the selected research topics. The advanced research activity takes place in 8 out of 14 perception modules described above and spans the following fields, also highlighted in Figure 10:

- Efficient spatial and state representation of the static and moving parts of the environment including pedestrians.
- Track id maintenance between side-rear and frontal areas surrounding the host-vehicle.
- Road boundary detection and tracking.
- Pedestrian detection and tracking based solely on vision.
- Road scene classification for environment semantic understanding.
- Frontal near range perception that functions under rapid scene changes and is coupled with a powerful situation assessment implementation for recognition of not easily detected but unavoidable crash situations (e.g. at cross-roads).

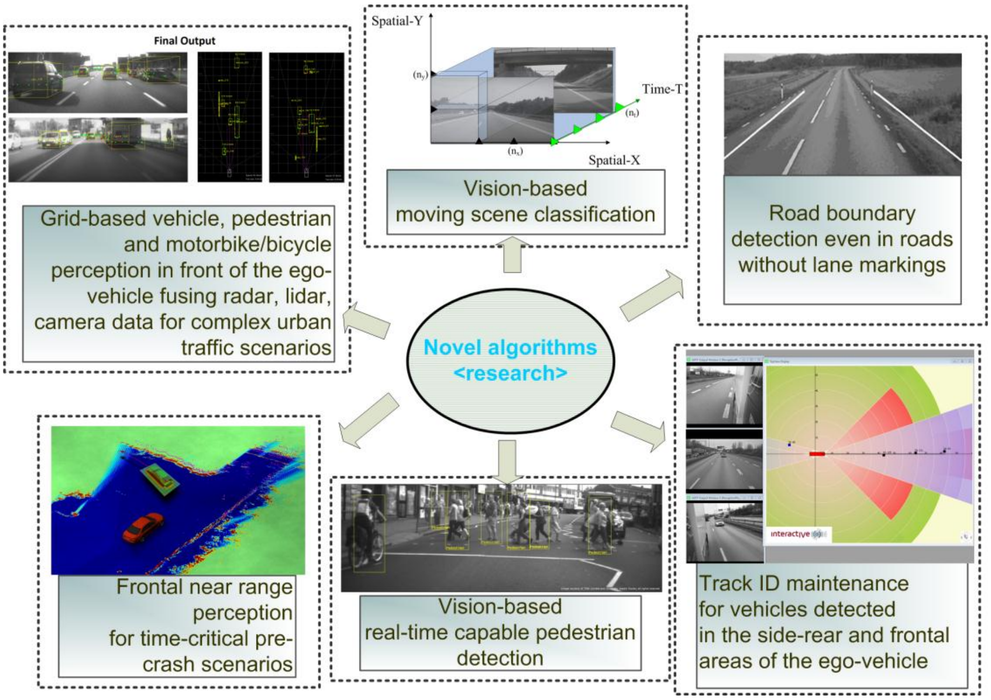


Figure 10: Advanced research activity overview scheme

The research modules developed - they either extend the interactIVe Perception platform functionality by adding more intelligence to the existing Perception modules (cases of FOP-MOC, OP and RED modules) or develop from scratch a new Perception research module in order to investigate an agreed research target not covered by the reference implementation (cases of FNRP-RUCS, MSC, PD and RB modules). Research results and remarks on sensor data fusion strategies limitations and potentials can be found in an analytic way in project deliverable D2.2 [INT D2.2].

2.2.6 Description of the reference Perception Platform

The Perception Platform consists of the sensor interfaces, the perception modules and the output interface (Perception Horizon). SP2 provided a reference implementation of the Perception Platform called Reference Perception Platform (RPP). The RPP design considers the functional, SW, HW and PH (Perception Horizon) requirements for PP modules, derived by SP2 in close co-operation with the VSPs, and is reported in Deliverable D2.1 [INT D2.1]. The D1.0 included detailed information of the RPP implementation, while the actual Perception Platform installed on each of the interactIVe demonstrator vehicle can be found in the demonstrator dedicated chapters and was adapted according to the actual vehicle equipment.

The RPP is a software-environment where the perception modules are integrated and their algorithms are executed within a common time framework. Moreover, the RPP implementation provides. a set of generic sensor decoders as well as the Perception Horizon decoder complemented by a Diagnostic module and a Data Logger module. For its implementation the Assist Automotive Data and Time triggered Framework (ADTF) tool was used. A high-level functional architecture overview of the reference Perception Platform is presented in Figure 11. The actual physical allocation of each PP module is presented in this figure. The architecture also includes logical sensors or external PP modules (running in a different PC) located in specific input elements of the main platform (at the left of the PP input manager). This fact reflects the specific architecture design followed for interactIVe demonstrator vehicles based on the selected set of physical and logical sensors.

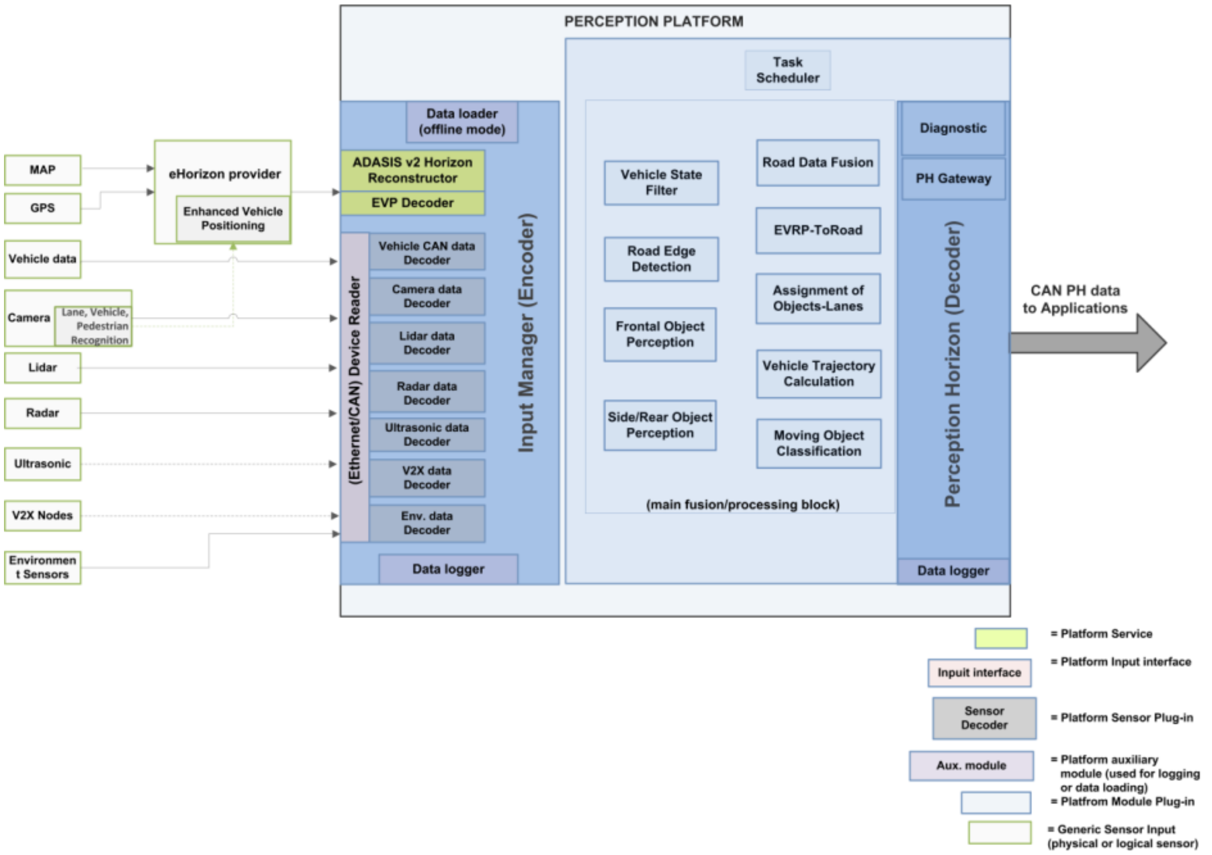


Figure 11: SW functional components of the Reference Perception Platform and its inputs/outputs.

Each of the SP4, 5, 6 sub-projects had its own target scenarios fulfilled by specific application functionality, and each function obtained a part of the perception “awareness” it needed from the perception layer. For demonstrating the use of a unified Perception layer, three of the demonstrator vehicles, namely the VTEC, FORD and CRF demonstrators used the Perception Platform reference implementation and carried out situation assessment based on the defined Perception Horizon interface.

Reference Perception Platform internal architecture:

The reference Perception Platform was designed following the principles of modularity and processing levels flexibility. This latter is defined by three principles:

1. A central, synchronous Modules’ triggering is applied for each sequence of processing (Task Scheduler or Cycle controller component).
2. Sequential module processing is used when imposed by the fusion strategy (e.g. the case of Assignment Of-Objects-To-Lanes module that requires the inputs of RDF and FOP modules). In each sequence each module is triggered by one module of the previous level in the sequence.
3. Parallel module processing is used for modules implementing an independent perception task (the case of FOP-MOC module in CRF demonstrator).

Please note that (3) constitutes an update from D1.7 and was included in order to cope with the high processing requirement of FOP-MOC module without violating the overall update rate of the platform cycle.

An example of the Perception Platform internal processing flow as customized for the CRF demonstrator is shown in Figure 12.

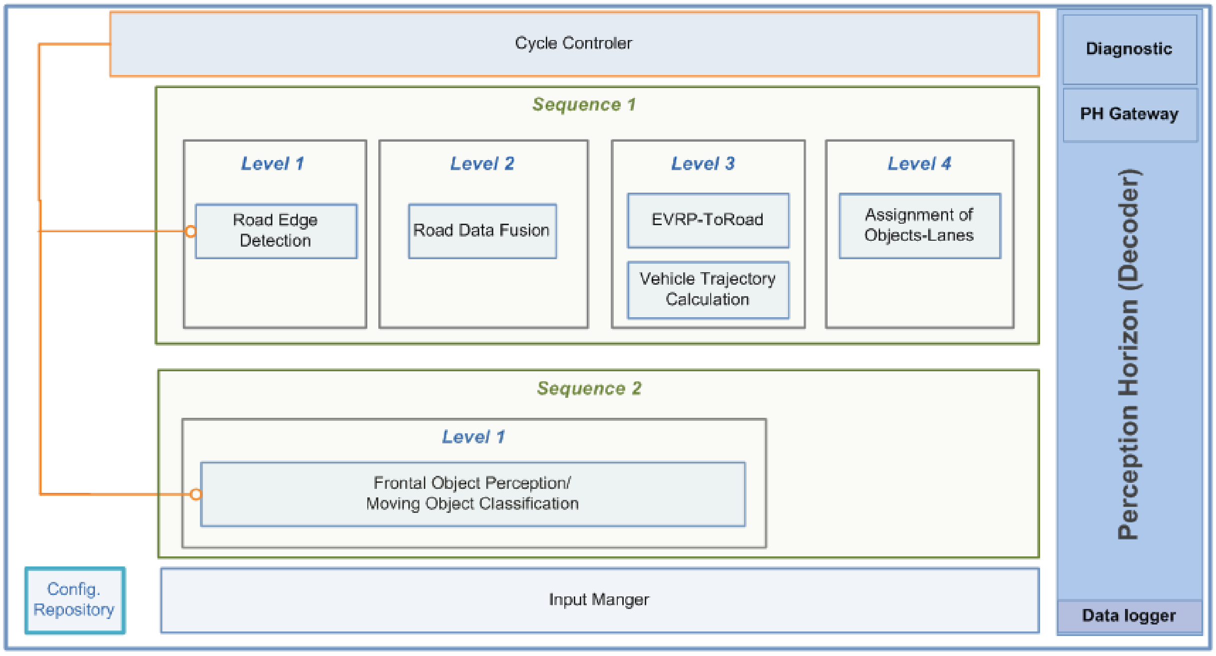


Figure 12: Example of internal processing flow in CRF Perception Platform: two sequences of processing run in parallel, triggered by the Cycle Controller.

2.2.7 Perception Modules evaluation

SP2 evaluation of the research modules was based on logged data provided during the development of the Reference Platform by both the VSPs and the SP2 teams. More specifically, one research vehicle was implemented and dedicated to the FNRP and RUCS modules' testing, namely the DAI vehicle demonstrator while the three demonstrator vehicles using the reference platform, namely the VTEC truck, the CRF vehicle and the FFA vehicle along with the VCC vehicle were used during different perception modules' evaluation. Evaluation methodology for each of the research modules was adapted either to the applications' objectives or to scientific standards. Semi-automatic annotation tools for video verification data were developed specifically for SP2 evaluation purposes due to lack of detailed ground truth data (public or from the project). Examples of the tools developed for Perception Platform evaluation are provided in Figure 13.

a) Daimler test car with external crash bumper and impact detection sensor installed;
b) Road boundary manual annotation visualization: The white lines mark the bounds of the labelled area. Each hypothesis within this area is assumed to match the road boundary. The dashed line marks the centre of the area, which represents the ground truth of the lateral offset.
c) and d) Road objects semi-automatic annotation tool developed for he purposes of the project.

Figure 13: Perception platform evaluation tools

2.2.8 Perception research conclusions

The development of the reference Perception platform in interactIVe provided the first integrated test bed for testing the concurrent use of a wide range of ADAS applications in real-world scenarios. In part of these scenarios, the requirements for active intervention used in time-critical collision avoidance situations pushed the know-how in the development of integrated information processing platforms that are able to use a synchronization framework that supports parallel processing (multi-threading) and close-to real time capabilities. Modules that used image processing techniques were proved quite time-consuming so different feature extraction and object tracking techniques were tested in order to guarantee low processing times. Specific limitations due to multi-threading support in the PC operating system were identified from the reference platform processing time evaluation, leading to the conclusion that real-time operating systems are more appropriate for future deployment of such a Perception Platform on a PC or on an embedded environment. The generic sensor interfaces as well as the unified Perception Horizon output interface show the road for a plug and play concept in sensor data fusion platforms. Although perception sensor development (radar, camera and laser scanner) is an ongoing topic since years there is still demand for improvements in case new functions and applications should be served that demand for higher reliability in object detection and highly accurate position and velocity measurements at the same time. For radars and cameras in near range perception and side-rear perception applications a wider field of view would be beneficial. For perception systems based on sensor fusion technology externally triggered sensors and low signal latency times would be another main development target for the sensor industry in the future.

The set of the Perception modules implemented and used inside the reference platform are considered to advance the state-of-the art in real time processing capability. Furthermore, in the sensor data processing and fusion, the state-of-the-art was advanced by the Road Edge Detection module, Moving Scene Classification Module, Frontal Near Range Perception, Frontal Object Perception and Surrounding id maintenance modules through the development of novel perception concepts. In terms of road data representation, road edge annotations for highways as well as roads with no lane markings were provided by the project for the first time in the literature and revealed the need for complete road representation groundtruth data. Results from the fusion of camera and map data for road representation revealed the need for more detailed and precise map data (e.g. lane width, number of lanes) based on the fact that vision-based road edge tracking has always the limitations of a short range. Based on the evaluation of the research modules developed for environment perception, scientific and technical recommendations as well as directions for future research are provided in the Annex 1.

2.3 Information, Warning and Intervention (IWI) strategies

2.3.1 Objectives

Information, Warnings and Interventions (IWI) determine the function from a driver perspective. If the driver's perspective and actions are neglected, information and warning on approaching safety critical situations could be missed by the driver and a system initiated support action such as a collision avoidance manoeuvre, although technically optimal, might be counteracted by the driver.

Following this, it was crucial to consider the interplay between the vehicle, the automation and the driver when in the design process in order to reach the intended effect from the vehicle based safety function(s).

The objectives for sub-project 3 was to develop so called 'IWI strategies' for the vertical, application-oriented sub-projects (SP4-6). IWI strategies can be seen as design guidelines which refer to how, when and where driver information, warnings, and interventions need to be activated (see also Figure 14).

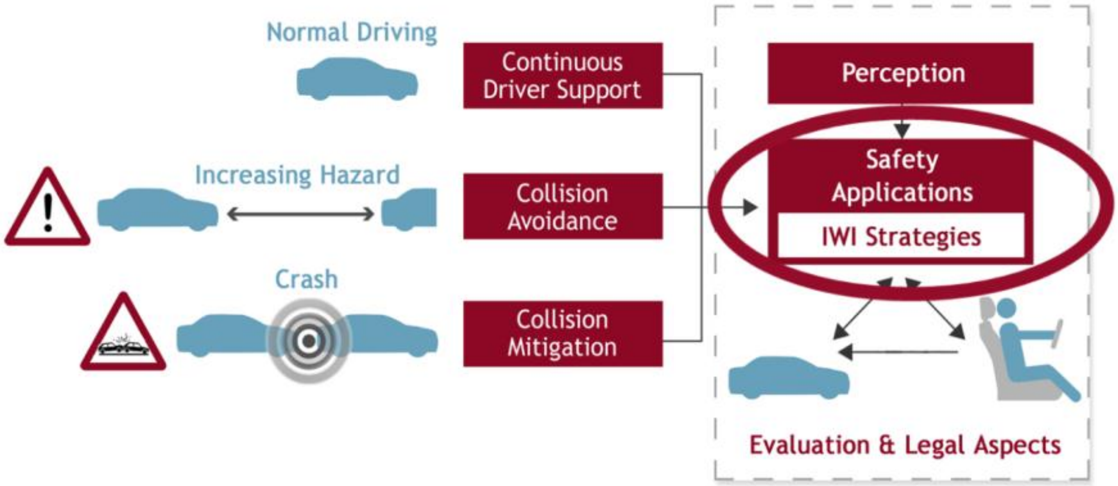


Figure 14: Information, Warning and Intervention strategies as main output from SP3

On a general level this involves guidelines on how to create successful integration of ADAS information, warnings, and interventions into an overall function. Following this the work of SP3 included also the integration of multiple ADAS with respect to their intended effects on driver behaviour and driving performance.

2.3.2 Target scenarios and use cases

The work in SP3 was initiated by the development of detailed use-cases. The use-cases describe how the functions in the different demonstrator vehicles should resolve so called target (or accident / hazardous) scenarios.

The target scenarios in interactIVe were created by the vertical sub-projects (SP4-6) with the main focus on accident prevention and mitigation and an emphasis on the events leading to the crash. In interactIVe target scenarios consisted of descriptions on two levels (Figure 15):

- *Level 1:* A prototype scenario in general terms, based on some existing *accident typology*. The accident typology is normally linked to one or more accident databases. For each Level 1 accident scenario, general statistics regarding (absolute and relative) frequency and injury level distributions as well as key contributing factors were reported based on accident data. Level 1 descriptions included simple pictograms illustrating the accident type (derived from the chosen typology), a general narrative (a short “story” describing a typical flow of events) together with general statistics on the frequency and injury levels associated with the accident type.

- *Level 2:* Descriptions provide details on the flow of events and causal mechanisms behind the accidents. This may include both driver-related failure mechanisms (e.g. inattention, erroneous situation understanding etc.) as well as approximate values of relevant vehicle kinematics parameters (e.g. speed distributions). In order to capture all relevant aspects a narrative, a sketch and a sequence diagram was made.

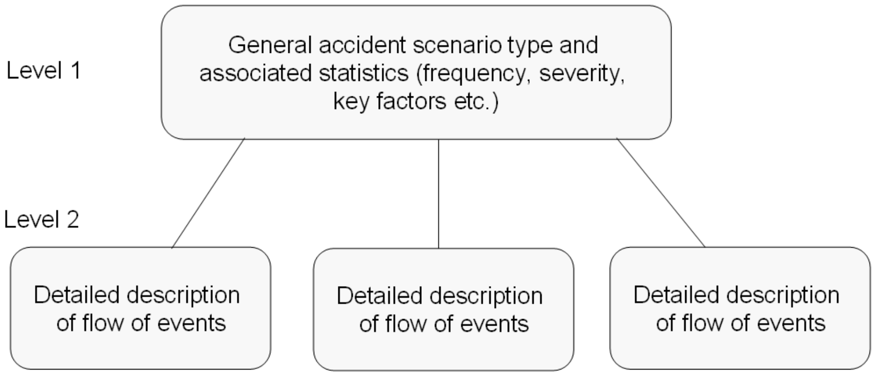
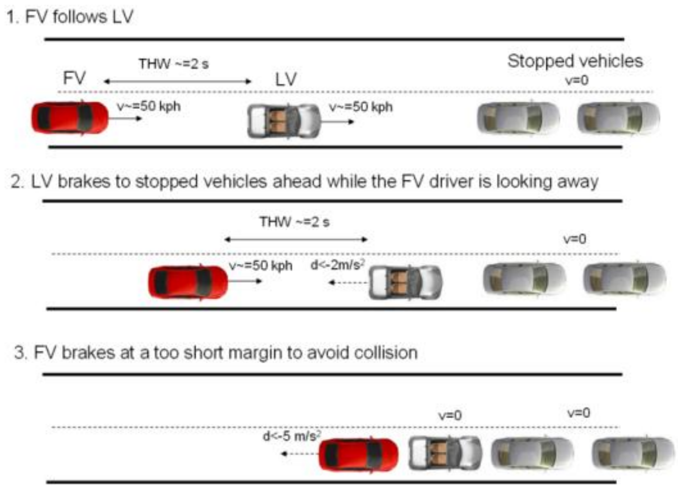


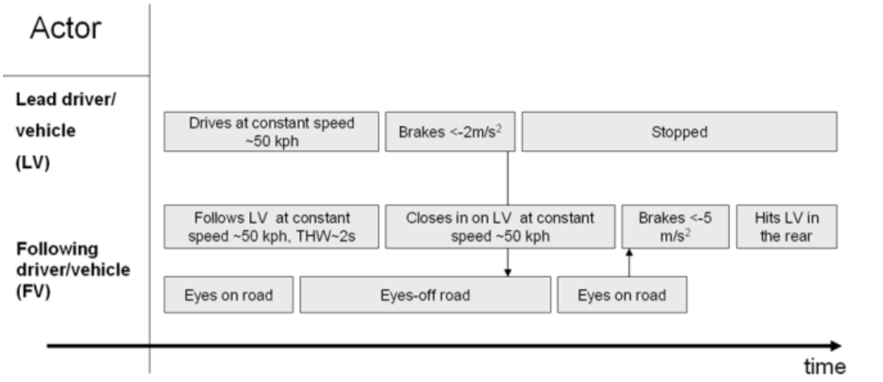
Figure 15: Two level structure for target scenario descriptions

The Level 1 descriptions provide general information on the frequency and severity of general accident types while the Level 2 scenarios serve as the direct basis for the use case definitions. An example of a target scenario can be found in Table 3 below.

Table 3: Example of level two description for a target scenario, with narrative, sketch and sequence/flow diagram

Narrative	*"A following vehicle (FV) is driving behind a lead vehicle (LV) in a rural area at a speed v of about 50 kph at a time headway (THW)[1] of about 2 s. Both vehicles are lightweight cars. The FV driver briefly looks towards an in-vehicle display. During the off-road glance, the LV brakes sharply to stop with deceleration d <-2 m/s² due to a traffic cue ahead. When closing in on the stopped LV, the FV driver's gaze is drawn back to the road by perceptual cues in the peripheral field of view (the optical expansion of the LV). When detecting the emergency situation, the FV driver brakes sharply but the margin to the LV is too small to avoid a rear-end collision."*
Sketch	

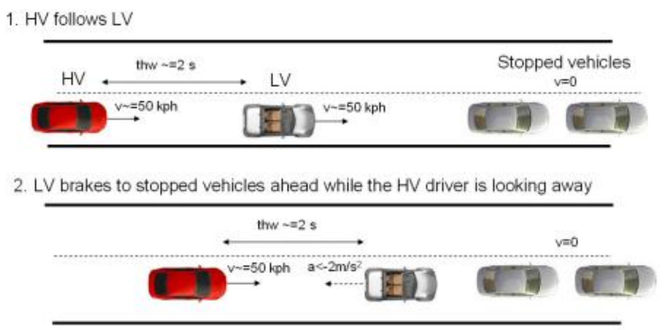
[1] Time headway=the time it would take a following vehicle (FV) to travel the current bumper-to-bumper distance to a lead vehicle (LV) at the current speed.

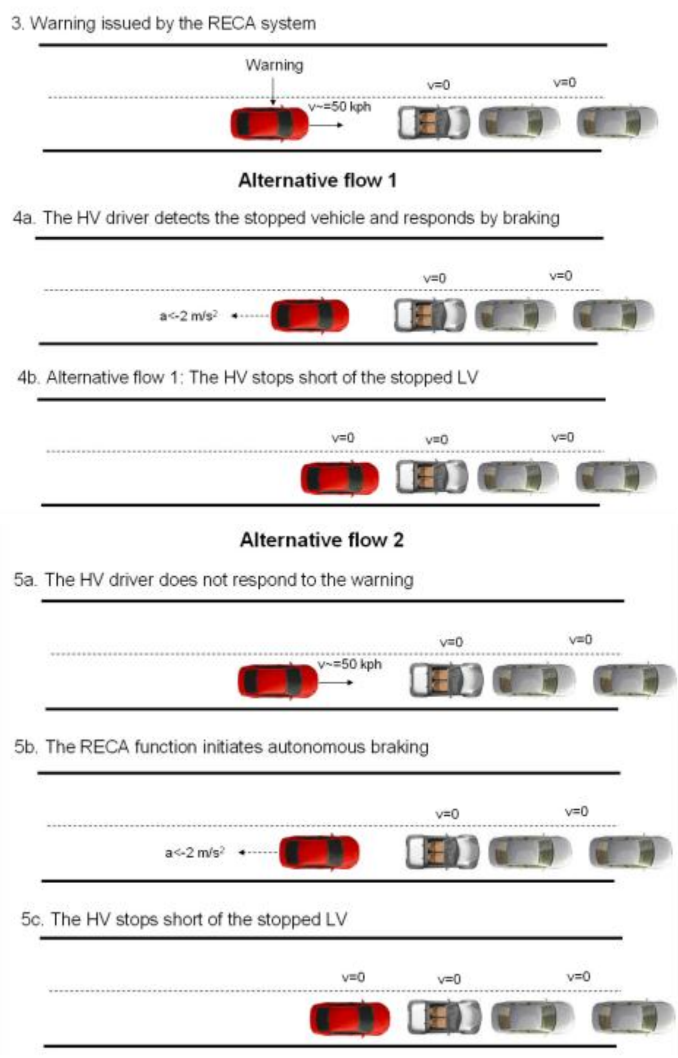
Sequence diagram	

Based on the target scenarios, the use-cases were defined. A use case in interactIVe could consist of several alternative flows of events, which represent different possible solutions to a similar problem. Alternative flows may include different possible interactions for similar use cases or an escalating sequence of events.

Since the use-cases reference back to the target scenarios (e.g. accidents in a queue/rear end collisions) they are created in a similar way, i.e. with a narrative, a sketch (Table 3) and a sequence/flow diagram (Figure 16).

Table 4: Example of use-case descriptions with narrative and sketch.

Narrative	*"The host vehicle (HV) is driving behind a lead vehicle (LV) in a rural area at a speed v of about 50 kph at a time headway (thw) of about 2 s. Both vehicles are lightweight cars. The HV driver briefly looks towards an in-vehicle display. During the off-road glance, the LV brakes sharply to stop with deceleration a <-2 m/s2 due to a traffic queue ahead. The RECA function detects the lead vehicle closing and issues a warning to the driver.* *Alternative flow of events 1:* *The warning redirects the driver's attention and gaze towards the road so that the HV driver is able to perform a braking or steering avoidance manoeuvre in time to avoid crashing into the rear of the LV.* *Alternative flow of events 2:* *The HV driver does not respond to the warning and the HV continues to close in on the LV. The RECA function then initiates autonomous braking which enables the HV to avoid crashing into the LV"*
Sketch	

The sequence/flow diagrams can be used to further describe the driver and vehicle actions as well as environmental and driver states.

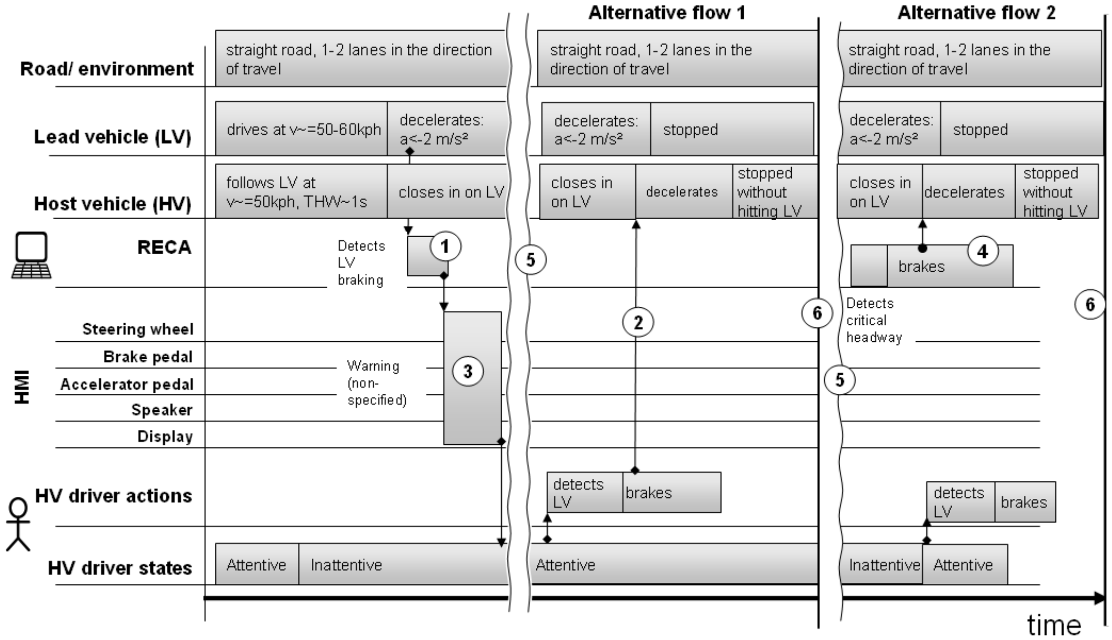


Figure 16: Illustration of the nomenclature for sequence diagrams

The boxes represent approximate time duration of events. What the function intervention is supposed to do (see ① in Figure 16).

Arrows represent when an event directly causes another event, for example a deceleration following a braking action (see ② in Figure 16).

HMI-related actions may be more or less specified with respect to modality and if a specific HMI modality is intended (e.g., an auditory warning), this could be defined by placing the box in this modality. If the specific intended HMI modality is missing, the standard template could be added.

However, if no specific modality is intended, the box should cover all HMI modalities and it should be clearly indicated that the HMI modality is non-specified (see ③).

Autonomous interventions by the assistance function should be specified in the “Assistance Function” field (see ④ in Figure 16).

Alternative flow of events that represent a sequence of actions by the assistance function may be represented in the same sequence diagram with a common beginning and different outcomes.

The end of the common beginning and the beginnings of the alternative flows of events are then represented by a “jigsaw” lines (see ⑤ in Figure 16).

The end of each alternative flow is represented by a straight solid line (see ⑥ in Figure 16).

A thorough description of target scenarios and use cases can be found in Deliverable 1.5 [INT D1.5].

2.3.3 IWI strategies

One of the main outputs of SP3 is the Information, Warning and Intervention (IWI) strategies. The IWI strategies should be applicable both to the specific demonstrator vehicles in the interactIVe project as well as to ADAS beyond the project.

The general IWI strategies can be seen as human factors guidelines or general functional requirements for ADAS. While this report provides an overview of SP3 activities a detailed list of guidelines can be found in Deliverable 3.2 [INT D3.2]. The *applied* functional requirements as well as the Human Factors related non-functional requirements are presented in Deliverable 3.3 [INT D3.3].

The development of IWI strategies in SP3 was done iteratively (Figure 17). The use-cases and initial requirements from the vertical sub-projects served as a starting point for the functions definition. Strategies were evaluated in simulator and test track experiments and updated based on the outcome of the experiments.

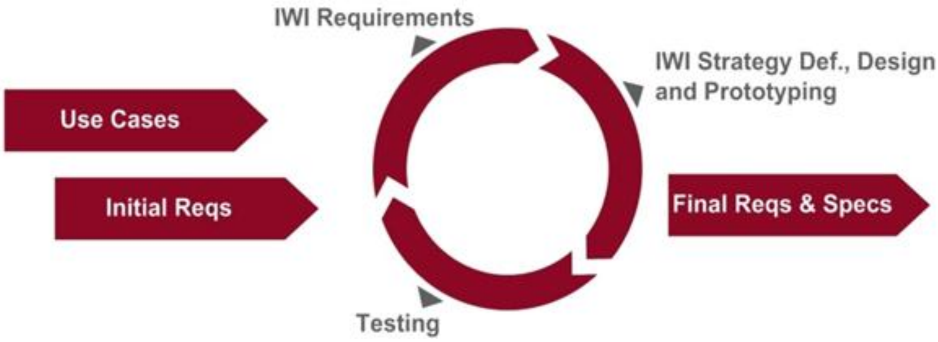


Figure 17: Development process as iterative design-prototyping-testing cycle

A first set of strategy *categories* were defined (Figure 18).

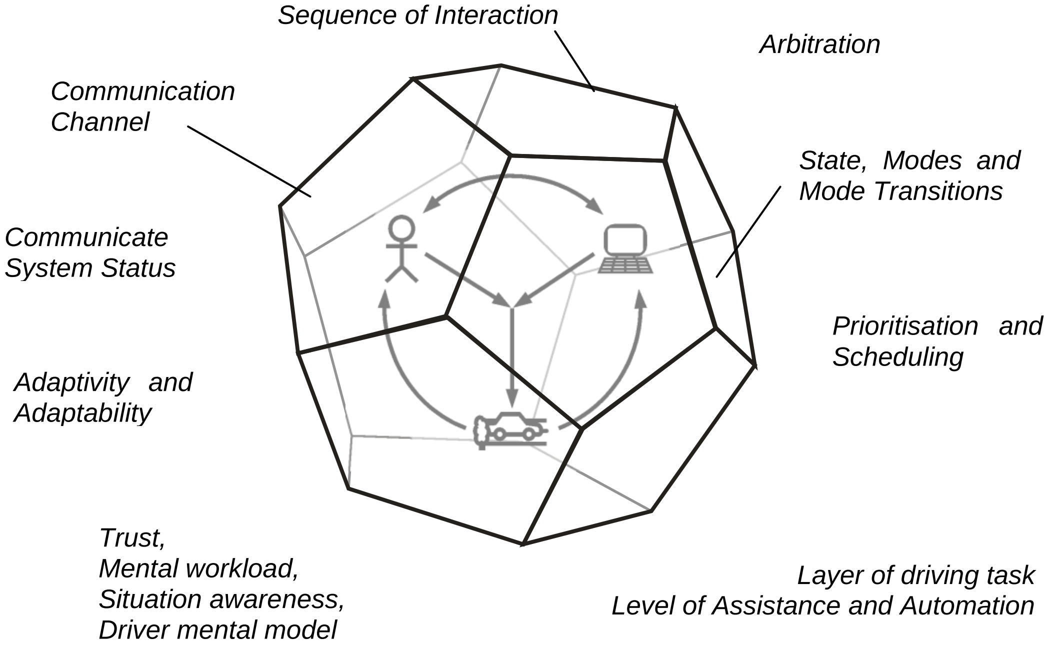


Figure 18: IWI strategy categories

The IWI strategy categories served as a basis for an in-depth literature search. The initial strategy categories should be seen more as structuring concepts in order to be able to proceed with the design:

- *Layer of Driving Task:* On which layer of driving task is the driver supported? E.g. navigation, guidance, stabilisation. In interactIVe an version has been used based on work by [Bernotat 1979], [Donges 1982] and [Michon 1985]. These levels can be used to group, design and model driver assistance systems and to ensure an inner compatibility between driver and technical system, e.g. by structuring the technical system in the same levels and making the technical system on each level compatible to the human driver.

- *Level of Assistance and Automation:* How much assistance and automation is offered to the driver? E.g. driver assisted, semi-automated, highly automated. For the level of automation (of a task) several classification schemes exist, often ranging from one side where the human being has full control to the opposite where automation has full control. Those classifications have been used in marine [Sheridan & Verplank, 1978], aerospace [Billings, 1997] and in road traffic [Endsley & Kaber, 1999]. Automation can also be classified as discrete levels on a one-dimensional automation scale [Flemisch 2008]
- *Situation Awareness, Mental Model, Mental Workload, Trust:* How can the information, warnings and interventions be easily understood and accepted by the driver; e.g. how the selection between braking and steering intervention is done in order to be comprehensible for the driver?

IWI strategies were defined for each of the remaining strategy categories:

- *Range of Operation and Availability:* What are meaningful ranges of operation for the assistance and automation functions; e.g. what are the sensor capabilities and how do they affect the detection of certain objects in different speed ranges, weather conditions etc?
- *Communication Channel:* What communication channel (visual, auditory, haptic) should be used by the system in order to interact properly with the driver; e.g. [Salvendy, 1997]. Should an acoustic warning be accompanied by a steering wheel vibration for lateral threats?
- *Sequence of Interaction:* How does the assistance evolve in specific situations; e.g. should a driver be given visual or auditory warnings before a steering or braking intervention? How should certain functions escalate.
- *States, Modes and Mode Transitions:* What states and modes exist for the overall system? Which is the default mode after the ignition cycle? What transitions exist and how are they initiated; e.g. should all assistance functions be grouped into a low number of modes, where an emergency function can be on by default when ignition is turned on, while other functions have to be activated by the driver? How can mode confusion be avoided [Flemisch 2008]? A system state is defined as “one of several stages or phases of system operation” [ISO22179, 2009] referring to a technical sub-system such as Adaptive Cruise Control (ACC). A mode of a system defines the behaviour of the overall system and in more complex systems there are certain sets of modes or mode configurations [Degani 1996].
- *Communicate System Status:* What information about current status is communicated to the driver? What elements could an integrated display design have; e.g. could current mode and detected objects be presented to the driver in the cluster display? See e.g. [Flemisch 2009] on availability indication.
- *Arbitration:* How should a disagreement between the driver and the function be resolved; e.g. should automated acceleration always be overrideable by the driver by

braking? Human-machine arbitration can be defined as a finite negotiation by means of proper interaction strategies aimed to reach a joint intent and adequate action of the human-machine system within the available time. Arbitration is a distinct part of the entire human-machine interaction process. See e.g. the INSAFES Warning Manager [Lind, 2006] and the IWI strategies related to prioritisation and scheduling in the American IVBSS project [UMTRI, 2007, LeBlanc 2008].

- *Prioritisation and Scheduling:* How can information, warning and intervention of several concurrently or subsequently active functions be integrated; e.g. should longitudinal threats and active support by braking be prioritised over lateral support by steering when concurrent situations happen simultaneously?
- *Adaptivity and Adaptability:* When and how do functions adapt themselves to the driver or the environment? When and how can a function be adapted by the driver? Which settings can the driver change; e.g. should the system be able to shift a headway distance and timing of emergency warnings automatically depending on observed driver behaviour? Should the driver be able to alter these settings in a menu? [Jameson 2003] defines adaptivity in the sense of an user-adaptive system as: “An interactive system that adapts its behaviour to individual users on the basis of processes of user model acquisition and application that involves some form of learning, inference, or decision making”. On the other hand adaptability refers to adaptable systems “which the individual user can explicitly tailor to his/her own preferences (for example, by choosing options that determine the appearance of the user interface)”.

Non-functional requirements were defined as well for the hardware units used to present information, warnings and interventions (Figure 19).

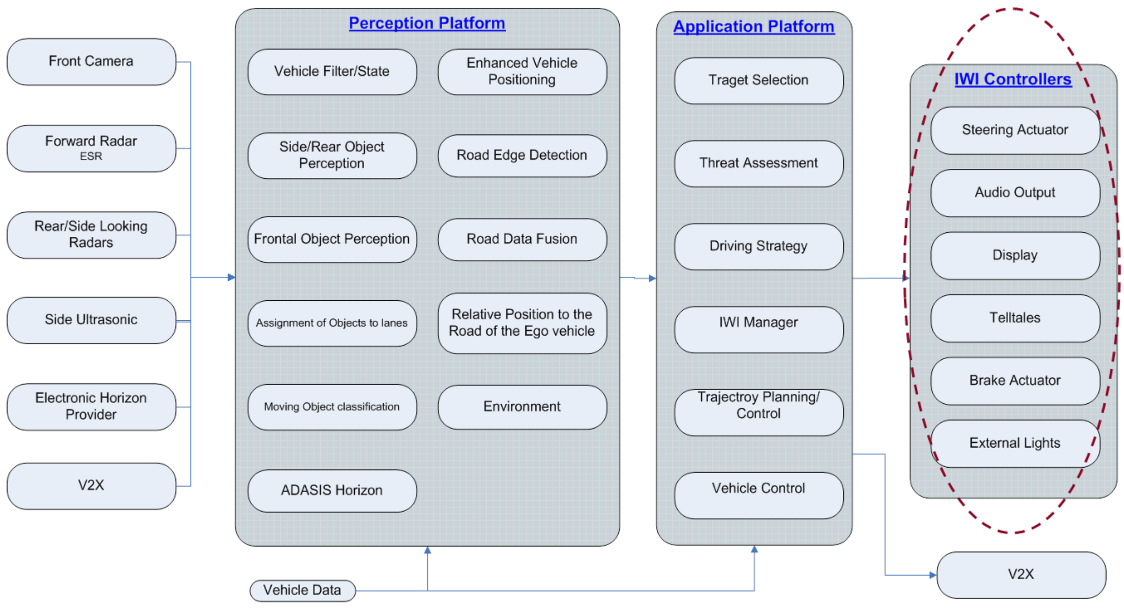


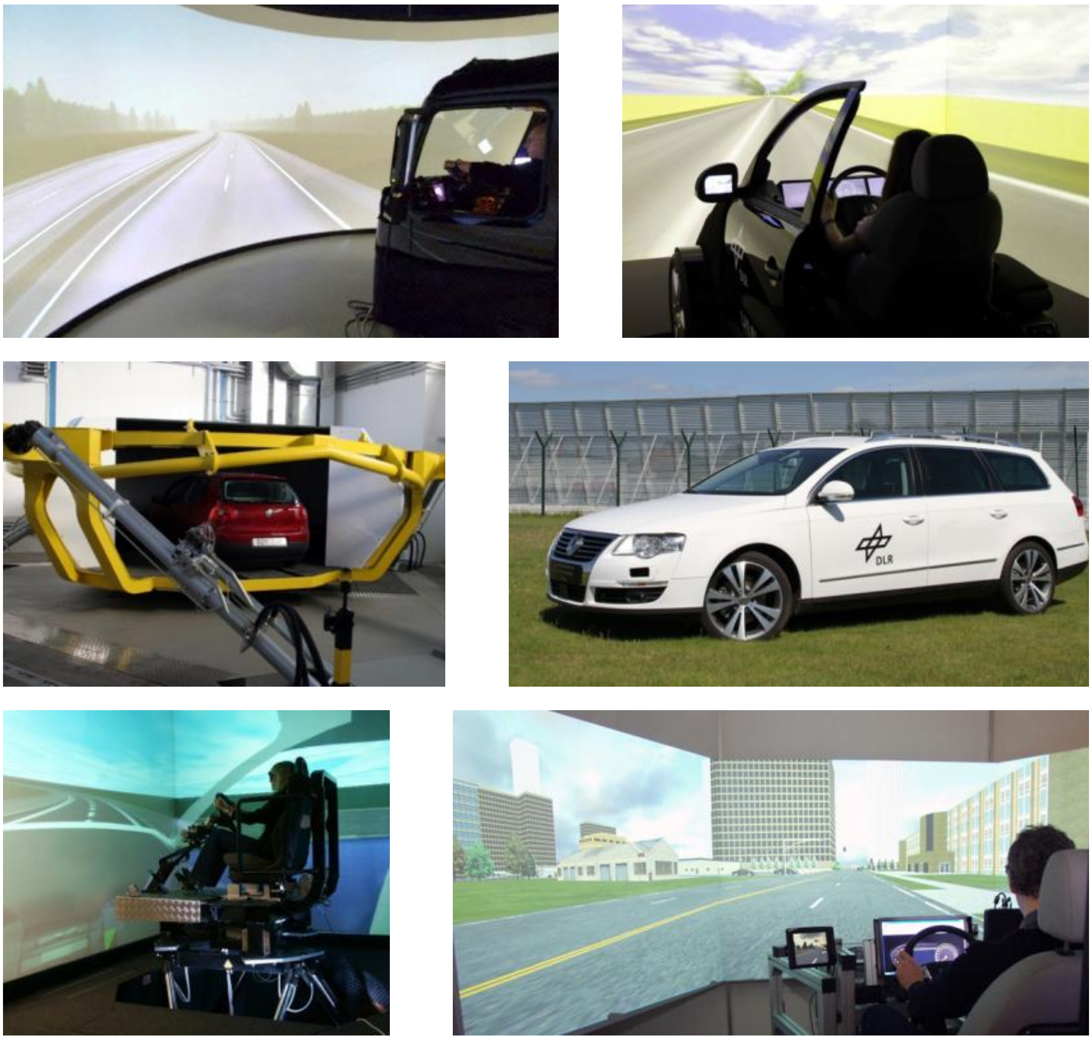
Figure 19: Output layer considered for the non-functional hardware requirements

Examples of specific non-functional hardware requirements were also covered in the course of the requirements definition.

2.3.4 Results from IWI evaluation

IWI strategies were designed based on the current state of art. It is evident however that there are a lot of research questions and design issues that have not yet been covered in research. Initial research questions in WP36 were therefore derived from the gaps identified in the literature search done in SP3 as well as on specific research needs identified by the demonstrator owners in SP4-6. A prioritisation of the derived research topics were then made in order to fit the available test facilities in the available resources in the time frame of the project. The aim was also to focus on research questions relevant to several demonstrators.

A set of experiments was carried out in SP3 involving professional drivers of commercial vehicles as well as private car drivers. Generic IWI strategies and prototypes were evaluated in order to provide input for updated IWI strategies, further development in the project as well as insight to Human Factors issues beyond the scope of the project. User-centred experiments were conducted in simulators and test vehicles provided by each of the four partners in SP3 (Figure 20).



Photos of: i) VTEC static simulator, ii) DLR fixed-base driving simulator, iii) DLR moving based simulator, iv) DLR research vehicle FASCar II, v) CRF moving based driving simulator, vi) Ford fixed-base driving simulator

Figure 20: Examples of available test facilities

In addition to those experiments, a smaller set of explorations was carried out together with the vertical sub-projects.

Based on the specific hypotheses selected for the experiments, specific experimental designs were generated. The scenarios were linked to the target scenarios describing the critical event to be resolved as well as the use cases defined early on in the project which describe roughly how the function is intended to work in a specific traffic situation in order to resolve accident scenarios. Independent and dependent variables were defined as well as sample selection and statistics. Since the tests carried out in SP3 were in the formative phase of the project and the research questions could vary to a large extent, each experiment could have a unique set up.

Based on those experimental results, the different IWI strategies were updated and input was given to the demonstrator owners in the vertical sub-projects. The most important impacts on the SP3 functional requirements are summed up in the following paragraphs.

Summing up, the experiments conducted in SP3 provide important insight in the driver-vehicle interaction into different use cases and applications addressed in the interactIVe project. In a structured approach research questions were selected that are tightly coupled with the interactIVe use cases, the functions, requirements and the IWI strategies. These research questions were answered by experiments in different test environments, ranging from basic and dynamic simulators to test vehicles. During the course of the studies much knowledge was gained for the continuous driver support e.g. on the IWI strategies and on the use of active devices as well as on emergency interventions e.g. on collision avoidance by steering or lane departure avoidance. As summarized above, several studies showed the successful implementation of the IWI strategies.

However, the results of the studies also show that there is still further research needed on specific topics. Future studies should help to further improve the effective human-machine interaction for continuous support, in emergency situations as well as during the transitions between these two. Because of the variety of the study objectives and use cases addressed separate study-specific conclusions and outlooks are stated in the final chapter of the document.

More details on the experimental activities are given in Deliverable 3.1 [INT D3.1].

2.3.5 IWI requirements and specifications

Human Factors related non-functional and functional requirements (IWI strategies) were applied and specified for the demonstrator vehicles in interactIVe (see [INT D3.3] for more detailed descriptions).

Relevant hardware used in the different demonstrators were described and linked to relevant non-functional requirement (Table 5).

Table 5: Human-Factors related hardware requirements linked to devices and applied to demonstrator vehicles
Legend: X=device installed in vehicle, OPT=by the time of the report still optionally considered.

Flow	Modality	Device	Req.	FORD	VTEC	CONTI	VW	CRF	VCC
Output	Haptic	Steering wheel vibration	H1	X	X				X
	Haptic	Steering wheel torque	H2	X	X	X	X	X	X
	Haptic	Accelerator vibration	H9	X					OPT
	Haptic	Accelerator force feedback	H10	X					X

Flow	Modality	Device	Req.	FORD	VTEC	CONTI	VW	CRF	VCC
	Haptic	Seat belt vibration	H11					X	
	Haptic	Brake pulse	H12	X			X		X
	Haptic	Accelerator inhibit	H14		X				
Output	Audio	Spatial sound	A2	OPT	X	X			
	Audio	Audio	A1-3		X	X	X	X	X
	Audio	Buzzer	A1-3						
Output	Display	Light on rear mirror – left	D1	X	X (A-pillar)				OPT (A pillar)
	Display	Light on rear mirrors – right	D1	X	OPT; if no display X (A-pillar)				OPT (A pillar)
	Display	IPC telltale	D3	X	X				
	Display	IPC text message on display	D5	X	X	OPT	X		
	Display	IPC graphics display	D6	X	X	OPT	X	X	
	Display	IPC fully reconfigurable display	D1-6			OPT	X	X	X
	Display	Centre Stack Telltale	D7					X	
	Display	Display - not specified	D1-10	OPT	OPT X (right A pillar display)	X	OPT		
	Display	HUD - direct reflection	D12-15						
	Display	HUD - projection optics	D12-15						
	Display	LED bar under windshield	D15	X	X		X		X
Output	Visual	Flashing headlights	V1	OPT	X				
	Visual	Flashing rear lights	V2	OPT					
Output	Implicit	Active braking	I1	X	X		X		X
	Implicit	Deceleration	I2	X	X		X		
Input	Manual	ON/OFF control	M1	X				X	X

More generic IWI strategies i.e. functional requirements were also iterated and applied to the interactIVe demonstrator vehicles in cooperation with the demonstrator owners.

In order to present more clearly the IWI solution chosen for the demonstrators, dedicated specifications were developed as shown in Figures 21 to 25.

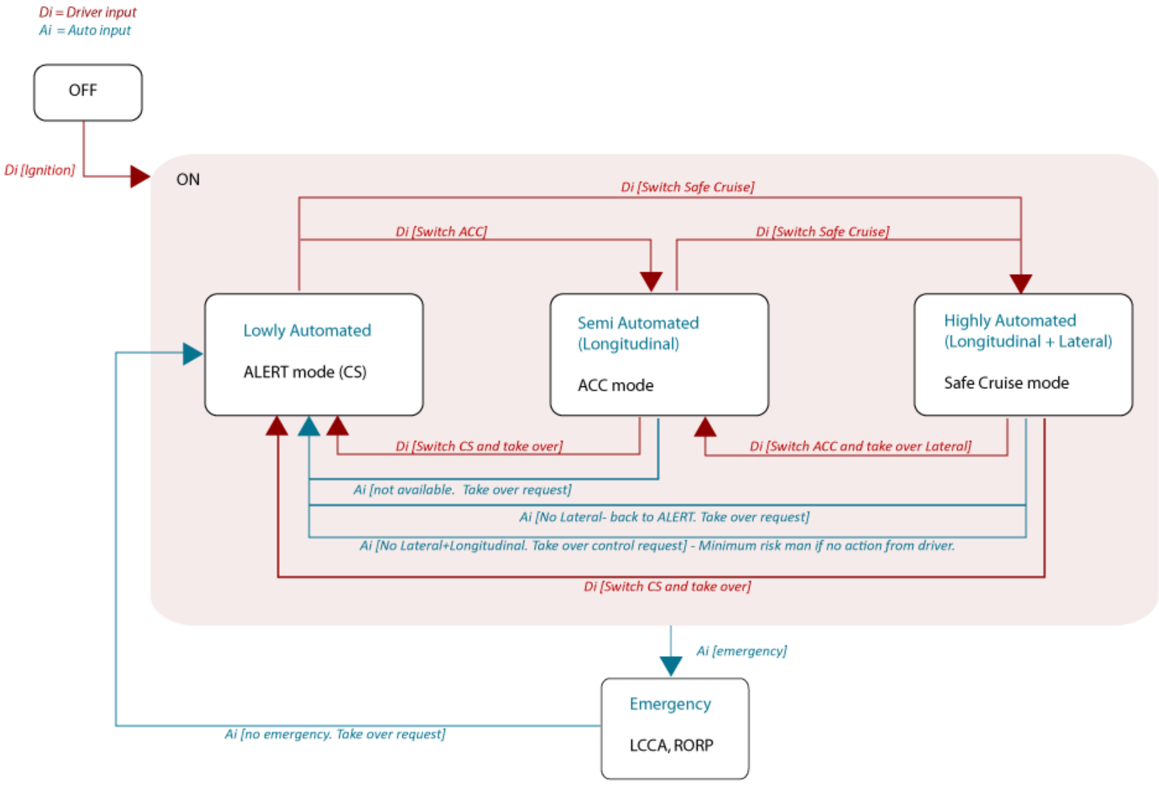


Figure 21: Example of system states, modes and transitions for the Volvo Car Demonstrator

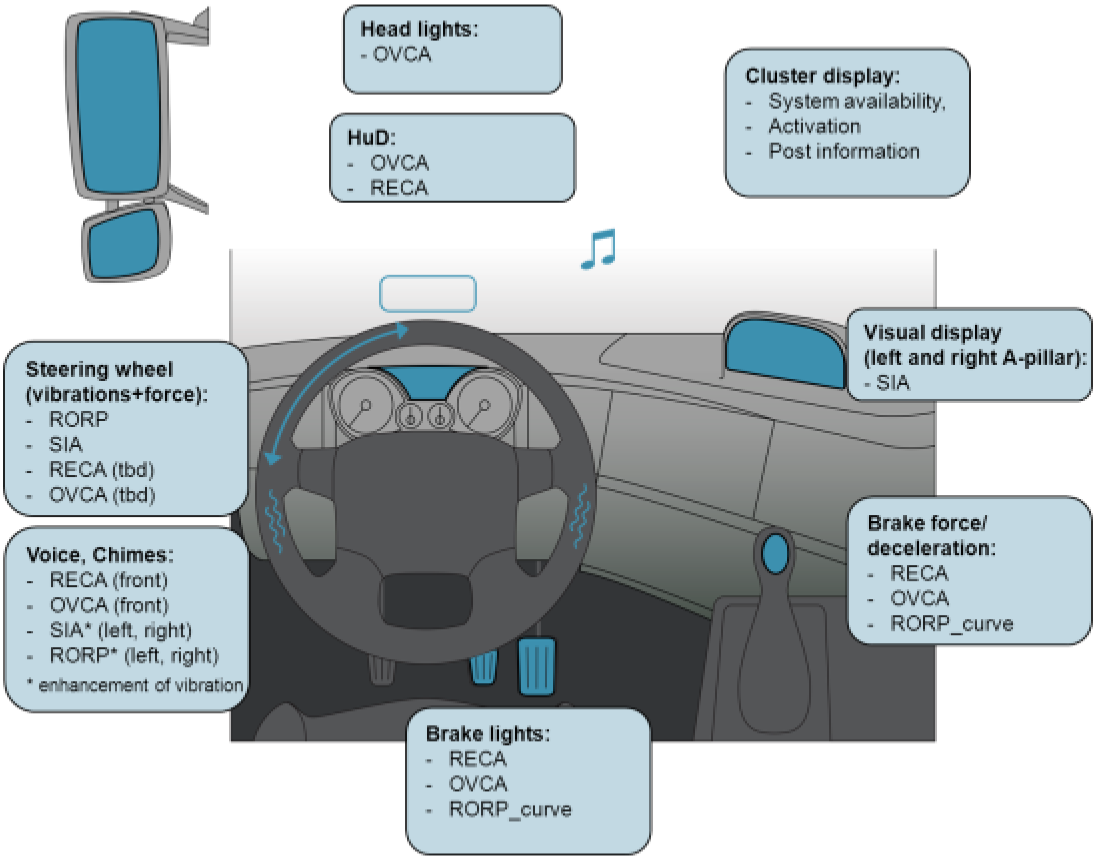


Figure 22: Example of specified communication channels linked to clustered functions for Volvo Truck Demonstrator

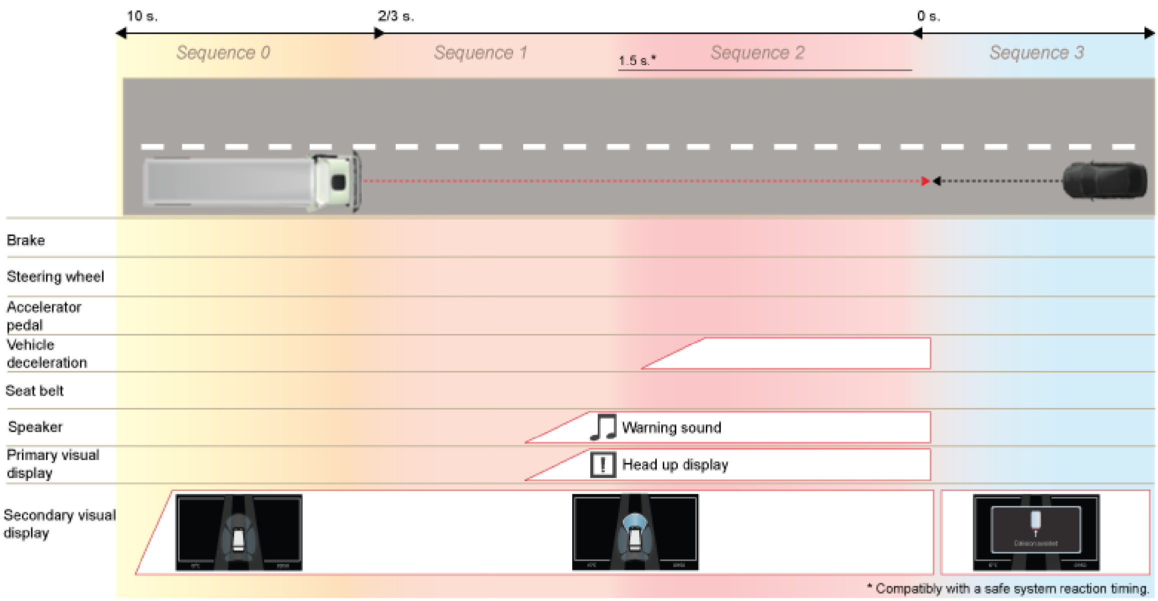


Figure 23: Example of sequence of interaction for OVCA in Volvo Truck demonstrator

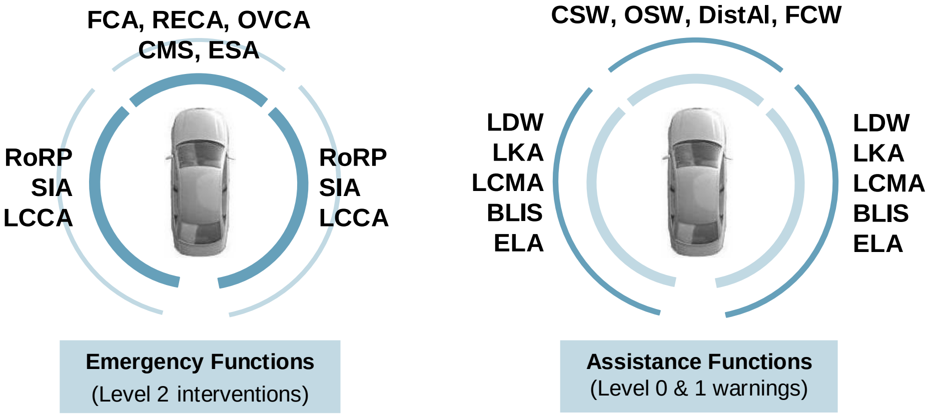


Figure 24: Grouping of functions according to type of support based on the timing/criticality and the strength of support

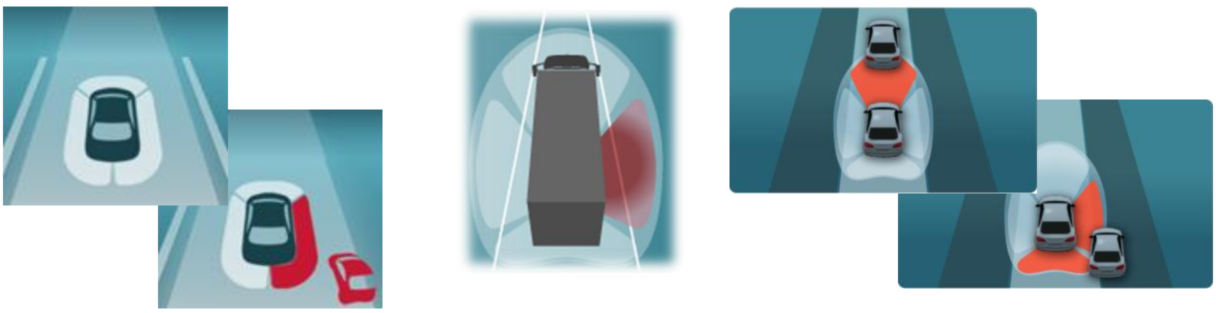


Figure 25: Examples of visual display concepts with safety shield indication according to the direction-criticality/distance-metaphor (spatial compatibility of warnings)

The requirements-process in interactIVe addressed the three major functionalities: (i) Continuous driver support (ii) Collision avoidance and (iii) Collision mitigation. These functionalities constituted a time-wise continuum. The first one aimed at assisting drivers also during normal driving, so that the ADAS ‘closer to an accident’ (avoidance, mitigation) does not need not to be put on trial. In more critical situations, then the two other systems can intervene: these systems can take direct control of the vehicle for a short period of time. Compared to previous developments like in PReVENT, there is more emphasis on active interventions that the IWI strategies now in detail handle. Considering the above mentioned approach, the focus of the present report is on requirements at the intervention level. Perception requirements were treated in a specific chapter 2.2.3. This part of the work dealt with the more specific IWI on how the driver and vehicle can be worked together in a harmonious manner so that all time there is the driver as much as possible in control of the vehicle. IWI strategies come in play when it is evident that the driver needs assistance or the accident is inevitable, and only the consequences can anymore be influenced.

3 Applications and functions development

3.1 Generic interactIVe architecture

The system's architecture comprises of discrete architectural layers that are common to all applications. In particular, a modular framework has been defined based on the following four layers: (i) the sensors layer, (ii) the perception layer, (iii) the application layer and (iv) what the driver perceives as the system, the Information, Warning, and Intervention (IWI) layer (Actuators/HMI).

Figure 26 below illustrates the generic interactIVe architecture. All demonstrator vehicles used the same basic architecture, but the actual implementation differed. For instance, not all demonstrators had the same sensors or the same actuators. The sensor layer (to the left in the figure) transmits all available input data to the perception layer which performs the low level and high level data fusion. Then the processed information derived by the perception modules is transferred to the application layer through the PP (Perception Platform) output interface, namely the Perception Horizon. The application layer performs situation analysis and action planning resulting in a system with different assistance level, ranging from pure information and warning via gentle activation of different actuators to full takeover of control depending on the real-time driving environment.

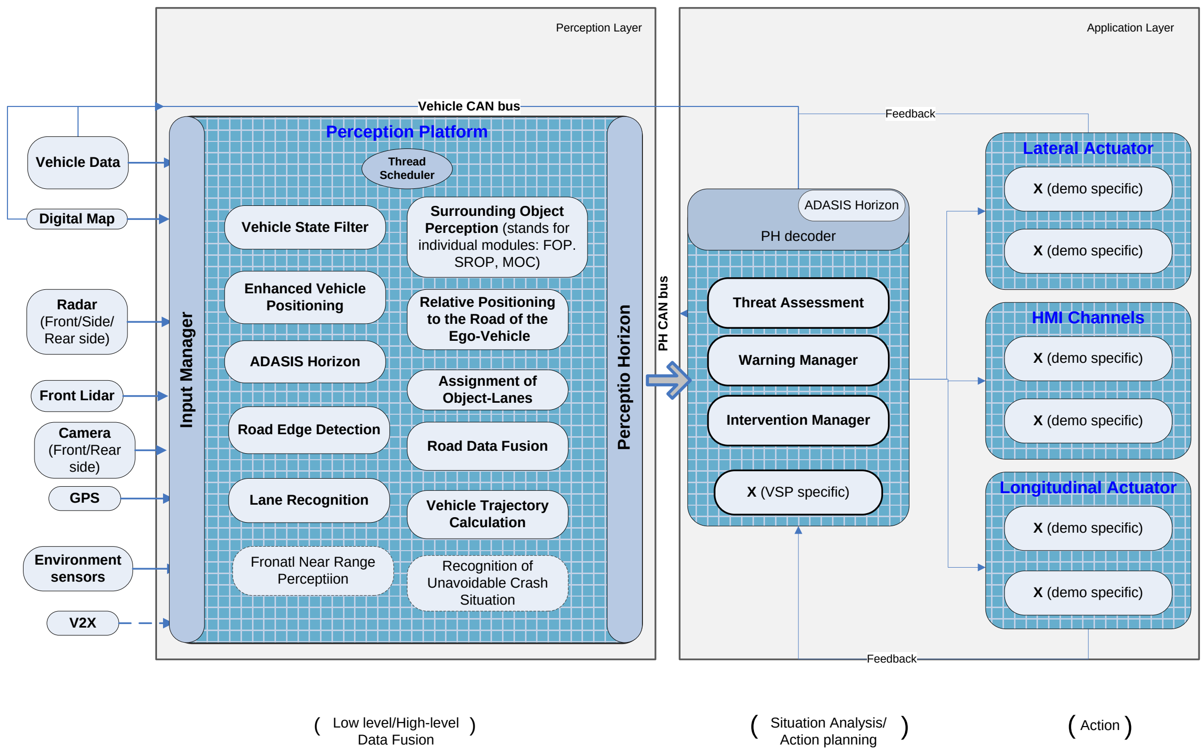


Figure 26: interactIVe generic architecture

The information flow suggested by the above architecture diagram goes as follows: The sensor layer transmits all available input data to the perception layer. During input data collection, the data are stored using the platform format (generic sensor interfaces) and acquire a common time stamp by the platform Input Manager sub-system. In the sequel, the various software modules of the Perception Layer process and fuse the sensor input and deliver their unified environment perception output to the applications via a unified interface, the Perception Horizon (PH). The application layer performs situation analysis and planning resulting in a system with a more energetic (different actuators are activated) or more passive (the system informs and warns the driver) driver assistant role depending on the real-time driving environment.

There are two development activities in interactIVe involving all functions and all demonstrators. One is a so called Reference Perception Platform (RPP), and the other one is called Information Warning and Intervention (IWI) Strategies.

3.2 Continuous Support - SECONDS

3.2.1 Objectives

The basic concept behind the development of interactIVe functions, and particularly for Continuous Support functions is as if there was a very skilled friend sitting next to the driver, and he would be usually silent but can give advice to the driver or, in the most dangerous cases, even take control of the car. When the danger is over, the control is handed over back to the driver.

Figure 27: Driver and “co-driver” as represented in the interactIVe video

This metaphor was presented in the interactIVe video. It is also the basic idea for the co-driver implemented in the project. The basic needs considered here are the driver safety and system acceptance. Driver safety means a system able to cover the maximum possible number of dangerous situations while system acceptance means a system that is almost always silent, except when it is really needed. These needs govern the basic objectives for the co-driver concept.

However, the development and test of these concepts by demonstrator vehicles poses a list of questions both on the technical side and concerning the interactions with the driver. This chapter describes how these concepts were implemented in order to understand what the main challenges were, and how they were addressed. This way a list of critical points and experimented solutions have been derived that can be useful for further development and market introduction.

3.2.2 Challenges

The implementation of the co-driver concept on real vehicles poses a list of challenges that have been addressed in the project as specific technical objectives. They are summarised below:

- Even if resulting from the combination of many different driver support functions, the Continuous Support should be perceived by the driver as an unique support system acting in similar ways in different traffic situations to be easily comprehensible.
- The implementation of driver support for many different traffic scenarios implies the use of an extended Perception Platform with fusion of information from different sources and sensors looking all around the vehicle (this topic was developed inside SP2 after definition in cooperation with vertical SPs).
- This also implies the integration of longitudinal and lateral support functions, and the integration of different driver support levels in a continuous and coherent way: warning, advice, support, automatic vehicle control.
- Installation and test of complex system architectures with use of multiple devices (sensors, communication, maps, processing units, driver interaction) should be hidden behind the capability of the system to give driver support in a simple and precise way.
- Easy use of developed technologies for production vehicles.

These challenges were addressed in the project by means of specific technical choices as described in the following paragraph.

3.2.3 Solutions

This paragraph lists the main technical solutions that were adopted in the project to address the following challenges:

- Following IWI requirements developed in SP3, multiple driver interaction channels are used, where the increasing danger level corresponds to more intrusive actions of the system with respect to the driver: visual information, haptic feedback, haptic support, acoustical warning, intervention.
- To be more intuitive, the feedback provided by the system also suggests in a haptic way the manoeuvre that the driver should follow (e.g. haptic feedback on the steering wheel with torque in the proper direction).
- This feedback is driven by a computation of the risk associated with the current driver manoeuvre and planning of the correct manoeuvre that the driver should follow in the specific driving scenario used as a reference target.
- This concept of correct manoeuvre synthesises at the driver action level all information about traffic scenarios (vehicle state, road geometry, obstacles, etc.) and driver intentions identified as current driver goal.
- Integration of longitudinal and lateral support is achieved by planning and evaluation of alternative manoeuvres that addresses simultaneously both lateral and longitudinal control tasks; among multiple manoeuvres, the one that better fits driver commands identified current driver goal.
- This approach based on identification of driver goals and reference manoeuvre used as a target is naturally open for switching between different support levels – depending on traffic situation and driver request - up to the integration with automated functions.
- Single modules and components defined the tasks that can be tested at the module level before the integration to manage system complexity.
- Use as much as possible of available sensors and actuators.

The next section gives an overview on how these solutions have been implemented in the demonstrator vehicles. More details can be found in the other project deliverables.

3.2.4 Description of SECONDS applications

3.2.4.1 CRF demonstrator vehicle

In order to accomplish the Continuous Support functionalities, the CRF demonstrator vehicle is equipped with a set of sensors, other information sources, processing units and driver interaction components as indicated in the following Figures.

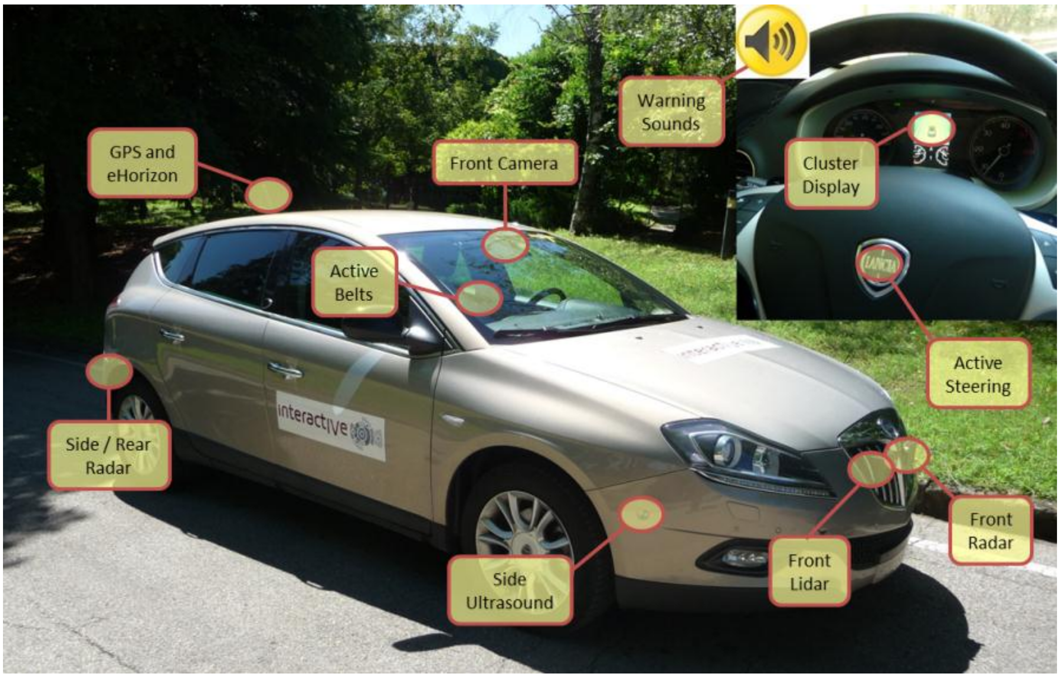


Figure 28: CRF demonstrator vehicle on Lancia Delta, with location of key components

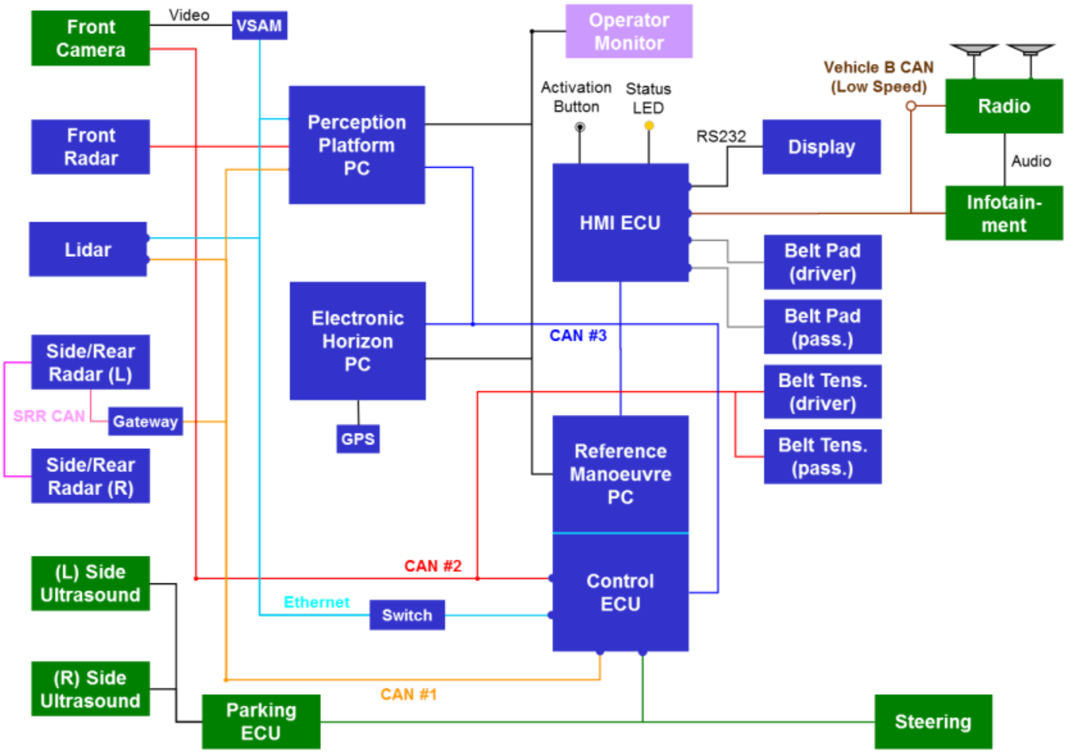


Figure 29: System topology for the CRF demonstrator vehicle

The use cases covered by the Continuous Support function implemented on the demonstrator vehicle are summarised in Table 6. In dangerous situations also sounds and active feedback are activated in steering wheel and safety belts.

Table 6: Implemented use cases on the CRF demonstrator vehicle.

Normal situation and unintended lane departure with no side obstacle. In unintended lane departure situation soft feedback on the steering wheel is provided.		
Exceeding speed limits and drift to side barrier. In drift to side barrier situation haptic feedback on the steering wheel and acoustical alarm are generated.		
Vehicle in blind spot (pre-warning and imminent). Imminent warning is generated when lane drift occurs with side vehicle and is associated with haptic feedback on the steering wheel.		
Collision with vulnerable road user and rear end collision (pre-warning and imminent). Imminent warning is associated with acoustic alarm and haptic feedback on safety belt.		
High speed when approaching a curve (pre-warning and imminent). Imminent warning is associated with acoustic alarm and haptic feedback on safety belt.		

The CRF implementation of the Continuous Support function is based on the metaphor of a co-driver. An artificial Cognitive System has been developed which reproduces human driving, understands driver intentions and supports the driver accordingly. The system is based on recent theories of human cognition by simulation and mirroring [Bertolazzi 2010, DaLio 2012, Saroldi 2012, DaLio 2013, Bosetti 2013].

3.2.4.2 FORD demonstrator vehicle

The FFA demonstrator vehicle is a Ford Focus equipped with additional sensors (orange), processing units, HMI elements (pink) and actuators (blue) as shown in Figure 30. The demonstrator is used for continuous support functions as well INCA functions.

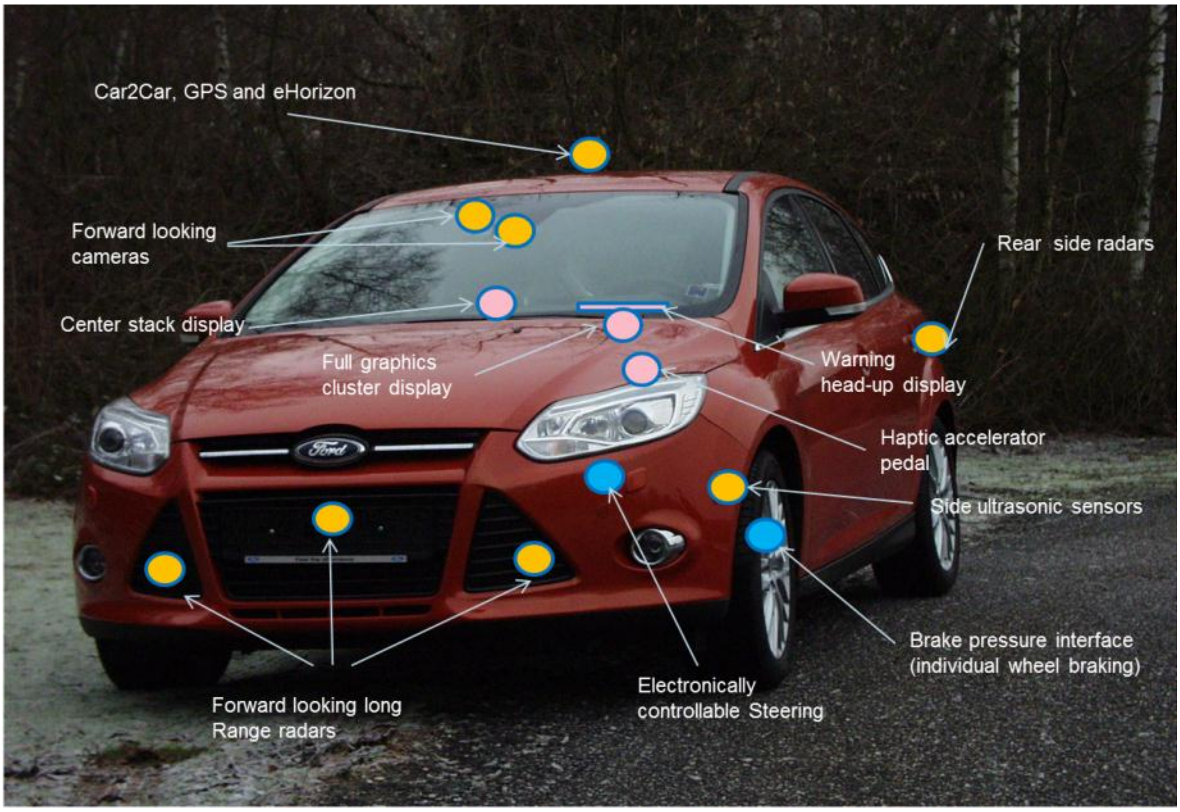


Figure 30: FORD demonstrator vehicle on Focus, with location of key components for the applications

The system topology with all added components is shown in Figure 31. All sensor data are provided via a sensor CAN to the CarPC on which the Perception Platform is running. Additional information for the Perception Platform is provided by GPS and a digital map. This CarPC contains also the HMI generation (graphics and sound). The assessment and controls are implemented on an Autobox which is connected with the actuators.

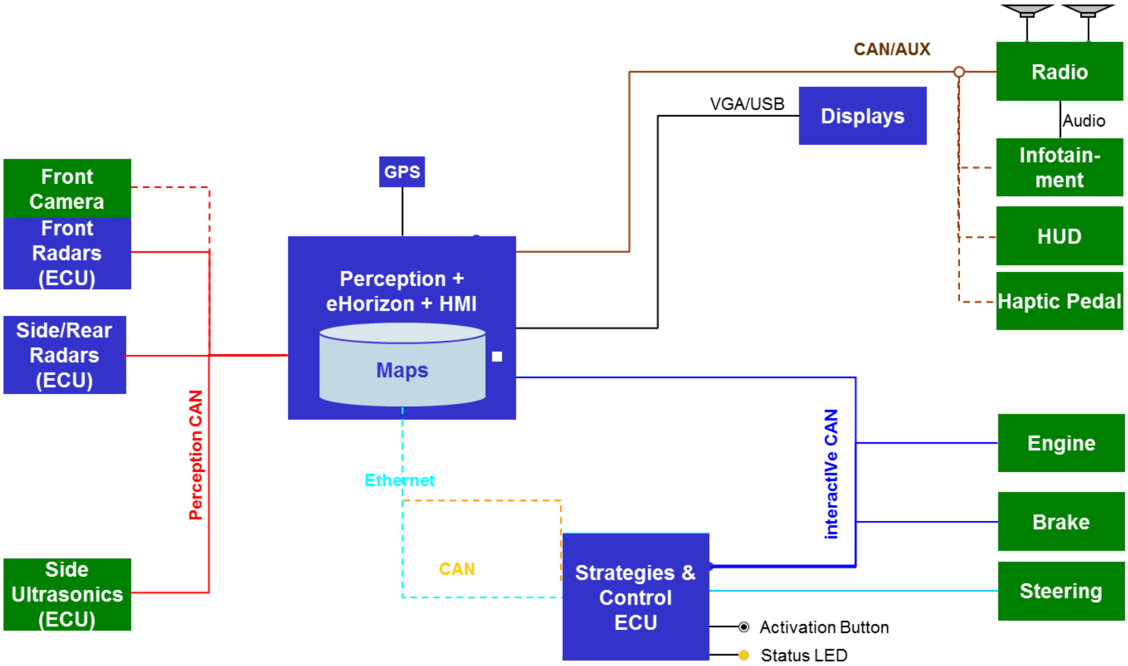
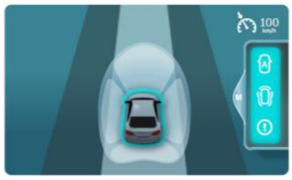


Figure 31: System Topology for the FORD demonstrator vehicle

The following table summarizes the Continuous Support applications that are implemented in the FORD demonstrator. Although addressing the same use case the Ford applications are divided in three modes: (i) The alert mode provides warnings to the driver in hazardous situations (ii) the active mode supports the driver additionally by haptic feedback (iii) in the assisted mode the driver gives control to the vehicle which drives automated under defined conditions. The corresponding mode can be chosen by the driver if it is available under the given conditions.

Table 7: Implemented use cases on the FORD demonstrator vehicle.

Normal situation and unintended lane departure with no side obstacle. In unintended lane departure situation a warning (*Alert*), corrective steering action (*Active*) or an autonomous steering (*Assisted*) is provided.		
Vehicle in blind spot or approaching from behind on the next lane. A warning (visual and acoustic in alert mode) is generated when lane drift occurs with side vehicle and haptic steering feedback is given in case of Active mode.		
Collision with object in front. In Alert mode a warning is presented to the driver in visual (cluster and HUD) and acoustic form. In Active mode the warning is additionally associated with haptic pedal feedback.		

High speed when approaching a curve. In Alert mode a visual and acoustic warning is given. In Active mode additionally haptic feedback is provided by the accelerator pedal. In Assisted mode the vehicle adapts its speed automatically to the curve radius ahead.	
Automatic longitudinal and lateral control. In Assisted mode the vehicle takes over longitudinal and lateral control and keeps a safe distance to vehicles ahead and stays in current lane.	

3.2.4.3 VCC demonstrator vehicle

The VCC demonstrator vehicle (Figure 32) is a modified Volvo S60 containing a set of visual, audible and haptic displays and also equipped with a state-of-the-art sensor system feeding the interactIVe functions via the sensor fusion module from SP2. The car is also equipped with C2C communication to be able to interact with nearby vehicles. A new control system was developed and integrated following the guidelines of interactIVe where the functions of SP4 and SP5 are integrated. A full graphics cluster display was integrated presenting information and warnings to the driver (Figure 32).

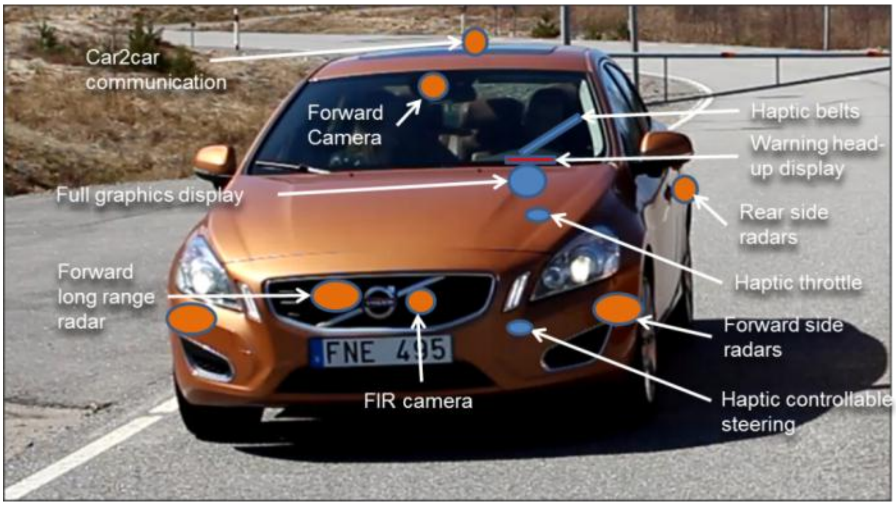


Figure 32: VCC demonstrator vehicle on Volvo S60, with indication of key components for the applications

Figure 33: Full graphics cluster on the VCC demonstrator vehicle

The SP4 and SP5 developed functions/use cases that have been integrated in the vehicle as presented in Table 7. A number of functions listed below are not actually developed within the project, but they are listed, since they are part of the full vehicle assessment regarding the HMI implementation as defined by SP3.

Table 8: Implemented use cases on the VCC demonstrator vehicle

Normal situation and unintended lane departure with no side obstacle. In unintended lane departure situation soft feedback on the steering wheel is provided supported by corrective steering.		
Exceeding speed limits and drift to side barrier. In drift to side barrier situation steering wheel haptic feedback followed by corrective steering and an acoustical alarm is generated.		
Vehicle in blind spot (pre-warning and imminent). Imminent warning is generated when lane drift occurs with side vehicle and is associated with haptic feedback using the steering wheel supported by corrective steering.		
Collision with vulnerable road user and rear end collision (pre-warning and imminent). Imminent warning is associated with acoustic alarm and haptic feedback on safety belt.		
Following situation where the vehicle automatically follows by means of steering and throttle at a safe adapted distance.		

High speed when approaching a curve (pre-warning and imminent). Imminent warning is associated with acoustic alarm, visual information and haptic feedback using safety belt.		

3.2.4.4 BMW demonstrator vehicle

In order to accomplish the enhanced Dynamic Pass Predictor functionalities, the BMW demonstrator vehicle is equipped with a set of sensors, other information sources, processing units and driver interaction components as well as the sensor fields are shown in the following figures.

Figure 34: BMW demonstrator vehicle on i535 with the sensor system

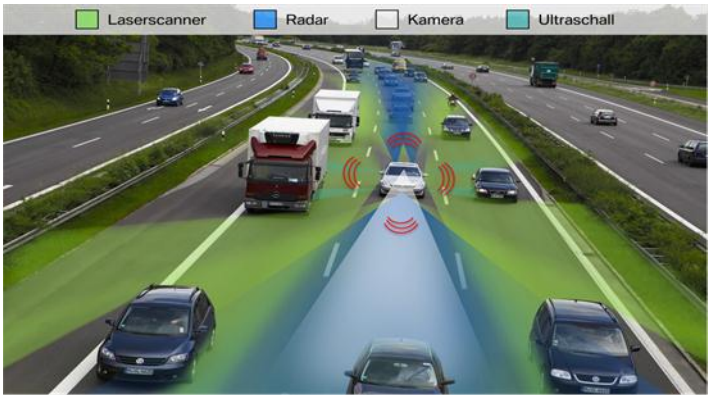


Figure 35: Sensor fields of the enhanced Dynamic Pass Predictor

The system topology of the enhanced Dynamic Pass Predictor (eDPP) is shown in Figure 35, where the “Speed Profile Server” has the goal to determine the exact overtaking speed ahead.

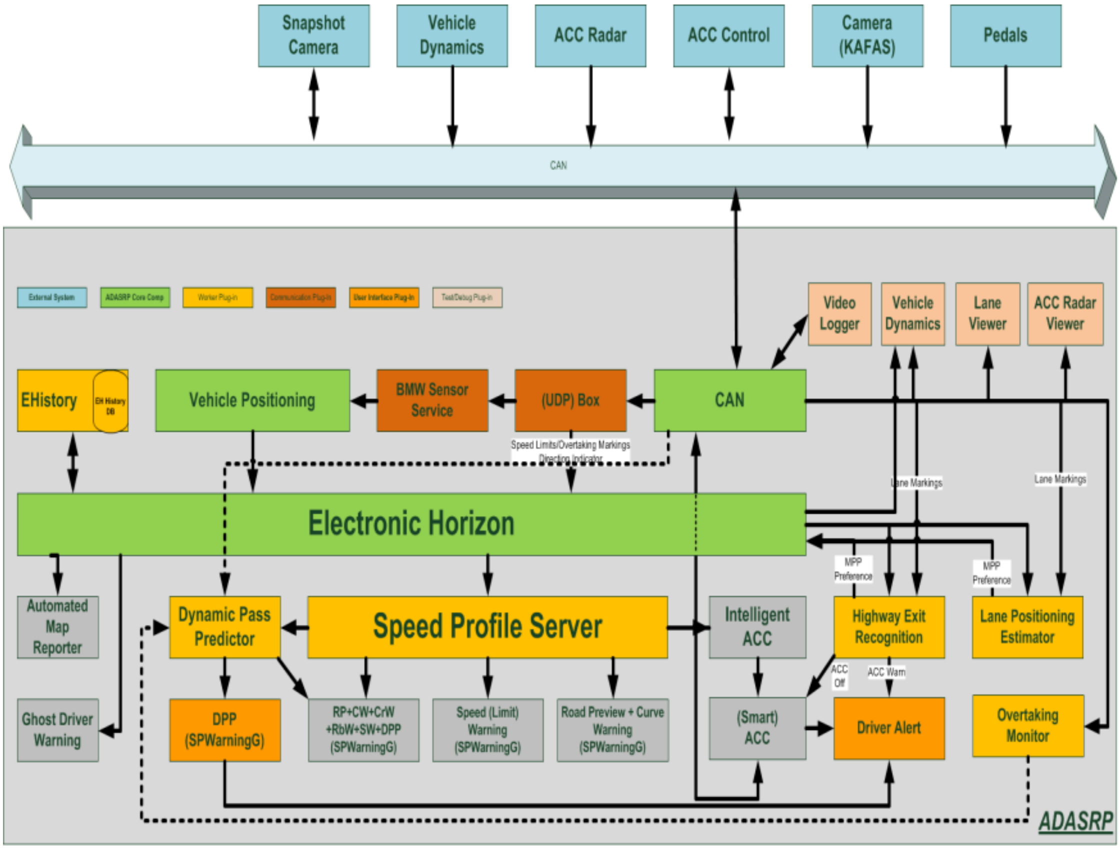


Figure 36: System topology for the BMW demonstrator vehicle

In an example in Figure 37 below, the vehicle is driving with eDPP on road sections not safe for overtaking (orange sections). So, the eDPP will adapt the speed to vehicles ahead, and then the driver is supported with a safe speed on the stretch of the road the he/she is currently driving. To provide this helpful support, the eDPP application with a given graphic in the instrument cluster in the cockpit (HuD and navigation display) present the sections not safe for overtaking. The driver will be further supported by given different traffic signs on road sections at his current location and situation.

Figure 37: enhanced Dynamic Pass Predictor and the navigation display

In order to interact with our prototype application and evaluate its usability, the eDPP assistance was integrated in the HMI of the test vehicle described earlier. The experiments conducted were designed to evaluate user acceptance of advanced and predictive overtaking support systems and HMI concepts under recognition of oncoming traffic and C2C data.

Figure 38: enhanced Dynamic Pass Predictor and head-up display

The full information is then displayed on the head-up display (HuD) by means of a specially developed eDPP HMI concept. As shown in Figure 38, the driver is being informed in the HuD about the speed, rpm and gears as well as the eDPP information.

3.3 Integrated Collision Avoidance and Vehicle Path Control - INCA

3.3.1 Objectives

The combination of lateral and longitudinal active interventions by autonomous braking and steering was the objective of this sub-project in order to extend the performance range of current collision avoidance and collision mitigation systems on the market today. As the sub-project name INCA suggests, the aim was to develop an integrated collision avoidance system by using information not only from a forward-looking sensor, but from the sensors looking around the vehicle. The sensor system, the selected sensor set-up and the sensor fusion system have been incorporated based on the development made in SP2 – Perception. The extended collision avoidance system also needed more sophisticated information warning and intervention strategies. Consequently, integration and development of information warning and intervention strategies were done in close cooperation with SP3 - Information Warning and Intervention strategies.

One specific objective in INCA was first to investigate and then develop a robust system for both passenger cars and heavy vehicle – heavy trucks. Especially, the difference in vehicle dynamic performance needed to be carefully considered.

3.3.2 Challenges

In this section, challenges during development and Implementation of the INCA concept on real vehicles were addressed:

- As the main concept of INCA, the system should be able autonomously to perform braking and/or steering manoeuvres in critical accident situations. This required a detailed and reliable sensing of the environment which can cover all around the vehicle.
- A real time implementation of such systems is always challenging, and especially when a rather great number of different sensing and computing systems are involved. Then it needed to be addressed with a reasonable approach.
- Even when having a perfect functionality, the interaction of the system with the driver is a challenge which needed to be considered during the function developments.
- Vehicle stability during and after an emergency avoidance manoeuvre were to be addressed which could constrain the functionality of the system when the situation is associated with uncertainties.
- Calculate risk for passing road edge or road barriers is new and has not widely done before, the sensor part was a more difficult task – especially compared to lane tracking.

INCA requirements dealt to a great extent with an important module inside Threat Assessment (see the interactIVe architecture). Those were path planning and path evaluation.

Path planning is performed prior to an intervention. During path planning, a reference path should be generated that can provide continuous and smooth profiles for the vehicle position, velocity, and acceleration. Simplicity and flexibility are also necessary in path planning to easily generate the reference path for different use cases. For both passenger cars and heavy vehicles a fifth order polynomial were considered and examined to generate a reference path.

However, not all fifth order polynomials serve as feasible paths for the heavy vehicle. On one hand, the controller should operate within the bandwidth of the steering actuator. Otherwise, the actuator cannot provide what the controller demands - which is based on the reference path for performing the manoeuvre. For example, the performance of the steering actuator in generating the steering wheel angle and rate is limited due to both mechanical limitations and safety requirements for the interaction with the driver. On the other hand, it should be possible for the heavy vehicle to follow the reference path safely without skidding or rolling over, *i.e.* the vehicle should stay within its manoeuvrability limits. Therefore, the feasibility of the manoeuvre needs to be ensured by comparing all parameters involved with the corresponding limits for all points along the reference path. To satisfy the constraints, it suffices to keep all parameters below their limits.

The critical path is the shortest feasible reference path that satisfies all conditions. In order to determine the critical path, all constraints shall be examined whether any of the constraints was violated, then boundary conditions need to be changed to calculate a new path. Among all boundary conditions, it is only possible to change final longitudinal position, since the other data are requirements that are either determined by the dynamical state of the vehicle or defined by the use case. Increasing the longitudinal distance consequently allows for a less severe manoeuvre. Then constraints will be checked again and the iteration will be repeated until all constraints are satisfied and the critical path is found with the required longitudinal distance, d_c. A schematic overview of the general procedure is shown in Figure 39.

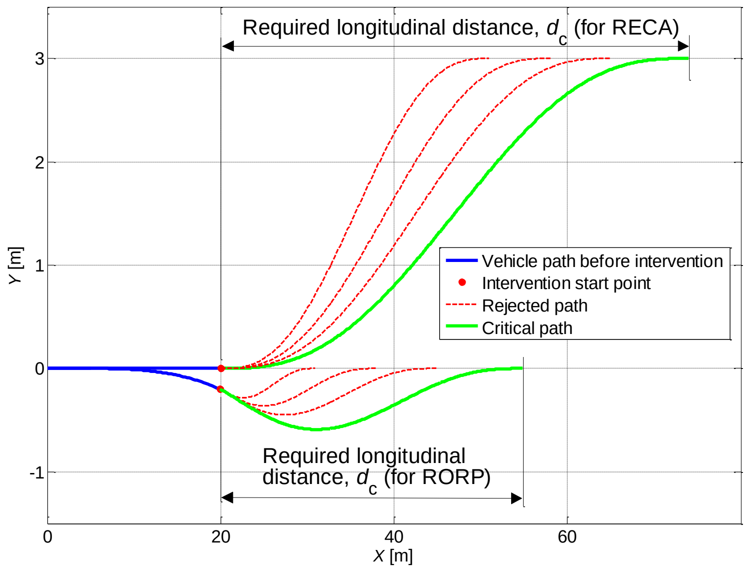


Figure 39: Schematic overview of the fifth order polynomial path planning for RECA and RoRP

The main advantage of the fifth order polynomial is that it provides a smooth and continuous path profile. Therefore, this path can be used to calculate the feed-forward steering input, and also other reference values for the feedback controllers.

3.3.3 Solutions

In order to execute last second critical emergency manoeuvres there is a need for understanding the vehicle dynamic behaviour for the different vehicle classes. Therefore, several different simulation environments were used and enhanced for the development of INCA functions.

More details of developed vehicle dynamic simulations and simulation tools can be found in Deliverable D5.1 [INT D5.1].

In cooperation with SP3 IWI strategies several driving simulator studies and expert evaluations were performed.

In order to address the challenge of preventing road departures specific sensor development for road edge and road barrier detection was carried out in close cooperation with SP2.

The INCA applications concern emergency situations. In Table 9 and in Figures 40 to 42 below the different functions developed in INCA are described, and also the target vehicle demonstrator for each function is summarized.

Table 9: INCA functions by manufacturer

Function	Volvo car	FORD	Volvo truck
Lane Change Collision Avoidance Side Impact Avoidance	YES	YES	YES
Oncoming Vehicle, Collision Avoidance / Mitigation	(YES)		YES
Rear End Collision Avoidance		YES	YES
Run-off Road Prevention	YES	YES	YES

Depending on the requirements for each function and also vehicle type, different strategies were implemented to support the driver in the best way. See, Figure 40, Figure 41 and Figure 42 showing the main interaction sequence for the following functions: Side Impact Avoidance (SIA) including Lane Change Collision Avoidance (LCCA), Rear-End Collision Avoidance (RECA) and Run-off Road prevention (RoRP). A number of alternative sequences and abort functionality are also implemented.

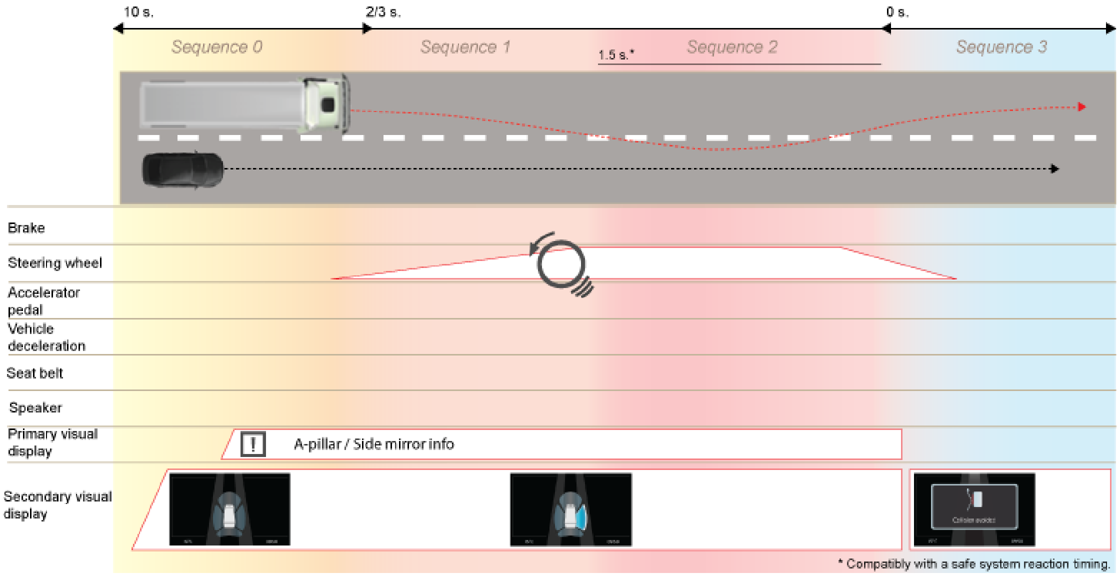


Figure 40: Main sequence of interaction for SIA (LCCA)

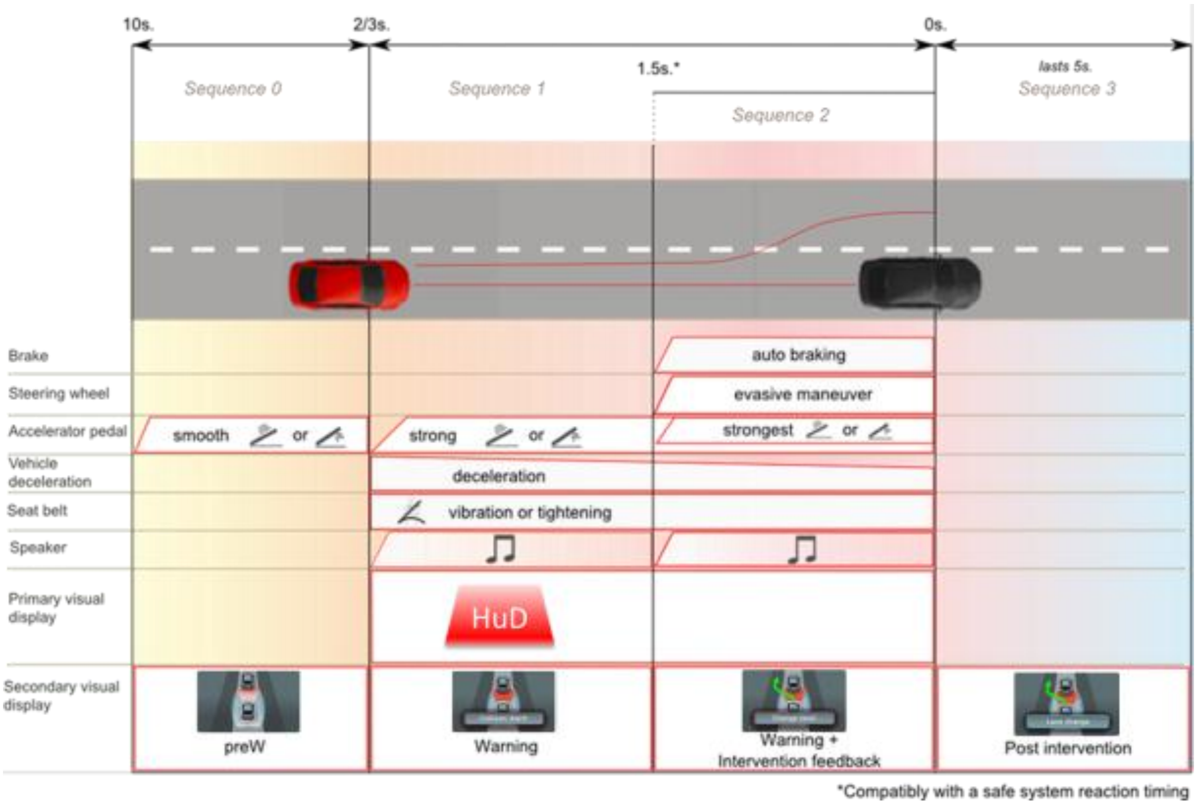


Figure 41: Main sequence of interaction for RECA

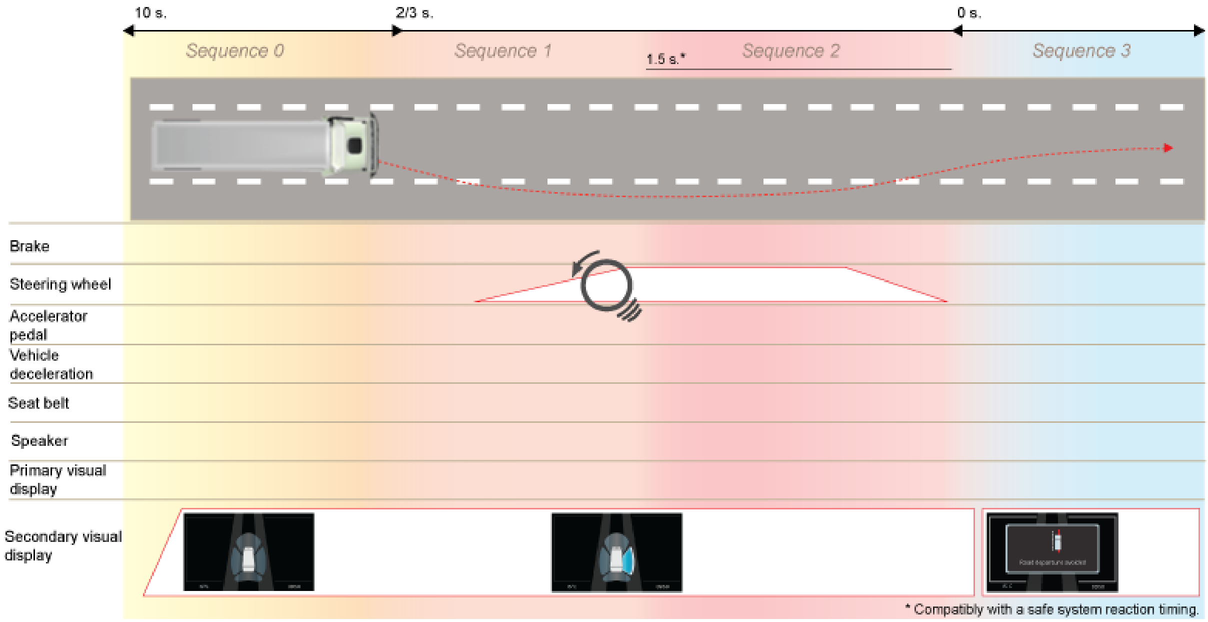


Figure 42: Main sequence of interaction for RoRP

3.3.4 Description of INCA applications

INCA has three demonstrator vehicles, two passenger cars from FORD and VCC and one heavy vehicle, a Volvo truck. Since the two passenger cars also served as demonstrators for SP4 (and are described in the previous chapter), the focus here was on the truck demonstrator.

The sensor installation providing all-round coverage of the truck is shown in Figure 43. One front camera, one front radar, two side radars, two rear radars and GPS for e-horizon.

Figure 44 shows the interactIVe architecture implementation in the demonstrator truck.

3.3.4.1 Volvo truck demonstrator

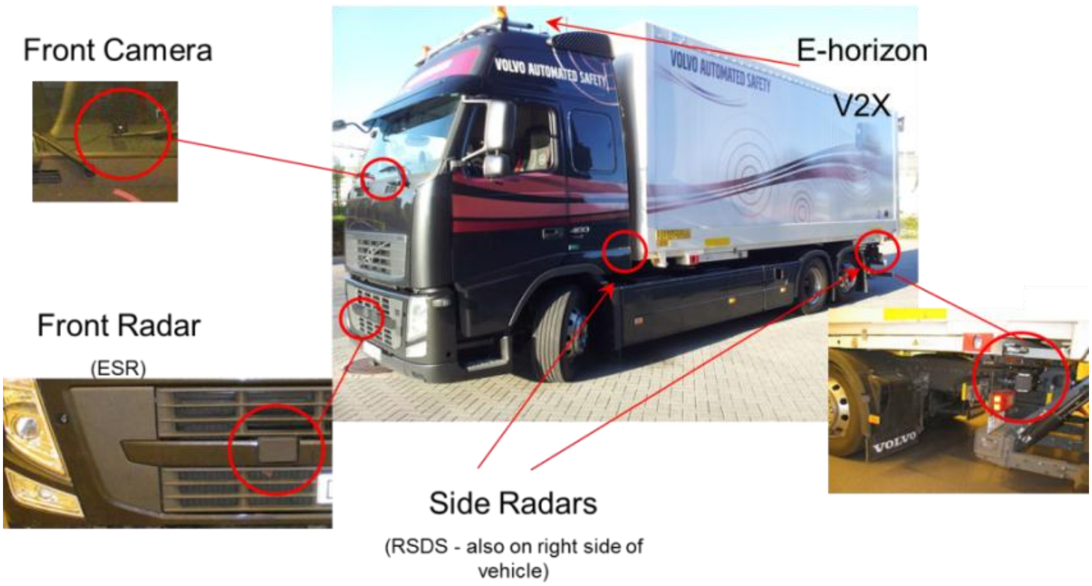


Figure 43: VTEC demonstrator vehicle - heavy truck

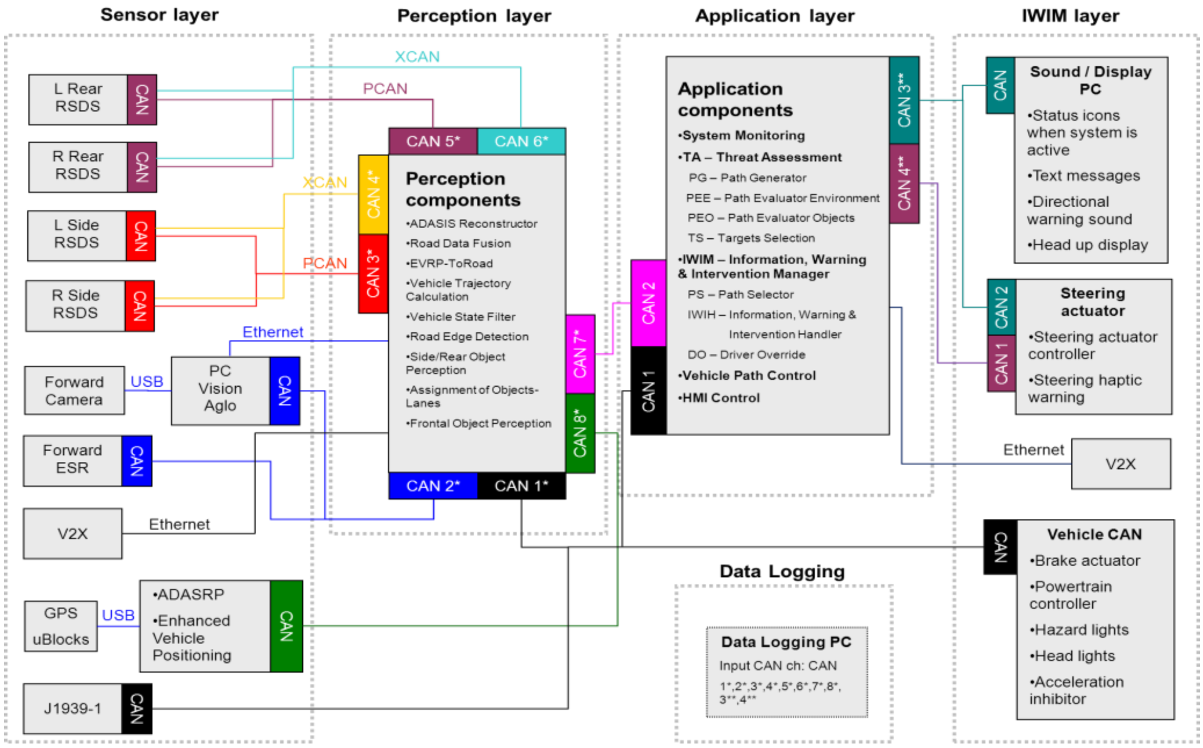


Figure 44: Implementation of interactIVe architecture for the truck demonstrator

3.4 Cost-efficient Collision Mitigation – EMIC

3.4.1 Objectives

The objective of this sub-project was the development of affordable collision mitigation systems having a significant impact on the reduction of accident severity. Therefore, known collision mitigation concepts for reducing accident severity were extended with specific attention to vehicle architectures in the low- and medium-segment passenger vehicles.

3.4.2 Challenges

The following challenges were addressed and solved in the EMIC sub-project:

- Development of cost-efficient collision mitigation functions: Usage of available low-cost systems, namely sensors and actuators already available in low- and mid-size segment passenger cars. The functionalities were developed as add-on to existing ADAS systems. This approach leads to a compromise between limited sensor capabilities and the potential safety benefit.
- In a defined set of target scenarios the accident severity should be reduced significantly by means of emergency driver support and automated intervention systems.
- Coverage of a wider range of target scenarios: Due to the use of existing sensors, which are all forward-looking sensors, the addressed target scenarios are still limited to the frontal direction. However, the new target scenarios include crossing traffic and pedestrians. Both scenarios are very complex and challenging regarding detection and intervention strategies. To handle this wider range of

scenarios, also steering interventions were included in the functions to control the lateral vehicle path.

- Driver-vehicle interaction: The complete warning and intervention strategy should be implemented in the demonstrator vehicles to show the functional chain from the driver warning to driver support and automated intervention. This development work was done in close cooperation with SP3. New warning concepts were evaluated in simulator studies and later on implemented in the demonstrators.
- Intervention by automated braking and steering: Highest priority in collision mitigation has the reduction of the impact velocity realized by automated braking. As a further step in EMIC, also steering interventions are considered as a possible intervention to control the lateral vehicle path. Depending on the specific situation, this combination results in a collision with optimized point of impact (compatibility) or in collision avoidance in certain scenarios. To decide for the most suitable intervention strategy, a very intelligent decision algorithm was required.
- Development and evaluation of a driver model: An additional aspect addressed by EMIC was the development and the use of a driver model. The driver model allows the adaptation of the warning and intervention strategy to the driver state. For example, this permits an earlier triggering of the function in case the driver is distracted. Due to the earlier intervention, the benefit of the application can be increased. On the other hand, the false alarm rate can be reduced if the driver is very concentrated. Following the low-cost approach, as input for the driver model only in-vehicle data were used without any additional driver sensing.
- Benchmarking of different available low-cost sensor systems: The goal of the sensor benchmark was to evaluate a given set of available low-cost sensor technologies with respect to the performance in forward collision warning and automated emergency braking scenarios. The scenarios and the key performance indicators were partly defined as update of the newly released EURO-NCAP scenarios for collision mitigation systems.

Further details on how the challenges were addressed and solved by the EMIC sub-project can be found in the available project deliverables.

3.4.3 Solutions

In the coming years the number of vehicles equipped with continuous support functions will increase considerably. This requires from vehicle sensor systems reliable environmental perception and object detection. The approach of EMIC is to use the available in-vehicle sensors in combination with vehicle actuators, namely the braking and steering system, to develop low-cost add-on functions with the focus on collision mitigation. Whereas collision avoidance requires expensive environmental perception, collision mitigation can be realized at a reasonable cost.

The specific scope of EMIC is on vehicle architectures in the low to medium segment passenger cars in order to ensure a high market penetration not possible for luxury cars.

First generation emergency braking systems are already on the market covering a limited set of critical situations. In the near future these systems will be also considered in the EURO-NCAP consumer rating.

Based on this, the EMIC sub-project took the next step regarding collision mitigation. In addition to automated braking, automated steering interventions were considered and evaluated as a new topic.

All accidents can't be avoided by the driver or intervening systems. In those cases the EMIC collision mitigation functions should at least help to reduce the accident severity. New concepts were developed and implemented in two demonstrator vehicles. Finally, the developed functions were evaluated to analyse the possible benefits.

3.4.4 Description of the EMIC applications

EMIC developed two different applications. The first one is the Emergency Steer Assist (ESA) and the second one Collision Mitigation by Braking and Steering (CMBS).

The addressed target scenarios are shown below (Figure 45).

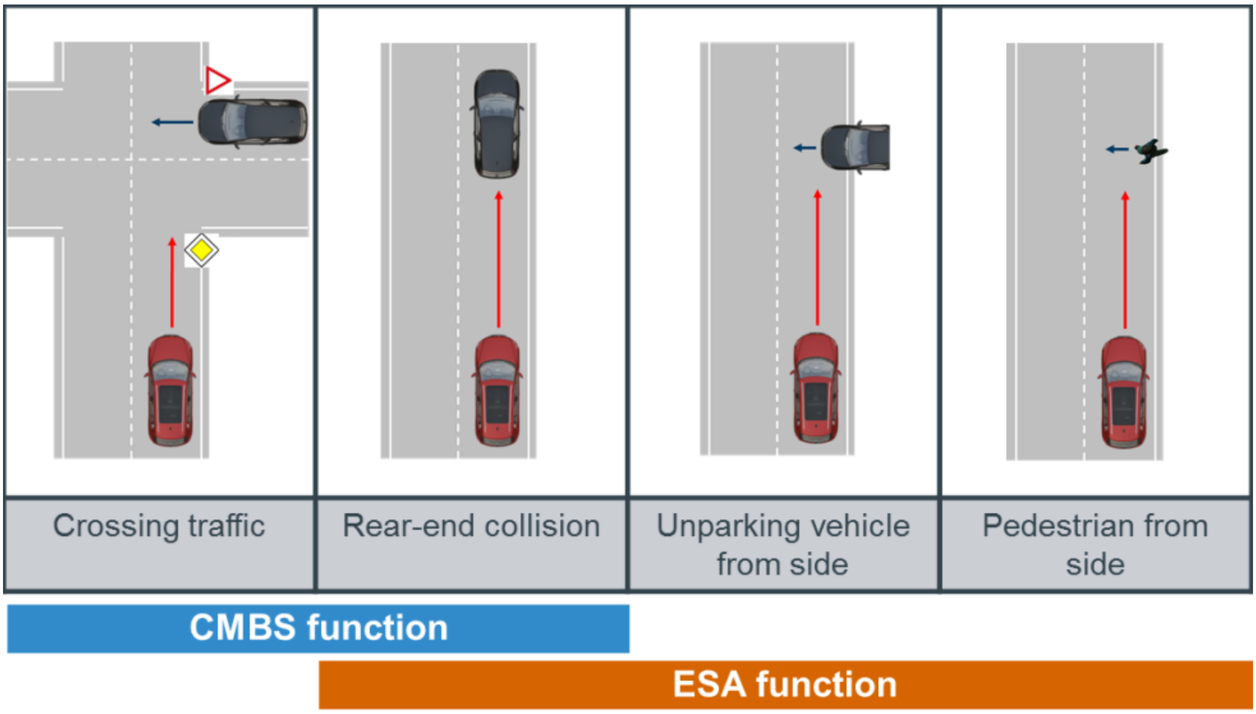


Figure 45: Main target scenarios of EMIC

<u>Emergency Steer Assist (ESA)</u>

The Emergency Steer Assist (ESA) supports the driver in those critical situations when he is trying to avoid an imminent collision by steering (Figure 46). In order to support the driver in those situations, the function observes the surrounding environment. If an imminent collision is detected by the on-board sensors, the function will at first warn the driver. If then the driver starts a steering manoeuvre to avoid the collision, the function will support the driver in his steering (in this case mainly by the Electric Power Steering EPS and the Electronic Stability Control ESC) to stabilize the vehicle and to follow the required trajectory.

Compared to the SP5 functions, it is important to point out that the function does not help to avoid the accident if the driver does not start a steering manoeuvre himself. The ESA function only supports the driver, when he reacts with a too weak or too strong steering. Since the function is triggered by the driver, less environmental information is required compared to SP5, and only frontal sensing can be used.

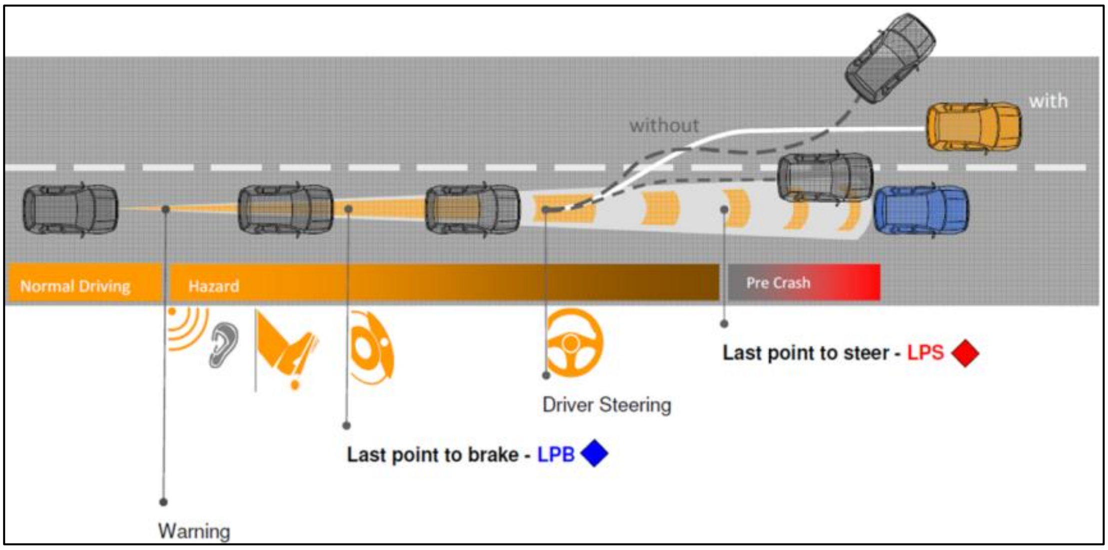


Figure 46: Sketch of the Emergency Steer Assist application

<u>Collision Mitigation by Braking and Steering (CMBS)</u>

The Collision Mitigation function should mitigate the consequences of an accident by intervention in the driving behaviour by means of braking and/or steering (Figure 47). The objective of the braking manoeuvre is to reduce the impact speed. The objective of a steering intervention is to optimize the point of impact and the impact orientation in order to mitigate the consequences of an accident.

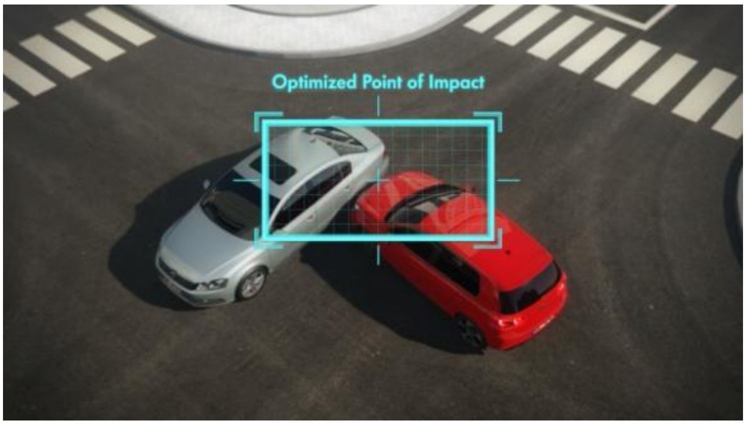
Due to the two available mitigation strategies, it is essential to choose the best mitigation strategy depending on the current situation. Therefore, the function observes the surrounding traffic by means of the on-board sensors. Based on this information, the function determines whether a collision is imminent. If an unavoidable collision is detected, the function will calculate the probable point of impact and possible alternative impact points. For these points an assessment is made regarding the resulting passenger injuries. Based on these calculations, an intervention strategy is chosen to guide the vehicle towards the most favourable point of impact. Depending on the intervention strategy, the braking and steering actuators are applied.

Before the intervention by braking and/or steering, the function also warns the driver.

The warning and intervention strategy of the function depends not only on the criticality of the event, but also on the driver reaction. Therefore, depending on the driver reaction, four different reactions to the function can be distinguished:

- Strong driver reaction after the warning: The driver will only be supported by the standard braking assist, and the CMBS will not initiate an intervention.
- Weak driver reaction after the warning: If the driver brakes too weakly, the driver will be supported during the braking by the CMBS function. If the driver starts to steer, the function intervention will be activated.
- No reaction of the driver after the warning: When the driver does not react until the collision becomes unavoidable, the CMBS will be activated. The function will brake and/or steer automatically in order to reduce the accident severity.
- Intervention without a warning: If the warning about an imminent collision cannot be issued (e.g. due to the sensor limitations), the CMBS will intervene without any driver warning.

Any braking and/or steering intervention of the CMBS function can be overridden by the driver.



Host / Target

Initial collision	Targeted collision	Intervention type
Not a frontal Collision for host car (sidecollision)	No intervention	No intervention (this is not addressed by system)
Collision with front end	Right longitudinal Rail hits front wheel/axle	1. Partial braking 2. No Steering
Collision with front wheel/axle	No intervention due to high injury risk involved in possible resulting compartment collision	No intervention
Collision with compartment	Left longitudinal rail Hits rear wheel/axle	1. Full braking 2. Additional steering if required to produce lateral offset
Collision with rear end	Avoidance	1. Full braking 2. No steering

Figure 47: Intervention strategy for Collision Mitigation by Braking and Steering with crossing traffic

3.4.4.1 VW demonstrator vehicle

The VW demonstrator vehicle is a Volkswagen Golf VI GTI passenger car. To implement the CMBS function, the vehicle was equipped with additional hardware components like environmental sensors, computing units and driver interaction components (Figure 48).

Figure 48: VW demonstrator vehicle on Golf VI GTI, with sensors and HMI components

3.4.4.2 CONTIT demonstrator vehicle

Introduction

The CONTIT demonstrator is a VW Passat demonstrating the application Emergency Steer Assist ESA.

There are two main environment sensors supporting the emergency steering function, radar and an advanced stereo camera for automotive applications. Both are connected via a so called measurement interface to get direct access to all data provided by the sensors. The perception layer is deployed on a PC framework and is connected to the sensor layer via CAN/USB, the output is published in CAN-format. The application layer is realized on an ECU for enabling fast information processing cycles required for the algorithms, output is again realized by a CAN interface. Final element of the function components is the IWI-layer containing mainly the EPS Steering Actuator (which is enabled via a CAN-request) and interfaces for warnings and indications of system failure.

Figure 49 shows the system architecture of the CONTIT demonstrator vehicle.

Perception Components

The frontal object perception consists of the sub-modules *Sensor Fusion*, *Object Perception*, *Data Alignment* and Information *Flow Check*.

The first module performs an information-fusion between the data-sources “stereo-camera” and “radar-sensor” and unites the specific advantages of the deployed sensor-principles:

- Radar: Accurate detection of object distance and relative speed
- Stereo-Camera: Accurate detection of lateral object positions

The object perception module resolves hypotheses regarding the detection of potential collision obstacles provided by the sensor-data respectively the results of the sensor-fusion part. The third component aligns the incoming information temporarily, so that the fusion process can be carried out. In a final step, plausibility of incoming information is checked.

Application Modules

Based on the results of the sensor-fusion part and a vehicle model, the predicted trajectory for an evasive manoeuvre is calculated. The module *Activation Control* checks if the system should be activated. This decision is based on:

- Vehicle is moving forward over ground
- System self-check successful
- System was activated during vehicle start-up
- Vehicle speed is between 30-140 kph
- Incoming environment-model is reliable
- System failure, in this case it gives this information to the driver

An *Advance-Warning Generator* detects, if there is a dangerous situation where evasive steering is potentially needed. This module informs the driver about such situations to enable the driver in principle to engage the evasion manoeuvre in the needed magnitude by himself (without support from ESA).

A control algorithm (steering torque actuator) calculates the required actuation magnitude to achieve the necessary resulting steering wheel angle for driving the calculated safe evasion manoeuvre. It also ensures that the support has no destabilizing effects. A general assumption is a high friction coefficient of 1.

The DID (*Driver Intention Detection*) derives information about the intention of the driver in the current situation from his steering actuation and other driver driven values from the vehicle sensors like the actuation of the brakes. The *Information Flow Check* module checks plausibility of outgoing information

IWI Modules

The steering actuator supports torque and gives predefined information which enables an arbitration block (outside the scope of this application) to assess the importance of the steering support. The Visual/Auditive Device generates advanced warnings and failure information.

HW components

For realizing the emergency steering system, the demonstrator vehicle shown in Figure 49 is equipped with several sensors. These are a radar sensor ARS300, a stereo camera SMFC300 and a standard sensor cluster. For data processing, automotive PCs and prototype ECUs are used. IWI units are brake pulse, steering wheel torque, IPC graphics display, evaluation display, audio device and an ON/OFF button.

Figure 49: CONTIT demonstrator vehicle on VW Passat, with sensor system

3.5 Summary of the interactIVe demonstrators

More than 45 use cases realized in 11 intelligent functions by using 7 vehicles in the interactIVe integrated project. Each vertical sub-project developed and built sophisticated demonstrator vehicles to test and validate the integrated set of functions. All these vehicles were demonstrated in the project Final Event in the Ford test track at Lommel (Belgium). These live demonstrations included specific avoidance manoeuvres even in hazardous situations by reconstructing reference scenarios with other cars or dummy obstacles.

Table 9 below shows how different subsets of the full interactIVe functionality were implemented in various demonstrators. In addition, Table 10 presents the main characteristics of each platform, in particular the perception components and a selection of specific features which were addressed with particular focus in that demonstrator.

Table 10: interactIVe functions per demonstrator

	SECONDS				INCA					EMIC	
DEMONSTRATOR	Continuous Support	Curve Speed Control	Enhanced Dynamic Pass Predictor	Safe Cruise	Lane Change Collision Avoidance	Oncoming Vehicle Collision Avoidance/Mitigation	Rear End Collision Avoidance	Side Impact Avoidance	Run-off Road Prevention	Emergency Steer Assist	Collision Mitigation System
FORD	✔	✔			✔		✔	✔	✔		
CRF	✔	✔									
BMW			✔								
VCC	✔			✔	✔				✔		
VTEC						✔	✔	✔	✔		
VW											✔
CONTI										✔	

Table 11: Main features of the demonstrator vehicles

Demonstrator	Perception	Basic functionality	Selected specific features
FORD	Two cameras (front) Radar (front , side/rear) Ultrasound (side) Car2Car, GPS, e Horizon	Collision avoidance, continuous support	On-board intelligence to coordinate the different applications. Automated driving. Use of different braking strategies. Haptic support.
CRF	Camera (front) Radar (front , side/rear) Lidar Ultrasound (side) GPS, e Horizon	Continuous support	Co-pilot concept. Shared driver-system control. Haptic support and HMI solutions (steering wheel, active safety belt).
BMW	Camera (front) Radar (front, rear) Laserscanner Ultrasounds Car2Car, eHorizon	Enhanced dynamic pass predictor	Data fusion and threat assessment specially adapted to overtaking situations. Accelerator Inhibit. Head-up display.

Demonstrator	Perception	Basic functionality	Selected specific features
VCC	Camera (front) + night vision Radar (front, side/rear and forward) Lidar Ultrasound (side) GPS, V2X	Collision avoidance, continuous support and safecruise	Focus on sensor data fusion. Longitudinal/lateral control integration. Head-up display. Haptic accelerator pedal and steering wheel.
VTEC	Camera (front) Radar (front, 4 lateral and rear) enhanced GPS, V2X, eHorizon	Collision avoidance and run-off road prevention by braking and steering	Sensor platform adapted to truck requirements. Longitudinal/lateral integration Stability considerations for heavy vehicles.
VW	Short range radar Mono camera, stereo camera Camera with 180° field of view Laser scanner (for reference)	Collision mitigation by braking and steering	Cost-efficient sensors and advanced data processing algorithms. Longitudinal/lateral integration. Optimised mitigation strategies for crossing traffic.
CONTI	Radar (front) Stereo camera	Emergency steering assistance	Advanced fusion of radar and vision. Longitudinal/lateral integration. Optimised evasion trajectories.

4 Evaluation

4.1 Objectives

In order to evaluate the developed ADAS within interactIVe, an evaluation framework is required. The sub-project 7 "Evaluation and Legal Aspects" is a part of interactIVe and provided this framework, supported other sub-projects in their evaluation work and conducted a safety impact assessment. In interactIVe SP7 represented the third horizontal activity (HSP) that supported the vertical sub-projects (VSP) focusing on the function development.

The support from SP7 for the VSP and SP7's role in the project answered the following topics:

- Definition of a test and evaluation framework for each application with respect to human factors and technical performance.
- Development of test scenarios, procedures, and evaluation methods as well as definition of test and evaluation criteria.
- Provision of tools for evaluation like equipment, test catalogues, questionnaires or software and support for testing.
- Conduction of safety impact assessment.
- Analysis of legal aspects for broad exploitation of the interactIVe applications. The results for the analysis have been reported in the interactIVe deliverable D7.3 [INT D7.3].

4.2 Evaluation scope and framework

The scope of evaluation concerned the action of vehicles as provided by the joint operation of human driver and applications in test scenarios. Applications are realized as research functions, i.e. they will undergo changes when perfected to production readiness. Outside the scope are sensors and actuators, as they were already tested to comply with relevant regulations. Algorithms and software to bring sensors and actuators together and developed in interactIVe were also not in the scope of evaluation. Instead, the application is considered as black box and the scope is on the action of that application, either virtual or real.

The framework provides the sequence of steps that lead from system considered to procedures for testing and, finally, to an assessment of the impact of the function on e.g. traffic safety. The intermediate steps already provide needed insight for improvement of the systems or even redesign from a technical or user point.

The evaluation of the function was split into three assessments dealing with different aspects of the function:

- Technical assessment: Evaluate the performance of the developed functions of interactIVe and collect information and data for safety impact assessment.
- User-related assessment: Evaluate the functions from the user perspective, and provide further input to the safety impact assessment.
- Impact assessment: evaluate in which way and to what extent the interactIVe functions influence traffic safety.

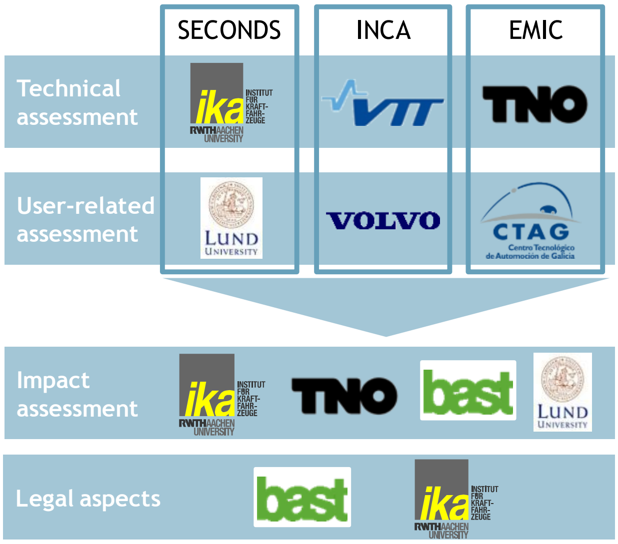


Figure 50: Structure of evaluation in interactIVe and related SP7 partners

In general an assessment is always carried out against certain requirements respectively goals or against a reference as in impact assessment. Being closer to the development stage, testing is different. The process of system development and testing is best described in the V-model, which is a proven process in automotive system development (Figure 51).

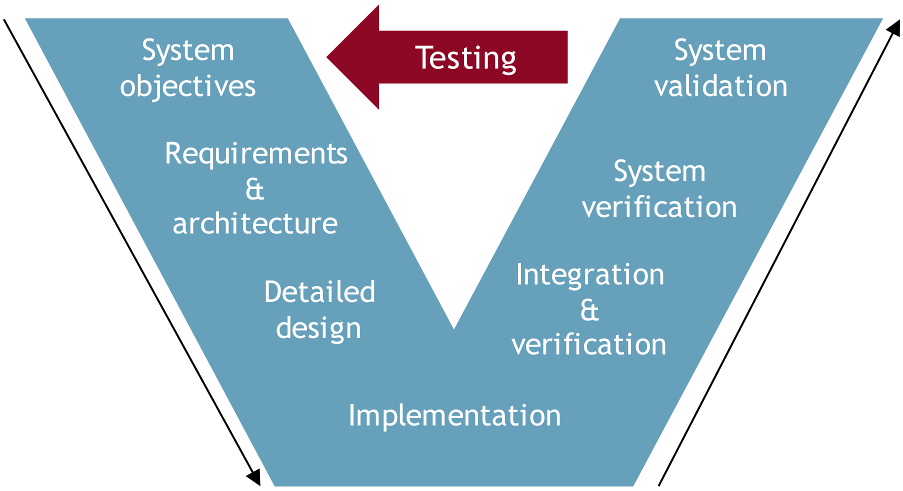


Figure 51: Generic V-model for system design and testing.

Based on a literature review on evaluation methods SP7 selected the methodology used in the PReVAL project [SCH 2008] as a basis, which ensured a solid evaluation assessment method. One of the main objectives of PReVAL was to define a framework for estimating the safety impact of active safety systems, which were developed in the PReVENT integrated project.

The evaluation methodology was selected, because it provides a comprehensive framework containing technical, user-related and safety impact evaluation. The evaluation in interactIVe is focused on a function level; the subcomponents (e.g. perception or function logic) are not assessed.

The main objective of the evaluation was to assess how well the different interactIVe functions perform to fulfil their objectives as specified by their target scenarios. Hence, the functions were evaluated from a development point-of-view.

The general procedure of the methodology identified following five steps:

Step 0: System and function description

In this step information is gathered on what the interactIVe function is supposed to do and how it should work:

- General information,
- Functionality and use cases,
- Targeted accidents limitations and
- Subsystems.

Results of system and function description are given in deliverable D1.5 [INT D1.5].

Step 1: Expected impact and hypotheses

Based on the function description relevant research and evaluation questions were defined. This step was conducted in WP 7.3 and reported in the deliverable D7.1 [INT D7.1]. Afterwards, based on the research questions the hypotheses were defined. These hypotheses were classified in two categories per assessment category (technical, user related and impact):

- General and
- System / function specific (SECONDS, INCA, and EMIC).

Once the hypotheses were formulated, the indicators for establishing the impact or testing the hypotheses could be derived. This needs to be carried out for each function. The definition of the hypothesis and indicators were provided in WP7.4 and reported in the SP7 deliverable D7.2 [INT D7.2].

Step 2: Test scenario definition

In this step the test scenarios for the evaluations were defined. Indeed, these scenarios must be defined in a way that they are relevant for evaluating the hypotheses. The basis for this step were the use cases and target scenarios of the interactIVe functions reported in D1.5 [INT D1.5]. Also other projects, like e.g. the ASSESS scenarios [BAR 2010] have defined relevant test scenarios, which were considered in interactIVe.

The role of test scenarios in evaluation differs for each type of evaluation. Test scenarios are directly applicable to the technical tests and to some extent to the user-related tests. They are only to a certain extent directly applicable in the safety assessment.

This step has been taken into account in D7.2 and is updated in D7.4 [INT D7.4].

Step 3: Evaluation method selection

With the hypotheses, indicators and scenarios available, the most appropriate evaluation method must be determined. Testing can be done through full simulation, software-in-the-loop simulation, hardware-in-the-loop simulation and real world trials on test tracks or on public roads either by professional drivers or (potential) users. The choice of the method depended on numerous factors. The most important ones were:

- Required outcome (e.g. opinion of a driver on the acceptance of the system or the amount of reduced speed at impact, determining false alarm rate etc.).

- Safety of a scenario.
- Required number of vehicles for a scenario.
- Availability of suitable targets (dummy vehicles).
- Availability of simulators.
- Time and budget constraints and
- Legal aspects (e.g. the vehicle is not certified to drive on public roads) and company constraints (e.g. only professional test drivers are allowed to drive the demonstrator vehicle).

Once the evaluation method was chosen, the identification of suitable and available tools followed naturally. The final evaluation method is described in D7.4.

Step 4: Measurement plan

In this step the actual measurements and evaluations were specified. This involved defining the signals to be logged, the experimental design of the test including the number of tests and subjects, and other details which are required to acquire statistically significant results in order to test the hypotheses and carry out the impact assessment.

For the assessment it was necessary to carry out various tests to get the needed data for the evaluation of the functions. It would not be sufficient to test the function only in different scenarios, because this would only provide a clear picture on the function behaviour for one parameter configuration. In fact, the function must also be tested for different parameter configurations (e.g. velocities) in order to analyse how the function behaves e.g. over its speed range.

Step 5: Test execution and analysis

This final step consisted of conducting the tests and analysing the results. This step considered also the hypotheses testing. The main challenge in this task was the coordination of the tests as the VSPs are responsible for the testing and recording the data (supported by SP7, as agreed at the joint SP7 and VSP workshop in November 2010). The analysis and assessment were carried out by SP7. The execution of the technical and user-related as well as the analysis of the tests is reported in more detail in D7.5. Based on these results the impact assessment was conducted.

These five steps are also reflected by the succession of SP7 deliverables. The initial point for the interactIVe evaluation framework was the internal report i-3 “Draft evaluation plan“, which described first ideas of the development process for the evaluation framework. An overview of the project structure as well as on the SP7 deliverables is given in Figure 51.

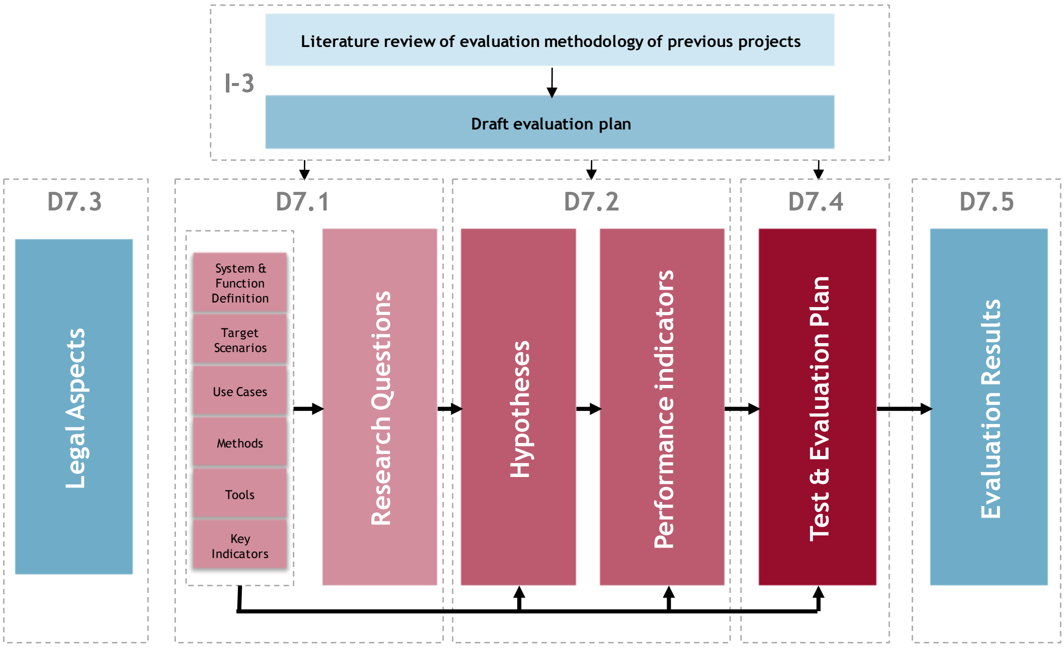


Figure 52: Overview of the structure for sub-project 7: Evaluation and legal aspects

4.3 Results

The detailed results as well as a detailed description of the applied approaches for the different assessments are presented in deliverable D7.5 “Impact Assessment of Developed Applications – Overall interactIVe Assessment” [INT D7.5].

4.3.1 Technical assessment

Basis for the evaluation in the technical assessment are 908 test runs. The tests started in August 2012 with the CMS functions. The other functions were assessed from March 2013 on. The last tests took place in June 2013. An overview on the conducted tests as well as on the tested scenarios is given by Table 12.

Table 12: Within the technical assessment conducted test in interactIVe.

Demon-strator vehicle	Test sites	Test scenario								Used target objects	Number of test runs
		Rear-end	Head on	Lane change	Crossing	VRU	Unint.lane departure	Excessive speed	Traffic rule violations		
BMW	Königsdorf (public road)		X							2 Real vehicles (one equipped with V2V)	23
CONTIT	Frankfurt (test track)	X			X	X				Balloon car, crashable up to 70 km/h suspended pedestrian dummy	119

Demon-strator vehicle	Test sites	Test scenario								Used target objects	Number of test runs
		Rear-end	Head on	Lane change	Crossing	VRU	Unint.lane departure	Excessive speed	Traffic rule violations		
CRF	Orbassano (test track)	X		X		X	X	X	X	Stationary vehicle object (balloon car) ika pedestrian dummy Real vehicle	261
Ford	Lommel (test track)	X		X			X	X		ADAC balloon car ADAC Target Real vehicle	308
VCC	Hällered (test track)	X	X	X			X	X	X	Static targets Real vehicle	133
VTEC	Vårgårda (test track) E6 (Public road near Gothen-burg)	X	X	X			X			Balloon vehicle Towed balloon car	27
VW	Ehra (test track) Helmond (VeHIL)	X			X					Static foam cubes Towed balloon car Cardboard crossing target and rear-end (VeHIL)	37

An example for the work on technical assessment will be given in the following as a spotlight on one of the 30 general and 63 specific hypotheses. This example concerns a result for one interactIVe function in one test scenario.

The selected hypothesis is “**Hyp_T_gen_TecU_01: The driver has enough time to react and avoid the accident, when the warning is issued**” and the selected function is the Continuous support (CS) function in the rear-end test scenario. Although the function is integrated in different demonstrator vehicles, the spotlight is focused on only one implementation of the function.

The warning time is the first evaluation need. The driver is able to avoid an accident, if the available time is sufficient to start a reaction and to perform the needed evasive respectively braking manoeuvre. Hence, the reaction time of the driver ($t_{Reaction}$) as well as required time for the manoeuvre ($t_{Manoeuvre}$) must be taken into consideration for this hypothesis.

Generally it can be stated, that the driver has two options to react on a situation. The driver can either perform a braking manoeuvre or conduct an evasive manoeuvre. Of course the chosen manoeuvre influences the required reaction time. Furthermore, the strength of the manoeuvre will also affect the required time. In order to determine the required time to solve the situation, it is assumed that driver always chooses the best collision avoidance strategy. The duration of the manoeuvre is:

$$t_{Manoeuvre} = \min([t_{brake}, t_{evasion}])$$

For the lateral evasive manoeuvre it is assumed that the velocity of the host vehicle is constant and the required lateral displace to solve the situation is W = 3.75 m

$$t_{evasion} = \frac{x_{evade}}{v_{HV} - v_{OV}} \quad \text{with} \quad x_{evade} = \sqrt{\frac{2\, v_{HV}^2}{a_{y\,HV}} W - W^2}$$

with v_{HV} (velocity host vehicle), v_{OV} (velocity other vehicle), $a_{x\,HV}$ (deceleration host vehicle).

For braking manoeuvre, the remaining time is calculated from the distance needed for braking (until target vehicle velocity), assuming that at the start of the manoeuvre both vehicles are moving at constant speed:

$$t_{Remaining} = dx_{warning}/(v_{HV} - v_{TV}) - (v_{HV} - v_{TV})/2a_x$$

It is assumed that the drivers are able to brake in a dangerous situation with a deceleration of 7 m/s² and perform an evasive manoeuvre with a maximum lateral acceleration of 5 m/s².
For the hypothesis testing the remaining time to collision (TTC) in the moment of the issuing of the warning – shown in Figure 54 - must be considered. Based on the TTC at the warning point in time and the manoeuvre time ($t_{Manoeuvre}$) the remaining reaction time can be calculated for each test run. The results are given in Figure 53.

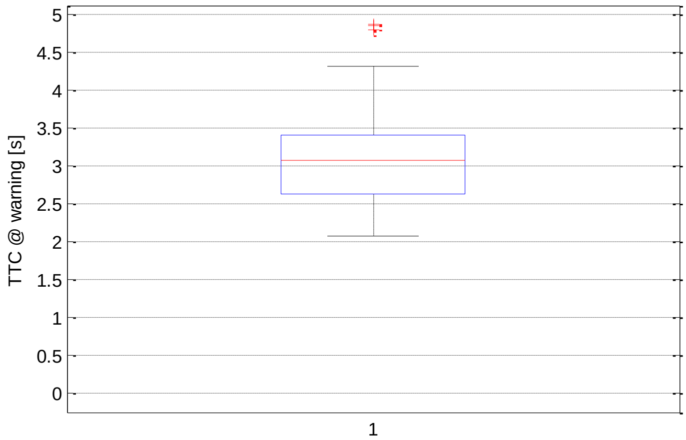


Figure 53: TTC at warning for all rear-end test of tested implementation of the CS function

Analyzing the hypothesis (H_0: TTC @ warning - $t_{Manoeuvre} > t_{Reaction}$) leads to the following conclusion. For the driver reaction it is presumed that nearly all drivers can react within a time period of $t_{Reaction}$ = 1.5 s. The test case in which the function has not issued a warning is excluded. The one tail z-test over all test runs of the rear-end scenario yields that that the alternative hypothesis is true ($Z = 8.6263$, $p < 0.0001$). Hence it can be stated for this implementation of the CS function the driver is warned in time so that he or she can react and avoid the accident successfully.

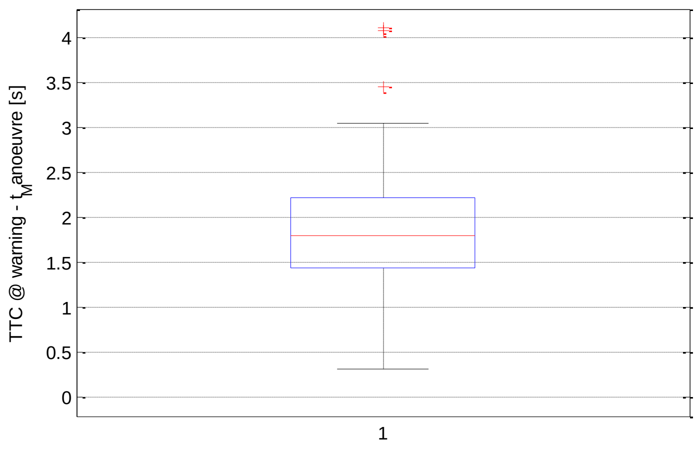


Figure 54: Remaining reaction time for all rear-end test scenario of test implementation of the CS function

Since there are some differences between the test cases, a closer look on test case 1.7 is taken. For the test cases with a static target or a constant moving target the warning is issued earlier than in the test case 1.7 (decelerating of other vehicle in front). The calculated remaining reaction time during the test scenarios with constant or stationary target vehicles is 1.97 s (sd = 0.7 s). For the test scenario 1.7 the remaining reaction time is 1.36 s (sd = 0.32 s). In this case a driver with a maximal reaction time of 1.5 s might not be able to avoid a collision. However, as for most drivers the reaction time is below 1.5 s, it is likely that the accident can still be avoided by a considerable number of drivers. Hence, the hypothesis is confirmed in this case.

The technical assessment focused on the overall performance of all interactIVe functions. With respect to the technical performance in general, it can be concluded that the functions behaved as intended. This means the developed functions in general covered the use cases defined and acted in the use cases in the defined way. With respect to the false warning behaviour of the functions differences between the interactIVe functions were observed during the tests. For some functions false warnings were observed. For a research project this is a minor issue, but if these functions are introduced in the market, this issue must be solved. At this point, it also must be mentioned that for other functions, no false warnings were observed during the tests.

General statements on the functions are difficult, since the eleven developed interactIVe functions and even their implementations in the different demonstrator vehicles are different. Especially the variety in implementation of one function makes it difficult to draw general conclusions, because classification in good or bad function behaviour is often not possible. Other criteria, like e.g. the design followed by the developer, must be considered and may lead to different results. Curve speed warning in Continuous Support integrated in the VCC and CRF demonstrator is a good example for such a consideration. In one demonstrator the function had a low and in the other a high warning threshold. A lower threshold reduces the risk that a driver is not able to drive through a curve. However, the risk that the driver is annoyed by the warning increases with the number of warnings. The avoidance of the “nuisance” warnings was the aim of the implementation with the high warning threshold. The question whether a warning is necessary or not, depends strongly on the driver and on his/her driving style or preferences. Hence, it is difficult to decide in general, whether the warning threshold is good or bad. With respect to safety and in the context of the project most important is that the function is able to warn the driver in the addressed situations.

With respect to interventions, the tests have shown that the interactIVe functions intervene as specified in the scenarios tested. In the collision mitigation functions, the functions are able to achieve the maximum theoretical acceleration of 1 g in longitudinal (e.g. braking CMS function) as well as in lateral direction (e.g. ESA function). In collision avoidance functions, tests have shown that collisions can be avoided both by steering and by braking, while remaining in the “comfort” zone of the driver. When interventions are preceded by warnings, the warnings are in general provided in time so that “normal” drivers can react and avoid the accident. Both the development of the functions and the operation of tests have proven to be very challenging, and not all the planned tests could be performed within the limits of resources and time. The main picture is rather complete, however, and further testing is on-going to contribute to the discussion of legal aspects not covered here.

4.3.2 User-related assessment

Nine studies with 263 subjects provided the basis for the evaluation of the user-related assessments. The tests were carried out between March 2013 and June 2013. To investigate drivers’ reactions to the functions developed, naïve subjects tested them in relevant driving situations in driving simulators or in instrumented vehicles in real traffic (if the function in question was allowed to be driven on public roads and by naïve drivers). An exception were functions that were not allowed to be driven by the subjects at all. They were evaluated by presenting the function to the subject, who then discussed relevant issues with other naïve drivers in a focus group and/or answered an individual questionnaire. Table 13 below summarizes the studies conducted.

Table 13: User assessment tests performed in interactIVe

Partner	Test sites	Test design	Test persons
BMW (SECONDS – eDDP)	Aachen	Video presentation of the function to participants in two focus groups.	17 persons from the public, 5 females and 12 males of age 18-64.
CONTIT (EMIC – ESA)	Porriño (CTAG)	Simulator study	68 persons from the public, 20 females and 48 males of age 21-57.
CRF (SECONDS – CS including CSW)	Turin	Small field test including driving without- and with the function on public roads.	24 persons (employees of CRF, not related to interactIVe) 11 females and 13 males of age 25-64.
FFA (SECONDS – CS & CSC)	Aachen	Driving with the function on a test track by participants of two focus groups.	19 persons from the public, 9 females and 10 males of age 18-65+.
FFA (INCA – SIA & RECA)	Aachen	Driving with the function on a test track	25 persons from the public, 11 females, 14 males of age 22-73.
VCC (SECONDS – SC including Speed Support)	Hällered	Driving with the function on a test track	10 persons (employees of VCC) 4 females and 6 males of age 25-64.
VCC (INCA – SIA & RECA)	Hällered	Driving with the function on a test track	10 persons (employees of VCC) 4 females and 6 males of age 25-64.

Partner	Test sites	Test design	Test persons
VTEC (INCA – OVCA, RECA, RoRP, SIA)	VTEC simulator	Main drive with a between groups design: driving with/ without functions + concluding test session where all participants could try out the functions.	31 persons (professional truck drivers), all males of age 22-63.
VW (EMIC – CMS)	Porriño (CTAG)	Simulator study	59 person from the public, 14 females and 45 males of age 21-57.

An overview is given in the following by presenting some results for all functions tested, especially those that give advice on improvement. Again, the full details are given in D7.5.

Driving with CS revealed that Curve Speed Warnings gave the expected effects; there was a better speed adaptation to the speed limits and situations, there were less dangerous lane changes with the system active, however, there were slightly more late adaptations of speed before intersections and obstacles. The test drivers were of the opinion that the system was useful; it would enhance safety especially in overtaking situations on motorways. Blind spot warning was found especially useful in the overtaking process. It was appreciated that the system did not give information all the time.

Improvements are possible for the following items:

- False alarms must be eliminated.
- The speed limits indicated must be coherent with the speed limit signs.
- The pressure of the seat belt warnings was either not correlated with the real hazardousness of the situation and it came additionally to the acoustic warning.
- Warnings came too late and some possibly dangerous situations were already recognised before the system showed it.
- In emergency situations no visual information was given or it was shown only for a too short time, so the test persons didn't know the reason for the haptic or acoustic warning.

The driver interface can be improved as follows:

- The signal for the forward collision warning could be "stronger" in order to get the attention of the driver in situations when he/she might be distracted.
- The warning icon should be kept for a longer period after the warning was issued.
- The visual display for the forward collision warning should be put as high as possible so that it will not be covered by the steering wheel while driving through a curve.
- The test persons would prefer an additional haptic warning for the blind spot warning.
- Safety belt tensioning should not be used for speed or forward collision warning.

The opinions about the eDPP were that a head-up display was a good way to inform the driver. However, it would only be used on rural roads, but not in bad weather conditions (rain, snow, black ice).

The opinions about the Safe Cruise (SC) function were that it was well-functioning and easy to use, it had a clear visual and haptic information/warning, it would be used mostly on motorways, day time and clear weather and less on urban roads, in rainy or snowy weather and during night time.

During the simulator test for the INCA function the following items were observed:

- When driving with Oncoming Vehicle Collision Avoidance/Mitigation (OVCA), the test drivers braked harder, they adjusted their brake pedal position when the function warned. The test drivers had a somewhat low acceptance for the system, they thought it was less useful to improve safety and its main use would be on rural roads.
- When driving with Rear End Collision Avoidance (RECA) in the simulator, only one collision occurred whereas without the function there were 12 collisions. However, no difference in reaction time could be shown. There was high user acceptance; the test drivers thought it was useful to improve safety. Main intended usage was indicated on motorways and rural roads.
- The opinions about the Lane Change Collision Avoidance (LCCA) function were that the function was well-balanced and well-designed. It got high usability and acceptance ratings. Highest intended usage rate was indicated on motorways, but high usage rate was on rural roads and in urban areas too.
- When driving with Side Impact Avoidance (SIA), fewer collisions occurred (9) compared to driving without (14). However, no difference in reaction time or reaction strength could be shown. It got high usability and acceptance rating and it was thought to be useful to improve safety. It was indicated to be used on both motorways, rural roads, and in urban areas.
- When driving with Run-off Road Prevention (RoRP), reaction time was shorter and reaction was stronger. It got high usability and acceptance ratings and it was thought to be useful to improve safety. It was indicated to be used on motorways and rural roads.

Driving with Collision Mitigation System (CMS) reduced brake reaction time. The test persons found it useful and satisfying.

Driving with Emergency Steer Assist (ESA) reduced reaction time considerably. The test persons appreciated the system; especially that it did not interfere with driving. It would be used mostly on motorways.

The mean level of intended usage of the assessed interactIVe functions, which derived from a questionnaire, is presented in Table 14. The table indicates where and how much the test persons would use the interactIVe functions. Overall, it can be concluded that the test persons would use most of the interactIVe functions more often on motorways than on urban roads.

Table 14: Mean level of intended usage of interactIVe functions as percentage of driving time on different road types.

Road type	SECONDS				INCA				EMIC	
	CS	eDPP	CSC	SC	OVCA	RECA	LCCA & SIA	RoRP	CMS	ESA
Motorways	72%	20%	82%	66%	55%	76%	78%	70%	31%	42%
Rural roads	62%	65%	72%	61%	58%	55%	76%	68%	43%	40%
Urban roads	53%	16%	58%	52%	76%	62%	70%	44%	55%	32%

The test persons' willingness to pay for different functions is presented in Figure 54 per use case. In this figure the interactIVe functions have been cluster by four scenarios, which are addressed by most of the interactIVe functions (Rear-end: CS, RECA, CMS and ESA; Run-off-road: CS and RORP; Oncoming: eDPP and OVCA; Blind-spot: CS and LCCA /SIA). The figure shows a high fraction in the area between 0 and 250 €. This high portion results mainly from the warning functions, for which the test persons in general are willing to spend less money compared to the intervening functions. Furthermore, the oncoming function have the highest proportion of all use cases in the “>1000 €” and “500-750 €” bins, whereas the rear-end collision avoidance function have the highest proportion in the “750-1000 €” bin. In the blind spot scenario the test persons are willing to spend less money, which is indicated by the overall distribution as well as the fact, that the highest proportion is located in the “250-500 €” bin.

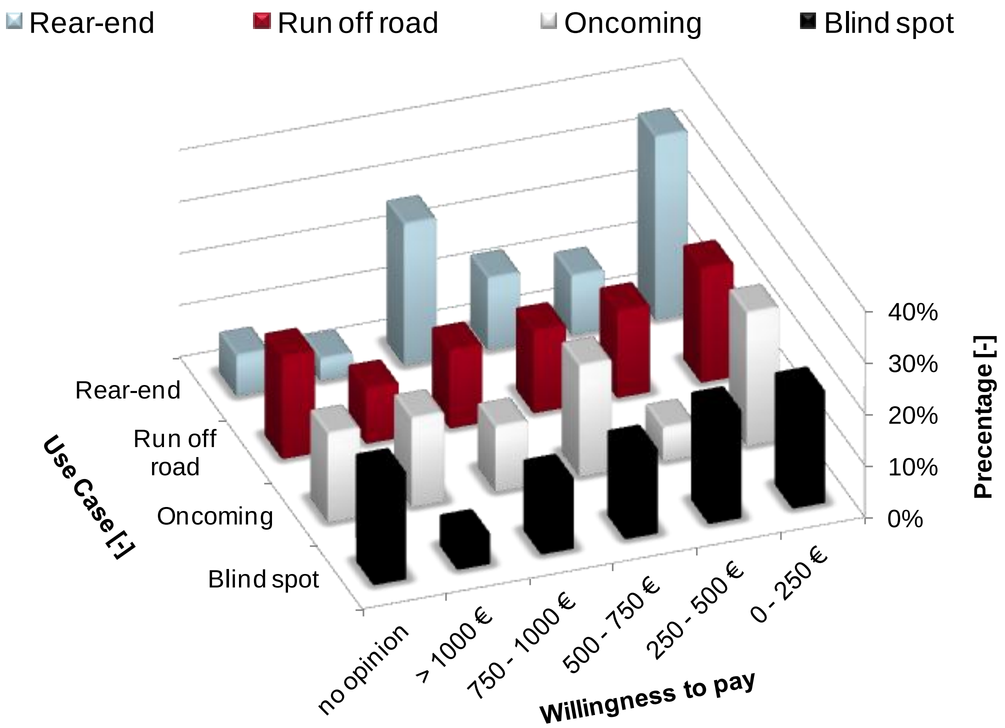


Figure 55: Willingness to pay for different by the interactIVe functions addressed use cases.

For the user-related assessment it can be concluded in general that the test persons found all interactIVe functions under assessment useful. Moving from the test track to public roads with such a system, however, would imply relevant challenges both from the technical and from the user-related point of view. For the developer, the logged data combined with the user and observer comments provide an important data set that can be used in order to identify major problems (mainly false alarms) and improve system performance.

4.3.3 Impact assessment

Based on the results of the technical and user-related assessment the safety impact of the interactIVe functions was analysed. The method as well as the limitations, which need to be taken into account for the results of safety impact assessment, is described in D7.5.

Basis for the safety impact assessment is the SP7- developed tool SIMPATO (Safety IMPact Assessment Tool). This tool analyses the direct effects of the interactIVe functions by re-simulating the original accidents with the interactIVe function. The starting point is an accident scenario where the function is not present, which is obtained from an in-depth accident database. For the alternative case, where the system is present, the accident evolution starts from the same initial condition as the reference case. This initial condition is a point on the evolution sufficiently far before the accident (in time) that it can be considered as pre-critical. From this initial condition, an alternative evolution is determined which can differ from the reference via two mechanisms:

1. The function warns and after some time the driver reacts by braking or steering.
2. The function intervenes by braking or steering.

The re-simulation of accident requires certain input parameters and assumptions, which are not available respectively cannot be made for some accident scenarios. Hence, these accident scenarios could not be analysed in detail but were analysed at a general level.

In the safety impact assessment real rear-end, blind spot and run-off road accidents of the GIDAS database were re-simulated with the function under study. As a second step the changes for the different injury levels were calculated.

The results for the interactIVe function, which address either the rear-end, blind-spot or run-off road accident scenario, are given in the following table.

Table 15: Results of the accident re-simulation based on the GIDAS accident database.

Function	Accident scenario	Number con-sidered accidents	Avoided scenario relevant accidents	Mitigated scenario relevant accidents [2]	Not effected accidents	Outside opera-tional conditions
CS	Rear-end	364	21% - 27%	65% - 70%	8 %	0% - 1%
CS	Run-off road	65	34% - 73%	-	27% - 66%	0%
RECA (Car)	Rear-end	364	77%	22%	0%	1%
RECA (Truck)	Rear-end	32	30%	70%	0%	0%
RoRP (Car)	Run-off road	65	31% - 34%	-	55% - 67%	1%
RoRP (Truck)	Run-off road	65	81%	-	17%	1%
CMS	Rear-end	364	34%	42%	0%	24%
ESA[3]	Rear-end	364	77%	2%	0%	21%
CS LCCA / SIA	Blind-spot $\Delta v <$ 35 km/h	104	60%	-	40%	-
CS LCCA / SIA	Blind-spot[4] $\Delta v <$ 60 km/h	104	86%	-	14%	-

[2] Only considered in the rear-end accident scenario

[3] Driver must initiate an evasive manoeuvre before the function starts to intervene. According to [ADAMS 94] the percentage of the driver, who start a steering manoeuvre in a rear-end conflict is below 10 %. This limits the safety impact of this function.

[4] Re-simulation of accident did not lead to robust results. These assumptions lead to the result that depending on the parameters of the analysed function either all accidents or none accidents are avoided. With respect to the real world this behaviour of result is at least questionable. Therefore, the reduction of accidents was estimated based on the share of cases that show speed differences similar to the scenarios of the technical assessment, in which the system showed avoidance.

If the current accident situation (Table 16) is considered and the determined effectiveness of the interactIVe function is applied to the accident numbers it is expected to reduce the number of traffic fatally and severely injured by the in Table 17 given values. However, it must always be taken into account that only a small fraction of the road fatalities were considered in the analysis. Please note also, that various interactIVe function address the same accidents e. g. ESA and CMS, hence the results may not be added up.

Table 16: Safety impact in terms of reduced number of fatal and severely injured on basis of the current accident statistics in EU 27 (approx. n_{fatal} = 28 000; n_{sever} = 250 000).

interactIVe function	CS	RECA	RoRP	SIA & LCCA[5]	**CMS**	ESA
Considered number of severely / fatal injured car occupants						
In road departures accidents	7850 (3.14%) / 1439 (5.14%)					
In rear-end departures accidents	6325 (2.53%) / 218 (0.78%)					
In lane change accidents	1700 (0.68%) / 232 (0.83%)					
Severely injured car occupants in accidents on EU-level						
Reduction in road departures accidents	0.02 - 0.42%	-	0.04 - 0.52%	-	-	-
Reduction in rear ends accidents	0.74 - 0.75%	1.73%	-	-	0.86%	2.22%
Reduction in lane changes accidents	0.41%	-	-	0.41 - 0.58%	-	-
Total reduction in terms of number of severely injured road users	**3375-3975**	**4325**	**100-1300**	**1025-1450**	**2150**	**(5550)**
% Reduction of severely inj. car occ. in relevant accidents	**22 – 25%**	**68%**	**1 – 8%**	**60 – 85%**	**34.0%**	**(95%[6])**
Fatally injured car occupants in accidents on EU-level						
• Reduction in road departures accidents	0.05 - 0.85%	-	0.07 - 0.53%	-	-	-
• Reduction in rear ends accidents	0.18 – 0.18%	0.49%	-	-	0.11%	0.78%
• Reduction in lane changes accidents	0.42 - 0.62%	-	-	0.42 - 0.62%	-	-
Total reduction in terms of number of fatally injured road	**277-465**	**137**	**11-148**	**118-174**	**31**	**(218)**

[5] For the SIA & LCCA the potential was calculated based on the tested difference velocity and not based on re-simulation of accidents.

[6] Driver must initiate an evasive manoeuvre. According to [ADAMS 94] the percentage of the driver, who start a steering manoeuvre in a rear-end conflict is below 10%. This limits the safety impact of this function.

users						
% Reduction of fatally inj. car occ. in relevant accidents	**15 - 25%**	**62%**	**1 - 10%**	**51 - 75%**	**14%**	**(100%[3])**

Besides the accident types, for which the results were presented in the previous chapters, the interactIVe functions address also other accident types:

- Head-on collision.
- Cross traffic collisions.
- Collisions with vulnerable road users (VRU).
- Excessive speed accidents.
- Traffic rule violations.

For these accident types a re-simulation of the accident with a system under study is not possible and hence also a detailed analysis of the effects due to the lack of input data on initial conditions for a re-simulation. For re-simulation the trajectory of the involved accident partners need to be described. However, if already slight changes in the trajectory lead to a completely different accident outcome, it is also difficult to re-simulate the accident. This is the case e.g. for the crossing scenario and the VRU scenario. Due to these constrains it has been decided not to re-simulate the above mentioned accident types. Instead only the potential effect, which can be achieved by the interactIVe function in these accident types, has been assessed. In the following table the interactIVe function, which address the not re-simulated accident types are presented.

In order to identify the potential effects of the interactIVe functions the accident scenarios were analysed based on three categories:

- Frequency of the accident type.
- Severity of the accident type.
- Limitations of the interactIVe functions.

The expected effects with respect to traffic safety are summarized for the affected functions in the Table 17.

Table 17: Expected effects on traffic safety of interactIVe functions in not re-simulated accident scenarios

Expected effects of not in detail analysed accident scenarios							
	CS	**CSC**	**eDPP**	**SC**	**OVCA**	**CMS**	**ESA**
Head-on collision	-	-	Low	-	Medium	Medium / High	Low
Collisions with vulnerable road users (VRU)	Medium	-	-	-	-	-	Low
Excessive speed accidents	Medium	Medium	Medium		-	-	-
Traffic rule violations	Medium	-	Medium	Medium	-	-	-

An explanation how to derive the expected safety impact is given in deliverable D7.5 [INT D7.5].

The safety impact assessment has shown some high numbers of simulated accidents that could be avoided by interactIVe functions. The analysis presented here (and detailed in D7.5) is valid with the assumptions and limitations given. The results cannot include as yet unknown side-effects in real accidents that lead to a different outcome and/or user behaviour that differs from the simulated one.

4.3.4 Legal Aspects

The chapter on Evaluation has shown how results have been derived, which indicate the potential effects of the research functions in real traffic. The improvements collected for next steps towards ma73

rket-introduction will be handled in industrial development. SP7 has shown that users are willing to pay for functions – and marketing needs to ascertain that our functions will not be offered at the initial costs but with view on cost-reductions due to a future high take-rate. The last statement in deployment will come from the prospective buyer of a new vehicle – who might still take a wholly different view on the need for combined ADAS packages at the sum of individual (willingness) prices. However, much earlier before deployment to the market, legal barriers must be identified and solved that are outside the industry. Such barriers can also hinder the field operational tests which are needed to fine-tune assistance functions that also exert lateral control.

SP7 has identified in D7.3 [INT D7.3] the current state of legal aspect that concern deployment of assisted or even automated driving. These potential legal barriers and obligations must be considered and adapted, if the interactIVe systems should be introduced to the market. The analysis of the legal aspects is divided into two parts. First, the vehicle type-approval for interactIVe functions according to relevant UN ECE is analysed. Afterwards the legal framework on EU-level is analysed.

It needs to be noted that the following results are based on the deliverable D7.3 that was finalized in January 2012. Therefore the following results refer to the status at that time.

Vehicle Type Approval Requirements

Vehicles of any kind have to be approved for roadworthiness. This process usually incorporates the assignment of a registration number and requires the vehicle to conform to specific requirements, e.g. for vehicle safety or environmental aspects. The mandate to approve vehicles for traffic belongs to the government of each country, with most countries however accepting those requirements defined by the United Nations Economic Commission for Europe's World Forum for the Harmonization of Vehicle Regulations (UN ECE WP.29). There are two different types of vehicle regulations: The 1958 agreement[7] system which requires vehicles to be certified by an independent technical service (Europe, Japan, rest of the world) and the 1998 agreement[8] which requires the vehicle manufacturers to certify their vehicles themselves (USA, China, most of the 1958 states).

[7] AGREEMENT CONCERNING THE ADOPTION OF UNIFORM TECHNICAL PRESCRIPTIONS FOR WHEELED VEHICLES, EQUIPMENT AND PARTS WHICH CAN BE FITTED AND/OR BE USED ON WHEELED VEHICLES AND THE CONDITIONS FOR RECIPROCAL RECOGNITION OF APPROVALS GRANTED ON THE BASIS OF THESE PRESCRIPTIONS (former title: Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts)

[8] Agreement concerning the establishing of global technical regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles

ECE regulations provide requirements for functional systems of a vehicle or a vehicle itself. The interactIVe demonstrator vehicles are based on production vehicles that are produced for traffic and therefore conform to type approval regulations. The added functionality involves warning systems and intervening systems. 'Warning only' systems are not covered by ECE regulations. Intervening systems are allowed as long as they conform to relevant regulations. For intervening systems that act on the vehicle brakes, throttle and steering systems the regulations (R13, R13-H, R79) are of relevance concerning the type approval of the added functionality. The requirements for the different intervention can be summarised as:

Table 18: Requirements for type approval according to UN ECE 1998 agreement

Intervention	Description
Brake intervention	For interactIVe, considered that the interactIVe functions are added to systems and system architectures that have already been type-approved, only the added functions themselves are relevant. Automatically commanded braking is permitted, as long as the function is declared. Brake lights and emergency braking signals will need to be turned on according to the criteria defined.
Steering intervention	Vehicle functions need to fulfil the following requirements: For interactIVe, considered that the interactIVe functions are added to systems and system architectures that have already been type-approved, only the added functions themselves are relevant. The regulation R79 does allow • autonomous steering control (without the driver being in the steering loop) at low speeds (< 12 km/h) and • steering assistance (with the driver still in the control loop) only for a limited time, to maintain the basic desired course or to influence the vehicle's dynamic behaviour. • All signals used for the control system must be initiated on-board. • Tactile warning on the steering wheel is allowed. All other interventions (e.g. autonomous steering at higher speeds) through the steering actuator are not allowed.
General requirements	The added functionality needs to conform to specific functional safety requirements, either defined within R13, R13h and R79 or e.g. in ISO 26262. All systems also need to conform to electromagnetic compatibility requirements defined in R10.

Most interactIVe functions defined within interactIVe already conform to current UNECE regulations. Those systems that implement steering functions which neither help in keeping the basic desired course nor stabilize the vehicle do not conform to current UNECE

Table 19 summarizes the results of the detailed analysis of all interactIVe functions and also mentions the reasons. Recommendations for further development of relevant regulations are derived from this table.

Table 19: Summary of possibilities for type-approval of interactIVe functions according to current regulations

interactIVe function	Result	Reasons
Continuous Support	OK	

interactIVe function	Result	Reasons
Curve Speed Control	OK	
enhanced Dynamic Pass Predictor	OK	
Safe Cruise	Not OK	Corrective Steering intervention not for a limited period of time (Reg 79) / autonomous steering not allowed for speeds > 12 km/h
Lane Change Collision avoidance	Not OK	Steering intervention neither helps in keeping the basic desired course nor stabilizes the vehicle.
Oncoming vehicle collision avoidance / mitigation	OK, see comment	Flashing headlights as warning signal must conform to relevant headlight regulations.
Rear end collision avoidance	Not OK for steering, see comment	Specific brake light signal needs to conform to ECE 13 and 13h. Steering intervention neither helps in keeping the basic desired course nor stabilizes the vehicle (Reg. 79).
Run off road prevention (curve)	OK	
Side impact avoidance	OK	
Collision Mitigation System	Not clear, see text	Steering intervention neither helps in keeping the basic desired course nor stabilizes the vehicle. But the function acts autonomously only if the accident cannot be prevented (pure mitigation system). It is not clear whether this will conform to regulation 79.
Emergency Steer Assist	OK	

Legal Framework on EU-level

In addition to the issues concerning ECE-Regulations as described above the applications being developed within the interactIVe project raise different questions from a legal point of view.

The inteactIVe functions are affected by the existing legal framework on EU-level mainly with regard to product liability (basing on Directive 85/4374/EEC) and – connected with that – with regard to the 1968 Vienna Convention on Road Traffic.

Considering the Vienna Convention with regard to the functions developed within the interactIVe project, the focus is on Articles 8 (5) and 13 (1) VC: Those provisions constitute the driver's obligation to be always in control of his vehicle. This basic idea of permanent controllability assigns the driving task to the driver and therefore makes it seem sensible to put forward the driver's will as far as possible. This may be achieved by means of a function design which allows the driver to override automated braking and/or steering interventions.

In case a function detects an impending accident the adherence to the driver's will (in terms of controllability) can be enhanced by calling forth the driver's will by means of corresponding warning strategies. Information respectively warnings give the driver the basic opportunity to initiate braking or steering him-/herself in order to avoid or to mitigate the collision – or even to override an upcoming automated braking and/or steering intervention if necessary. Moreover, automated braking and/or steering interventions do not run contrary to Articles 8 (5) and 13 (1) VC as long as the intervention occurs in an area which is beyond human capability to react.

Another crucial aspect to be investigated concerning the functions developed within the interactIVe-project is product liability. It is remarkable that product liability systems in the EU Member States show a significant extent of similarity[9]: Liability claims arising from damages caused by a defective product may be based on three distinct liability systems: product liability (based on the Product Liability Directive 85/374/EEC), contract (contractual liability) and/or tort (extra-contractual liability).

The general findings concerning product liability on EU-level can be summarized as follows: Relevant provisions concerning product liability can be found in the Product Liability Directive 85/374/EEC and the corresponding individual EU Member States´ laws which implemented the Directive into national law. With regard to the liability deriving from those sources of law a product should comply with the state-of-the-art in science and technology – in order to be able to prove that this state-of-art was adhered to during the design, the construction and the production processes and with that in order to reduce product liability risks, relevant systems of rules like the RESPONSE 3 Code of Practice respectively technical standards like [ISO 26262] (Road Vehicles – Functional Safety) should be observed. From a product liability point of view it is recommendable to design the functions developed in the interactIVe-project in a way allowing the driver to override automated braking and/or steering interventions any time the driver wishes to do so.

Functions providing for mere information respectively warnings can easily be overridden and hence be controlled by the driver. Functions providing for automated braking and/or steering interventions bring along an increased product liability risk since the driver has to do more than simply ignore a false-positive warning: he/she will have to counteract actively on a false-positive intervention.

Non-overrideability of automated braking and/or steering interventions increases the product liability risk since the driver cannot counteract a false-positive intervention in this case.

Partly automated functions taking over longitudinal and lateral guidance of the vehicle for a certain period of time or in specific situations – how can they increase the product liability risk? This has been examined by the BASt-project group ‘Legal consequences of an increase in vehicle automation’ which presented its first findings in 2011.

Product liability risks have to be addressed appropriately, also with regard to the Vienna Convention on Road Traffic which constitutes the requirement of controllability. An overview on potential product liability risks for the interactIVe functions is given in Table 20.

Table 20: Summary of potential product liability risks for the interactIVe functions

interactIVe function	Reasons
Continuous Support	Increased product liability risk to be addressed (due to risk of excessive use by the driver [not intended by the manufacturer])

[9] see Lovells, p. 9

interactIVe function	Reasons
Curve Speed Control	Increased product liability risk to be addressed (due to risk of excessive use by the driver [not intended by the manufacturer])
Enhanced Dynamic Pass Predictor	No particular risk provided the product liability risk is addressed appropriately
Safe Cruise	Increased product liability risk to be addressed (due to risk of excessive use by the driver [not intended by the manufacturer])
Lane Change Collision avoidance	No particular risk provided the product liability risk is addressed appropriately
Oncoming vehicle collision avoidance / mitigation	No particular risk provided the product liability risk is addressed appropriately (and provided that non-overrideable interventions are not included in the OVCA function)
Rear end collision avoidance	Critical with regard to product liability risks and Vienna Convention due to non-overrideable braking interventions
Run off road prevention (curve)	No particular risk provided the product liability risk is addressed appropriately
Side impact avoidance	No particular risk provided the product liability risk is addressed appropriately
Collision Mitigation System	No particular risk provided the product liability risk is addressed appropriately (and provided that non-overrideable interventions are not included in the CMS)
Emergency Steer Assist	No particular risk provided the product liability risk is addressed appropriately

4.4 Summary on interactIVe Evaluation

The overall methodology applied for the evaluation was presented. In the technical assessment it has been shown with spotlight on one function and one hypothesis, how the hypotheses were analysed. The results in the three evaluation areas were summarized. A much more detailed evolution of Evaluation and its results is given in D7.5.

Overall in the sub-project 7 “Evaluation and legal aspects”, 11 different functions of the three vertical sub-projects “SECONDS”, “INCA” and “EMIC” have been tested and evaluated. The interactIVe functions were integrated in different combination in seven demonstrator vehicles. The technical tests as well as user-related studies were conducted at several test sites in Europe. The basis for the testing and evaluation was the test and evaluation plan defined in deliverable D7.4. Based on the test the hypotheses, which were defined in D7.2 and revised in D7.4, were analysed. Furthermore, based on the results of the technical and user-related assessment the safety impact assessment was conducted. With the assessment also ideas were collected how to improve the systems from a user perspective. The safety impact assessment showed that all functions developed in interactIVe would provide a potential safety benefit in the analysed accidents. The amount of the safety effect of the functions depends on the function as well as on the by the function addressed use cases. In the rear-end case some functions were shown in simulations to avoid nearly all accidents. However, the considered number of road fatalities in this scenario is lower compared to other scenarios. Hence, the achieved safety benefit with respect to the total number of road fatalities in this scenario is also limited.

For all results of the safety impact assessment it must be taken into account that they are only valid inside the limitations of the analysis. The main issue for the safety impact assessment is the missing input data with respect to accidents and missing data on side effects from the functions. The existing databases provide not enough detailed accident information – in particular with the information on the pre-crash phase - in order to apply the accident re-simulation to all accident types. Furthermore, also for the analysed accident types more data regarding the available data set would be desirable.

5 Dissemination and exploitation of project results

Dissemination of project objectives, concepts, and results to the different audiences held a very important role for interactIVe. This did not only concern the iterative design of the proposed collision avoidance systems, but also for studying the market penetration and general acceptance of avoidance systems. In addition, requirements of a constant and focused stakeholder communication have been addressed.

At the level of targeting the expert community, special attention was paid to the presentation of project results at **international conferences**, submission of articles to renowned **scientific journals** and establishing cooperation with other relevant European and national research projects. At the level of addressing the general public, the interested people were addressed via announcements and news in the project website, the press, newsletters and other dissemination media, as well as via the organisation of the final event. This final event publicly showed a variety of demonstrators for people to actually experience in real life the technical innovations of interactIVe.

In order to disseminate the project achievements and results to the abovementioned target groups the interactIVe consortium has given more than 63 presentations in international conferences, workshops or other events, published 35 papers in different conference proceedings and submitted three papers in renowned peer reviewed scientific journals.

Moreover vehicle owners took every opportunity to **demonstrate the interactIVe prototypes** on several occasions. Through this effort the interactIVe consortium had a continuous and strong appearance in the most worldwide known scientific and industrial events i.e. the annual ITS world Congresses, ITS European Congresses, Transport Research Arena, EUCAR conferences, FUSION conferences, IEEE conferences, AHFE conferences, SAE Convergences etc., promoting and disseminating its evolutions and results to the scientific community, the market, the policy makers and the general public.

Through this huge dissemination effort, the interactIVe partners took all opportunities to **liaise with other projects**, companies and several stakeholders in order to achieve the maximum dissemination of its developments and results. It is worth to mention that interactIVe consortium organised common dissemination activities with the euroFOT, MiniFaros and 2WIDE-SENSE European projects while it has participated in numerous EU projects meetings and other events for presenting the interactIVe achievements and networking with the different stakeholders.

In addition, interactIVe organised or participated in relevant special sessions in **international conferences**. Specifically, four special sessions have been organised during the project's runtime:

- During the TRA conference in April, at Athens, Greece, in cooperation with euroFOT Integrated project.
- During the ITS World Congress in Vienna, Austria in October 2012 in cooperation with the MiniFaros and 2WIDE-SENSE European projects.
- During the FUSION 2013 Conference in Istanbul in July 2013.
- During the 20th ITS World Congress in Tokyo, Japan in October 2013.

One of the major scientific dissemination activities of the project was the organisation of the **interactIVe Summer School.** More than 70 participants arrived in Corfu Island, Greece from 4 to 6 July 2012 to attend the project's Summer School. During this event project partners, stakeholders from the automotive industry and PhD students had the opportunity to discover the state-of-the-art on Perception Systems, Advanced Driver Assistance Systems (ADAS) and Human Machine Interfaces (HMI) for safer and more efficient driving as well as the interactIVe latest developments and results during the six Summer School tutorials. Finally, poster and demo sessions took place during the Summer School where 16 technical posters and one demonstration were presented to the attendees highlighting the latest technological developments in the above mentioned fields.

Finally, a very significant effort to communicate the interactIVe final results and evolutions was the organisation of the project's **final event.** The interactIVe Final Event was held on November 20th and 21st, 2013 at the Eurogress Convention Center in Aachen (Germany) and the Ford Proving Ground in Lommel (Belgium) in cooperation with the eCoMove project. eCoMove has created an integrated cooperative solution for energy efficiency in road transport through eco-driving support and eco-traffic management and concluded its activities at the same time. The decision to combine these two events was made to gain every benefit from this synergy, and maximise the impact of the event.

The basic aim of the interactIVe final event was to bring together some 300 people. During the first day (20th November 2013) all interactIVe and eCoMove high level and technical presentations were held, while in parallel a common exhibition will be available for the participants at the Eurogress Convention Centre in Aachen (Germany). Through this exhibition participants had the opportunity to learn more about the projects' technical results through technical posters, pc based demos and simulations. In the second day (21st November 2013) both interactIVe and eCoMove live demonstrations took place. Especially for interactIVe advanced functions were presented during a driving session with the interactIVe demonstrator vehicles held at the Ford Proving Ground in Lommel (Belgium).

All the project's dissemination and liaison activities were reported in detail in the deliverable [INT D1.3], as well as in the standard project report presented at the end of the research.

6 Outlook and conclusions

6.1 Project results

In this report the three main pillars developed within interactIVe have been presented: (i) Continuous Driver Support (ii) Collision Avoidance and (iii) Collision Mitigation.

These pillars have been much advanced with respect to the situation at the time when the project concept was developed in April 2009. In the meantime, of course, the progress of assisted driving in everyday vehicles has also advanced – in ordinary driving such as in a traffic jam or parking. Current activities at a production level have explored to a lower extent the region of the driving task which encompasses critical situations, or where incidents appear as possible precursors of serious accidents.

If we look at **series-production vehicles and ADAS**, considerable improvement has been made with systems able to monitor objects in front of the vehicle to help prevent collisions at speeds up to 15 km/h, and reduce the severity of impacts at speeds up to 30 km/h. These functions for cars are active only at a lower speed range. For trucks fitment of AEBS (advanced emergency braking system, up to full truck speed) will become mandatory for new type of vehicles in November 2013.

For higher velocities, sensor performance and computer power need to be raised by a more than linear factor: actually, not only is the time for a decision shortened but also the potential for false positive alarms is larger. This can be ideally solved by a more reliable system of sensors and a faster computer or by a parallelization of algorithms (itself a subject which is difficult to quantify in terms of safety factors). The larger concern remains that the consequences of a false alarm at high velocity can result in serious injuries. In summary a considerable non-linearity exists.

The solution in interactIVe was to integrate functions, and in particular, to deploy multiple sensors and data fusion in order to improve the robustness and speed of detection. In addition, the perception layer can be used in a modular fashion, allowing specific and proprietary aspects to be implemented in the applications.

Considerable progress for perception is visible through the design of standard interfaces (so that a clear definition of the signals could support an easy integration inside our vertical SPs). These interfaces are the outcome of the architecture of the Perception Horizon and the intelligence applied to understand the relevant scenarios. Data fusion as it has been applied and improved in SP2 is the basis for a future deployment of interactIVe technology. It remains to be seen to which extent fusion ideas will remain in later development stages, e.g. at which control unit the computational power will be placed – or if a more robust design will require redundant solutions to guarantee a resilient behaviour.

As a result of the work on **IWI strategies**, a number of guidelines have been produced for the interaction design. Especially, the IWI strategies give several important structuring elements such as a given sequence of interaction, a safety shield and automation scale which allow the integration of the high number of ADAS into a single integrated experience for the driver.

The tight integration between **IWI strategies** and the vertical SPs led to a host of solutions which will serve as off-the-shelf building blocks for strategy implementations, of course with some elements visually adapted to integrate brand aspects. The methodology of an iterative development-testing cycle including tools such as a theatre system technique, simulator studies and test vehicles allowed to include human factor aspects already from the first design phases. The IWI strategies pave the way for short term deployment of ADAS and automation functions in the on-going product cycle following holistic and integrative concepts for interaction and display design.

The **demonstrators** developed in interactIVe are, looking from the outside, advanced prototypes not so distant from series vehicles. The tests performed with these demonstrators have shown good potentialities for meeting driver's needs. However, most of the functions are realized in research vehicles, not approved for public roads. The functional safety concerns, needed for product development, have not been fully integrated in the research design. Functional safety in full force appears at a later gateway in the industry development process; considering for instance the probability of failure on chip-level required for SIL-standards and various probability-versus-consequence considerations. These concerns can only be taken into account when the series components are known. The computer equipment in our vehicles is designed with future industrial development in mind, but still would not be feasible for any series standard regarding size, cost and complexity.

The concept of a co-pilot or **virtual co-driver** in interactIVe is a good analogy to an intelligent vehicle. A clear representation has been shown in the interactIVe project video.

The **evaluation** of our functions led to the development of an evaluation framework including test procedures for different accident scenarios necessary for the combination of sensor and actuators and the overarching applications. The safety impact assessment, based on parameterizations from accident data and our test results provide a first base for understanding the far reaching effects of interactIVe applications in certain accident scenarios. The need for intelligent vehicles is apparent, and the impacts are, in the limits of current knowledge on accident causation, a clear indication for deployment. The on-going penetration of ADAS in new vehicles will provide further insight with insurance data – which can be seen as comprehensive field tests for new technologies.

The up-coming changes in the euroNCAP rules serve as an excellent motivation to deploy interactIVe functions as automated emergency braking and all-around view of the environment into early introduction.

Another research area is the necessary legal discussion on bringing the Vienna convention into the 21st century. Many of the interactIVe applications require a **code of practice for automation** to serve as a strict guide for deployment. The work on **legal aspects** has collected the current limitations and is a much needed stepping stone for future work. In this context, the presence of demonstrators is a fundamental step to stimulate discussions and actions concerning the changes needed in legislation. Demonstrators not only show what will be possible to a wider audience in a more tangible way than white papers, but also serve to the experts to reach the finer points of operability, in a clearer, alas more expensive way than simulators.

Project partners are confident that the current consolidated path towards full driver support, now leading to the successor European project AdaptIVe, will use the wealth of experience gained in this project to come nearer to a fulfilment of the interactIVe vision of zero accidents.

6.2 Lessons learnt

As a general background to the lessons learnt during the project, the role of interactIVe can be seen in the frame of several years of advancements for ADAS, starting with European research projects in the 1980s, and still on-going. An important step – especially important for industrial competition and public awareness – occurred recently in 2013 with the introduction of a rating for Autonomous Emergency Braking systems by euroNCAP, so recognising the value of active safety in the interest of consumers.

All these developments during the years were characterised by repeated R&D cycles, constantly improving performances and the capability of supporting the driver. The technology transfer from research to products in the market was often slower than anticipated, but the commitment of industries, the European Commission, and the other stakeholders was constantly present.

In this panorama, the lessons learned for interactIVe should be considered as a part of a general evolution. A major consolidated trend which was followed by the project is the progress towards increased control by the system. Particular aspects addressed by interactIVe are functional integration, perception techniques and active interventions.

The following paragraphs summarize some specific lessons learnt for each topic of research covered in the project.

Regarding **perception:**

- Sensor and actuator technology for automated driving support is becoming available in modern vehicles. Sensor data fusion research is close to provide continuous driver support. However, reliable real-time performance in complex urban environments is still under pursuit.
- Another important difficulty faced by the project is the limited availability of precise road structure ground-truth data, including road boundaries. This was partly solved by a manual check of data and video recordings, but improvements are certainly needed to qualify tests and to speed-up the developments.
- Vision based object/scene recognition is very promising and has the advantage of a low-cost sensor set-up.
- In the R&D stage, Linux based Operating Systems are recommended for real-time integrated perception.
- Generic sensor interfaces pave the way for a plug-in concept.
- High level object based fusion is more appropriate than low-level fusion for time-critical applications.
- Methods for surrounding Track ID maintenance should be improved.
- Camera techniques for detecting the visual distraction of the driver are an appropriate approach, but robustness of existing systems is still an issue.
- Perception for Collision Mitigation should be enhanced for urban scenarios, with dense traffic, VRUs, multiple obstacles, etc.
- Future systems are expected to better exploit results from the on-going work on V2X communication for cooperative applications.

On **IWI strategies and driver behaviour**:

- It was difficult to create general strategies and still make them specific/usable for the project and beyond; this is related to the wide range of vehicles and functions addressed by the project, and the fact that Human Factors were a key aspect.
- It is appropriate to create clusters of functions (e.g.: increasing degree of automation, type of support, direction,…); in this frame, IWI strategies should ensure a smooth transition with regard to the different levels of human and system control. Driver acceptance is expected to increase if transitions are clearly communicated by the system and the system can adapt in time to the driving patterns of the user.
- The drivers should be allowed to overrule the functions. Which strategy is best depends on the function.
- Additional studies are needed to investigate driver reactions on active interventions on steering and braking: simulator studies where driver actions can be decoupled are among the interesting approaches.
- Warning modalities remain a subject of research, in terms of timing, duration, most effective channels, acceptability, etc. In particular, more field tests and simulation studies are required for multi-thread management. In this context, the progress towards a continuous reduction of false positive alarms (without penalising the preventive functionality) should not be slowed down.

- It is suggested to use simple driver interaction schemes to ensure acceptance: tests demonstrated that haptic interactions are suitable when well designed.
- From the point of view of work organisation, some recommendations can be derived from the project experience: work early on use cases, ensure dedicated HMI staff working closely with application developers to improve the transfer of IWI strategies, define priority criteria for selecting experiments in advance.

With respect to the **applications:**

- Deep integration of driver assistance systems is not an easy task, due to several aspects like complex architectures, asynchronous data flows, different kinds of data. This complexity also generated difficulties when tracking the fulfilment of requirements along project life. New approaches and tools supporting this task would be very useful.
- The study of vehicle stability during and after an emergency avoidance manoeuvre required considerable efforts, in particular for heavy vehicles with consideration of dynamics and loads. An extended use of virtual methods is recommended for this type of analysis.
- Addressing the risk of passing road edge or road barriers was a new topic with limited prior experience, in particular with respect to perception. Further research work is certainly needed in this area.
- If the path of enhanced automation is chosen for future vehicles, then several aspects should be deeply examined, and in particular: (i) Improve shared control strategies, (ii) Consider how to engage the driver back in the loop, (iii) Regard arbitration as a continuous process (not one negotiation), (iv) Explore if shared control can lead to new types of human error.
- The approach for identifying driver distraction from time-series untypical patterns, as tested in the project, is still at research level.
- It was sometimes difficult to find a good trade-off between limited sensor capabilities and the expected benefit, for those cases focused on a low-cost target. Some compromises in the range of covered scenarios were finally necessary.
- Continuous driver support has shown interesting capabilities for providing warning and elaborating a correct escape alternative manoeuvre. The system still presents limitations in dealing with some difficult cases, in particular the approach to an intersection, where understanding the intentions of other road users is often fundamental.
- Collision avoidance based on the full perception of surrounding could conveniently integrate obstacle evasion and path control, both for cars and for trucks. Regarding perception, a very high reliability is needed for the lane change manoeuvre to insure that the adjacent lane is free. Also, more efforts seem appropriate to improve the estimate of the vehicle position, e.g. by implementing all the available signals and fully exploiting the GNSS techniques.
- Collision mitigation has shown a high potential to reduce the consequences of a crash for the occupants: this benefit is generally not well perceived by the public. The approach for identifying driver distraction from time-series untypical patterns is still at research level. Therefore, the evaluations in driving simulator should be improved, especially by additional tests with real traffic data.
- interactIVe results also triggered the industry to re-think and revisit their sensor strategy. The results have shown that even though the industry is at the forefront of the sensor technology, more innovative sensors need to be developed for more

complex driving manoeuvers and automation. The increasing market demand of these functions (partially through clarification of the impact through projects like interactIVe) will also make it possible for the supplier industry to lower the cost of these sensors enabling the path towards faster market penetration and more innovation because of the favourable business case that these kind of applications now created.

Regarding **Evaluation:**

- Preparing a test and evaluation plan in the early project phase was a good approach. However, the plan must incorporate some flexibility, to cope with possible restrictions, delays and new findings (e.g. Naive driver were not allowed to drive on public roads, winter weather caused delays, etc.). This was particularly true for interactIVe, characterised by a large number of use cases, parameters and implementations of a given function.
- Consolidated test methodologies were lacking for heavy vehicles (scenarios with incoming traffic or lateral obstacles, soft targets, etc.).
- Further efforts are needed to improve and standardise accident data bases, in order to obtain precise information especially for the pre-crash phase.
- Especially for Collision Avoidance, an additional focus is recommended on testing scenarios with VRUs.
- When benchmarking off-the-shelf sensors, the SW for processing sensor data was found still immature.
- Enhanced automation requires completely new approaches in the test methods. In fact, existing accident data bases do not provide suitable information when new vehicle missions and new types of accident will be considered. Probably more simulation will be needed to evaluate these advanced functions with enhanced automation.
- Extrapolation of test results to derive safety benefits on a large scale remains a critical aspect which depends very much on the assumptions. When presenting impact data, the hypotheses leading to the final conclusions should be clearly described and missing data should be identified.

6.3 Potential follow-up activities

The tangible results of interactIVe exist as demonstrators, which prove the technology and as deliverables, which report on the architecture, the advances in perception, HMI-expertise and the test methodology. After the end of the project the Final Event in Aachen created an opportunity to see the results of interactIVe in an easy-to-understand way. The demonstrators will be probably dismantled; but the experience gained on sensors, actuators and algorithms will be used in follow-up vehicles. The deliverables will remain as well as the networking developed between industry and research.

The following paragraphs synthetically present some of the activities, which are needed to continue the work towards a more intelligent vehicle.

interactIVe technologies can be deployed to work as stand-alone applications in every day driving. The industry development process is in place to fulfil the required standards of safety, robustness and usability in developing mature functions. User assessment has shown that the benefits from the technology are understandable and that the user wants to have integrated safety systems – although it remains to be seen at what cost. Barriers exist, which hinder the technology to be exploited in a vehicle on public roads - even if the technology could be proven to work in all scenarios. These barriers are (in 2013) missing legislative measures for type approval. They are subsumed as legal aspects of partly automated driving. To solve them a consolidated effort is needed.

Research, industry and legislative need to be in close communication and helping each party to understand the needs and see obstacles at the other sides. The functions ESC (Electronic Stability Control), Brake Assist, and recently, Lane Keeping Assist are precedents for the gradual appearance of assisted driving in our vehicles.

Perception, which delivers the environment view, is clearly in need of so called ground-truth data to improve existing algorithms and sensors. Ideal ground-truth is constructed with a sensor equipped vehicle on public roads and, for critical scenarios, on test tracks with dummy obstacles. Raw data from sensors as well as their pre-processed output is collected and later annotated in a labour intensive process labelling all objects which have not been already recognized by the best algorithms (which are not yet suited for real-time processing). In this way e.g. road edge data is added or corrected, half-hidden pedestrians are checked and missing obstacles are identified. In the lab the developer can drive a virtual vehicle along the same road and compare perception results with the previously labelled data. In reality ground-truth is sensitive to a change of sensor and even sensor set-up (angle, location, and update-frequency). Some ground-truth data (e.g. world trajectories of many objects in complex scenarios) can be accurately acquired at large scale only with a significant effort in specialized sensors.

Therefore a standardized process is necessary to economize the processing with new sensor set-up or inclusion of altogether different sensors and to allow cross-comparison of research algorithms for a benchmarking. Benchmarking will add the much needed trust in robustness of the systems (true positive detection and no false positive results) for activation of avoidance manoeuvres, to give an example of a critical missed or false alarm. The intended result (a particular system works in all tests as required) is a much needed input for the discussion on legal aspects.

Regarding the on-going success of Open Source Software a publication of ground-truth in an open competition on virtual driving (as e.g. robot football tournaments) could help in development efforts. This should as well increase public attention and foster the discussion around the need of more automation for not only comfort and technical advances but driving safety in view of an aging society.

The upcoming FP7-project AdaptIVe has been mentioned. The momentum gathered in interactIVe will be taken up there and new research avenues will be explored. In the past the FP7-project euroFOT (Field operational tests) has already delivered very positive results on a small sample of functions, and DRIVE C2X will add results for cooperative driving. The feedback from insurance statistics regarding accident data with ADAS equipped vehicles is expected to add stringent arguments for more assistance and automation of the driving task.

interactIVe and other large European integrated research projects on vehicle development are the stepping stones for an, as yet, vehicle-centred automation. Cooperative driving is a necessary functionality (considered in this report for two demonstrators) which increases the sensor range and helps to avoid difficult scenarios (one example being cross traffic and sudden traffic jams). Cooperation will also add to a web of safety around the car. Far from the vehicle, and not considered in this report, is the role of infrastructure, e.g. the ideas around dedicated lanes for automated vehicles (e.g. in a near future for platooning vehicles). Infrastructure is also present where new ideas for construction of airports or even cities are concerned. One example is the airport and city centre parking area which can be located further away for automated vehicles.

Evaluation of automated functions is a topic which breaches the distance between technology and legislative in providing clear facts on the range of applicability of automated driving. All serious development projects put great emphasis on this topic – but a wider scope is necessary to produce a sufficient sample set for statistical analysis for a sound impact assessment.

The increased application of electronics and informatics, which will be the telling sign of automation, requires more research in reliability of control units and algorithms. Supervisory units, smaller systems and much more of them for increased robustness need lifecycle and robustness analysis with a detailed consideration of failure risks in case of malfunction.

Drivers can be seen as passive monitors, act as a back-up to the automation or actually participate in the control through some sort of partnership with the automation. Based on research in aviation and nuclear power plants it is evident that human beings are bad monitors (vigilance problems) and lose the ability to take over control if left outside. Shared control between driver and automation and potentially different intentions need arbitration.

Driver and vehicle need to share intent and selected action. Driver state monitoring is a crucial factor. The way monitoring should be done needs to be synched with the intended functions and the information needs to be communicated in an optimal way. A successful design leads to mode awareness and a comfortable feel of the vehicle.

The diversity of available functions in the vehicles creates a need for harmonisation between brands on the system design (e.g. range of operability, type of information, warnings or interventions). This will increase the possibility that the driver can build a correct mental model of these functions and build up trust in the automated functions.

In summary, the best way to find more automation in our vehicles is a lively communication between all stakeholders and between research projects. A sine-qua-non is a public understanding that automation is not rocket science but a sound basis for improved safety and efficiency in road transport.

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Partner list

Partner name	Short name	Country
Ford Forschungszentrum Aachen	FFA	DE
BMW Forschung und Technik GmbH	BMW	DE
Centro Ricerche Fiat SCPA	CRF	IT
Daimler AG	DAI	DE
Volvo Personvagnar AB	VCC	SE
Volvo Technology AB	VTEC	SE
Volkswagen AG	VW	DE
Autoliv	AUTO	DE
Continental Teves AG & CO. OHG	CONTIT	DE
Delphi Delco Electronics Europe GmbH	DEL	DE
Navteq B.V.	NVT	NL
TRW Limited	TRW	UK
Continental Automotive GmbH	CONTIA	DE
Bundesanstalt Fuer Strassenwesen	BAST	DE
Fundación Para La Promoción De La Innovación, Investigacion y Desarrollo Tecnológico en la Industria de Automoción de Galicia	CTAG	ES
Deutsches Zentrum für Luft - und Raumfahrt e.V	DLR	DE
Institute of Communication and Computer Systems	ICCS	GR
Rheinisch-Westfälische Technische Hochschule Aachen	IKA	DE
Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek – TNO	TNO	NL
Valtion Teknillinen Tutkimuskeskus	VTT	FI
Lunds Universitet	LUND	SE
Universite Joseph Fourier Grenoble 1	UJF	F
Chalmers Tekniska Hoegskola AB	CHAL	SE
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Ceske Vysoke Uceni Technicke v Praze	PRAG	CZ
Universita degli Studi di Trento	TRENT	IT
Allround Team GmbH	ATG	DE
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European Center for Information and Communication Technologies GmbH	EICT	DE

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Abbreviations

ADAS	Advanced Driver Assistance Systems
ADASIS	Advanced Driver Assistance Systems Interface Specifications (http://www.ertico.com/adasisforum)
ADTF	Automotive Data and Time triggered Framework (development SW from Elektrobit Corporation)
AH	Adasis Horizon
AOL	Assignment of Objects to Lanes
BD	Boundary Detection
CAN	Controller Area Network
CMBS	Collision Mitigation by Braking and Steering
C2C	Car-to-Car
EC	European Commission
eDPP	enhanced Dynamic Pass Predictor
EPS	Electric Power Steering
ESA	Emergency Steer Assist
ESP	Electronic Stability Control
EVP	Enhanced Vehicle Positioning
EVRP	Ego-vehicle Lateral Position to the Road
FOP	First Object Perception
FOV	Field of View
GPS	Global Positioning System
HMI	Human Machine Interface
HSP	Horizontal Sub-Project
HUD	Head-up Display
INCA	Integrated Collision Avoidance and Vehicle Path Control (SP5)
ITS	Intelligent Transportation Systems
IVS	Intelligent Vehicle Systems
IWI	Information, Warning and Intervention (SP3)
EMIC	Cost-efficient Collision Mitigation (SP6)
FNRP	Frontal Near Range Perception
FOP	Frontal Object Perception
LCCA	Lane Change Collision Avoidance
MOC	Moving Object Classification
MSC	Moving Scene classification
OP	All-around Object Perception
OPT	Optional
OVCA	Oncoming Vehicle Collision Avoidance
PC	Personal Computer
PD	Pedestrian Detection
PH	Perception Horizon

PP	Perception Platform
RB	Road Boundary Detection
RDF	Road Data Fusion
RECA	Rear-End Collision Avoidance
RED	Road-edge Boundary detection
RoRP	Run-off Road Prevention
RPP	Reference Perception Platform
RUCS	Recognition of Unavoidable crash Situation
SECONDS	Safety Enhancement through Continuous Driver Support (SP4)
SIA	Side Impact Avoidance
SP	Sub-Project
TTC	Time-To-Collision
VRU	Vulnerable Road User
VSF	Vehicle State Filter
VSP	Vertical Sub-project
VTC	Vehicle Trajectory Calculation
WP	Work-package

Annex 1: Recommendations on future sensor systems and their specification

Multi-sensor platform

- The successful sharing of different Perception modules inside the Reference Perception Platform instantiations of three demonstrator vehicles showed the advantages of an integrated perception approach and shows that parallel processing of demanding processing modules is possible to coexist in one customized Perception Layer. Generic sensor interfaces show the road for a plug and play concept in sensor data fusion platforms.
- Robustness of the algorithms in a broad set of possible driving scenarios requires tuning of the algorithms for different environmental conditions and speeds.
- Selection of the SW/HW modules should be carefully tuned based on the real-time requirements of the applications.

New ADAS

- Different limitations occur when the application is needed to assess the most likely paths of road users during emergency situations. The very low processing times required in order to detect an emergency scenario poses constraints for a carefully selected sensor set that can offer the possibility of object-level processing assisting the more complex task of situation refinement.
- Ground-truth data sharing (e.g. accurate object positioning and dynamics through specific typical and complex scenarios as those evaluated in interactIVe, road structure reference data as lanes or road boundaries) for evaluating various object-fusion tasks is a pre-requisite for a Europe-based and worldwide comparison of ITS algorithms and an important task for the ITS research community as it can boost the data processing and fusion developments towards autonomous vehicles. Obtaining the ground-truth data in an automatic or semi-automatic way should also be an important cornerstone of future research since manual annotations can be a laborious and very time-consuming task.
- V2V can be used for enhancing ego-vehicle object tracking based on the GPS-coordinates of targets transmitted by remote vehicles. In this direction, the need for accurate synchronization among vehicles nodes should be further investigated while a universal coordinate system should be constructed. Furthermore, if the other vehicles are equipped with positioning and eHorizon sensors then the overall perception of the road environment can be greatly extended by using the Horizon created by the remote vehicles. For example a perception module like interactIVe RDF module could extend its road geometry reconstruction by using the short road geometry (even if this is based only on a camera sensor that provides 40m horizon) provided by co-operating vehicles ahead.

Technical considerations

Multi-sensor fusion

Although perception sensor development (radar, camera and laser scanner) is an ongoing topic since years there is still demand for improvements in case new functions and applications should be served that demand for higher reliability in object detection and highly accurate position and velocity measurements at the same time.

For radars and cameras in near range perception applications a wider field of view would be beneficial. For perception systems based on sensor fusion technology externally triggered sensors and determined and known signal latency times would be another main development target.

To enable sensor fusion approaches benefitting from earlier signal levels (before the object level), as they were developed in the frame of this project, it should be possible to achieve data links with higher capacity inside the vehicle which fulfills automotive requirements. These more complex signal processing algorithms raise the demand for low latency data transfer, time stamped sensor data and higher amount of computational resources at the ECU's.

Reliable real-time object detection in complex urban environments is still under pursuit and the following approaches seem promising:

- Avoid false alarms by better filtering of non-moving targets
- Surrounding object tracking for track id maintenance
- Reliable road boundary detection (where ground-truth data are in lack)
- Recognize scene context information in order to increase performance of high-level fusion modules.

In the **road edge detection** we deal with the separation of the road into the drivable area and the non-road area. Investigation of different image-processing techniques based on texture and edge information proved that texture cues are appropriate for the recognition of the homogeneous road part. The radar sensor is complementary to the camera in terms of its all weather performance and kinematic properties. Concentrating the radar sensor on the detection and tracking of solid road barriers flanking the road side it gives useful information about the road endings.

Due to the fact that we are working on very low level information like pixels and untracked targets provided by the radar, we decided for an early fusion strategy within a particle filter framework. In constrast to a Kalman filter the particle filter has the ability to model a multivariate probability distribution and hence follow more than a single hypothesis of the road trajectory. Additionally, it is not necessary to derive complex linearizations of a non-linear problem as it has to be done using an Extended Kalman filter, but it is sufficient to represent the innovation by the likelihood function based on the particle's state.

Integrated platform development for close to real time applications

ADAS applications that have to interact with the driver in a short time horizon impose hard processing constrains in the Perception Platform development. This gets even more challenging when the objective for an integrated system hosting multiple perception modules with unique I/O access has to be handled. In this case, the HW and OS requirements for systems that can manage parallel multi task scheduling are very important.

Real Time Linux provides the capability of running special real-time tasks and interrupt handlers. These tasks and handlers execute when they need to execute no matter what Linux is doing. The worst case time between the moment a hardware interrupt is detected by the processor and the moment an interrupt handler starts to execute is under 15 microseconds on RTLinux running on a generic x86 (circa 2000). A Real Time Linux periodic task runs within 25 microseconds of its scheduled time on the same hardware. These times are hardware limited, and as hardware improves RTLinux will also improve. Standard Linux has excellent average performance and can even provide millisecond level scheduling precision for tasks using the POSIX soft real-time capabilities. Standard Linux is not, however, designed to provide sub-millisecond precision and reliable timing guarantees. Real Time
Linux is based on a lightweight virtual machine where the Linux "guest" was given a virtualized interrupt controller and timer, and all other hardware access is direct. From the point of view of the real-time "host", the Linux kernel is a thread. Interrupts needed for

deterministic processing are processed by the real-time core, while other interrupts are forwarded to Linux, which runs at a lower priority than real-time threads. Linux drivers handle almost all I/O. First-In-First-Out pipes (FIFOs) or shared memory can be used to share data between the operating system and RTLinux. On the other hand Windows are not optimized for real time applications. Their timer has a resolution of 10-15msecs depending on the hardware. And the management of threads is very difficult to be accomplished due to large delays when scheduling them.

Recommendation table

GENERAL	Each processing and fusion algorithm should be carefully selected according to the objective of the **data fusion task** (object refinement or situation refinement) and the existing limitations imposed by the sensor set or the scenario itself. Multi-sensor approaches shall be favored in a **situation refinement task** while in an **object refinement task** cost-efficient vision-based solutions can also be successfully applied even for complicated tasks as the pedestrian and road boundary detection and tracking. In all cases, sensor data fusion offers extra reliability as we are able to overcome sensor limitations at a very small extra processing expense (see D2.2).
	Longitudinal and lateral optimal control models for understanding driber's intentions can proliferate from cognitive science based driver models; Co-drivers enable cooperative swarm behaviors as they can exchange each other goals (see Annex 2).
	Sensor data fusion research is close to provide continuous driver support but more contextual information is needed in order to handle specific complex scenarios in complex situations (road restriction, entering a cross-road). **Context inference in dynamic driving scene** can proliferate from recent advances in machine learning theory (e.g. regression analysis for understanding large data or pattern recognition for images). (see Dynamic scene classification approach in D2.2 or distraction detection in D1.0-EMIC application).
	For highly automated ADAS applications, it is necessary to focus on **high precision digital maps**, where all static road infrastructure is stored and dynamic changes can be applied on. In combination with a highly accurate localization, C2X communication and the next sensor technologies the development towards automated driving, safety concepts and continuous support functions can be approached.
	Specific and dedicated tools for sensor and platform **data collection and synchronization, analysis** (e.g. using data mining tools) and processing is considered very important for the evaluation of various real-world scenarios on real roads.
TECHNICAL	Providing a **geo-referenced road appearance mosaic** would speed up and simplify the evaluation of driving environment perception modules dealing with road geometry, by enabling the verification of the road markings or the end of asphalt without the need for on-location measuring. Furthermore, the recovered road surface map can be vectorized and stored in a suitable GIS database [Wang 2008]. More general, a **standardized evaluation method for road or lane pathways** would help to benchmark different algorithms that deal with road geomtery attributes.
	Methods for precise **temporal alignment of multiple input data** derived

	from sensors with different update rates should be investigated for a successful integrated platform.
	Arc spline-based digital maps for vehicle self-localisation using landmarks (in absolute world coordinates with lane accuracy is possible in real-time) is considered very promising approach for **reliable road geometry estimation**.
	Intelligent applications that tackle accidents caused by a lane change manoeuvre would proliferate much from a **global track id maintenance** approach (180 degrees coverage around the ego-vehicle achieved by multiple sensors with overlapping field of views).
	Real-time sensor platform should support very **fast multi-thread management** (10-15 ms resolution should be supported).

Directions for future research

Frontal object perception and classification: The implementation of moving object detection in the FOP-MOC module is performed at tracking level. We classify the objects once lidar processing detects the probable moving obstacles. We believe that performing classification at detection level, i.e., classify the observations or targets coming from lidar, radar and camera sensor can improve the early knowledge about the detected objects and therefore improve the moving object detection and classification. Besides, our moving object tracking approach discovers the motion model of the objects over time. This process takes into account all the possible motion models of the detected moving objects. Representing the class of the objects as an evidence distribution may help to reduce the number of motion hypothesis and accelerate the tracking process based on sensor beliefs and tracking updates about the class of objects.
For frontal near range perception used for time critical applications, we refer the reader to Annex 3 section C-(4).

Vehicle Trajectory Calculation: Taking into consideration the driving style is considered to be very beneficial. Instead of using constant acceleration and yaw rate, detect the intention of the driver and apply the identified driver model in order to extract the future path of the vehicle. Associate the driver behavior with the road environment and extract patterns like for example increasing the yaw rate when entering in a curve section of the road, moving with a constant turn rate in the curve and decreasing the yaw rate when exiting the curve section. In order to achieve these, neural networks can be used in order to extract generic driver models or even create more sensitive profiles specific to different drivers.

Road geometric representation: Clothoid model representation is motivated by linear changes of curvatures and hence assumes a smooth steering behavior for the driver. Furthermore, the curve provided by the polynomial approximation of a clothoid is sensitive to the curvature of the road at the starting point. Future work should investigate the more complex but more promising NURBs and splines models.

Road edge representation: In the RED module implementation where a third-order polynomial approximation of a clothoid is used, the left and the right road border are considered as parallel. That means that the left and the right border are modelled as parallel shifts of curvature and heading taken from the centre of the road, but estimated and updated by measurements taken at the road edge. The assumption made by this consideration is that the pathway of the road borders is the same for the left and right side, which is true for nearly all normal streets. In order to model special situations like bus stops, parking bays or intersection areas a.s.o. this kind of road model is not valid anymore. That's the reason why we like to give the recommendation for future systems, to track all pathways, single lanes and road endings with their own state vector and a well-chosen model type (polynomial, spline, circle). Such an approach of different left and right edge modeling is followed in the

RB research module. In the RB module, the state vector is estimated by calculating the weighted sum of all samples. Nevertheless one advantage of the particle filter is the possibility to track multimodal distributions. Often, especially at forking or joining parts of the road, more than one hypothesis is available. Replacing the weighted sum by a clustering process would provide estimations for multiple hypothesis. Since for example at a forking an new hypothesis is already tracked while the prior one is still present a smooth transition is possible.

Dynamic scene classification: In the proposed MSC approach, scene recognition is tackled in a novel way that goes beyond the static image classification by borrowing clues from the image evolution through time (= video). Although most of the video scenes recognized by the approach include static categories of a scene like rural, highway and urban (categories that can be easily provided by a static map information provider), we included also a differentiation between highway with traffic and highway with no traffic class: these two classes show the applicability and usefulness of the method to recognize dynamic semantic characteristics of the scene that cannot be provided by a GPS-based system. In this sense, the ultimate goal of such an approach is to be able to recognize the context of what is happening in front of the driver by recognizing events like “jam before a roundabout”, “road construction ahead”, “empty rural road”, “vertical cross-traffic”, “vertical passing of a bike”, or even a more general class of “change of context = unusual behavior in front”. The ability to recognize the driving context is a primary objective of an adaptive future driving assistance system and these classes can be used internally for system behavior tuning. Furthermore, such vision-based approaches are very useful in developing functions for automatic driving. Camera sensors as well as vision-based recognition have been greatly advanced in the last few years. This fact coupled with the optical sensor small cost, makes the scenario of a modern vehicle which is equipped with a smart camera system prominent for the upcoming years and thus a full exploitation of the information captured by the camera is desirable.

Annex 2: Planning of multiple manoeuvers

Inside SP4, the simultaneous planning of multiple manoeuvres was developed inside the co-driver, that is a core module inside the application developed in CRF demonstrator vehicle. This co-driver concept, as implemented in the CRF demonstrator, is widely described inside a paper submitted to IEEE Transactions on Intelligent Transportation Systems [DaLio 2013]

If accepted, after review, the paper will be available both on paper and free on-line, thus contributing to the dissemination of scientific project results. Here the paper abstract is reported, further details can be found in the paper.

This paper introduces the concept of artificial “co-drivers” as an enabling technology for future intelligent transportation systems.

In the first section the design principles of co-drivers are introduced and framed within general human-robot interactions. Several necessary contributing theories and technologies are review to clarify what is needed for making co-drivers. We identify architectural issues, humanlike sensory-motor strategies and, above all, the emulation theory of cognition as necessary building blocks.

In the second section we present the co-driver developed for the EU project interactIVe as an example, showing how it follows the above guidelines and clarifying limitations and performance of our implementation.

In the last section we analyze the impact of the co-driver technology: identify application fields (showing how it is a universal enabling technology for both smart vehicles and cooperative systems) and point out future research needs.

Annex 3: Perception modules results not included in D2.2

In this Annex the evaluation of Perception Modules not included in D2.2 based on new logged data and ground-truth measurements are presented. Note that this evaluation is limited to the purposes of SP2 modules and thus the objective is to quantify the accuracy and robustness of the modules' output parameter estimations on a subset of the test cases. Parts of this evaluation work makes use of SP7 logged data but, with the exception of part C, that contains a situation assesement module evaluation (RUCS), there is no evaluation of the impacts of these results on the application functionality which was the objective of the SP7 work.

A: Reference Platform Modules: Road Data Fusion, Vehicle Trajectory Calculation, Ego-Vehicle Relative Position To the Road and Assignment of Objects to Lanes

The logged data included the following test cases:

Test Case	Repetitions	Test Case	Repetitions	Test Case	Repetitions
1.4.1	6	1.7.1	6	6.1.3	6
1.4.2	7	1.7.5	5	6.1.7	7
1.4.3	7	8.1.1	5	6.1.5	5
1.4.4	8	8.1.2	5	6.1.2	7
5.1.1	5	8.1.3	5	6.1.1	6
5.1.2	5	8.1.4	5	5.1.6	5
5.1.3	10	8.1.5	6	6.3.2	6
1.4.6	7	8.1.6	3	6.3.4	7
1.4.5	7	6.1.4	8		

Some of the recorded scenarios that did not fulfil the necessary prerequisites (missing data, some sensor not working, etc) for the evaluation, has been excluded from the calculation of the performance indicators.

For a reference to the CRF test scenarios, we refer to the Annex D of the document "Deliverable D7.4 – Test and Evaluation Plan" [INT-D7.4].

1) Road Data Fusion (RDF)

The evaluation of the Road Data Fusion (RDF) module has been performed using CRF logged data, which include accurate measurements of the ego vehicle's position using a differential GPS. The output parameter of this module that is going to be evaluated is the **curvature of the first segment ahead of the vehicle**, which is calculated by fusing the curvature from the digital maps, the lane recognition module and the road edge detection module.

The real curvature of the road must be known in order to evaluate the performance of the estimated curvature. To achieve this we examine scenarios where the vehicle is moving in curved segments of the road and we use the filtered values of the velocity and the yaw rate of the vehicle. A prerequisite that should be fulfilled in order for this method to be applied is that the vehicle should not be performing manoeuvres, so as the calculated curvature, using ego vehicle's velocity U and yaw rate ω, to match the real curvature of the road. The formula that is used to retrieve the real curvature is the following:

$$C^{real} = \frac{\omega}{U}$$

So, the curvature performance indicator at time t_i will be:

$$cpi_i = 1 - \frac{\left|C_i^{real} - C_i^{est}\right|}{C_i^{real}}$$

where C_i^{est} is the estimated curvature of the first segment ahead of the vehicle at time t_i and $1 \le i \le N_O$. N_O is the total number of scans, which is:

$$N_O = \sum_{t=1}^{NT} \left(\sum_{m=1}^{IT} N_{m,t} \right)$$

where IT is the total number of iterations for the specific test case and NT is the total number of test cases.

The average performance indicator will be then:

$$cpi = \frac{\sum_{i=1}^{N_O} cpi_i}{N_O}$$

Using the CRF logged data, the average perfomance indicator of the RDF **estimated curvature** was calculated to be around 88%.

2) Vehicle Trajectory Calculation (VTC)

The evaluation of the Vehicle Trajectory Calculation (VTC) module has been performed using CRF logged data, which include accurate measurements of the ego vehicle's position using a differential GPS. Also, the ego velocity is also recorded from the can bus and used in order to evaluate the performance of this module.

The methodology for estimating the performance of VTC is based on the following method. A buffer holding the global position of the vehicle is created using the GPS-measurements. The timestamp of the position is also saved for every record in this buffer. Then, in every scan having the current GPS-position, the corresponding record is located and starting from this position inside the buffer all the following records are extracted until the time difference between the last position and the current is equal to the time length $T + dt$ of the predicted path from this module (where dt is the refresh rate of the GPS).

Let's assume the buffer has N records $\left(t_i, x_i^{gps}, y_i^{gps}\right)$, where $1 \le i \le N$ and the sub-buffer K records $\left(t_k, x_k^{gps}, y_k^{gps}\right)$ where $i \le k \le i + K - 1$. The following step is to transform, all these coordinates of the sub-buffer to the local coordinate system (LCS) of the ego vehicle using the current GPS-position and heading. The transformed sub-buffer will have also M records $\left(t_m, x_m^{lcs}, y_m^{lcs}\right)$, where $1 \le m \le K$.

Finally, the estimation error for the position is extracted using the following formula:

$$pe = \frac{\sum_{i=1}^{N_O} pe_i}{N_O}$$

where epi_i is calculated

$$pe_i = \sqrt{\frac{\sum_{j=1}^{M} \left(x_j^{vtc} - x_j^{i-lcs}\right)^2 + \left(y_j^{vtc} - y_j^{i-lcs}\right)^2}{M}}$$

at time t_i, and the points $\left(x_j^{i-lcs}, y_j^{i-lcs}\right)$ are extracted using interpolation between the two coordinates $\left(x_m^{lcs}, y_m^{lcs}\right)$ and $\left(x_{m+1}^{lcs}, y_{m+1}^{lcs}\right)$ of the transformed sub-buffer, which are selected so as $t_m \leq t_j \leq t_{m+1}$. Lastly, N_O is the total number of scans, which is:

$$N_O = \sum_{t=1}^{NT} \left(\sum_{m=1}^{IT} N_{m,t} \right)$$

where IT is the total number of iterations for the specific test case and NT is the total number of test cases.

Using the CRF recorded data, the estimation error has been calculated to be around 0.4m, (trajectory calculated for 4 sec in future) and this is caused by the acceleration or manoeuvres due to the fact that we have considered a constant acceleration model which is efficient only for short time periods.

The same methodology has been applied also for the velocity. In this case the estimation error has been calulated to be 4m/sec because it is affected more if the dynamic behaviour of the vehicle is not constant.

3) Ego Vehicle Relative Position to the Road (EVRP)

The evaluation of the Ego Vehicle Relative Position – To Road (EVRP) module has been performed using CRF logged data, which include accurate measurements of the ego vehicle's position using a differential GPS. The output parameters of this module that are going to be evaluated are the lane index, the lateral offset to the right lane, and the lateral offset to the right road line.

The methodology for the evaluation of the lane index assignment will be based exclusively in the video from the camera. The estimated lane index in every scan will be compared with the lane index which is extracted by visually inspecting the camera frame at that time. Finally, a percentage factor will be estimated which represents the correct assignments of the ego vehicle to lane.

The methodology for the other two parameters will be based in calculating the true lane offset using the d-GPS-position of the ego vehicle and the current position in the Adasis reference line, which is located in the middle of the road (for the specific tests). By estimating the distance between these two points, and using the real lane width W_L, which is known, the real lateral offset from the right lane L^{real} can be extracted. Then, the performance indicator will be:

$$lpi_i = 1 - \frac{\left|L_i^{real} - L_i^{est}\right|}{L_i^{real}}$$

at time t_i, where L_i^{est} is the estimated lateral offset to the right lane at time t_i and $1 \le i \le N_O$.

The average performance indicator for the lateral lane offset will be then:

$$lpi = \frac{\sum_{i=1}^{N_O} lpi_i}{N_O}$$

where N_O is the total number of scans, which is:

$$N_O = \sum_{t=1}^{NT} \left(\sum_{m=1}^{IT} N_{m,t} \right)$$

where IT is the total number of iterations for the specific test case and NT is the total number of test cases.

The same methodology is applied also for the lateral offset to the right road line. So, the average performance indicator is calculated using the following formula:

$$rpi = \frac{\sum_{i=1}^{N_O} rpi_i}{N_O}$$

where the performance indicator at time t_i is:

$$rpi_i = 1 - \frac{\left| R_i^{real} - R_i^{est} \right|}{R_i^{real}}$$

and R_i^{real} is the real lateral offset to the right road line and R_i^{est} is the estimated lateral offset to the right road line which is estimated using EVRP module.

Using the recorded data the **average performance indicator** for lane index assignment has been found to be around 95%, for the lane offset equal to 89% and finally for the road offset equal to 72%.

4) Assignement of Objects to Lanes (AOL)

The evaluation of the Assignment of Objects to Lanes (AOL) module has been performed using CRF logged data, which include accurate measurements of the ego vehicle's position using a differential GPS. The output parameter that is going to be evaluated is the lane index of the detected objects. For making the analysis easier, the performance indicator will be evaluated only for the closest object in front of the ego vehicle.

The methodology for the evaluation of the lane index assignment will be based exclusively in the video from the camera. The AOL estimated lane index in every scan will be compared with the lane index which is extracted by visually inspecting the camera frame at that time. Finally, a percentage factor will be calculated which represents the correct assignments of the object to lane.

After examining all the logged files which included a moving or stationary object in front of the ego vehicle, the **average performance indicator was calculated to be around 96%**.

A confidence value for every lane assignment is provided. This value is extracted based on the longitudinal distance of the object and the lateral distance from the left lane marking. For example for vehicles that are far away from the ego vehicle the confidence is very low. Also, for vehicles moving on top of the lane marking (during a lane change when the lateral distance of the centre of gravity of the vehicle from the lane marking is almost zero) there is no confidence since you cannot decide in which lane the vehicle is located. Also, when the vehicle is far away there is the possibility to be located on a different path than the most likely path that is provided from the maps so the decision is also wrong. In most cases the wrong lane assignments were combined with very low confidence so the system was able to reject them. Since most of the vehicles that were assigned in wrong lanes were located far away from the ego vehicle, the interactIVe ADAS applications were not affected from the 4% failures.

B. Perception Modules evaluation in VCC platform

For a reference to the VCC test scenarios, we refer to the Annex D of the document "Deliverable D7.4 – Test and Evaluation Plan" [INT-D7.4].

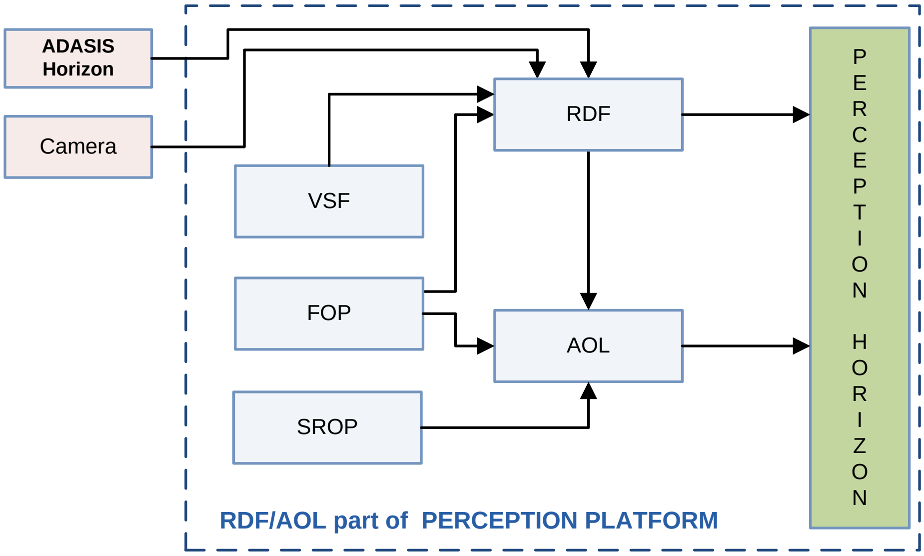
1) Road Data Fusion (RDF) and Assignment of Object to Lanes (AOL)

For reasons of self-containment of this Annex we provide hereafter the VCC Perception Modules functional architecture and methods used before proceeding with the evaluation results of the modules.

- *Functional architecture*

  The RDF module does fusion of the near range road geometry in the spatial domain and derives the polynomial coefficients of a second order polynomial or the centre of the current host lane, as well as the lane and road boarders to the left and right. Furthermore, the lateral offset between the centre of the host lane and objects tracked by the FOP module are also used to improve the estimate of the road geometry as well as to assign the objects to lanes in the AOL module.

  Fusion is only considered for the geometry of the road. The other attributes about the road are just passed through from the electronic horizon.



- *SW tools used (e.g. optimization algorithms/ libs)*

  The algorithms are developed in Mathworks' Matlab 2011b using the Embedded Matlab subset of functionality. Production grade C-version of the module can than automatically be generated and compiled using Mathworks Embedded Coder which can be deployable in rapid prototyping hardware or directly in host processor.

- *Outputs*

  The output of the RDF module is depicted in the Figure below. All geometry shapes are parameterized as a 3rd degree polynomial. The output of the AOL module is

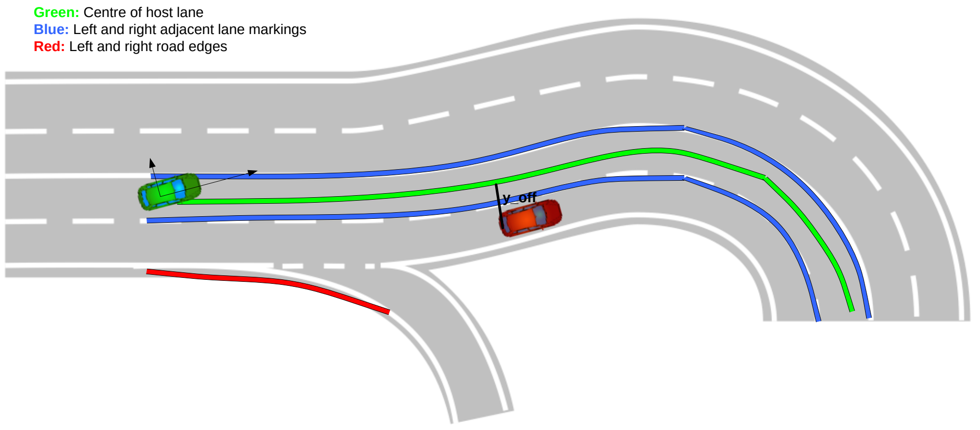


Figure A1: RDF and AOL outputs visualization in VCC perception implementation

With the VSP test scenarios we can assess the functionality of the modules RDF and AOL by the assessment of the function but only in restricted scenarios on test track. The VSP scenarios will only cover parts of the functionality such as lane assignment for one oncoming object and road data accuracy in one case. To be able to assess the full performance of the module a more real world performance evaluation was needed.

- *Evaluation methodology*

The attributes we want to evaluate for RDF/AOL modules is the lateral offset from the centre of the host vehicle lane of all observed objects. From this measurement the Lane Assignment of each object can be derived by using the lane width.

The lateral offset to the centre of the host lane depends on three measurements:

- the lateral position of the object relative host
- the road geometry
- the host lateral position in the lane.

The host lateral position relative the lane markings is known by the lateral offset of the reported lane marker, i.e. the first coefficient in the lane marker polynomial. This measurement has been verified on test track to be very accurate with errors in the order of 5-10 cm.

The lateral position of the object relative host is an output from the FOP module and is verified by d-GPS on test track; see VCC FOP module evaluation section (section B.2). The longitudinal object position error is less than 1 m. The lateral position error depends on the range and if the object is seen by radar only or if it is a fused radar-vision object. A fused object usually has a lateral error < 0.5 m whereas a radar only car can have a lateral position error of 1.5-2 m on 200 m range.

The road geometry estimation is based on fusion between lane markings and objects on the road. The assumption is that the objects on the average follow the lane. Thus there are uncertainties both in the object measured lateral position and the true position in the lane since the object may not follow the lane.

The evaluation is done using a ground-truthing tool in the Matlab environment. It utilizes information that can only be known offline. Because it has access to future data it can by forehand know how the road geometry will be where the ego vehicle will be in the future. It can then use this information to calculate the lateral offset relative the ego lane for all objects, which can be used as comparison with the RDF output estimates.

There is an uncertainty in the position of the objects as well as the uncertainty in the road geometry estimate. It therefore needs to be analysed offline since wrong object positions and correct road geometry estimate can results in wrong lane assignment. To be able to focus on the situations that are troublesome for RDF one needs to be sure that it is the RDF that is the source of the error and not the object measurements.

Because the RDF utilizes objects to estimate the road geometry, large object position errors will have an effect on the estimate. Hence that is interesting to have knowledge about when analysing the results offline. The RDF does not utilize all available objects but instead chooses a subset to minimize the computational complexity of the algorithm. The ground truthing tool hence becomes important in the work when evaluating the choice of objects used in the filter.

In

Figure A2, a snap shot of the RDF, AOL display of the evaluation tool is presented.

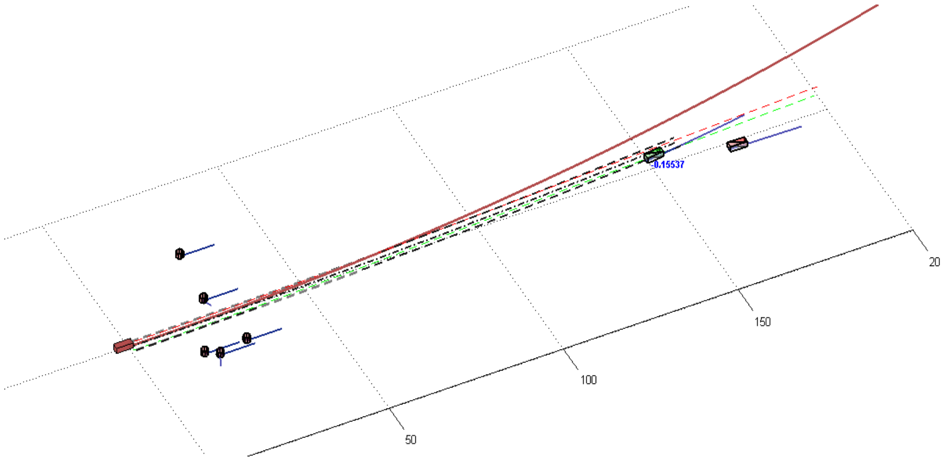


Figure A2: RDF, AOL visualization display in VCC implementation

The picture above shows the red host vehicle and two target vehicles. The green and the red dashed line are the groundtruth lane markers. The red solid line ist he host yaw rate. The grey dashed lines are the input lane markers and the black dashed lines are the output road geometry from the RDF module. This is a good example where the concept works and the target is assigned to the right lane.

- *Evaluation results*

The error in estimated lateral offset (lane assignment) for all vehicles in a log file was measured and the result is visualized in the following Figure.

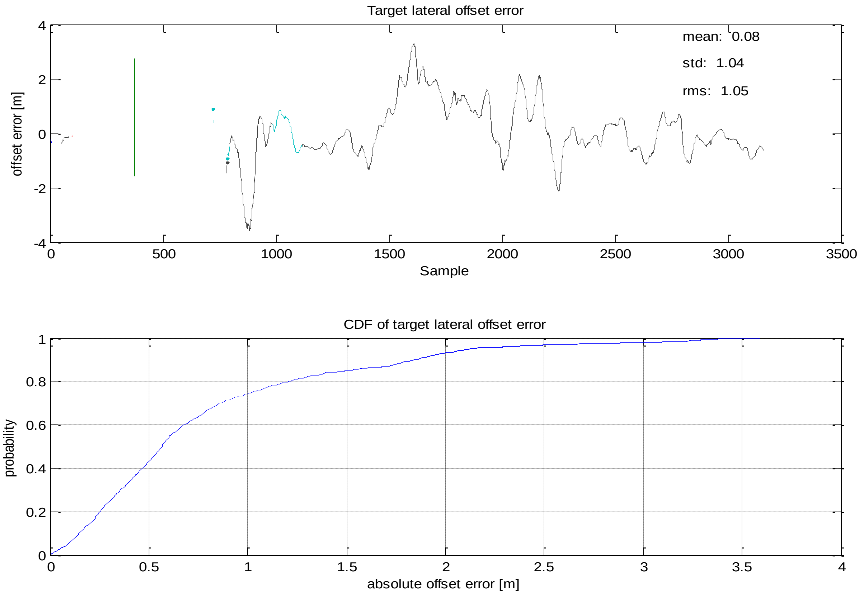


Figure A3: Target lateral offset error diagram

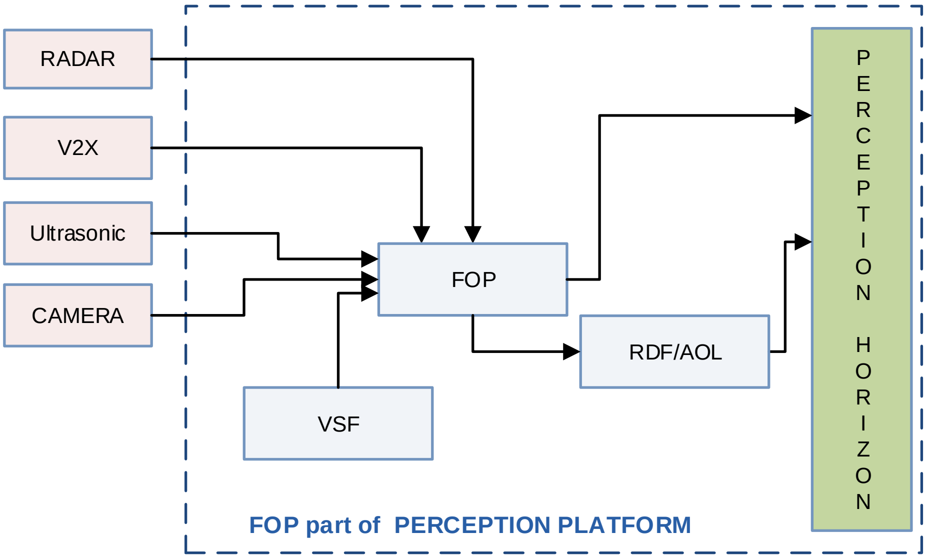
The upper picture shows the error in lateral offset for an object in a highway scenario. The lower picture shows the cumulative distribution function (CDF) of the error for the same data. The results from this scenario show that the error in lateral offset is less than 1.5 m 85% of the time which means that the Lane assignment is correct 85% of the time if we assume that the object stays within 1.5 m from the lane marker.

1) Frontal Object Perception (FOP)

For reasons of self-containment of this Annex we provide hereafter the VCC Perception Modules functional architecture and methods used before proceeding with the evaluation results of the modules.

- *Functional architecture*

  In the FOP module used in the VCC demonstrator track level fusion is performed between information from a radar, a camera and ultrasonic sensors. The algorithm is partitioned such that information from the radar and vision sensors are fused separately. The output from the FOP module is track information and classification of objects in front of host vehicle. The classifiction is mainly performed by vision. The front side radars and ultrasonic sensors are used to support at the near range in front and side of the host vehicle where the long range radar and Camera are limited. if V2V information is available, the observed object tracks and classification are then associated and updated/confirmed with the object information communicated via V2V. Host vehicle data from Vehicle State Filter (VSF) is used in the FOP module to compensate the objects positions for the movement of the host vehicle. The output from FOP ie. object track information is then provided to the Perception Horizon and to the Road Data Fusion and Assignment of Objects to Lanes (RDF/AOL) module.



- *SW tools used (e.g. optimization algorithms/ libs)*

  The algorithms are developed in Mathworks Matlab 2010b using the Embedded Matlab subset of functionality. Production grade C-version of the module can than automatically be generated and compiled using Mathworks Embedded Coder which can be deployable in rapid prototyping hardware or directly in host processor.

- *Outputs*

  The FOP module outputs the position, velocities and accelerations of tracked objects in Cartesian coordinates where the position is relative to the host vehicle while the velocities and accelerations are over ground. Furthermore, object type information and width and length estimates are provided if such information is available from the vision system or over V2V communication. A visualization of the desired FOP representation in provided in below.

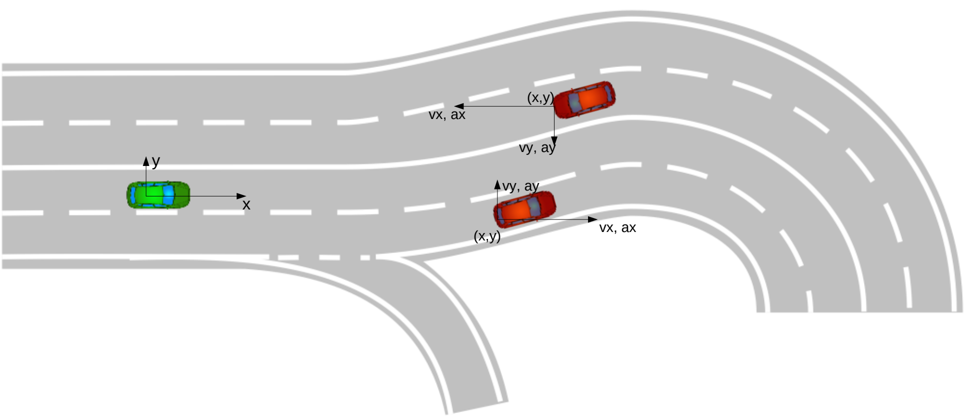


Figure A4: FOP output visualization in VCC perception implementation

- *Evaluation Methodology*

  The module is responsible for measuring various target parameters such as position, speed and acceleration. The measured signals are also compensated for ego vehicle motion and the delay introduced by the sensor processing and the communication between the sensor and the FOP module. To test the performance of these capabilities two vehicles, one host and one target, were fitted with d-GPS-equipment

(RT-Range, Oxford Technical Solutions). This equipment makes use of an inertial sensor block together with a high-grade GPS-receiver to deliver a position measurement that is much more accurate than an ordinary GPS-position. The equipment in the both vehicles communicates using a wireless network in order to provide synchronized range measurements that can be used as reference when testing the measurements acquired by the cars sensors.

- *Evaluation results*

  The example below shows the results of tracking one vehicle in VCC test track at relatively short range (20-50 m) meaning that radar and camera data has been fused by the system. The position and speed signals match the d-GPS-reference very well, indicating that the received measurements are of high quality and that the ego motion and sensor delay compensations work as intended. The acceleration reference signal is corrupted by noise caused by some issue with the RT-Range unit, but it can be seen in the figure that the sensor signal follows the trend in the noisy d-GPS-signal. It should also be noted that the acceleration signal is used in the delay compensation of the speed and position signals, meaning that if the acceleration signal was incorrect it would be reflected in the other signals.

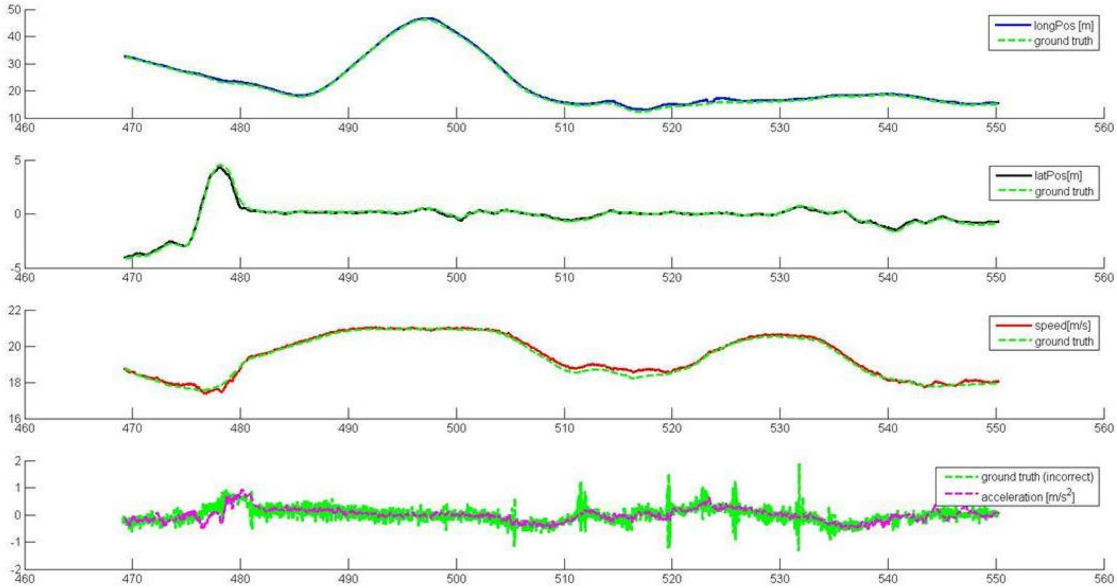


Figure A5: Extract from VCC FOP results for one target object

C. SP2 research activity evaluation (D2.2 updates): Frontal Near Range Perception (FNRP) and Recognition of Unavoidable Crash Situations (RUCS)

1) FNRP/RUCS assessment scenarios

a) Straight driving tests with collision or nearby passing of a single object, as shown in Figure A6

   This test represents already a lot of normal driving scenarios in normal traffic situations. Depending on the parameters ego vehicle speed and acceleration and the positions of the object relative to the vehicle driving path this scenario represents a crash or no crash situation.

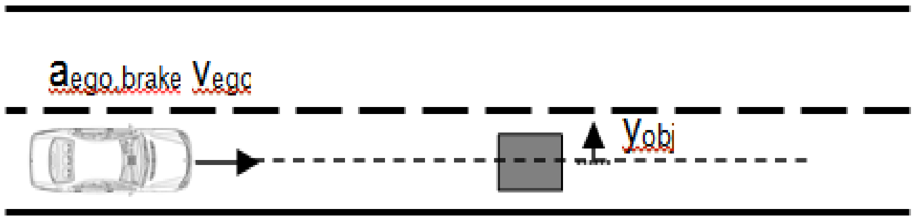


Figure A6: Scenario illustration of the ego-vehicle approaching a moving target: a_{ego},v_{ego} the acceleration and velocity of the ego-vehicle and y_{obj} the lateral displacement of the moving target w.r.t to the ego-vehicle estimated short future trajectory.

b) Traffic situations with moving objects as shown in Figure A7:

In these set of test scenarios close passing scenarios with oncoming traffic and following of other moving traffic participants is tested. A variation of the speed of objects allows the performance evaluation of the perception module in terms of detection rate and accuracy of output attributes in traffic scenarios with moving objects.

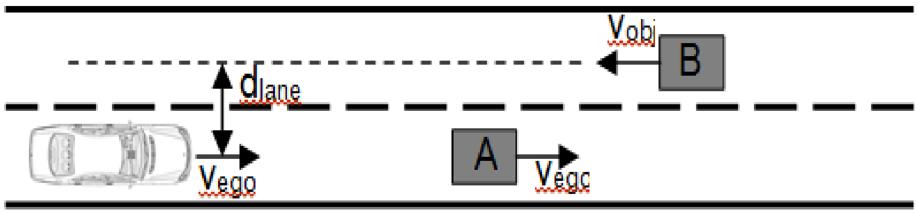


Figure A7: Scenario illustration of the ego-vehicle approaching a target ‘A’ moving in the same direction with the ego-vehicle while another target B is approaching in the opposite direction to the ego-vehicle trajectory.

c) Crossing traffic situations with moving objects as shown in Figure A8:

In this assessment set-up a variety of parameters simulates crash or near crash situations with crossing traffic. Tests parameters are the ego vehicle velocity, the speed and type of the crossing object and the existence and distance of a structure hiding the crossing traffic. Overall this leads to different situations at which point of time sensors can detect the crossing object.

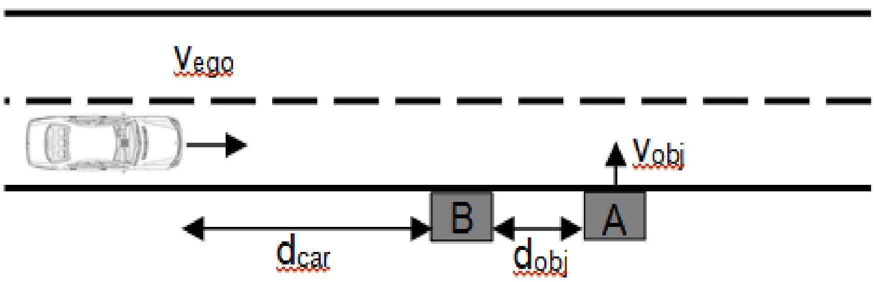


Figure A8: Scenario illustration of the ego-vehicle approaching a target ‘A’ moving in a vertical direction to the ego-vehicle trajectory while a structure ‘B’ hinders visibility of the driver to the target ‘A’: $d_{car/object}$ the distance of the ego-vehicle and of the target ‘A’ respectively from structure B.

2) FNRP evaluation (update to D2.2)

The evaluation of the frontal near range perception module has been done by using recorded data of different no-crash scenarios with a dynamic target. Due to a new measurement campaign with improved ground truth data an in-depth evaluation compared to the results published in D2.2 was possible.

The errors of the tracker states are summarized in Tab. A1. The scenarios pose different difficulties for the tracking algorithm. Each scenario was evaluated in 10 runs. The particle filter converges in each of these runs to a single cluster. However, due to the inherent randomness of a particle filter, the result is not exactly the same in each run. Table A1 shows the mean value. The deviation of the result of each run was in the range of only 4 cm as a maximum in the position errors. The qualitatively biggest deviation was observed in the estimation of the yaw-rate which is the state variable that is the most difficult to estimate. The maximum deviation from the mean value was about 3 °/s of a run in scenario 2. Increasing the number of particles decreases the impact of the randomness, but it increases the computational load at same time.

In scenario 1 and 2 a sinusoidal target trajectory with high dynamics was tracked. In scenario 2 the ego vehicle is following the sinusoidal curve of the target. Ego motion errors exacerbate tracking in this case and the length estimation of the target vehicle is made more difficult.

High errors in the length result from the fact that the RMS error with respect to the ground truth is averaged over the overall time of the scenario. However, the length is not observable at each moment and especially not at the beginning of the recorded data. Figure A9 illustrates this issue.

In scenarios 3 and 4 linear target motions are tracked. The ego vehicle follows the target in scenario 3, while in scenario 4 the target vehicle is oncoming on the left lane. These scenarios are related to the second use case described in chapter C.1.

Scenario 3 does not allow tracking the target length. Scenario 4 poses the challenge to keep the yaw angle accurate when the target vehicle leaves the field of view, which was successful.

Scenario 5 evaluates the performance of tracking crossing vehicles (third use case in chapter C.1). Since the whole scenario only lasts 2 seconds the average length error is also quite high. This results from the starting phase when the target enters the field of view and cannot be fully captured by the laser scanners.

Table A1: Averaged tracking results of 5 different scenarios

Scenario	Δx [m]	Δy [m]	$\Delta \Psi$ [°]	Δv [m/s]	$\Delta \omega$ [°/s]	ΔL [m]	ΔW [m]
1	0.2659	0.1611	2.3643	0.2226	4.6472	1.4684	0.1855
2	0.4523	0.2832	2.9658	1.9112	6.3787	2.9220	0.2266
3	0.2602	0.1591	2.3468	0.2110	5.1846	2.8379	0.1762
4	0.2981	0.1911	2.2142	0.2146	4.7332	3.0538	0.1546
5	0.1157	0.2679	2.9866	1.5775	4.3895	1.0053	0.1753

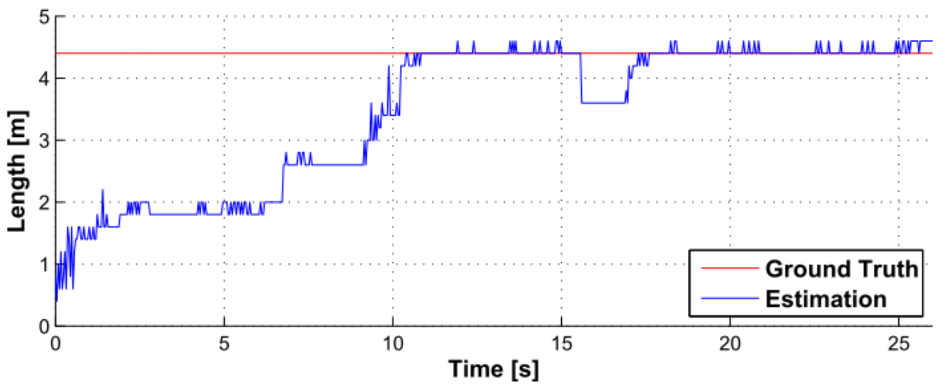


Figure A9: Estimation of the target length for scenario 1. Because of the sinusoidal trajectory the length can be estimated correctly at around 10.5s when the full length of the target is observable.

Disregarding all the scenarios and time frames where the object length is unobservable it is evident, that the averaged length error is in the same region as the width error (ΔW) stated in table 1.

To evaluate the position estimation errors of static obstacles several runs of a single scenario were averaged. The scenario contains two pillars with a distance of 2.4m that form a gate which is crossed by the ego vehicle within a curve with different curve radiuses and velocities. Due to the fact that this is a worst case scenario of the first test use case in chapter C.1 the result gives a representative picture about the achieved performance of the perception system.

Table A2: Mean estimated width of narrow passage between two pillars

Scenario	Distance d [m]	Distance error Δd[m]
Narrow gate passage	2.489	0.089

The evaluation of the time to detect dynamic objects is evaluated within the requirements for the FNRP module. That means objects have to be detected within a range of 40m. In 8 of the 11 scenarios it takes the minimal three initialization steps until tracking begins and the detection task is accomplished. In other scenarios the minimum number of measurement points the algorithm requires to begin tracking is below three and tracking is delayed by at most 2 cycles.

Table A3: Mean time and cycles to detect an object in 11 different test cases

Object detection time [ms]	Object detectiontime [Cycles]
134.55	3.36

3) RUCS Module evaluation (an update to D2.2)

The evaluation has been done by using the data of crash and no-crash scenarios recorded during several measurement campaigns on different test tracks. Some of these scenarios are described in chapter C.1. Other scenarios used in the evaluation are e.g. driving a curve through a narrow passage or crashes against moving soft crash targets. The sensor data is processed by the FNRP (Frontal Near Range Perception) module and its output is used as input source for the RUCS module.

As ground truth data the impact sensor system described in D2.2 [INT D2.2] was used. However for some test trials the impact sensor has not been triggered correctly, e.g. when the overlap between obstacle and vehicle was too small. Therefore these test data could not be used to calculate the time-to-collision-error.

The RUCS module is optimized by defining a crash threshold which minimize the false-positive and false-negative rate. The results of the evaluation are displayed in the tables below. The first table, Table A4, shows the detection rate, including false-positive and false-negative rate.

Table A4: Mean time and cycles to detect an object in 11 different test cases

	Crash occured	No Crash occured	Overall tests
RUCS classified Crash	27 96%	2 4%	29
RUCS classified No Crash	1 4%	43 96%	44
Overall tests	28	45	73

To give the right impression of the results it has to be mentioned that most of the test cases used during the evaluation are especially designed to test boundary situations in a controlled environment. The most difficult situation for our system where narrow passages, where estimation errors (small errors in width estimation and position) of the FNRP module can lead to a scenario where the passage seems to be impassable.

The second table, Table A5 below displays information about the TTC (Time To Collision) that is estimated by the perception module. For these results only the first prediction of an unavoidable crash situation was used. Minimum, maximum and mean values computed over all test crash test scenarios are displayed in the table.

Table A5: Mean time and cycles to detect an object in 11 different test cases

	Estimated TTC [ms]	TTC Error [ms]
Mean	181	13
Maximum	402	24
Minimum	35	0

The determined values are below the targeted decision horizon of 600ms. However for the evaluated scenarios a longer horizon is not possible, because the crash is still avoidable, with the assumption that steering, breaking and acceleration parameters of a car can be applied immediately at any point in time within the physical limits of the test car.

To enlarge the prediction horizon it would be necessary to consider a) the intervention activity and strength of the driver on the steering wheel, brake and acceleration pedals as well as b) the delay and progression behaviour of the vehicle based on the driver controls. These actions were not in the focus of this signal processing focused project and would require further research in other fields as well as the possibility for enhanced driver behaviour monitoring.

The investigated scenarios showed that for many situations evasive manoeuvres would succeed to avoid the crash even if braking manoeuvres already fail. Therefore, the prediction horizon is longer for scenarios, where the evasive manoeuvres are limited e.g. due to traffic barriers or for scenarios where the evasive manoeuvres to avoid hitting the obstacle must be stronger e.g. due to larger obstacles. But crash tests have to be arranged in environments with a lot space around for safety reasons and the crash object size is restricted due to limit the effect of the impact forces during the crash. These effects have also influenced the resulting TTC figures and avoided a larger time horizon.

4) Evaluation summary and outlook

The FNRP and RUCS perception modules were developed with the goal to build a consistent sub-processing chain to handle time critical high dynamic driving scenarios that typically can occur in upcoming crash situations.

As a general statement the results are improved related to the work established in the frame of preceding projects were similar sensor set-ups were used. The improvements are mainly related to the accuracy of the position and motion state estimation but in addition new features like the heading angle and yaw rate of moving objects can be delivered by the FNRP perception module in a reasonable quality. The implemented particle filter approach converged with a negligible accuracy distribution of the result. With the current status of the algorithms pre-selection of threatening objects is a key enabler to keep real time constraints which requires the combination with an attention based approach. The utilization of a grid based environment processing for stationary objects is another measure to relax the computational load and enable the sophisticated tracking solution for the remaining dynamic objects.

Furthermore due to the use of extensive ground-truth measurement equipment we were able to determine the accuracy and robustness of the parameter estimations at least in some controlled test cases.

For the RUCS perception module these improvements in the environment description raised the complexity of the algorithms a lot. Real time capable crash estimations using direct time prediction methods are no longer feasible taking into account reasonable processing performance available in today's vehicles. Therefore a classification algorithm based approach was implemented to overcome these limitations. The behaviour of this approach, taking into account the huge variety of situations in the real world environment, could not be finally investigated yet.

For almost all of the tested scenarios we found that the performance is now at a level that would be sufficient for the control of reversible counter measures in case of detected crash situations. This statement is also valid taking into account the set of near crash scenarios that were intentionally selected to test the false alarm rate of the algorithms. Since the tests only included a limited subset of “real world scenarios”, which is owing to the nature of the target scenarios, it is clear that this cannot be a final assessment.

For the deployment of the investigated technology there are still some barriers that need to be overcome. One of the most obvious points is still the missing availability of a serial production laser scanner delivering a data quality comparable to the sensors used in the project. Additional confidence in further improvements originates from the increased performance in terms of velocity measurement and wide field of view that can be observed for the new generation of short range radar sensors that is currently introduced in the market.

The absence of the possibility to externally trigger the different sensors or at least the possibility to access synchronized sensor generated measurement time stamps turned out as a further limiting factor of the object quality. This is another point that should be kept in mind for future projects and products.

On the algorithm side dealing with situations including moving objects suddenly entering the observable area of the Perception Platform (e.g. behind occlusions) in an appropriate way is one of the remaining future challenges. In these cases the correct processing of signals with initially incomplete or imprecise information has to be investigated. Potential improvements could further be realized by approaches that incorporate object type dependent tracking algorithms.