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SIXTH FRAMEWORK PROGRAMME

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Executive summary

PReVAL addresses the possible safety impacts of functions developed and demonstrated in the PReVENT integrated project. One of the major aims of the PReVAL project is the assessment of the work performed in the PReVENT subprojects.

This deliverable reviews the evaluation results from the different PReVENT subprojects. The deliverable is both a deliverable for the PReVAL subproject and for the PReVENT IP (IP D10 “Validation results of first phase PReVENT projects”).

The safety potential of an application is determined by both the technical performance and reliability of the system, human factors (the interaction between the driver and the vehicle) and the traffic safety level. For the safety impact analysis, the behavioural effect approach, which has been developed and is used by the eIMPACT project, is used.

The PReVENT subprojects are classified according to the time to risk: tight and short interactions related to collision mitigation and avoidance (< 1s: i.e. APALACI, COMPOSE, INTERSAFE); short interactions with other moving vehicles (1-5 s: LATERAL SAFE, SAFELANE, SASPENCE) and more distant interactions (>5s: MAPS&ADAS, WILLWARN).

The work is divided according to the following aspects: technical performance evaluation, human factors evaluation and safety potential estimation.

For the technical evaluation, PReVENT subprojects have followed the CONVERGE approach, with slight differences in the implementation. The technical evaluation is performed in two stages: verification of the subsystems and validation of the complete system. PReVENT subprojects addressed very new and innovative concepts and technologies, for which no well established standard assessment procedures exist. So, besides of the challenge to build such innovative concepts, the evaluation procedure in itself is innovative. Methods which are used for validation include the use of simulation tools, vehicle hardware-in-the-loop tests, trials on test tracks and trials in real traffic. For all functions, Correct, False and Missed Alarm Rates are calculated. All subprojects reported good results for the scenarios and conditions tested. Starting from an analysis of the evaluation in PReVENT, best practices for technical assessment are derived. Since PReVENT is not an assessment dedicated project, the evaluation procedure has been constrained to a tight schedule. Due to this fact, there has been in general a limitation on the number of repetitions for each scenario, a fact that plays a role in the related statistical confidence intervals. A fundamental outcome from PReVENT is that each function has looked at several technologies in order to improve the performance. PReVENT subprojects make use of a large set of sensors (environmental sensing, maps, telecommunications etc) and data fusion in order to provide reliable detection and positioning inputs for the proposed assistance functions. PReVENT subproject provide a large “basket of new technologies”, which are fundamental main bricks for preventive safety systems.

Human factor and HMI related results have been analysed for six PReVENT sub projects; INTERSAFE, SAFELANE, MAPS&ADAS, WILLWARN, SASPENCE and LATERAL SAFE. The major methods used in the analyses include driving simulator tests, trials on test track and in real traffic. Prestudies with simulators and research vehicles were used to test different HMI alternatives. For each of the projects, the results on acceptance, usability and driving performance and driver behaviour, have been analysed. All the analysed subprojects report positive results on driving performance and driver behaviour, as well as for acceptance and usability, however with a variation in the significance and distribution of the results. Most projects emphasize the need for further experiments with a larger amount of scenarios and a larger group of test subjects for achieving statistically significant results. Also further tests for optimising the HMI solution is mentioned in some projects. There is a need for assessing the long term behaviour of the driver.

A first qualitative safety potential assessment of PReVENT functions is made. The safety potential assessment consists of two phases: a qualitative assessment, which is described in this report, and a more quantitative safety assessment, which will be described in D16.4. The safety potential assessment is based on the behavioural effect approach, developed by the eIMPACT project. The qualitative safety potential assessment focuses on the impact mechanisms first evaluating how the functions affect driver behaviour and travel behaviour. The functions are selected so that they cover the whole scope of functions when the analyses conducted by the eIMPACT project are taken into account. For each of the mechanism, a literature study is performed to search for evidence from systems, preferably experimental data, if available. Based on the state of the art knowledge, the relevant safety impact mechanisms for each PReVENT system were defined in qualitative terms. In addition to the overall analyses, the expected effects were assessed by circumstance (i.e. type of accident, road type, vehicle type, weather conditions etc.).

1 Introduction

The main objective of PReVAL is to address the possible safety impacts of functions developed and demonstrated in the PReVENT integrated project.

Opposed to passive safety functions, in preventive safety applications, the driver is in the loop. The safety potential of preventive safety functions is not only affected by the technical performance, but also by the human factors, which include the driver reaction to the Human Machine Interface (HMI) and changes in driving behaviour. The safety implications can be classified into three aspects – 1) the technical reliability, 2) the driver behaviour level (human factors) and 3) the traffic safety level (safe operation of the traffic system, interaction between users and non-users) [1]. These three different aspects need to be taken into account when considering the safety potential of a preventive safety function.

In deliverable D16.1 the work on the assessment process in the different PreVENT subprojects and other related projects has been collected and reviewed. The main purpose of deliverable D16.2 is to collect and analyse the evaluation results of the PReVENT Subprojects in an aggregated form.

The results presented in this deliverable D16.2 include 1) a review of the technical performance assessments from the different PReVENT subprojects, 2) the results related to the HMI design and 3) a qualitative analysis on the safety impacts of the different subprojects.

The analysis work has been organised according to the three aspects mentioned above: the technical performance assessment, the human factors assessment and the safety potential assessment.

Chapter 2 gives an overview of the method, used to gather and process the results from the different subprojects.

Chapter 3 contains a review and analysis of the technical evaluation results, and provides conclusions about the PReVENT functions in terms of technical performance. PReVENT subprojects addressed very new and innovative concepts and technologies, for which no well established standard assessment procedures exist. So, besides of the challenge to build such innovative concepts, the evaluation procedure in itself is innovative. Starting from an analysis of the evaluation in PReVENT, best practices for technical assessment are derived.

Chapter 4 gives an overview of the human factors evaluation work in the different subprojects. Human factor and HMI related results have been summarized for six PReVENT sub projects; INTERSAFE, SAFELANE, MAPS&ADAS, WILLWARN, SASPENCE and LATERAL SAFE. These projects were selected for being particularly relevant for human factor evaluation due to their degree of interaction with the driver.

Chapter 5 makes a first qualitative safety assessment of PReVENT functions. Safety potential assessment focuses on the impact mechanisms evaluating first how the functions affect driver behaviour and travel behaviour. The functions were selected so that they cover the whole scope of functions when the analyses conducted by the eIMPACT project are taken into account. Based on the state of the art knowledge, the relevant safety impact mechanisms for each PReVENT system were defined in qualitative terms. In addition to the overall analyses, the expected effects were assessed by circumstance (i.e. type of accident, road type, vehicle type, weather conditions etc.). A more quantitative safety assessment of selected PReVENT functions will be reported in the final deliverable D16.4.

2 Methodology

The data collection and analysis work in PReVAL has been organised according to the three aspects: 1) technical performance assessment, 2) human factors assessment and 3) safety potential assessment.

2.1 Technical Performance Assessment of PReVENT systems

This task collects and analyses the evaluation results produced by the PReVENT subprojects. Special attention is given to:

1) The situations in which the data was collected (road type, road design, traffic conditions, environmental conditions…),
2) The elements that may have influenced the quality of results and their statistical significance.

The evaluation results are analysed and harmonised taking into account the nature of the tests conducted in subprojects. Conclusions about PReVENT functions in term of technical performances are provided.

In order to gather the information, a template has been developed in collaboration with the other workpackages, which collects and processes the information in a consolidated way. The template has been developed together with the other work tasks in order to avoid any overlapping and redundancy in data collection. The template is included in this deliverable as Annex C. For the technical performance analysis, the template includes a short technical description, the description of the tests and results of the verification of the subsystems, and the tests and results of the validation of the functions.

Each of the subprojects is analysed by two partners, according to Table 1.

Table 1: Distribution of the analysis of the technical performance results to partners

Project Name	Main contacts and information	Analysing partners
SASPENCE	CRF	**TNO,** VCC
WILLWARN	TNO	**ICCS,** LCPC
MAPS&ADAS	UHA	**UHA,**DC
SAFELANE	ICCS	**LCPC,** IKA, VTEC
LATERAL SAFE	CERTH	**VCC,** TNO
INTERSAFE	IKA	**IKA**, UHA
APALACI/ COMPOSE	CRF	**CRF,** ICCS

2.2 Human factors assessment of PReVENT systems

In Deliverable 16.1 the methods used for human factors assessment in the PReVENT subprojects have been gathered, based on available evaluation plans and evaluation results. A summary of the evaluated functions, the evaluation objectives, the methodology and experimental design and a brief overview of available results were provided in the deliverable. The availability of the final results from human factors assessment was however limited at the time for writing the deliverable D16.1. The focus in this deliverable D16.2 is in the final results and conclusions from the human factors related evaluations with respect to driver behaviour, driving performance, user acceptance and usability.

The results are presented to the extent to which they are available at the release of this deliverable.

In deliverable D16.1 the methodology applied for evaluation was summarized for the following subprojects:

1. SAFELANE
2. MAPS&ADAS
3. LATERAL SAFE
4. SASPENCE
5. INTERSAFE
6. WILLWARN

This report will summarize the available results from the same subprojects.

To gather the results in a consolidated form between the partners, a template, which is also used by the other work tasks (see Annex C) has been developed. The information collected for the human factors evaluation is structured as below:

1. **Status of results**

   Deliverable D16.1 was written before the end of the evaluation in different projects. At the start of this phase, the status of the projects and availability of the results was checked. If updated information was available, the final results were summarised.

2. **Summary of results on**

   i. **Driving performance / driver behaviour**

   ii. **Acceptance**

   iii. **Usability**

   The work has been distributed between the partners according to Table 2:

Table 2: Distribution of the SP Human factor analysis to partners

Subproject	Responsible partner for gather information on results	Responsible partner for summarizing and formatting gathered information.
SAFELANE	VTEC	VTEC
MAPS&ADAS	UNIHAN	VTEC
LATERAL SAFE	VTEC	VTEC
SASPENCE	VTT	VTEC
INTERSAFE	UNIHAN	VTEC
WILLWARN	VTT	VTEC

2.3 Safety impact analysis of PReVENT systems

2.3.1 Overview of methodology and selected functions

The methodology used to estimate the safety potential is the behavioural effect approach developed in the eIMPACT project, based on previous work [2]. The rationale of this approach is to assess the impact mechanisms first evaluating how the functions affect driver behaviour and travel behaviour. The methodology is described in more detail in D16.1, section 5.3.

The functions to be analysed by the PReVAL project were selected so that they cover the whole scope of functions. The complementarity with the eIMPACT project is taken into account. eIMPACT analyses the following PReVENT functions:

- WILLWARN (Warning about stopped vehicle and Warning about reduced friction of visibility)
- LATERAL SAFE
- INTERSAFE (Traffic light assistance and Right-of-way assistance)
- SAFELANE
- COMPOSE (autonomous braking and road user protection)

The functions analysed by PReVAL are selected so, that they do not overlap with the work of eIMPACT. The analysis by the eIMPACT project is performed on a general level (i.e. with no specific variations of functions). eIMPACT will report the results in their public deliverable D4 (Impact assessment of Intelligent Vehicle Safety Systems). This report summarizes traffic and safety impacts, and will be available in 2008.

The analysis by the PReVAL project uses a similar safety framework as the one used by eIMPACT. The safety analysis will be performed in two phases:

- **Phase 1:** Based on the state of the art knowledge, the relevant safety impact mechanisms for each PReVENT system will be defined. Specifically, the following safety effects will be considered: direct modification of the driving task, indirect modification of user behaviour and non-user behaviour, modification of interaction between users and non-users as well as modifications of road user exposure, modal choice, route choice and accident consequences. The PReVAL functions analysed are:
    - Safe speed and safe following: SASPENCE, MAPS&ADAS
    - Lateral support: SAFELANE
    - Intersection safety: INTERSAFE left turn assistance
    - APALACI/COMPOSE (autonomous braking, pre-fire and pre-set)
- **Phase 2:** more specific safety analysis for specific functions. After the definition of the main impacts, behavioural and safety impacts will be analyzed in detail. The focus is in fatal

accidents, since reliable data is available throughout EU-25. Injury accidents are included, provided that data are available. The impacts will be structured in the analyses according to the CARE database classification. Quantitative estimates of safety impacts, i.e. percentual changes in accident occurrence in each category for each selected application will be provided. The percentual changes are applied to the accident data organized according to CARE classification. The results will show an overall impact on accident reduction and accident consequences.

This report will give the qualitative safety assessments and the literature review (Phase 1). The quantitative safety assessments are reported in D16.4. Each of the projects is assessed by three partners, according to Table 3:

Table 3: Distribution of the SP safety assessment to partners

Subproject	First safety assessment draft	Cooperation with/ literature review with
SASPENCE	TNO	VTT, LCPC
SAFELANE	CERTH/HIT	UNIHA, VTT
MAPS&ADAS	UNIHA	CERTH/HIT, IKA
INTERSAFE	VTT	IKA
APALACI/COMPOSE	LCPC	VTT, VTEC, CRF

2.3.2 Qualitative safety assessment steps

The safety assessment goes through the following steps:

2.3.2.1 System description - from technical functions to main scenarios

a. Function description

This step has been reported in deliverable D16.1. For more information on the system descriptions, please see Annexes G-N to D16.1. These descriptions do not provide all the information needed for a consolidated analysis of the results. A common system description template (Annex C), for use by all the workpackages has been developed. The information gathered for the different workpackages is included in Annexes D-K

b. Technical limitations – when the system is developed to work and what are the limitations

From the technical evaluation, information is provided on the circumstances in which the system does not work at all (i.e. has not been designed for), works possibly, and the circumstances in which the system has been tested.

c. Circumstances, ”target accidents” – which type of accidents can therefore be addressed

The main objective of the impact analysis is the reduction of fatalities, but the CARE database contains also some information about injuries. The selected structure is as follows:

A. Road class: motorway, outside urban area and inside urban area
B. Vehicle type: car and heavy vehicle (including buses)

C. Collision type: chain or rear, frontal, angle, side-by-side, pedestrian, single vehicle accident, single vehicle accident with obstacle, single vehicle accident no obstacle, other and unknown.
D. Weather conditions: normal and bad (fog or mist, rain, snow)
E. Lighting conditions: daylight or twilight and night
F. Road section type: no junction and at junction

The circumstances are addressed in two phases – technical limitations and driver behaviour related effectiveness of the system in different circumstances

a. The systems' technical limitations are considered by accident categories (circumstances) and these limitations will reduce the safety potential (i.e. the safety system cannot address all accident situations)
b. The effectiveness of the system in different kind of circumstances (e.g. detecting an on-coming vehicle at night is more difficult for the driver than detecting the vehicle in daylight).
c. Driver behaviour needs to be addressed separately, since drivers might behave differently in different circumstances (e.g. increased exposure only in adverse road conditions etc.)

2.3.2.2 Literature review

Quite limited research information is available about the safety impact of preventive safety systems. Therefore evidence has to be searched from similar systems. Experimental data is used, if such information is available. Otherwise, expert assumptions or simplifications of the situation are used. Literature data and evidence is presented for each of the mechanisms, listed in the following paragraph.

When searching for information, attention is paid to the transparency and reliability of the information, i.e. source of the information: accident data, empirical evidence from PReVENT or similar systems, predicted expert evaluations.

2.3.2.3 Relevant safety mechanisms

Draskóczy, Carsten and Kulmala [3] compiled a list of mechanisms, via which ITS affects safety. The list is the following:

1. **Direct in-car modification of the driving task** by giving information, advice, and assistance or taking over part of the task. This may influence driver attention, mental load, and decision about action (for example, driver choice of speed)

2. **Direct influence by roadside systems** mainly by giving information and advice. Consequently the impact of this influence is more limited than of the in-vehicle systems.

3. **Indirect modification of user behaviour** in many, largely unknown ways. The driver will always adapt to the changing situation. This is often called behavioural adaptation and will often not appear immediately after a change but may show up later and it is very hard to predict. Behavioural adaptation may appear in many different ways (for example, by change of usage of the car, by change of headway in a car following situation, by change of expectation of the behaviour of other road users)

4. **Indirect modification of non-user behaviour.** This type of behavioural adaptation is even harder to study because it is often secondary. Non-equipped drivers may for example change their behaviour by imitating the behaviour of equipped drivers (for example, driving closer or faster than they should, not having the equipment).

5. **Modification of interaction between users and non-users**. ITS will change the communication between equipped road users. This change of communication may influence the traditional communication with non-equipped road users. To a large extent this problem may appear in the interaction between drivers and unprotected road users.

6. **Modification of road user exposure** by for example information, recommendation, restrictions, debiting. This is certainly an area where introduction of ITS will have a large impact for example by changing travel pattern, modal choice, route choice etc.

7. **Modification of modal choice** by for example demand restrains (area access restriction, road pricing, area parking strategies), supply control by modal interchange and other public transport management measures, travel information systems. Different travel modes have different accident risks, therefore any measure which influences modal choice, has also impact on traffic safety.

8. **Modification of route choice** by demand restraints by route diversions, route guidance systems, dynamic route information systems, hazard warning systems monitoring incidents. Different parts of the road network, i.e. different categories of roads, have different accident risks, therefore, any measure which influences route choice by diverting traffic to roads of different category, has also impact on traffic safety.

9. **Modification of accident consequences** by intelligent injury reducing systems in the vehicle, by quick and accurate crash reporting and call for rescue, by reduced rescue time.

Starting from a thorough descriptive analysis of the PReVENT function, and the literary survey, a list of the relevant impact mechanisms is provided.

3 Analysis of technical performance evaluation results

3.1 Introduction

PReVENT subprojects can be classified in different function fields, which correspond to different type of interactions. The “time to risk” is the major key differentiated parameter. Directly related to the “time to risk”, the horizon (in time or distance) to be considered is also a key differentiated parameter. Those function fields are consequently fed by technologies showing complementary information access capabilities in terms of time and distance. In this chapter, a distinction is made in 3 function fields. They are briefly introduced below.

1. The first function field deals with to tight (<1s) **and short interactions related to collision mitigation and avoidance**. There is a risk of immediate collisions with obstacles. The time and distance related parameters are very short. The technologies able to address those circumstances are based on perception sensors located on-board. The explored concepts are based on pre-crash, collision prevention and mitigation systems. 3 PReVENT subprojects address this function field: APALACI, COMPOSE (frontal imminent collisions, tight interactions), INTERSAFE (side and frontal collisions especially those related to intersections, short interactions)

2. The second function field addressed by PReVENT relates to **short interactions** with other moving objects constantly managed by the driver **(1 to 5 s).** The time and distance related parameters are short and can be addressed again by on-board technologies. Maps and vehicle-to-interface communications can be used as additional sensors. Three PReVENT subprojects address this function field: SASPENCE (frontal interactions), LATERAL SAFE (lateral and rear interactions), SAFELANE (lateral interactions with the lane and road sides)

3. The third function field corresponds to **more distant interactions**. The time and distance related parameters are longer **(~> 5 s).** The decision time is not critical; the implied correction operations can be assimilated to precaution more than accident prevention. The concept is based on the creation of an electronic horizon that enables foresighted driving. A distinction is made between two classes of addressed risks:

- A first class of risks, addressed by MAPS&ADAS, is permanent and located on the road. The technologies are localisation techniques and digital maps. The PReVENT subproject covering this function field is MAPS&ADAS.
- A second class of risks, addressed by WILLWARN, is non permanent and cannot be accessed through maps alone. Dynamic access to the information is needed, and telecommunications and localisation techniques are the “natural technologies” to be considered in this function field.

An additional remark has to be made. PReVENT subprojects address many new concepts and technologies, for which no well established standard assessment procedures exist. So, besides of the challenge to build such innovative concepts, the evaluation procedure in itself is innovative as well, specially taking into account the tight time constraints, since PReVENT is not an assessment dedicated project.

The information for the different subprojects is collected by means of a template, which is described in Annex C. The description of the system, including technical specifications, is shortly included with the evaluation results. More information is in Annexes D-K.

3.2 Evaluation results: Function field 1: Tight and short interactions related to collision mitigation and avoidance

3.2.1 APALACI results

3.2.1.1 Function description

The APALACI subproject covers the functional area of Collision Mitigation, and has as main objective to improve the protection of the driver and the passengers.

The APALACI system is based on sensor fusion techniques to capture obstacle dynamic data before an imminent crash. The general objective is to mitigate a possible unavoidable collision by two types of actions:

- intervention on the brake in order to optimize the braking manoeuvre and reduce the impact energy
- optimization of advanced restraint systems to improve the protection of passengers.

The final safety impact is therefore a reduced risk of fatalities and severe injuries for both the vehicle occupants.

a) Collision Mitigation

The application aims at reducing the energy of impact when a crash is unavoidable. In the CRF demonstrator this function is performed semi-autonomously. When the system recognizes a critical situation, it gives to the driver an acoustic (with a buzzer) and a haptic (with a soft activation of the electrical belt pre-tensioners) warning, advising him to brake. Then, after the brake driver intervention, the braking pressure is enhanced in order to reduce the vehicle speed and the impact consequences significantly.

b) Pre-Fire

The Pre-fire application aims at protecting drivers and passengers when a crash is unavoidable, by controlling and activating the reversible safety systems, such as electrical belt pretensioners. In the CRF APALACI demonstrator, the system activates the pretensioners with maximum force a few hundred milliseconds before the crash during the semi-autonomous braking manoeuvre.

c) Pre-Set

The use of pre-crash information allows an improved protection of drivers and passengers when the impact is unavoidable, by transmitting additional data to initialize and pre-condition the existing safety systems such as airbags. In this way the type and characteristics of airbag deployment can be tuned according to the impact conditions, and the time of firing can be optimized. In the CRF prototype the system provides a message on the CAN bus that could be used as a trigger signal for airbag activation, in the interval between the Pre-Fire function and the impact .

Accident types:

It is possible to identify three different accident addressed by the functions:

- Head-on collision with a moving vehicle coming from the opposite direction. Looking at accidents studies this scenario is the most frequent in real road situations and generates the highest number of injuries.
- Rear-end collision with a slower/stationary vehicle; in this scenario the vehicle equipped with the system crashes with a vehicle that is moving very slow in the same direction or with a stationary vehicle.
- Collision with a stationary object. More specifically, the host vehicle is following a target car, in front of that there is a stationary object (e.g. another car); when the target car changes lane and the stationary object becomes the new target.

The application scenarios for APALACI should consider all road types (focusing on urban and extra-urban roads, in particular) and in general, it should be operable in all traffic situations.

3.2.1.2 Technical Specification

Sensors:

- Two medium range radars (frequency 24 GHz) positioned behind the bumper penetrable for radar pulses
- A digital monocular grey level camera that will be installed in the driver compartment behind the central mirror in the windscreen.

Actuator:

- In order to perform the collision mitigation application, an active booster for the braking system is installed, equipped with a CAN interface to drive the brakes by computer control. An integration of manual and automatic brake actuations has been implemented, according to the requirements of the semi-autonomous mode for the collision mitigation function.
- For the actuation of the Pre-Fire function, both on the driver and the passenger seat, reversible belt pretensioners are installed, receiving a trigger from the APALACI dedicated CAN.

3.2.1.3 Validation

For the validation of the three functions implemented on the CRF APALACI demonstrator the following key indicators reported in Table 4 are considered.

Table 4: Key indicators for the APALACI functions for the CRF demonstrator

Evaluation Category	Indicator	Abbr	Description
Parameters for quality of measurement	Position Accuracy	Ep	The accuracy of the estimated position of target objects [m].
	Impact speed accuracy	Es	The accuracy of the calculated relative speed of objects [km/h].
	TTC accuracy	Ettc	The accuracy of the calculated time to collision [ms].
Parameters for quality of functionality	Detection rate	Fd	The number of detected objects related to the number of existing objects. The value is usually given in *percent* (%).
	Missed Alarm Rate	MAR	The number of missed critical situations related to the real number of measured scenarios. The value is usually given in *percent* (%).
	False Alarm Rate	FAR	The number of wrongly detected critical situations related to a time or a distance of normal driving. The value is usually given in number related to time or distance.

In order to calculate the first three keys and to evaluate the APALACI applications implemented in the CRF demonstrator vehicle a specific reference measurement system has been designed and integrated in the car. This reference measurement system is explained in more detail in Annex D.3.

CRF performed the tests in two different environments:

- On test-track in order to evaluate the system in terms of reliability and missed alarm rate
- In real traffic in order to evaluate the false alarm rate (semi-automatic brake deactivated).

Collision mitigation

Tests were performed according to the Evaluation Plan deliverable [9]. Table 5 reports the tests performed for the Collision Mitigation function in the test truck and the different parameters used.

Table 5: Test conditions for Collision Mitigation

Scenario	Host Speed (km/h)	Target Speed (km/h)	Offset (cm)	Weather condition
Head-on collision	30,50,70	0	0,90,180	Clear sky, cloud
Rear-end collision	30,50	30,50,braking	0	Clear sky, cloud
Collision with stationary object	30,50,70	0	0	Clear sky, cloud

The different scenarios have been reproduced considering all combinations of parameters and for each situation three repetitions are performed.

Pre-Fire and Pre-Set

For the Pre-Fire and Pre-Set functions the same kind of tests are performed on a test track. Table 6 below shows the test conditions for the different situations. For each situation three repetitions are performed.

Table 6: Pre-fire and pre-set test conditions

Scenario	Host Speed (km/h)	Target Speed (km/h)	Offset (cm)/ Angle (˚) /Separation (m)	Weather condition
Centred wall crash	10,20,30,40,60	0	0/ 0,15,30/-	Clear sky, cloud
Displaced wall crash	20,40,60	0	0,50,100/ 0,20/-	Clear sky, cloud
Pole crash	30,40,60	0	0,50,150/0/-	Clear sky, cloud
Multiple objects pole in front of the wall	30	0	0/0/0.5,1,2,3	Clear sky, cloud
Multiple objects pole behind displaced wall	30	0	1/-/0.5,1,2,3,4	Clear sky, cloud

3.2.1.4 Validation Results

Table 7 shows the results from the Collision Mitigation tests.

Table 7: Results of the collision mitigation tests

Scenario	Detection rate	Missed alarm rate	False alarm rate
Head-on collision	100%	0%	0%
Rear-end collision	100%	0%	0%
Collision with stationary object	100%	0%	0%

From Table 7, it is possible to see that we have a good result of 0% of missed alarm rate (MAR) and false alarm rate (FAR), and 100% detection rate (Fd). However these results have been obtained on a test track in very simple and reconstructed scenarios.

Table 8 reports the results for the Pre-fire and Pre-Set tests.

Table 8: Results of the Pre-fire and pre-set tests

Scenario	Detection rate	Missed alarm rate	False alarm rate
Centred wall crash	100%	0%	0%
Displaced wall crash	100%	0%	0%
Pole crash	100%	0%	0%
Multiple objects pole in front of the wall	100%	0%	0%
Multiple objects pole behind displaced wall	100%	0%	0%

Also here we have a good result of 0% of missed alarm rate (MAR) and false alarm rate (FAR), and the 100% of detection rate (Fd). Also in this case these results have been obtained on a test track in very simple and reconstructed scenarios. In conclusion it is possible to validate that the system worked correctly.

3.2.2 COMPOSE results

3.2.2.1 Function description

COMPOSE developed collision mitigation systems for the protection of other road users. In case of an unavoidable collision, the consequences are mitigated by reducing the vehicle speed before impact. The project cooperated with the APALACI and UseRCams subprojects.

The technical verification and evaluation of the developed in-vehicle systems within COMPOSE has been carried out at two main levels: *Perception* and *Application*.

System tests have been performed both on closed test tracks and on public roads (without actuators enabled) to evaluate positive and negative test cases and get a measure of potential false alarms. The tests were carried out both for cars and trucks.

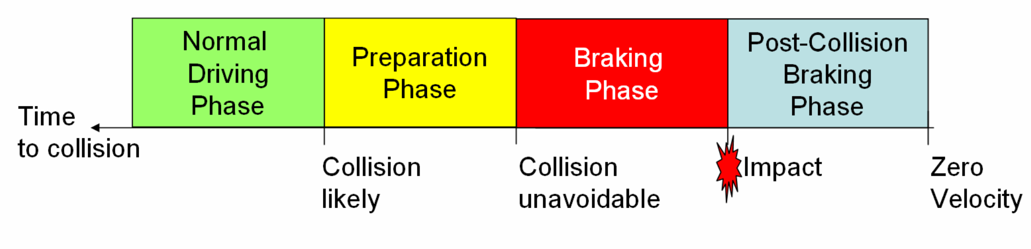


Figure 1: Collision Mitigation Time Scale

Table 9: Summary conditions of function specifications

Vehicle type concerned	**Passenger Car/Heavy Duty**/ Bus
Target considered (when relevant)	**Pedestrian**/Two-wheels/**Car/Heavy duty**
Road Type	**Rural/Urban/Highway**
Weather Conditions	**Normal**/Adverse
Light Conditions	**Day**/Night
Level of cooperation	**None**/Veh. to infra./ Veh. to Veh.

3.2.2.2 Verification and validation

The test and evaluation plan follows the CONVERGE approach and includes:

1. ***Analysis of traffic accident statistics*** leading to a description of realistic accident use cases to be accommodated by the APALACI & COMPOSE applications.
2. ***Reconstruction of the traffic scenarios*** from a list of *generic test scenarios*, including a list of independent variables that can be used to specify the test set-up and list of relevant key indicators used to evaluate the test results.
3. ***Test specification per application*** listing different sets of values for the independent variables.

Three different test types or test environments have been used:

- Tests using simulated target data
- Tests on a test track
- Tests in real traffic

Table 10: gives an overview of the COMPOSE evaluation,

Table 10 : COMPOSE evaluation overview

Pilot site	Applications/ Systems evaluated	Demonstrator used	Type of trials carried out
Test Track Aschheim	Collision Mitigation for Cars (BMW FT)	BMW passenger car	Scenario 1: Rear-end collision
Test Track Aschheim	Collision Mitigation for Cars (BMW FT)	BMW passenger car	Scenario 2: Collision with stationary objects
Test Track Aschheim	Collision Mitigation for Cars (BMW FT)	BMW passenger car	Scenario 3: Collision with pedestrians or vulnerable road users
Munich	Collision Mitigation for Cars (BMW FT)	BMW passenger car	Real urban traffic
Gothenburg, Volvo Test Track Hällered	Collision Mitigation for Trucks	VOLVO Truck	Application evaluation on test track
Gothenburg, Varberg, Borås Area	Collision Mitigation for Trucks	VOLVO Truck	False Alarm evaluation under normal traffic conditions

In the case of Collision Mitigation in Trucks, the following scenarios were considered:

i. Collision with a stationary object;
ii. (Virtual) collision with a moving object;
iii. Near collision with a stationary object, and
iv. Tests in real traffic scenarios.

The following main assessment categories have been used for evaluation in COMPOSE:

- Verification of sensor platforms and data fusion techniques
- Accuracy and reliability assessment of situation assessment algorithm and sensor systems.

Table 11: COMPOSE application system test for missed alarms results summary

Application vehicle	Number of scenarios/ clips	Missed Alarm Rate (MAR)
Cars	30080 (simulated)	1 %
Trucks	15 (driven on test track)	0

The performance of the perception system in terms of detection rate and false alarm rate has been evaluated in detail only for the car demonstrator vehicle. The results are summarized below:

Table 12 : COMPOSE perception system test results

Criteria (indicators)	Number of scenarios	Number of detected Objects	Detection Rate (Fd)	Classification Rate (Fc)
Perception System, Scenario 1 (Vehicle-Vehicle)	61	61	100%	100%
Perception System, Scenario 3 (Vehicle-Pedestrian)	94	93	100%	98.9%
In total:	155	154	100%	99.4%

For the false alarm rate, investigations in real traffic have been performed with actuators disabled. The results are summarized in Table 13.

Table 13: COMPOSE false alarm test results summary

Application vehicle	Number of scenarios/ clips	False Alarm Rate	Time (Qt) in h
Cars	253 situations	2 per 01:38 h	01:38 h
Trucks	(continuous driving)	0	05:18 h
Sum	**n/a**	**2**	**06:56 h**

3.2.2.3 Conclusion, discussion

For both systems, the tuning of parameters has shown to be an important issue. Too high thresholds will result in late emergency braking; too low thresholds might produce false alarms. Thus, the fixing of decision thresholds concerning autonomous braking always is a trade-off between false alarm and missed alarm rate.

Generally, the collision mitigation functionality has shown to significantly contribute to reducing impact speed and thus crash energy. The actual amount of velocity reduction achieved varies depending on the own and the object's speed. But even small speed reductions can at higher speeds reduce crash energy.

Today, it is usually not possible to completely avoid a collision with this technology. Most importantly, the driver is in the loop to actively avoid dangerous situations and brake and/or steer to avoid any collision, but – once a collision is unavoidable – the described system can contribute significantly to reduce the consequences of a crash.

The collision mitigation functionality is meant to intervene only when a collision has become unavoidable by any means of the driver. Consequently, it has no other user interface than the execution of the vehicle brakes and braking preparation. Thus, no dedicated evaluation of the HMI has been foreseen.

3.2.3 INTERSAFE results

3.2.3.1 Function description

The INTERSAFE system concentrates on improving the traffic safety by avoiding collisions at intersections. The addressed scenarios are shown in Figure 2. It concerns only warnings and information (no intervention).

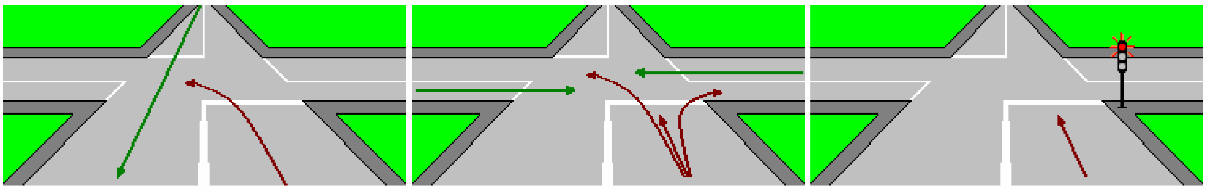


Figure 2: Scenarios addressed by INTERSAFE: Left turn, Lateral traffic and Traffic light

The INTERSAFE system has two main functions:

Intersection Assistant (IA) warns the driver to avoid a potential collision with other road users. Onboard sensors like Laser scanner can detect information about other vehicles, such as speed and position. The controller checks the risk of the situation, according to the speed and the distance to the conflict area of both vehicles (host and other vehicle). If not safe, warnings will be given to the driver with a risk indicator.

Traffic Light Assistant (TLA) warns the driver to avoid the red light violation. Based on the speed and distance to the traffic light as well as the timing of traffic light phases (collected by WLAN-communication), potential red violation can be predicted. The driver will get a speed recommendation if safe crossing at green is possible by keeping to the speed limits or a warning in case of a potential violation at red.

3.2.3.2 Verification

Description

The sensors and processing modules (Laser scanner, camera system and sensor fusion respectively) were tested to verify fulfilment of their function requirements in the INTERSAFE application. In this test, the sensors' performance could be measured, e.g. the maximum detection range, localisation accuracy and so on.

The following objects were selected as sensor targets: Honda VFR800 (silver motorcycle), VW Lupo (black compact car), VW Golf (silver estate car), BMW 325i (red middle size car), BMW 728i (black large size car), Pedestrian (dark clothing) and Wooden dummy target for the test of position accuracy

Test methodology

All field tests were executed at an intersection on a test site.

Detection range of the Laser scanner: In this test the Laser scanner's maximum detection range for all five test vehicles and the pedestrian was determined. Tests were carried out at a speed of about 30km/h twice for each target and each angle.

Distance resolution of the Laser scanner: The distance resolution of the sensor was tested with the target vehicle VW Golf for 6 times. The demonstrator vehicle and the target face each other. Then the demonstrator vehicle drives forward and performs uniform braking in front of the target.

Max. error of object velocity of the Laser scanner: The VW Golf was used as the target vehicle in this test. The Laser scanner provides the absolute ground speed of the target vehicle. In the tests, the target vehicle stands still either facing or perpendicular to the demonstrator vehicle. The demonstrator vehicle approaches the target vehicle (three times with at 50km/h and three times at 30km/h).

Max. error of object position of the Laser scanner: A wooden dummy was used as the sensor target in this test. It was positioned either directly in front of the demonstrator vehicle or in a 45° position. In order to determine the accuracy at different distances, the demonstrator vehicle stands still and the target was moved in every test (7 positions in each angle).

Active sensed range in localisation status of the camera system: This test was designed to test the active sensed range of the camera system in the localised state (at which the camera is able to localise the vehicle position in intersection). In the test, the demonstrator vehicle moves forward as slowly as possible. The distance between the camera and the furthest point perceived at a road marking is determined as the active sensed range. Tests are repeated 5 times.

Field of view in localisation status of the camera system: The demonstrator vehicle moves forward as slowly as possible. As soon as one end point of the road marking is lost by the camera system in the localised status, the longitudinal and lateral distances between the camera and that point are measured. From these two distances the opening angle can be calculated. Tests are repeated 5 times.

Localisation accuracy: This test is applied to inspect the localisation accuracy of the Laser scanner, the video system and the fusion output. In order to measure the demonstrator vehicle’s distance to the intersection, a microwave sensor (Correvit) and a light barrier sensor are mounted at the rear end of the car. Four reflectors are put on the ground as reference positions for the light barrier. When the vehicle passes the reflector, the light barrier gives a signal out. According to the vehicle speed measured by the microwave sensor and the reference positions by the light barrier, the vehicle ground-truth position can be calculated. By comparing the localisation information from the sensors to the ground-truth position, the accuracy can be measured. Tests are repeated 5 times.

Test results

Table 14: Main results of the sensor test.

Sensor	Test item	results
Laser scanner	Detection range to car	200 m *
Laser scanner	Detection range to motorcycle	146 m
Laser scanner	Detection range to pedestrian	111 m
Laser scanner	Distance resolution of object detection	0.05 m
Laser scanner	Max. error of object velocity	-0.5 %
Laser scanner	Max. error of object position	-0.1 m
Camera system	Active sensed range in localisation status	14.2 m
Camera system	Field of view in localisation status	34.9°
Laser scanner	Localisation accuracy	0.13 m
Camera system	Localisation accuracy	0.21 m
Sensor fusion	Localisation accuracy	0.14 m

*: limited by the size of the test intersection

In conclusion, all sensors can fulfil the requirements/specifications.

3.2.3.3 Validation

Validation methodology

The target of system tests is to determine the rate of correct alarms, false alarms and missing alarms of each system function. The tests were done on the test track.

Definition of the key indicators:

- Input is an ALARM situation and output is alarm → Result is counted as Correct Alarm (CA)
- Input is ALARM situation and output is no alarm → Result is counted as Missing Alarm (MA)
- Input is NO-ALARM situation and output is alarm → Result is counted as False Alarm (FA)
- Input is NO-ALARM situation and output is no alarm → Result is counted also as Correct Alarm (CA) (extended definition of CA)

From these definitions the rates are calculated with respect to the total number of situations:

$$CAR = \frac{\sum CA}{\sum Situations};\ MAR = \frac{\sum MA}{\sum Situations};\ FAR = \frac{\sum FA}{\sum Situations}$$

Assessment results

Table 15: Correct (CAR), false (FAR) and missing (MAR) alarm rates

System	CAR [%]	FAR [%]	MAR [%]
IA left turn	93	7	0
IA lateral traffic	100	0	0
traffic light assistant	90	10	0

Conclusion, discussion

- Positive aspects: Good results achieved, no dangerous missing alarm occurred
- Uncertain aspects: System can be further improved to reduce false alarms
- Confidence in evaluation method: Tests only done at an intersection on test track
- Aspects not considered in evaluation: The influence of weather, the complexity of an real intersection: pedestrians, houses/trees and more vehicles.

3.3 Evaluation results: Function field 2: Short interactions with other moving vehicles

3.3.1 SASPENCE results

3.3.1.1 Function description

The SASPENCE (= SAFE SPEED and SAFE DISTANCE) system is an assistance system that provides suggestions (warnings or advices) to the driver, related to maintain the safe speed and safe distance. The information is given in an optimal way, by an appropriate HMI.

The aim of the SASPENCE system is to reduce the number of accidents, by preventing hazardous and risky situations and by avoiding collisions that are related to either an inappropriate distance or relative speed to a lead vehicle, or an inappropriate speed relative to posted speed limits, for a set of driving scenarios. [97]

3.3.1.2 Verification of the subsystems

The verification of the system was performed in several stages:

1. Component Testing

Each component was tested in isolation with the necessary test tools to ensure that it was operating correctly. All wiring and interfaces with the vehicle were also tested.

For example: the camera and related image processing module for lane detection and recognition are tested dynamically and no particular problems have been encountered.

The operative range of the radar sensor in the detection of standing obstacles such as bridges and overhead signs is limited to about 50 meters. Beyond this distance, false alarms are generated from bridges or overhead signs detected without the possibility to distinguish them from ground obstacles.

2. CAN Interaction Testing

When all components were installed on the vehicle, CAN integrity was tested and it was ensured that all components communicate successfully on the CAN bus; no component degrades the performance of the bus; or interferes with other ECUs communicating on the bus. The bus load was monitored to ensure that it is within safe operating levels.

Some CAN errors were reported, but the level of error frames was not sufficient to bring the CAN bus down and affect operation of the system.

3.3.1.3 Validation

The SASPENCE system is evaluated with randomized simulation studies (in PRESCAN), with vehicle in the loop tests (no driver, VeHIL tests) for critical scenarios resulting from the simulation studies, with technical tests on real roads and with subjective driving studies.

The system is evaluated with the following *evaluation criteria*, which are defined from the system requirements with emphasis on measures that relate to an appropriate interaction with the driver

- *Safety,* in terms of missed alarm rate. This performance measure is calculated by comparison of the SASPENCE output with a reference system which gives information on the warning level, and when the warning should be given (based on empirical data from a representative set of drivers)
- *Reliability* in terms of false alarm rate
- *Appropriateness* indicates whether the warning level is appropriate
- *Timeliness* indicates whether the warning is in time, too soon or too late
- *Safety effect* in terms of minimum time to collision during the scenario
- *Comfort* during a scenario in terms of the RMS of the value of the longitudinal acceleration

Randomized simulation studies

The comfort, performance and dependability of the system are evaluated for a representative set of traffic scenarios, operating conditions, and driving characteristics.

The simulation model is developed in PRESCAN as described in [98]. 2000 simulations are carried with the SASPENCE system on (1000) or off (1000).

Varied parameters are: scenarios, scenario parameters ((relative) velocity, (relative) position, acceleration…), driver characteristics (conservative, moderate and aggressive), and operating conditions (infrastructure, road layout, weather conditions (dry, rain or snow)). Exact parameter values are not available.

VeHIL tests

To provide a preliminary functional validation of the SASPENCE system in an early stage of its development, most critical scenarios that were identified with the simulation study, are reproduced in the VeHIL laboratory at TNO Automotive (the Netherlands). More information on the tests is given in [98].

Critical scenarios are defined as scenarios where small values for the TTC occur. Varied scenario parameters are: velocities, accelerations, initial distance, initial lateral offset and driver characteristics. Approximately 150 tests were carried out.

Test results 147 VeHIL tests	CAR: Not Available	MAR: 7.5%	FAR: 4%
Comments	Inappropriate alarm rate: 2.2%		

MAR and FAR are defined as the amount of time that MA or FA occurs (during the VeHIL test) divided by the total (VeHIL) testing time. This is not corrected for the frequency at which these kind of critical scenarios occur. So in fact, the performance of the system is supposed to be much better than the numbers suggest.

On average, the timeliness of the warning is correct. However, the time difference ranges from 5 s too early to 5 s too late. So, in practice, the timeliness should be improved.

Test Drives

The completed system was tested on public roads to test whether alarms are given a) when speed limit was exceeded, b) when landmarks such as pedestrian crossings are detected, c) when the distance threshold to the preceding vehicle is exceeded and d) to check that the correct speed limit is displayed by the HMI at all times. It was found that some false warnings were generated especially during roundabouts. In some cases,, no warnings were given at pedestrian crossings and incorrect speed was shown (assumed to be due to mapping errors on the test route)..

	Covered by validation		
Road type (motorway/ rural/ urban)	M: **Yes**	R: Yes	U: **After specific tuning/modification**
Vehicle Type (passenger car/ heavy good vehicle /bus)	P: **all**	HGV: **0**	B: **0**
Road weather (adverse/ normal)	a: **9% Yes**	n: **91% Yes**	
Comment	Rain: 7 %, snow: 2% (only in simulation study)		
Light conditions (day / night)	d: **Yes**	n: Yes (to investigate if performances are reduced)	

3.3.2 LATERAL SAFE results

3.3.2.1 Function description

LATERAL SAFE is aimed towards assisting the driver to avoid collisions with vehicles and obstacles to the sides of the ego vehicle through three functions.

Lane Change Assistant (LCA) The driver is informed about vehicles present in the blind spot or approaching from behind in adjacent lanes. Directional information about threats is given with different levels of urgency (from visual to combined visual and auditory) depending on how high the risk for collision is. There is no intervention.

Lateral Collision Warning (LCW) The driver is informed about dangerous lateral movements towards obstacles in left and right side area of the ego-vehicle. A directional sound/light warning is given when the ego vehicle is approaching vehicle/obstacle to the side with risk of collision. There is no intervention.

Lateral and Rear Area Monitoring (LRM). The driver is informed about vehicles to the sides of, and behind, the ego vehicle. Vehicles in particularly dangerous positions are highlighted alternative colours. The information is meant to enhance the driver's understanding of the traffic situation, thereby reducing the likelihood of him/her making a dangerous manoeuvre, particularly in cases of limited visibility or heavy mental workload.

Accident types:

LATERAL SAFE has reviewed accident statistics sources, and resumed them in Figure 3 [38] showing the benefit potential for the LATERAL SAFE systems. 12 target scenarios were derived.

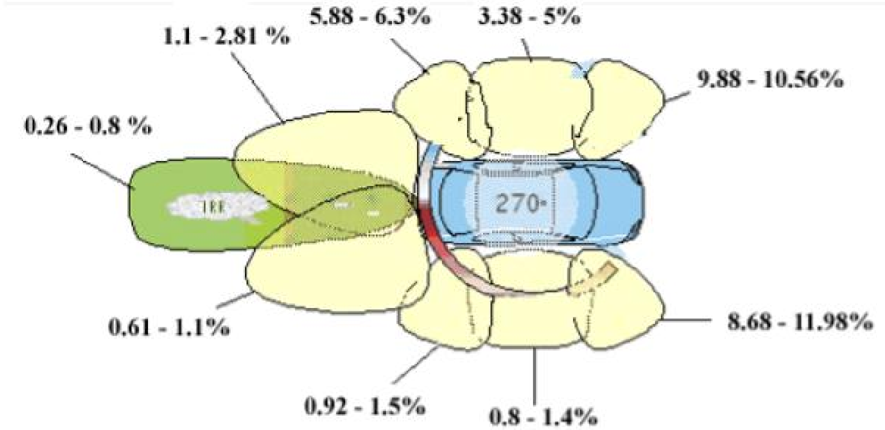


Figure 3: Benefit potential for LATERAL SAFE systems

3.3.2.2 Verification of the subsystems

Technical verification took place during on-road tests with demonstrator vehicles, on which the prototype systems had been installed[1]. For the CRF demonstrator, testing was performed on Fiat's private test track in Turin, as well as on a 130 km predefined route on normal roads around Turin (same route as used in SASPENCE, SAFELANE, APALACI, etc). The tests with the DC demonstrator was performed on small roads within the DaimlerChrysler Research Centre premises at Ulm, a 1.5 km rectangular roundcourse with a speed limit of 30 km/h, and on a high speed test track (7.5 km oval course) at the Idiada test site in Spain.

During this evaluation, the reliable detection of all relevant road obstacles has been validated: moving and stationary objects like trucks, cars, motorcycles, bicycles and pedestrians and road infrastructure objects like curbs, guard rails, slopes, tunnel walls, poles and buildings. Some traffic scenarios have been investigated like active/passive overtaking situations with and without lane change and cars passed with very low difference in longitudinal speed, which drift towards the ego-vehicle. The technical evaluation on the rate of false and missing alarms of the LATERAL SAFE applications on on-road tests has been also conducted, based on the subjective perception by the driver and by the on board assisting technician about the criticality of the scenarios and with respect to the expectations [36].

For LCW the functional requirements are repeated in [36] and it is stated (with comments) whether or not the requirement is achieved.

3.3.2.3 Validation

The LATERAL SAFE applications have been implemented in the CRF demonstrator vehicle and also in a driving simulator (VTEC).

[1] HMI and impact assessment are referred in D32.8 [37], chapters 4 and 5.

The applications have been evaluated in relation to three main scenarios:

- **Typical Lane Change,** where one vehicle changes lanes intentionally, and sideswipes or is being sideswiped by a vehicle in the adjacent lane.
- **Drifting towards another vehicle or towards the road barrier**
- **Tailgating**

In the LRM for trucks evaluation, a number of further scenarios were also defined and evaluated (D32.3 [38]).

For the evaluation of false and missed alarms 12 drivers drove 7 times on the 130 km route, 4 times during daytime and 3 times at night. The day and night time drive setup was identical, first on control drive, then two drives with LCA and LCW active, and finally one drive with LRM active (see table from [36] below):

User	Day				User	Night		
	Trial 1	Trial 2	Trial 3	Trial 4		Trial 1	Trial 2	Trial 3
1	Control	LCA	LCW-CRF	LRM	7	Control	LCA	LCW-CRF
2	Control	LCA	LCW-DC	LRM	8	Control	LCA	LCW-DC
3	Control	LCW-CRF	LCA	LRM	9	Control	LCW-CRF	LCA
4	Control	LCW-CRF	LCW-DC	LRM	10	Control	LCW-CRF	LCW-DC
5	Control	LCW-DC	LCA	LRM	11	Control	LCW-DC	LCA
6	Control	LCW-DC	LCW-CRF	LRM	12	Control	LCW-DC	LCW-CRF

The technical evaluation of the rate of false and missing alarms of the LATERAL SAFE applications during these on-road tests were based on the subjective perception by the driver and by the on board assisting technician about the criticality of the scenarios and with respect to expectations. The test subject and technician's perception of the alarm as correct, false or missing was saved on the log file (using dedicated buttons). The extraction of CAR/MAR/FAR is therefore done from the logfiles, but the assessment of CAR/FAR/MAR is subjective to begin with.

The safety-relevant indicators that were studied included speed and speed variation, proximity related metrics like TTC and metrics related to steering.

Vehicle speed and day time have been selected as independent variables for the LCA and LCW, while vehicle speed has been selected as the only independent variable for the LRM (since night was not selected as of high expected impact for this application in WP 32.300).

Two levels of vehicle speed, 40 km/h and 70 km/h, have been selected, representing the two speed ranges with the highest expected impact from the implementation of LATERAL SAFE applications. Day and night have been selected as the two alternatives for the day time parameter.

LRM for Trucks has been tested in VTEC's driving simulator. 21 drivers with no previous LATERAL SAFE knowledge and a valid truck licence took part. They drove for 20 minutes, half of which was control driving (system off) and half with LRM switched on. The participants were exposed to a total of 14 scenarios (but no driver experienced more than 7 scenarios), for which LRM was thought to make a difference [36],[39].

3.3.2.4 Validation Results

The test results report D32.9 [36] reports the CAR/FAR/MAR ratios, as well as effects of different speeds and daytime/nighttime issues. According to the evaluation, false and missing alarms remain at satisfactory levels according to the set requirements. No significant effect of vehicle speed or day time on false and missing alarms was found. Figure 4 shows the effect of system LCW on the standard deviation of steering wheel angle. A significant reduction in this variable with system switched on is observed in this case. The full list of test results including all standard deviations analysis is included in the final version of D32.9 [36].

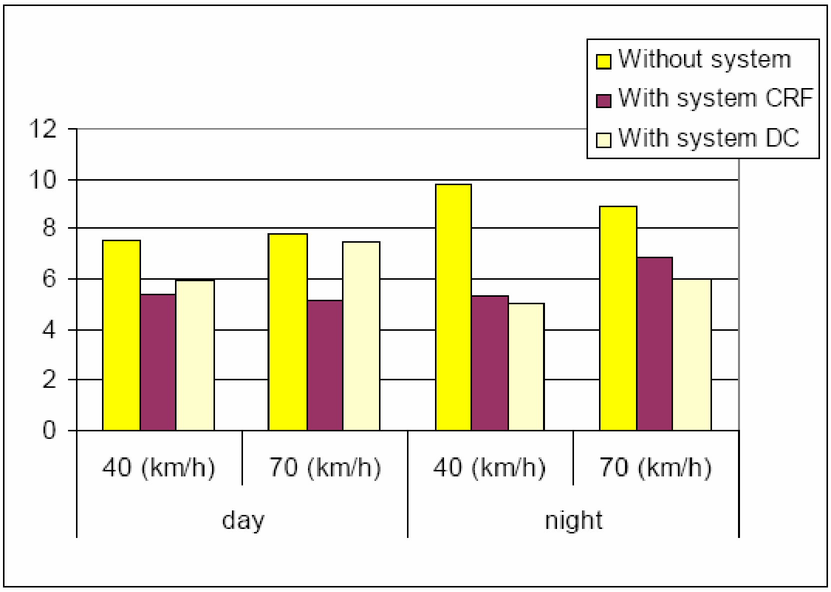


Figure 4 : Standard deviation steering wheel angle for LCW

Table 16: False and Missed Alarm Rate for LATERAL SAFE

	LCA	LRM (3 cameras)	LRM (BSD-based)	LCW-DC (SRR based)	LCW-CRF (fusion based)
False alarms/ total incidents (%)	0.7	4.5	1.3	2.8	2
Missing alarms/ total incidents (%)	6.1	10.5	0.7	3.6	2.4

SRR: short range radar. BSD: blind spot detection

3.3.2.5 Conclusion, discussion

LCA: The number of missing alarms for the lane change scenario in the LCA evaluation is higher than for the other two scenarios (Table 16). This could probably be attributed mainly to the warning strategies of the application itself and the selected thresholds of the relevant parameters (application layer). For the safety indicators, no clear effects were found for SD (standard deviation) of steering wheel angle. However, a tendency towards higher minimum TTC’s were seen with the system activated: the minimum measured TTC’s were higher with the system switched on than with the system switched off. This result reached significance for some of the higher test speed conditions (70 km/h, daytime).

LCW: There are some differences in the false and missing alarms of the two versions (SRR and fusion based). The fusion based application seems to be most advantageous. LCW-DC warning criteria seem to be better suited for the high speed case. Also and interestingly, the number of false alarms increased as a function of visibility, i.e. when visibility is higher, more alarms were perceived as false by the test drivers. For the safety indicators, the SD of steering wheel angle was significantly lower with the system switched on than with the system switched off for almost all conditions in the evaluation scenario “Target vehicle drifting”. With respect to the minimum TTC, the same trend as above has been observed, i.e. higher minimum TTC’s with system on than off.

LRM: High rates of false and missing alarms were detected for the LRM-SVIP (Synthesized Vision Image Processing) system, especially under foggy and sunny weather, signifying the impact of high intensity / shadow conditions on the performance of camera-based systems. A small dependence of false and missing alarms was found with vehicle speed for the LRM-SVIP system. Lane change and target overtaking are more critical scenarios regarding missing alarms for the LRM-SVIP system.

3.3.3 SAFELANE results

3.3.3.1 Functional Description

SAFELANE develops an enhanced and model-based lane keeping support system which is mainly characterized by an enhanced environment perception, a model-based adaptive decision component and an active steering component.

One of the main original safety features of SAFELANE keeping systems is the conception of a multi sensors situation model based decision system. This situation model builds a model of the current situation from the sensor data. With map data, radar or obstacle detector data and vehicle sensors, much more input is available than in traditional lane keeping systems.

Depending on the prototype implementation the system provides different warnings or actions:

1. Visual (information) warning
2. Acoustic warning
3. Haptic warning (symmetric wave forms)

4. Haptic action suggestion warning (dissymmetric waveforms in to suggest direction of correction by the driver)
5. Corrective action (automated correction)
6. Constant lane keeping

The functions 3 to 6 are implemented through an action in the steering wheel (warning (3,4) and intervening (5,6))

3.3.3.2 Verification

Radar

Description

Dynamic tests have been done with a cooperative vehicle travelling in front to the vehicle equipped with the radar. Typical manoeuvres were: tracking of vehicle at the same speed, tracking of vehicle at lower speed, tracking of vehicle at higher speed, tracking of static obstacle, lateral movement of the vehicle.

Test results

The localization of the frontal obstacle is accurate and the tracking of obstacles in all the described situations is quite good. On highway roads it has been noted that bridges or large traffic signs are sometimes seen like a static obstacle in the path of the vehicle. This fact limits the operative range in the detection of standing obstacles to about 50 m. The radar covers however more than 150 m.

Video sensor

Evaluation through simulation

Different scenarios have been tested, with bridges (generating shades) and discontinuous markers. The parameter accuracy meets and exceeds the specified accuracy (see Table 17).

Table 17: Specifications for the vision system.

Parameter	Range / Accuracy
Lane Width	2.5 to 4.5 m
Lateral Position Measurement Accuracy	± 5cm
Heading Angle	± 0.2º

SAFELANE lane tracker algorithm robustness

The following table gives an overview of the scenarios and the corresponding test results.

	Description	Test results
1.	Lane-marking not perfectly visible,	tracker works even if the lane borders are hardly recognizable.
2.	Interference of external elements,	tracker is not disturbed by the construction boundary posts.

3.	Lane disturbed by the vehicle in front.	tracker benefits from the obstacle mask generation module and plausibility checks of measurement points.
4.	Presence of secondary way (intersection) along principal way,	Use of map data, among others prevents the tracker from following the wrong lane markers.
5.	Guardrail considered as lane marking,	guardrail tracking is avoided by the use of map data and dynamic weighting of inner lane marking measurement points.
6.	Sidewalk considered as lane-marking,	sidewalk tracking is avoided with same technique.
7.	Asphalt discontinuity considered as lane-marking,	lane tracker follows the right lane borders, map data helps in that.
8.	Badly erased lane marking,	works as Asphalt discontinuity.
9.	Entrance and exit from a gallery or tunnel,	The high dynamic range property of the deployed camera prevents taken images at tunnel exits being overexposed.
10.	Shade of guardrail considered like a lane marking,	works as Asphalt discontinuity.
11.	Hazy water produced in rain day by a vehicle travelling in front	works as lane-marking not perfectly visible
12.	Trace left by a vehicle on the wet road surface,	works as lane-marking not perfectly visible
13.	Road works,	especially the ability of detecting unmarked lane borders makes it possible to track lanes in construction areas.
14.	others : ex. Night detection	works for night detection.

3.3.3.3 Conceptual expression

The lane tracker, a fundamental tool for the lane keeping system has been tested in many different real situations, as well as simulated. The added value obtained from the introduction of map data and data fusion has been highlighted indicating a good performance of the sensor. Some limitations have been detected concerning radar detection disturbed by bridges that are not critical since radar is not a crucial sensor in SAFELANE.

The improvements concern mainly the test of the sensor system under adverse conditions.

3.3.3.4 Validation

Validation methodology

All CRF tests have been performed in a motorway environment, under free flow traffic conditions, with dry road, on sunny or cloudy days. No absence of lane markers has been considered, that is, the lane markers were of good quality all the time.

Vehicle speed during tests was fixed at 80km/h, due to the fact that tests were performed on highway, with real traffic: so, for safety reasons, it has been necessary to maintain a speed >70 km/h.

The tests using the VTEC truck were due to safety reasons performed at the private Volvo test track in Hällered, Sweden. The track used is an oval-shaped motorway with good quality lane markings. Weather conditions were varying but for the most part the weather was dry and temperatures were subzero. To attain realistic vehicle dynamics the truck was connected to a 34 tons (gross weight) trailer during all the tests.

The FhG test vehicle is a BMW 325i passenger car. The tests conditions were varying, normally during daytime.

Each type of manoeuvre has been repeated 10 times.

SCENARIOS (note: correct activation rate refers to CAR, correct non activation rate refers to the complement of FAR and correct deactivation refers to the capacity of the system to let the driver override it).

Test description	Class of test
3.5.1.5 Intervention of the system on the right side of lane in a right curve.	correct activation
3.5.1.6 Intervention of the system on the left side of lane in a right curve.	correct activation
3.5.1.7 Correct activation of the system on the left side of lane in a left curve.	correct activation
3.5.1.8 Correct activation of the system on the right side of lane in a left curve.	correct activation
3.5.1.9 Insert in a right curve without steering, lane departure on the left side with a very high heading angle.	vehicle dynamic activation
3.5.1.10 Deactivation of the system by recognition of a voluntary lane departure in intervention zone on the right side of lane.	correct deactivation
3.5.1.11 Lane change without signalling	correct deactivation
3.5.1.12 Vehicle travelling on top of the lane markings	correct non activation
3.5.1.13 Overtake without signalling	correct non-activation

Assessment results

The above tests, carried out with VTEC and CRF trucks, and with the FhG passenger vehicle sum up 21x10= 210 tests, when considering all scenarios. For all cases, the technical requirements (correct activation, deactivation, correct non-activation and vehicle dynamic activation) have been fulfilled 100%. Zero false alarms have been obtained for all tests.

3.3.3.5 Conclusion, discussion

The system evaluation provides very good results (100% for CAR, 0% for FAR). The functions are tested in a high number of scenarios. Due to the time constraints for the evaluation, the number of repetitions for each test was low. Adverse conditions and night conditions could not be tested. Regarding different lane markers conditions, a nice point is that since many tests were carried out with the lane tracker only, which minimizes the number of scenarios avoiding still introduction of these conditions in them. Here we come to the reflexion of which parts of the system should be tested on simulations and which parts should be tested on real tests.

3.4 Evaluation results: Function field 3: More distant interactions

3.4.1 MAPS&ADAS results

3.4.1.1 Functional Specification

The system comprises of a digital map with additional information for hot spots and speed limits, a positioning system, and a human machine interface for driver warning. Additionally the system has sensor access to basic vehicle sensors: current time, current day, outside temperature, rain, vehicle speed.

The System has two functionalities: Speed Limit Warning (SLW) and Hot Spot Warning (HSW).

SLW: The concept of the SLW is to inform the driver in case the vehicle speed is higher than the speed limit by comparing the speed of the vehicle with the current static speed limit stored in the ADAS map. Speed limits may also depend on weather conditions, vehicle type, period of the year, etc. (D12.81.0 [42] Chapter 2.1, [46] Chapter 1.2.1)

HSW: The HSW provides an anticipatory warning of (potential) dangerous sites in the road network depending on environmental influences and current driving dynamics. (D12.81.0 [42] Chapter 2.2, [46] Chapter 1.2.1)

Limitations: The system is primarily intended for rural roads. Warnings can not be provided for any temporal hot spots, e. g., oil spill, road works, or variable speed limits provided by variable message signs.

3.4.1.2 Technical Specification

Sensors: Positioning system with map matching. This system is regarded as a complex 'black box'. A single analysis of sensors, e. g., gyroscope, is not performed. The systems' interface is the Horizon Provider. The Horizon Provider sends information about the most probable path to interested applications.

Digital Map Attributes are not a sensor. However they are a necessary source of information and their generation and processing influence the system performance very much.

3.4.1.3 Evaluation Specification

Classification

Accident Type: Any accident caused by speeding or at known dangerous locations, “Hot spots”

Advanced Driver Assistance Type: Accident avoidance by warning the driver

Target: Not Applicable

Road Type: Any public road, preferably rural roads

Use Cases/Manoeuvres: See [46] Chapter 3.

Type of target: Not applicable

Environment: Any environmental condition. The system estimates the environmental conditions based on appropriate onboard sensor data such as the wiper status for moisture, the temperature and the time. Warning behaviour is adapted to the estimated environmental conditions so that specific warnings are only displayed under specific environmental conditions.

3.4.1.4 Verification

Map Attribute

Deliverable D12.6 [45] chapter 6 discusses the ADAS Map quality without providing quantitative test results. Deliverable D12.5 [44] describes the problem and the availability of data. D12.82 [40]. Chapter 5.1 describes a test of speed limit information. Map information was visualized in a car and compared to the real signage. The results (16 % of incorrect speed limit data 10 month after a first data collection, most changes on Road class 3) correspond with previous test results of the LAVIA project in France (15 % of map information becoming obsolete in one year).

Hotspot information was specially processed for the MAPS&ADAS project which might cause various mistakes (as indicated in D12.82 [40] chapter 5.1.3) since no general test of information quality is described.

Positioning, Horizon Provider

For positioning and map matching existing, validated systems were used in the MAPS&ADAS project (see D12.92.1 [43] chapter 6). These long used research platforms are not tested or validated (D12.81.0 [42] Chapter 2). No quantitative indicators for error behaviour or latency are given.

However the correctness of the map information provided by these systems via the CAN-Interface was verified using various ADAS Reconstructors (D12.92.1 [43] chapter 10.7). No errors are reported.

CAN-Interface for Map Horizon Data

The communication of map data via a CAN interface was a major issue of the MAPS&ADAS project. This interface is not exclusively designed and tested for the Driver Warning System but as general information source.

A detailed description of the tests of the communication of map data via a CAN interface and the results can be found at the project deliverables D12.81.0 [42] and .D12.92.1 [43].

Detailed testing was performed using an offline test environment with recorded data of vehicles from BMW, DaimlerChrysler, Ford, and Volvo. In the test environment the map information was added to the normal CAN traffic in order to estimate the effect.

The typical latency for 8-Byte CAN frames generated by the horizon provider was around 230 µs. The position latency due to the CAN interface is below 1 ms, corresponding to a 7 cm positioning error. The additional latency of the existing CAN traffic as caused by the additional transmission of preview data is in the range of 0 to 30 µs, whereas isolated transmissions are apparently delayed by up to 270 µs.

During extensive testing of all horizon providers implementations no errors in the CAN traffic occurred. 100 % integrity of the map horizon was observed.

Environmental condition detection, vehicle speed

Conditional warnings (period of year, time of day, moisture, temperature, speed) are based on environmental onboard sensors which were not verified at the MAPS&ADAS project since these sensors are standard to all vehicles and assumed to be reliable.

3.4.1.5 Validation

Test Description

Various test cases have been described in the validation plan (see D12.91.2 [41], Annex). Based on these test cases the technical validation of the complete Driver warning system was performed, including positioning of the vehicle and providing a map horizon with available ADAS attributes and generating warnings based on this map horizon depending on other vehicle sensor data.

The results are described in detail at deliverable D12.82 [40].. The test cases include system switched off, no speed limit data available, CAN traffic is disrupted and combination of Speed Limit Warning and Black Spot Warning. Altogether more than 70 test cases were defined and tested. These test cases are not designed for validation only but also for determining optimized parameters for timing the Hot Spot Warning.

Basic test cases were performed with the vehicle at normal conditions (No rain, daylight, not freezing) as well as in the laboratory with recorded data. More specific test scenarios were performed in the laboratory only using manipulated recorded data or synthesized data.

Test Results

All tests of the Speed Limit Warning and Hot Spot Warning have been carried out successfully. The expected system performance has been achieved for all test cases. No missed warnings or false warning were observed according to the map data. However the map data have differed at several positions from real speed limits due to regulation changes.

No quantitative indicators have been determined. Information on the repetition of tests is not given.

The governing aspect is the map data. As no special mechanism for map update is mentioned we assume map actuality of 10 month on average. Regarding a production process of several months, this means a yearly map update for the system. We assume that from the 13% errors 8% are due to a lower real speed limit causing missed alarms and 5% to a lower real speed limit causing false alarms.

For the hot spot warning no numbers are available due to the uncertain process of map data generation. Only manually generated small test data sets were generated. However for further analysis the same numbers as for the Speed limit warning might be used.

Test Results	CAR: 87%	MAR: 8%	FAR: 5%

3.4.1.6 Conclusion

The technical verification and validation was complete despite the missing verification of hot spot data. A verification of hot spot data is not possible because data or general methods for creation of these data do not exist. The technical performance of the complete DWS (Driver Warning system) was validated successfully.

The failure characteristic of the horizon provider, CAN interface, and DWS can be neglected for an evaluation of the complete system since these errors are much smaller than those expected due to the map content. The performance of the positioning system has not been specially verified in the MAPS&ADAS project since it can be assumed that the negative effect on positioning errors due to very bad GPS conditions and the latency of the system is small. In terms of DWS the performance of existing positioning systems used for navigation are sufficient.

The map quality governs the system performance. Outdated or wrong geometry data might cause errors in the positioning and therefore false or missed alarms. Speed limits are more critical because the data collection is less complete and speed limits tend to be changed more often than road geometry.

Hot Spot information was specially collected and processed for the test sites. An assessment of the data quality in a general system can not be given.

The map data are the crucial point. The effect has not been taken in to account during the MAPS&ADAS validation phase because special prepared maps were used.

In order to provide more reliable data for a safety assessment and user acceptance analysis, the quality of map data has to be described in more detail. This includes the production process of the map data, the update process to the vehicle, as well as detailed statistics about the change of the map content.

3.4.2 WILLWARN results

3.4.2.1 Functional Specification

General function: Generation of hazard information by standard vehicle sensors; distribution of information in a car-to-car wireless network and early danger warning to the driver.

Description: WILLWARN supports the driver in safe driving by inter-vehicle communication based on the creation of an electronic horizon that enables foresighted driving. WILLWARN warns drivers early whenever a safety related critical situation occurs ahead, especially of obstacles, adverse road and weather conditions, and hazardous construction sites, even if it happens outside their field of view.

Table 18: Summary conditions of function specifications

Vehicle type concerned	**Passenger car**
Target considered (when relevant)	**Car**
Road type	**Rural/Urban**
Weather conditions	**Normal**
Light conditions	**Day**
Level of cooperation	**Veh. to Veh.**

3.4.2.2 Technical Specification

WILLWARN has the following main functionalities:

The **Hazard Detection module** (HDM) is responsible for sensor data collection and processing and through implemented hazard detection algorithms, for hazard detection. The HDM has the necessary know how for hazard detection and access to sensor data that might indicate hazards. After the recognition of a potential hazard, all data needed to describe the hazard and parameters for message distribution are passed to the WMM module.

The **Vehicle2Vehicle Communication module** (VVC) is responsible for sending and receiving hazard messages. Reliable transmission or sufficient retransmissions are mandatory so each interested node receives a copy with sufficient probability. It could be considered as equivalent of the physical and Data Link layers, in terms of OSI model. It should be noted that VVC module is assumed to provide general communication service not only to the WILLWARN application. Therefore it can not provide application specific services but only general distribution mechanisms.

The **Hazard Warning module** (HWM) is responsible for the preparation of the HMI warning message and the respective optic/acoustic warning message display to the driver. Periodic relevance checks of the stored hazard messages are performed, before displaying, through HWM module, warning messages to the driver, in order to maintain the database with respect to aging of messages and vehicle movement.

The **Warning Message Management module** (WMM) is responsible for warning packet generation and received packet evaluation in terms of redundancy, priority and relevancy. In the case where the new information is similar to already processed information, the new information is discarded by the WMM. Otherwise a new hazard message is prepared by the WMM module and stored inside the database.

3.4.2.3 Verification

General considerations

Verification covers testing of communication hardware, and modules for hazard detection, positioning, and relevance checks. The following evaluation methods were used:

- Communication component testing

- Vehicle tests
- Single vehicle tests for sub functions like hazard detection, positioning, and position relevance checks
- Two car tests for static and dynamic measurement of communication range
- Multi vehicle tests for performance evaluation of hazard messaging and full application
- Questionnaires and drive simulator study
- Questionnaires for acceptance of chosen WILLWARN functions
- Drive simulator study on the impact of the WILLWARN system on driver behaviour.
- Simulations of communication channel
- Studies for choice of communication parameters
- Traffic impact simulations

Communication System

Transmission power, line of sight communication distance, frequency dependent communication range, antenna propagation characteristics and diversity and other hardware modules (NEC router and the modified Madwifi driver) were tested and successfully validated (static range tests in May 2006) (note: by successful we mean that WILLWARN has had a proof-of-concept of the whole integrated system on the road). Static and dynamic range measurements showed that, despite not optimized antennas and cable length, the range is in between 350 to 500m, what is enough for the system.

Position Relevance Check

This module checks if the event location is on the path of the receiving vehicle. Successful testing of trace point casting and matching was done on all types of roads, even in complicated topological situations. The tests showed that GPS-quality is sufficient for position detection. This set of scenarios is: Receiving a hazard while driving on a straight road, Crossing a received trace chain, Two parallel roads, Chessboard (perpendicular scenario, typical for modern cities, industrial zones), Crossing motorway interchange, Going on another road while having a match with a trace chain, Driving on a cloverleaf, Roundabout, Long duration measurements from different road types (Highway, Rural road). Were not included: scenarios with tunnels, scenarios with large GPS measurement faults.

Hazard Detection Algorithms

Algorithms have been developed for the detection of obstacles, reduced visibility or reduced friction, based on detection by the vehicle on-board sensors. A warning is given for obstacles, when the deceleration is beyond a certain threshold (no validation tests were carried out for this). The distance of activation was determined for each situation dynamically.

Low visibility warning is given if the headlights, wipers, or fog lights are switched on. Reduced visibility is detected by multiple messages based on fog lights and wipers. Tests were done during winter season and bad weather. **Tests only proved that a warning is generated if the algorithm fires.** The focus of validation was mainly on the friction detection algorithms. Three different types of algorithms were tested on ice and snow. The results show that the algorithms are fully sufficient for a friction classification (friction detected on 2-3 classes) as it is used in WILLWARN.

Warning Dissemination

Testing of Message Transport with 5 cars and a Road Side Unit on a road network was successful in a full system test. The tests were carried out during a dry-run.

3.4.2.4 Validation

The validation of the system has been carried out on a qualitative basis.

The 'Early Warning' concept was evaluated within the Daimler work in INSAFES and a drive simulator study was carried out at the Daimler driving simulator, where a real car cabin is in a moving dome as part of a traffic simulation. The results are described in the Human Factors evaluation (Section 4.6).

Investigated situations are:

- Warning in front of fog
- Warning in front of a traffic jam within fog (sight 100 m)
- Warning in front an obstacle behind a curve

The complete WILLWARN system was successfully tested and presented in various use cases with 4 cooperating cars and a road side unit on public roads. The successful co-operation between modules in each car; the communication between cars, and with the road-side unit for all four critical scenarios specified in WILLWARN showed the suitability of the system design for OEM integration as well as for aftermarket systems.

3.4.2.5 Conclusion/discussion

WILLWARN has developed a concept for automatic detection, localization and relevance check of hazards through traffic and weather based on onboard sensors and a positioning system like GPS.

WILLWARN has developed a new warning message management for transmission, storage, and distribution of hazard warning ensuring driver information in time at the right spot. WILLWARN has developed, integrated and validated a car-to-car communication system for establishing a local self-organized decentralized communication network with oncoming and following cars.

WILLWARN has developed a warning system with automatic on-board hazard detection, in-car warning management, and decentralized warning distribution by car-to-car communication on a stretched road network. Positioning, relevance checks, and onboard message evaluation ensure driver information in time at the right spot. A new message management strategy using especially oncoming vehicles for information storage and transport will enable a high benefit even at low equipment rates and in rural traffic. A field operational test which was out of the scope of WILLWARN requires a high number of drivers with equipped cars and realistic scenarios like obstacles on the road, reduced visibility, and bad road conditions.

It is important to have a dedicated frequency range for safety applications in the near future to enable market introduction. Field tests in a larger scale than in WILLWARN should study effects of ad-hoc networks with more communicating partners. Hardware integration should be also a focus. The next generation of systems should be based on microcontrollers or at least on a Car-PC. HMI and driver behaviour should be investigated further. Optimal timing for early warnings is necessary for customer acceptance. Other behavioural effects like risk compensation have to be studied.

3.5 Best Practices

All validation plans were good and follows the CONVERGE methodology. In this section, we extract some important features that can be illustrated through the actual validations performed in PReVENT subprojects.

<u>Assessing subsystems prior to assessing the complete function:</u> although this point can be judged as of no direct meaning in the evaluation of overall function performances, its application in several subprojects (WILLWARN, SAFELANE…) shows that it provides sound assessment elements like the knowledge of some limitations and a kind of a sensitivity analysis to operational conditions.

<u>A central point in the methodology: ways to measure the indicators of success: the “reference measurement”:</u> in an evaluation procedure, two kinds of reference measurements are needed, spatial and temporal ones. These two kinds of measurements can be of absolute or relative nature.

a) Precise spatial reference measurement for localization accuracy: the following method has been used in INTERSAFE subproject. In order to have a reference measurement of the vehicle’s distance to the fixed point (an intersection for example), a microwave sensor (Correvit), a light barrier sensor, and reflectors placed at known distances in the road can be combined. When passing the reflectors the position is then precisely known. An integration of the speed given by the CORREVIT gives the position between two reflectors.

b) Precise temporal reference measurement for collision mitigation: the following method has been proposed in the technical assessment of APALACI subproject. In order to evaluate the accuracy of a perception system (for collision mitigation for example) different sensors can be integrated in the host vehicle. This system allows to compare the measurements provided by the perception system with reference values (e.g. for the time to impact estimation, obstacle distance…). The additional subsystem consists of:

- a photoelectric cell that provides a signal when the car passes the reflectors, which are placed at predefined distances from the dummy obstacle and at the impact point. This allows calculating the position accuracy;

- a contact sensor on the metallic buffer in front of the vehicle (which protects the body car from impact with dummy objects),

- an accelerometer on the metallic buffer in front of the vehicle.

The added system provides additional and independent measurements about the impact and the distance from the obstacle. These reference measurements can be used to calculate the TTC accuracy, by comparing the TTC calculated and provided by the perception system with the real TTC. The procedure can be applied for all TTC related actions (warning signal activation, brake activation signal, the belt activation signal and a possible air-bag activation signal).

<u>Combination of simulation environment with hardware-in-the-loop tests</u>: in a first phase of the validation a simulation study on a high number of scenarios allows identification of the most critical cases, which are subsequently tested in a hardware-in-the-loop environment. SASPENCE follows this process.

<u>From technical assessment to HMI assessment</u>: for a very HMI closely linked function like SASPENCE, it becomes necessary to exploit more than simply reliability indicators. Indeed, in SASPENCE a large set of indicators have been taken into account. This set contains: reliability indicators (MAR, FAR), comfort indicators (RMS value of the longitudinal acceleration), safety effect indicators (minimum TTC during the scenario), appropriateness indicators (is warning level appropriate? Linked to HMI) and timeliness indicators (is the warning in time, too soon, too late? Linked to HMI).

<u>Representativeness of the tests, lacks of standards</u>: this topic relates to the realism of the interactions considered in the tests carried out (either in reality on test tracks, open roads… or in simulation) to assess the technical performance. A central point is the definition of the dummy targets against which the perception systems are confronted. Due to the absence of standards, the diversity of dummies with respect to shape, colours is very high in PReVENT subprojects (the same in all projects of the same nature). A methodology begins to exist to decide the characteristics of the targets in the case of radar and lidar (cf. ISO15622); there is no such standard element for deciding how to define targets used to validate sensors based on cameras and image processing…

3.6 Conclusions of evaluation

In the following section the main points and results concerning the evaluation of PReVENT functions are summarised.

PReVENT functions can be classified into three function fields according to the time constants involved in the assistances.

Function field 1: Tight and short interactions related to collision mitigation and avoidance: APALACI, COMPOSE, INTERSAFE

The risks are immediate collisions with obstacles, with very short time and distance related parameters. The technologies able to address those circumstances are based on perception sensors located onboard. Since the assistance activates when the accident is unavoidable (APALACI, COMPOSE), the cooperation level between the assistance and the driver is very low.

The main challenges of APALACI (pre-crash & Collision Mitigation System, CMS) and COMPOSE (VRU protection & CMS), were the perception tasks in order to detect potential obstacles in very short time intervals (for both projects), classification of obstacles - making a difference between vulnerable road users and other obstacle type- (for COMPOSE). APALACI and COMPOSE have innovated by the use of several combinations of sensors that have been explored and tested : ultra-sonic sensors, short range radars and cameras for short distance, lidar and long range radars for long distance obstacle detection. Fusion & tracking techniques have been proved to be powerful: no missed alarms; weak rate of false alarms (2/253 situations; 0/5h18 driving); good classification rate (>98%).

The INTERSAFE subproject extends the collision assistance systems towards intersection contexts : INTERSAFE can be considered as the PReVENT subproject that deals with less mature technologies since collision prevention in intersections involves the development of a highly complex detection system (fusing information brought by precise maps and on-board sensors) that has to be able to locate and classify objects in the intersection. Quite good results (0% missed alarms, 7% FAR) have been obtained and demonstrated through very precise assessment tools.

Function field 2: Short interactions with other moving objects (1-5 s): SASPENCE, LATERAL SAFE, SAFELANE

The related time and distance constants are still short but larger than in the first function field and can be addressed again by on board technologies. Since larger time constants are present, the cooperation level between driver and assistance is higher demanding a stronger effort in the HMI conception. Also, since the available time before the accident is larger, a third challenge concerns the conception of a decision system able to choose which type of assistance suits better to each driving scenario.

In the SASPENCE (support for safe speed and safe distance) project, sensors (long range radar, digital maps, camera) provides data fused at multiple levels to furnish an enhanced view of the ahead environment (obstacle, ahead vehicle, road geometry). SASPENCE has innovated in a reference set of optimal manoeuvers that are calculated maximizing safety margins considering various risk factors. In SASPENCE, high effort has been put on searching suitable HMI. Combined technical and HMI evaluations have pointed out good results. The validation phase of

SASPENCE included the use of innovative and promising tools: digital and hardware-in-the-loop simulation (PRESCAN and VEHIL environments).

LATERAL SAFE (Lateral collision warning and lane change support) addresses the risks of collisions with vehicles or objects being on the side or approaching behind the equipped vehicle. Complementing a frontal support, lateral & rear 270° bird view monitoring is the concept. This is achieved through 3 information and warning systems based on short range radar (side), long range radar (rear), cameras (in side mirrors and rear window). At the technical level, fusion has proved to be powerful. Technical assessment was based on subjective perception of the driver and by on-board technicians. Reduced but actual false and missed alarm rates can be attributed partly to threshold alarm setting.

SAFELANE (Active lane keeping support aids drivers in staying in their lane through warning and corrective steering) has innovated first in a robust lane tracker that uses data fusion (map data, radar object trails, vehicle dynamics sensors and camera) that has been developed and thoroughly tested. A second innovation of SAFELANE is the decision system that comprises a situation model based on the knowledge of different elements (driving manoeuvres, road conditions, situation characteristics). The decision model decides which type of assistance the system is able to provide to the driver: Nothing, information, warning, correction. Through an extensive evaluation, the system showed very good results (~0% FAR and MAR).

Function field 3: More distant interactions (>5s): MAPS&ADAS, WILLWARN

The decision time is not critical, the implied correction operations can be assimilated to precaution more than accident prevention. These functions bring intelligence into the vehicle in relation to the technologies relative to distant events.

The cooperation level here is translated into an informative mode. The challenge is the CAN interface for map data and how to suit telecommunication technologies for driving assistance objectives.

MAPS&ADAS brought mainly in the PReVENT basket of technologies, a CAN interface for map horizon data (that can be a standard one for the future) and functions capable of providing hot spot and speed limit warning. Extensive testing of all horizon providers implementations have been carried out: no errors in the CAN usage occurred, 100% of integrity of the map horizon was observed. In terms of positioning, the performance of existing positioning systems used for navigation has shown to be sufficient. In sum, the map quality governs the system performance.

WILLWARN has enriched the creation of an electronic horizon through telecommunications. WILLWARN warns drivers early whenever a safety related critical situation occurs ahead, especially obstacles, adverse road and weather conditions or hazardous construction sites. WILLWARN complements the PReVENT capabilities with several modules : Hazard Detection Module (sensor data collection and processing), Hazard Warning Module (HWM), Warning Message Management Module (relevance check of the incoming messages, birth and death of relevant messages…), V2V Communication Module. The complete WILLWARN system was successfully tested and presented in various use cases with 4 cooperating cars and a road side unit on public roads. One should point out the contribution of WILLWARN to the position relevance check that verifies if the host vehicle is concerned by the receiving message. Moreover, further tests are needed to study the effects of more communicating partners through ad-hoc networks.

Additional Remarks:

PReVENT subprojects addressed very new and innovative concepts and technologies, for which no well established standard assessment procedures exist So, besides of the challenge to build such innovative concepts, the evaluation procedure in itself is innovative. Since PReVENT is not an assessment dedicated project, the evaluation procedure has been constrained to a tight schedule. Due to this fact, there has been in general a limitation on the number of repetitions for each scenario, fact that plays a role on the related statistical confidence intervals.

To conclude, a fundamental outcome in PReVENT is that each PReVENT function has looked at different technologies in order to improve the performance. PReVENT subprojects make then use of a large set of different sensors in a global sense (proprioceptives & extereoceptives, maps, telecommunications, …) that enter the data fusion module in order to constitute reliable detection/positioning inputs for the proposed assistances. PReVENT constitutes then a large “basket of new technologies”, fundamental main brick for preventive safety systems.

4 Results of the human factor related evaluation of the PReVENT subprojects

This chapter provides a summary on the human factors related results from the PReVENT subprojects INTERSAFE, LATERAL SAFE, MAPS&ADAS, SAFELANE, SASPENCE and WILLWARN. The results are based on the evaluations that have been performed in the sub projects.

The amount and nature of the results available from each of the above mentioned subproject is heterogeneous. In some projects the evaluation and analysis of the related safety system is still ongoing and only preliminary results are included in this summary. For each project the status of the results is therefore presented, prior to the section with presentation of the actual results.

Another difference between the subprojects is the number of studies that contribute to the human factor related results and the number of test subjects used which has influence in the significance in the results.

For evaluation of the system impact on driving performance and driver behaviour, reflecting traffic safety, logging of data for quantitative analysis has been made in most projects. Depending on the type of system that has been under evaluation and in what kind of traffic situation it has been tested, specific signals and indicators have been selected as representative for reflecting the system's impact on driving. Some differences occur between the subprojects with respect to which studies that form the basis and provide data for the quantitative analysis- simulator tests or tests on test tracks, and in what way the data is analyzed. Examples of indicators and parameters used are steering wheel parameters, speed related variables, driver reaction times and measures like for instance TTC.

Similarities between the sub projects are found, with respect to subjective data collection e.g. for evaluation of usability and acceptance. In general questionnaires have been used prior to and after test drives for evaluation of user acceptance and usability, however the questions addressed and the reply forms used are often different, even if there are similarities,

Due to the heterogeneity of the results, it was not possible to always present the results with the same structure. However, in the effort of harmonizing the presentation, the human-factor-related results were divided into three categories depending on their relation to:

1. Driving performance and driver behaviour
2. Acceptance
3. Usability

If more than one study has been used for obtaining results, the results from each study are first presented separately. In the end of each of the sub-chapter, a summary of the obtained and reported results is then provided.

Prior to the results, the safety systems' functions and experimental designs are briefly summarized so that the reader could have an overall picture of the evaluation methods applied in each of project for obtaining a better understanding of the results. The methods, scenarios and experiment design used in each study are described in more detail in deliverable D16.1.

4.1 INTERSAFE

4.1.1 Short Description

INTERSAFE is a safety system implementing three different functions: 1) the *Intersection Assistant – Left Turn Assistant*, 2) the *Intersection Assistant – Turning/ Crossing Assistant* and 3) *Traffic Light Assistant.* The INTERSAFE project has finalized its tests on evaluation and user acceptance [25]. In addition, the results from the evaluation of the intersection system on the driving simulator were published in D40.74b [26]. Since the three INTERSAFE functions have been tested separately in most of the cases, they are also described separately in this document (for more details, see Annex F).

4.1.2 Common Methods

The tests were carried out in two different test sites: 1) the BMW's driving simulator and 2) the ika's test track in Aachen where the demonstrator vehicles were used. In total, 47 subjects were recruited for the experiments in BMW's Driving Simulator. Each subject experienced only one of the systems. The tests at ika's test track were conducted with 16 subjects, each subject experienced all three systems but in different order. Only subjective user ratings were reported, not objective data concerning driving performance has been reported.

4.1.3 Review of the results

4.1.3.1 Intersection Assistant – Left Turn Assistant (IA-LTA)

Function description

The IA-LTA provides a collision warning if the driver tries to turn left against traffic without stopping at the intersection.

Results from test in the simulator

Subjective evaluations of IA-LTA whether the warning increases or decreases driver workload varied across subjected. Specifically, 10 drivers reported an increase in safety and 4 drivers reported no impact on road safety.

Subjects' safety perception of the optional pre-warning IA-LTA component also varied quite broadly: 9 drivers reported that it increased safety, 5 drivers reported no increase. However, the IA-LTA collision warning while starting from a complete stop was evaluated rather favourably, with 12 drivers feeling that it led to a "strong or very strong" increase of safety on the road.

IA-LTA reactions to gaps of different time length were also evaluated. Gaps 4-5s long were consistently judged acceptable for turning left, and IA-LTA reaction (which was no reaction in this case) was considered appropriate.

Results from tests with demonstrator vehicles

Results from the questionnaire that the subjects completed after trying the IA-LTA system are very encouraging. The system was rated (in combination with the Turning/ Crossing Assistant) on a 0-5 scale concerning helpfulness, usage, information during approaching the intersection, information during stopping at the intersection, information content, design of the icons, proposed velocity, timing, patronisation, acoustic warning, meaningfulness and helpfulness. All questions were answered rather positively, so that the acceptance and usability of the system could be considered quite fair.

4.1.3.2 Intersection Assistant – Turning/ Crossing Assistant (IA-TCA)

Function description

The IA-TCA provides a warning in case the driver intends to cross an intersection despite a risk of collision with other vehicles approaching the intersection from the side.

Results from test in the simulator

In general the IA-TCA system was positively evaluated, although different IA-TCA components received different levels of acceptance. For instance, the pre-warning (which is issued if the driver approaches a crossroad without slowing down) was considered either as too short or too late.

The collision warning during approach was deemed more acceptable and usable; all drivers reported that this system reaction increased safety. The collision warning when trying to enter an insufficient gap from a complete stop was considered very helpful. All drivers reported that IA-TCA could increase safety on the road. On the other hand, 4 of the 13 drivers could not reposition the car at the crossroad properly because of IA-TCA interference. This might reduce acceptability in real world driving situations.

LA-TCA reaction to gaps of different length was considered appropriate for 1.5-3s long gaps. For 3-4s long gaps, subjective acceptability of the gap length increased and acceptance of system reactions decreased.

Results from tests with demonstrator vehicles

IA-TCA was evaluated in combination with IA-LTA, see results above.

4.1.3.3 Traffic Light Assistant (TLA)

Function description

The TLA warns the driver to avoid red light violations at intersections. Drivers are provided with a speed recommendation if it is possible to safely cross the intersection while the light is green and keeping their speed within the speed limits. Drivers are provided with a warning in case trying to cross the intersection may result into a potential violation of the red light signal.

Results from test in the simulator

The TLA system was largely seen as an information system which could increase driving comfort and fuel efficiency (ratings and comments after the experiment). System output was understood easily and translated smoothly into driving behaviour (subjects had some problems describing the system verbally after the experiment, but not following its suggestions while driving).

Results from the simulator showed that the subjects drove more smoothly with than without the TLA system. In fact, the maximum of deceleration during approach was about -7 m/s^2 for rides without system and -3 m/s^2 for rides with system; mean deceleration was about -1.5 m/s^2 vs. -0.7 m/s^2. For situations where the traffic light was green when reached no consistent differences between rides with and without system could be observed. In addition, the effect of system availability was not stable over the duration of the experiment. If the situation was encountered again at the end of the test drive, subject behaviour with the system approached behaviour in rides without the system. The reason is not clear, but could be related to boredom (test rides were rather long).

The potential of work load management was also investigated. Overall, the introduction of a secondary task led to an increase in subjective measures of workload, but not to consistent changes in driving performance. In most of the situations the secondary task did not interfere with use of the assistance system.

Results from tests with demonstrator vehicles

Results from the questionnaire that the subjects completed after trying the TLA system were very encouraging. In fact the system was rated 4.5 in a 0-5 scale for helpfulness.

4.1.4 Summary of the results (on the overall system)

Driving performance and behaviour

When using the INTERSAFE system drivers drove more smoothly in the very short-term. However, longer term use of the system needs to be assessed since a large variability intra-repetition was found during the evaluation procedure.

Acceptance

Overall, subjects found the INTERSAFE system to be helpful and to improve safety. However, some results suggest IA-TCA acceptance may be lower in real driving situation.

Usability

Overall, the INTERSAFE system resulted to be intuitive and easy-to-use for the subjects. Also, subjects found appropriate the system behaviour and its way to convey information to the driver.

4.2 LATERAL SAFE

4.2.1 Short description

The main objective of LATERAL SAFE is to prevent collisions with vehicles and objects to the side of or behind the ego vehicle. The function consists of three subfunctions - Lane Change Assistance (LCA), Lateral Collision Warning (LCW) and Lateral and Rear Area Monitoring (LRM). The LATERAL SAFE functions have been realized in a solution in particularly adapted for trucks, and another solution adapted to passenger cars. (for more details, see Annex G).

The goal of the final evaluation from human factors perspective was to evaluate the performance in terms of *impact assessment* of the system's potential impact on traffic safety, by considering the effect of the system on *driver behaviour* and *driving performance*. Evaluation of *user acceptance* and *usability* was also performed. Prior to the final evaluation a pre study was performed in order to define the LATERAL SAFE HMI.

4.2.2 HMI prestudy

Objectives

Prior to the final evaluation a pre study was performed in order to define the LATERAL SAFE HMI. The main objective of this pre study was to implement several alternative HMI´s for the LATERAL SAFE functionality and evaluate the different solutions in terms of user acceptance, needs and preferences, in order to determine the final HMI to be designed and implemented.

Methods

The pre study was performed at three different sites (CERTH/HIT car simulator, VCC research vehicle and VTEC truck simulator) each with different HMI solutions. Detailed information on the methods and HMI applications is described in the internal report [37]. A brief overview is presented below.

VCC research vehicle

10 subjects were used, 8 male and 2 female, with mean age 36.9 years. 6 of them had previous experience of ADAS. 4 of the subjects tested 2 different HMI´s for LCA (Alternative 1 and 2). 3 of them tested an HMI for LCW. The last 3 subjects tested the LRM application. The test route was in real traffic environment around Gothenburg. Questionnaires were used before and after the tests. An overview of the HMI applications is presented in Table 19. Detailed information is provided in [37].

Table 19: Overview of LATERAL SAFE HMI applications in VCC vehicle

LCA 1	Closing vehicle information: Yellow light in side mirror. Blind spot information: Red light in side mirror. Blind spot warning: A red light lights up in side mirror in combination with a sound
LCA 2	Lane change information: At intended lane change in critical situations, a yellow light turns up in a-pillar.

	Lane change warning: Flashing yellow light in a-pillar in combination with directional sound.
LCW	A flashing red light in a-pillar in combination with a directional in case of risk situation.
LRM	A yellow light underneath the rear view mirror when close approaching vehicle from behind.

VTEC truck simulator

The pre study was performed in a desk top environment for the LRM application. 5 subjects were used, all Volvo employees with previous knowledge on ADAS. Post evaluation questionnaires were used. The LRM HMI is presented in Table 20

Table 20: LATERAL SAFE HMI for VTEC truck simulator.

LRM	Display next to instrument cluster with bird's eye overview of objects in lateral and rear position of vehicle: host vehicle and vehicles on sides and behind. For rear view information: Orange and red light if vehicles in potential critical position, green if vehicle in non-critical position no danger For lateral information: Blind spot information: Red colour if vehicle in blind spot, yellow if vehicle close at side.

CERT/HIT car simulator

In total 18 subjects were used; 10 male and 8 female, only one had experience of ADAS.

Three different HMI´s for cautionary warnings were evaluated in side mirror (warning triangle, led configuration and picture of two parallel vehicles), each of these were applied at three different levels of surrounding vehicles positions. In addition imminent warnings in rear view mirror were evaluated. Three led´s in parallel were lightened up together with an emitted sound for critical situations. Investigation of driving performance parameters and pre- and post questionnaires were used

Results

VCC HMI test

- LCA HMI in side mirror seems to be intuitive for the driver.
- The HMI in the a-pillar offers a better contrast and is in the driver's main view of sight. This could however be negative depending on the frequency of the warning (driver will always see it in his/her main view)
- Orange colour is preferred
- Adaptation of intensity for day and night should be provided
- One type of warning should be used for closing vehicle info and blind spot information to avoid confusion
- LCA warnings should be directional in all cases activated only when using turn indicator.
- LCW in a-pillar positively rated in general.
- LCW warnings should be flashing for imminent cases.
- LCW warning sounds should be bidirectional.

- LRM HMI for cars should use yellow light for first level (object behind not critically close) and three lights for second level (object behind critically close).

VTEC HMI test

- Solution not appropriate for passenger cars.
- Acoustic rear collision warning should be used only when reversing, otherwise only visual information.
- Different modes for traffic situations with respect to colour coding seemed accepted by test subjects.

CERTH/HIT HMI test

Cautionary warnings

- Outer part of side mirror appropriate locations for LCA/LCW
- All tested solutions for cautionary warning positively rated
- Detailed type of traffic scenarios does not seem to play a significant role in relation to the warning

Imminent warnings

- Central mirror light seem to have minor effect
- Warning sound was intuitive
- Common HMI for LCA and LCW should be used

Final recommendations

LCA

- Primary source visual
- Preferred type of visual information according to Figure 5

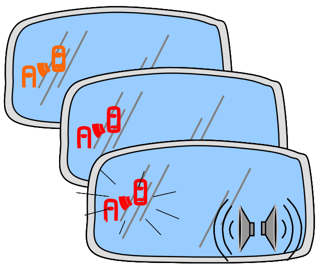


Figure 5

- Red or orange led’s, not yellow
- One type of warning for closing vehicle info and blind spot information
- Directional sound

LCW

- Primary source of information: sound
- Preferred visual signal should be according to Figure 6

Figure 6

- A-pillar location
- Visual warning colour: red
- Bidirectional sound for imminent warning

LRM for cars

- Primary and only HMI: Visual
- Use of led model underneath rear mirror
- Use 2 level warning; a single led when rear object not critically close, three led´s when rear object critically close.

LRM for trucks

- Display based
- Primarily source of information; visual

4.2.3 Final evaluation

4.2.3.1 Study 2- Evaluation in demonstrator car

Objectives

The objective with the CRF demonstrator cars was to perform an impact assessment; influence on driving performance and driver behaviour as well as assess the user acceptance. The demonstrator car of CRF was equipped with the LCA system, LCW system and LRM application for cars.

Methods

For the evaluation performed with the CRF demonstrator car there were 12 subjects. The application tested (LCA and LCW) consisted of a 2 level warning with visual information provided in the side mirror. In addition a directional sound was emitted for imminent danger warnings. The LRM system consisted of a 2 level warning; at 1st level a single orange led was lightened up in the rear-view mirror, for rear objects not critically close. The 2nd level provided three leds lightening up when a rear object was critically close. For the test drives with the CRF demonstrator vehicle a number of scenarios were selected, for example with vehicles appearing in the blind spot of the ego vehicle and overtaking.

Results

LCA

Acceptance was analyzed using the Acceptance scale of van der Laan. User stated that they would accept a certain level of false alarm rate, up to 5%. Most user's were positive to the usability of the LCA. One exception was the negative tendence on the issue of feeling patronized by the system. Usability was assessed by NASA-TLX indicators. All NASA-TLX indicators (mental demand, physical demand, temporal demand, performance, effort and frustration level) were positively rated. 7/12 subjects believed that LCA will increase traffic safety. 11/12 believes it will improve driver behaviour, 2/12 believed it will enhance traffic efficiency. 11/12 users stated they would like to have LCA in their car, only 1 was negative. 4/12 users think LCA will be irritating in presence of passenger in the cars. In order to perform an impact estimation, the driver behaviour and driving performance were analyzed. The number of warning per ride with LCA was analyzed; however no clear system effects could be seen. There was a tendency that min TTC increased however only significant when driving with the system in daylight and in 70 km/h.

LCW

In general users believe that the LCW would be adequate for all types of roads and al times of day regarding usability most users are positive, however some negative ratings concerning being patronized by the system and that the system itself could cause an accident was achieved.

Usability was positively rated. Most users believed that LCW will have positive impact. 10/12 user would like to have LCW in their car. 3/4 of the users believe the LCW would be irritating in case of other persons presence in the car.

In analyzing driving performance for impact estimation, a lower mean number of warnings per scenario were found with the systems. This could however be related to the user's trying to reduce system warning. The standard deviation of steering angle was lower with the system than without, significant for all conditions. It might be explained that the system helps the driver to maintain a steadier steering.

LRM

Satisfaction usefulness positively rated. Most users believe that LRM will be useful on highway at all times of day. Regarding usability, most user's answers are positively rated, with only exception that the system was unnecessarily complex. All 6 NASA-TLX indicators on workload were positively rated. 6/12 users believe that LRM will increase traffic safety, 11/12 that it will improve driving performance and 1/12 that it will increase traffic efficiency. 9/12 stated that they would like to have LRM in their car. Regarding driving performance there seemed that LRM lead to an increase in TTC values in cases of close following, while it lead to a decrease in TTC values in the cases of late overtaking.

4.2.3.2 Study 3- Evaluation in truck simulator

Objectives

The main objective was to test the user acceptance, usability and driving performance for the LRM application in a simulated truck environment.

Methods

21 subjects were used, 24% female, 76% male. For the simulator study a number of scenarios, specifically intended to test the LATERAL SAFE functions, were implemented. The scenarios were classified according to their level of criticality into "Critical" and "Non-critical – monitoring" scenarios. The scenarios were defined mainly on rural roads and included typically a demanded lane change of the host vehicle where vehicles were present or approaching from behind in the lane to which the host vehicle should switch.

Results

Acceptance, both satisfaction and usefulness positively rated.

Usability was positively rated, with the exception that the system integration could be improved for reducing complexity. Regarding workload 5/6 NASA-TLX indicators were rated lower with the system. Only performance rated slightly higher.

17/20 users answered that LRM will increase traffic safety, no user answered that it will improve driver behaviour. For critical scenarios there was found a lower mean longitudinal speed for critical scenarios and a lower standard deviation in lateral speed for critical scenarios, which was suggested to be positive for traffic safety. The standard deviation of speed was lower with the system compared to without; also mean longitudinal speed was lower.

4.2.3.3 Summary of the results from final studies (car and truck evaluations)

Driving performance and behaviour

In general all application proved to have a positive impact on traffic safety. However, this positive effect should be verified by conducting further experiments with a larger amount of test subjects and additional scenarios. Use for the LCW was concluded to lead to a steadier steering which is positive for traffic safety. Use of the LRM proved to lead to an increase in the TTC values in case of close vehicle following and lead leading to a decrease in late overtaking. Use of the LRM in trucks led to a lower mean longitudinal speed for critical scenarios and to lower standard deviation of lateral speed for critical scenarios. Both findings are expected to have a positive impact on traffic safety.

Acceptance

Users expressed a positive judgement on the LATERAL SAFE systems. For all applications LCA, LCW and LRM satisfaction and usefulness were positively rated prior to the tests, but these rating tended to decrease after carrying out the tests.

Usability

Regarding LCA all usability issues were positively rated, however the users stated that they felt patronized by the LCA system. Similar findings were found for LCW. For LRM all issues were positively rated, except for the complexity of the system. Further, users stated that the HMI should have been better integrated. This last comment was also valid for the LRM truck solution.

4.3 MAPS&ADAS

4.3.1 Short Description

The MAPS&ADAS functions use digital map data as the basis for implementing different driving support functions. Two main functions were evaluated: (1) Speed limit warning and (2) hot spot warning. The former informs and warns the driver about the legal speed limits, where a blinking icon is activated for small speed violations (larger than 6 km/h but smaller than 20 km/h) and a sound warning is issued for violations larger than 20 km/h. The hot spot warning warns the driver in potentially dangerous situations ahead, at sites that are known to be accident-prone (based on accident statistics). The general objective of the study was to assess the user acceptance, the induced mental workload and the overall effects on driving performance (for more details, see Annex H).

Up to now the questionnaires for subjective assessment have been analysed and respective results are available. Results concerning driver performance have been compiled as well. Detailed results will be "published" in MAPS&ADAS report D12.922 [60].

4.3.2 Review of the results

4.3.2.1 Study 1 – Evaluation in Demonstrator Vehicle

Objectives

The general objective of the study was to assess the user acceptance, the induced mental workload and the overall effects on traffic safety.

Methods

All data collection took place on a specified route outside Hannover, where subjects drove with and without the system in an instrumented test vehicle.

32 subjects were used in both, the control group and experimental group, with 16 male and 16 female in both groups. After a short briefing and a verbal description of both functions of the MAPS&ADAS Driver Warning System (Speed Limit Warning, SLW and Hot Spot Warning, HSW) but before the start of the test drive each subject was asked to fill in a "Van der Laan"-questionnaire [62] for each function. After the test drives subjects had to fill in the same questionnaire, which allows a before-after comparison.

During the test runs the driving speed was logged by grabbing speed data from vehicle CAN. So a comparison with the process data of the Driver Warning System (DWS), that was logged as well, allowed an estimation of the impact of the DWS on the driver's performance by analysing the overall speed reduction, the reduction of number and duration of violations of the speed limit, changes in the variance of speed and the reduction of speed near possibly dangerous locations (hot spots). The workload of the driver was determined by a Peripheral Detection Task [61] and the analysis of the Steering Wheel reversal Rate.

Results

Acceptance

Speed limit warning

Since the questionnaire for the analysis of Usefulness/ Satisfaction had been translated into German, a reliability check was necessary first. Cronbachs α turned out to be always above 0.7, usually above 0.8. The pairs of concepts belonging to the construct “usefulness” showed never any significant effects in comparison of ratings before and after the system’s use.

All subjects regarded the system after use more “pleasant” and more “nice” (while women’s emphasis was on “pleasant” and men’s emphasis on “nice”).

Small, but not significant trends can be seen: men regarded the system after use a little less useful and a bit more satisfying, while women’s appraisal concerning usefulness differs not at all. Satisfaction, on the other hand was judged higher.

Consequently, the Speed Limit Function can be regarded as a useful system, and users are satisfied with its performance and support.

Hot spot warning

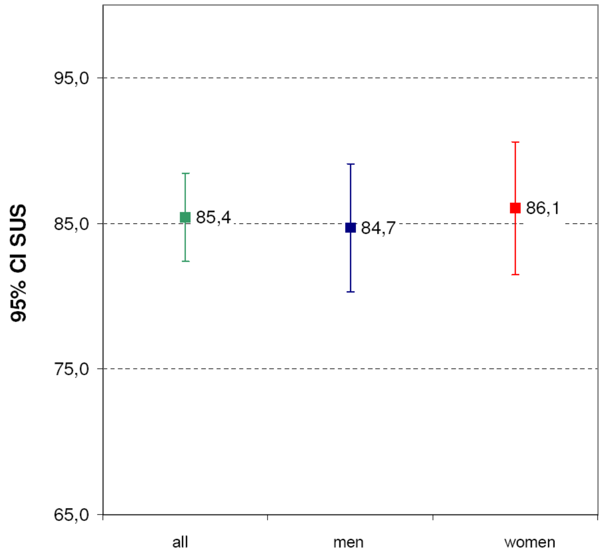
Nearly all pairs of concepts receive less good appraisals after system use, apart from the “sleep-inducing – raising alertness” pair, where small and medium size effects can be seen, but never significant. Merely men’s assessment reaches a near significant effect. Men seem to be more indifferent towards the support provided by the function, since their changes in scores in pairs of concepts are significant only in one case (unpleasant – pleasant). Women regarded the function less effective and less assisting after use. Nevertheless, values were never negative.

As a consequence it can be said that the Hot Spot Warning function is regarded as a useful and satisfactory system, since none of the values moves into negative ranges. Anyhow, high user expectations have not been met, which might be due to a probably not sufficiently accurate description of the function before the test drive.

Usability

Usability was estimated using Brooke’s System Usability Scale [49]. The range of values reaches from 0 to 100, where 0 indicates a very low usability and 100 perfect usability of the system under evaluation. Again, since the questions were translated, a reliability check was performed. Cronbach’s α was calculated to 0.522 for the SLW and to 0.791 for the HSW function. The low value for the SLW is below the usually accepted value of 0.7.[50] .

The usability scores for both speed limit warning and hot spots warning are presented in Figure 7.



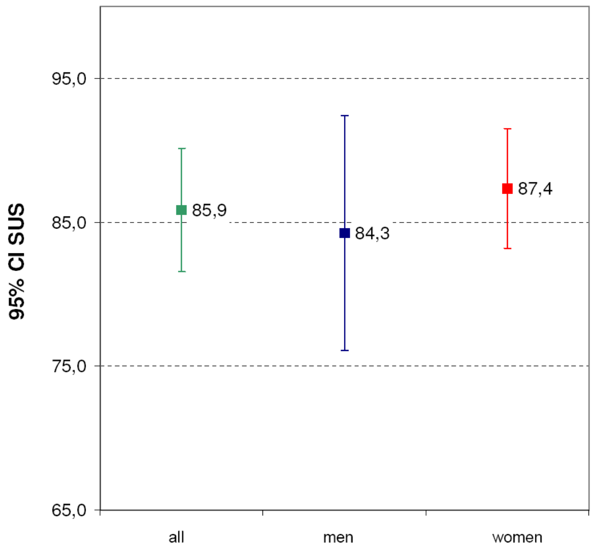


Figure 7 System Usability Scale Scores of (left) the Speed Limit Warning function and (right) the Hot Spot Warning function. Error bars indicate 95% confidence intervals.

Driving performance and behaviour

Speed

The analysis of the speed profiles reveals a highly significant reduction of the average speed of about 3 km/h for the users of the DWS regarding to a total lap. Also notable is the general decrease of the dispersion measures for the total lap and the single sections, which is an indication for a more consistent choice of speed around the mean value.

Speed limit Violations

Regarding the violations of the speed restriction two types were differentiated (6 to 20 km/h above the speed limit and more than 20 km/h above the speed limit). The number of 6 km/h-violations didn't change significantly for users of the DWS. Contradicting to that the number of 20 km/h-violations did decrease significantly for these of users. The DWS also caused a highly significant decrease of the durations of violations of speed restrictions in a total lap ($T(62) = 2.902$, $\alpha < 0.01$, $r = 0$).

Variance of Speed

Results show a decreased variance of speed in general for users of the DWS. The effect is more distinctive in sections 3 and 4. This can be explained by the track characteristics of these sections. They allow a higher speed on several parts, even higher than the speed limit, so some subjects were disposed to exceed the speed limit more often. Due to this characteristic the impact of the DWS was even higher on these parts of the track as documented by the bigger decrease of variance of speed in these sections.

Distraction

The distraction of the driver was measured by two methods. The Peripheral Detection Task showed that there is a significant difference between the reaction times (RT) of the control group ($RT^{Control}_{Lap\ 2}$ = 453.25 ms) and the experimental group ($RT^{Experimental}_{Lap\ 2}$ = 538.85 ms) on the second lap only (with t(64) =

2.182, $r = 0.263$, $\alpha < 0.05$). The comparison of the hit rates (HR) of both groups provides at least significant differences. The smallest impact can be identified for section 2 ($HR^{Control}_{Lap\ 2\ Section\ 2} = 0.978$, $HR^{Experimental}_{Lap\ 2\ Section\ 2} = 0.964$, $U = 348.5$, $r = 0.290$, $\alpha < 0.05$).

In contrast to this are the results of analysing the Steering Wheel Reversal Rate. There no significant changes that indicate any distraction occurred when using the system.

Speed near Hotspot

The speed in the validity area of Hot Spots was compared between both groups using the speed logged by the DWS. Speed in these areas was always normally distributed, differences between control and experimental group in the first lap did not differ significantly.

The analysis of mean driving speeds in the hot spots of section two in lap two revealed a decrease of speed from 55.86 km/h to 51.59 km/h, although the effect was not significant.

4.3.2.2 Summary of the results

Driving performance and behaviour

The DWS had a remarkable impact on the driver performance. The average speeds on the test track were reduced by about 3 km/h (approximately 5 %). The number (up to 36 %) and duration (up to 39 %) of violations of speed restrictions and the variance of speed (up to 15 %) were reduced as well.

For the distraction the results were contradicting. While the PDT test showed a decrease of hit rates and increase of reaction times when using the system, it did not have a significant effect on the Steering Wheel Reversal Rate.

The speed near hotspots wasn't decreased significantly as well.

Acceptance

Regarding the speed limit function, all subjects regarded the system after use more “pleasant” and more “nice”. Thus it is suggested that the Speed Limit Function can be regarded as a useful system, whose users are satisfied with its performance and support.

The Hot Spot Warning function is suggested to be regarded as a useful and satisfactory system, since none of the values moves into negative ranges. Anyhow, high user expectations have not been met.

Usability

The usability scores for both speed limit warning and hot spots warning was about 80-85%.

A reliability check performed due to the translation of questions resulted in a value lower than accepted for the speed limit warning. The usability scores for both speed limit warning and hot spots warning lies in the area of 80-85%.

4.4 SAFELANE

4.4.1 Short Description

SAFELANE is a situation-adaptive system for enhanced lane keeping support. The system reaction in critical lane departure situation comprises the control of warning actuators and an active motor priming steering actuator. SAFELANE system has been validated on 3 different demonstrator vehicles which were tested in several environmental conditions. SAFELANE *user acceptance* has been considered to be really important thus the objective of the evaluation criterion forced the overall system to guarantee a false alarm rate of 0% and a nearly 100% detection rate. *Driving performance* and *behaviour* while using SAFELANE, as well as SAFELANE *acceptance* and *usability,* were then further investigated in 1) a simulator study and by 2) having naïve, professional drivers trying the SAFELANE system and then answering a questionnaire. (for more details, see Annex I).

4.4.2 Review of the results

4.4.2.1 Study 1 – Simulator

Objectives

The main objective of this experiment was to determine in a controlled simulator setting whether or not motor priming can be achieved without negative interference, and, if there is some benefit, how this compared to more traditional auditory and vibratory warning devices.

Methods

20 subjects (age 19-57 yrs; 2 females and 18 males; driving experience 2-39 years) participated to this study. The data collection was carried out in a fixed-base simulator (Sim2, developed by INRETS-MSIS). Subjects were asked to drive in the right lane. During the experiment two unpredictable visual occlusions occurred: one before entering a bend and one on a straight-line section. As soon as the visual occlusion was over, lane departure assistance was given via 6 different kinds or combinations of auditory, vibratory, and visual warnings. Four parameters were used as indicators of driving performance: 1) the duration of lateral excursion, 2) steering reaction time, 3) maximum rate of steering wheel acceleration, 4) extent of overshoot toward the opposite lane.

Results

Results show that all driving assistances clearly improved drivers' global performances, resulting in a significant and large reduction in the duration of lateral excursion both in bended and in straight-line road sections. The greatest benefits were recorded for a specific kind of warning: the motor priming mode both alone or in combination with auditory warning. In fact priming mode reduced lateral excursion of 815 ms for bended and 467 ms for straight-line sections. In addition priming mode (alone or in combination with auditory warning) was twice as effective as the other warnings resulting in smaller steering reaction time, larger maximum rate of steering wheel acceleration, and no effect on overshoot toward the opposite lane. Further, in this study, all subjects spontaneously and correctly reacted to the priming mode warning.

4.4.2.2 Study 2 – Questionnaire

Objectives

This study was aimed at assessing drivers' acceptance of the SAFELANE system.

Methods

10 male subjects (age 30-60 yrs; all males and 2 females; naïve to driving assistance systems) participated to this study. Participants were asked to answer a questionnaire after experiencing the SAFELANE system at the Turin test-site.

Results

Participants liked the system and reported they exhibited better driving performance with the system than without. Further, overall participants expressed positive feedback on the systems by reporting for it to be safe, reliable, useful, intuitive, resting, reassuring, predictable, pleasant, good, annoying, effective, likable, assisting, desirable, and rising alertness. In addition, participants stated that, using the SAFELANE system, driving was easier, safer, less stressful, and more pleasant.

The participants have indicated positive and negative driving situation in which the SAFELANE warning system could be employed. Positive situations: 1) driving during night time, 2) when the driver is tired, and 3) in all cases when the driver is careless. Negative situations: 1) in narrow roads and 2) in extra-urban roads.

Ninety percent of the participants answered yes to the question "would you like to have the Active Lane Warning system in you vehicle, without considering the price?". Further, 40% of the participants wished for SAFELANE final cost to be less than 500 Euro, whereas 60% of the participants wished for it to be between 500 and 750 Euro.

4.4.2.3 Summary of the results

Driving performance and behaviour

Results from the simulator study demonstrated that drivers improved driving performance by using SAFELANE warnings. In particular priming mode warning resulted in the shortest reaction time and safest driving.

Acceptance

Results in test drives performed (more detailed in SAFELANE D.31 52/53) show that drivers really like SAFELANE system performances. Specifically, for instance, the system has been reported to be reassuring, likeable, desirable, and assisting.

Further drivers reported that driving with the system was easier, safer, and less stressful than driving without.

Usability

The SAFELANE user acceptance evaluation tests were designed so that a false alarm rate of 0% and a 100% detection rate were assured. The user tests have hence been performed under ideal conditions. Also, results from study 2 are very positive in terms of driving acceptability.

4.5 SASPENCE

4.5.1 Short Description

SASPENCE is an assistance system that provides information aimed for maintaining a safe speed and a safe distance from other vehicles accordingly to different external scenarios and conditions. (for more details, see Annex J).

4.5.2 General Methods

SASPENCE uses a generic methodological approach, consisting of the following validation methods:

1. Simulation tool PRESCAN
2. Laboratory tests in the VEHIL laboratory where vehicles were instrumented with a driver robot modelled after results from field and simulator tests. The aim was to evaluate TTC for different driver types.
3. Test drives on test track and public road
4. Macro-scenario simulations using ITS Modeller

Only studies 1 and 3 are relevant for the Human Factors evaluation and will be addressed here.

4.5.3 Results

4.5.3.1 Study 1 – Simulator

Objectives

To validate whether the SASPENCE system met its requirements in terms of quality of driving, traffic safety, and traffic impact. Also, to test the hypotheses that 1) SASPENCE will increase quality of driving experience and 2) SASPENCE will increase traffic safety.

Methods

Dynamic tests on the PSA driving simulator were performed in France, in January and February 2006. 34 subjects (age 18-44 years, 30 males and 4 females) were recruited among the PSA employees. 8 combinations of HMI were tested.

The subjects were asked to complete three driving tasks or approx 30 minutes each using the different HMIs. In addition, the subjects were asked to answer a questionnaire to express their opinion on usability and acceptance of the system.

Results

1. No clear effects on driver distraction (measured with distance to the centre of the road)
2. No difference in the drivers' reaction time was found testing the different implementations of the visual HMI. On the contrary, significant differences were found among the different haptic HMI implementations.
3. No significant interactions were found between the haptic and visual feedbacks.
4. Driver reaction times seemed to improve when SASPENCE HMIs were used. Pedal vibration usually caused the fastest response.
5. In safe-distance alarm tests, the difference in first deceleration has been as high as 0.9 seconds (2.2 s without SASPENCE, 1.3 s with force feedback pedal). The system also seems to cause higher peak deceleration values. For safe-speed alarms the difference in first deceleration was as high as 1.5 seconds.
6. Workload and emotional state were not affected by the use of the SASPENCE system.
7. 80% of the subjects was willing to pay for the SASPENCE system, but no one more than 750 €)
8. Drivers reported that:
    - they felt safer while using the SASPENCE system.
    - the risk of being caught speeding marginally decreased.
    - travel time was not affected by the SASPENCE system.
    - the increased comfort when driving was a larger benefit than the reduced fuel consumption, but not as big as safety effects.
    - the support on safe distance and information about current speed limit was found more desirable then support on safe speed.
9. Some drivers stated that the timing of the warning could be improved and should be more sensitive to the speed of own vehicle.
10. Visual HMI first selected in static tests was too complex to understand in dynamic conditions and changes were made.
11. From the driver questionnaire resulted that:
    - Males more irritated about the safe speed concept than women.
    - Singles are also more negative than married
    - Drivers who have been in accidents recently view more positive.
    - Acceptability was higher for speeds above 90km/h

4.5.4 Study 2 – Driving tests

Objectives

Evaluating the SASPENCE system with respect to accuracy and reliability of the warning functions.

Methods

20 test drivers (age 18-69, even gender distribution) were randomly selected inhabitants of Turin. The test drivers drove the test route twice. Half of the test drivers drove first without the system displayed and half of the drivers with the system displayed.

Between the two drives the driver answered a questionnaire measuring their workload. After the two drives the driver answered a more extensive questionnaire. The second questionnaire was modified slightly to cope with the interest of assessing differences between the warning levels.

Human factors related results

From the questionnaire:

- males more irritated about the safe speed concept than women.
- singles are also more negative than married
- drivers who have been in accidents recently view it more positively.

4.5.5 Summary of the results

Driving performance and behaviour

When using the SASPENCE system drivers exhibited 1) improved reaction time, 2) shorter deceleration time, and 3) higher peak of deceleration. Also, minimum TTC increased for conservative and medium drivers but decreased for aggressive drivers.

Acceptance

Subjects reported the SASPENCE system made them feel safer and more comfortable. Also, acceptability was higher for speeds above 90km/h

Usability

Workload and emotional state were not affected by the use of the SASPENCE system. However, some of the drivers stated that the warning could be improved. In addition, the visual HMI that was first selected in static tests was too complex to understand in dynamic conditions but changes were made to make it simpler.

4.6 WILLWARN

4.6.1 Short overview of functionality

WILLWARN (Wireless local danger warning) is a system for foresighted driving and early detection of hazards for safe driving and accident avoidance. WILLWARN extends the driver's horizon of cognition and delivers early warnings in case of hazards such as obstacle or reduced visibility. Thanks to these warnings, WILLWARN provides drivers the opportunity to adapt the vehicle speed and inter-vehicle distance early-on, leading to a higher situational awareness of potential unforeseen hazards. (for more details, see Annex K).

4.6.2 Review of the results

4.6.2.1 Study 1- Simulator study

Objectives

The main hypothesis of this study was that WILLWARN warnings would have resulted in speed and hard-breaking reduction in proximity of a hazard. This study was aimed at 1) determining the effects of WILLWARN warnings on driver behaviour by analyzing speed and breaking 2) investigating whether WILLWARN warnings could induce hard-braking, 3) comparing time-based and distance-based triggers for the warnings, 4) assessing drivers' acceptance of the WILLWARN system.

Methods

40 subjects (age 18-65 yrs; even gender distribution; driving experience 2000-15000 km/year) participated to this study. The data collection was carried out in DaimlerChrysler driving simulator. WILLWARN warnings concerned obstacle behind a curve and reduced visibility due to fog on two-three-lane motorway. The drivers approached a curve on the rural road with or without the warning for the scenario 1, *obstacle behind a curve,* or approached fog on motorway with or without the warning for the scenario 2, *presence of fog in 200/500 m*. The dependent variables included speed and the number/proportion of hard braking/strong decelerations. As HMI, a *virtual* head-up display was used for the warnings. The transparent overlay with a warning sign and text was generated and integrated in the video display of the scenery which was projected on the inner surface of the simulator dome. The display was accompanied by a warning sound. Variables analyzed for the WILLWARN effects evaluation were: speed, acceleration, deceleration, speed deviation, time gap and driver reactions.

Results

Obstacle behind a curve (scenario1)

1. Warned drivers reduced their speed short after receiving the obstacle behind a curve warning (they usually reduced the pressure on the acceleration pedal). After 2 seconds, the mean speed for warned drivers was 5 km/h lower than for drivers receiving no warning. After 15 s, the difference was 13 km/h.
2. Compared to drivers who do not received any warning, the warned drivers approached the curve with lower speed (50 km/h vs. 60 km/h) and responded faster when they saw the obstacle.
3. The maximum average speed reduction close to the obstacle was 38 km/h with the warning compared to 31 km/h without the warning.
4. Warned drivers approached the curve with a speed 10 km/h lower than drivers without warning and they approached the obstacle with lower speed when they recognized it.
5. After receiving the warning drivers decelerated with maximum average deceleration of -0,9 m/s2. Because of their lower

speed, when recognizing the obstacle car only a short braking time was necessary. The drivers who did not receive any warning showed needed a more extensive deceleration in order to reduce their speed.

6. Even thought the warning came too early, almost all drivers judged the warning as helpful or very helpful.
7. Because of the low traffic and good view, most of the drivers who did not receive any warning were anyway able to reduce the vehicle speed and to avoid obstacle behind the curve even without the help of WILLWARN.

Presence of fog in 200/500m (scenario2)

1. Warned drivers reduced their speed shortly after receiving the fog in 200/500m warning. During the first 10 seconds after the warning, they reduced their velocity approximately by 18%. On average, they entered the foggy area with a speed of 110 km/h, compared to140 km/h for not warned drivers.
2. After the warning, drivers usually reduced the acceleration pedal and only few drivers pressed the brake pedal.
3. The maximum average deceleration was about -1 m/s2 after the first warning and -0,8 m/s2 after the second warning. Drivers who did not receive the warning started their deceleration when entering the fog area and the maximum average deceleration was -1,5 m/s2 (which is higher than the warned drivers deceleration in their first scenario).
4. Most of the drivers were satisfied with the timing of the warning which came first in 500 m and then in 200 m before the foggy area. Also, the warning was judged as helpful by the majority of the subjects.
5. Time-based (and not distance-based) warnings, provided 10-15 seconds before the vehicle reaches the hazard, were found to be the best way to warn the drivers.

At the moment, no statistical analysis supporting the above-reported results is available

4.6.2.2 Study 2- Questionnaire

Objectives

This study was aimed at assessing drivers' perception on the advantages and disadvantages of using an early warning system while driving

Methods

52 subjects (age 32-63 yrs; 50 males and 2 females; driving experience 5000-80000 km/year) participated to this study. Participants were asked to answer a questionnaire where four different scenarios (fog, construction site, accident, reduced friction; describing target application for the WILLWARN system) were presented.

Results

1. Participants would have liked to have early warnings.

2. Participants were not concerned about the source of the warning.
3. Participants would have liked to have precise and up-to-date information. Participants wished for a repetition of the warning when they come close to the dangerous spot.
4. Participants did not want to be overloaded by a lot of warnings, which were not relevant for them. Also, Participants did not want to be distracted by accessing stored warnings.
5. Participants appreciated that early warning give them a chance to adapt their driving style and to react early.
6. Many participants had problems to estimate the required warning distance ahead up to the hazard spot.
7. All the four scenarios were treated similar by the participants and they considered an early warning as reasonable. Participants judgment of the criticality of the scenarios varied, however, all the scenarios were considered in the region of 'very dangerous'. Low friction and accidents were estimated as most dangerous and requiring an earlier warning. Road works were not judged so critical.

User needs for HMI of 'early warning systems'

1. 34% of the participants would have liked a visual message combined with speech. Because the visual channel is highly stressed while driving, most of the participants thought that the acoustic channel would have been a good alternative. Also, if the warning could be repeated on demand, the participants felt they would have more control on the road.
2. Only few of the participants could imagine a haptic warning. This was named always in connection with other forms of warning.
3. All test persons would have liked to have the radio messages anytime available in the car.

4.6.2.3 Summary of results

Driving performance and behaviour

The results presented in the first experiment suggest that WILLWARN warnings led to earlier and more extensive reduction of speed and also reduced the extent of the decelerations

Acceptance

The results presented in the second experiment suggest that WILLWARN system will be well accepted by the drivers.

Usability

Many subjects argued that the position of the head-up display warning should not have been in the centre of the view but in a lower position. Also, subjects argued that the size of the display should have been smaller and moved toward the left side.

4.7 Summary

The human factor evaluation of 6 projects (INTERSAFE, LATERAL SAFE, MAPS&ADAS, SAFELANE, SASPENCE, WILLWARN) have been analysed. These projects were selected particularly relevant for human factor and HMI evaluation due to their degree of interaction with the driver. The results from the subprojects were finalized at the time for writing this report, except for MAPS&ADAS and SASPENCE, where the results are preliminary and to some extent still under analysis.

Table 21 gives an overview of the human-factor-related results across subprojects.

Table 21: Status, availability, and prominence of the human-factor-related results for all the PReVAL subprojects considered in this chapter. .

Subproject	Status of the results	Results		
		Driving performance & behaviour	Acceptance	Usability
INTERSAFE	Finalized	+	+	++
LATERAL SAFE	Finalized	+	+	+
MAPS&ADAS	Preliminary	N.A.	+	+
SAFELANE	Finalized	++	++	++
SASPENCE	Preliminary	+	++	+
WILLWARN	Finalized	++	+	+

+ indicates positive results but with documented need for design improvement and/or further experimentation.
++ indicates complete and positive results.
N.A. stays for not available

All the analysed sub projects report positive results on driving performance and driver behaviour, as well as for acceptance and usability, however with a variation in the significance and distribution of the results.

Most projects emphasize the need for further experiments with a larger amount of scenarios and a larger group of test subjects for achieving statistically significant results. Also further tests for optimising the HMI solution is mentioned in some projects. There is also a need for assessing the long term behaviour of the driver.

5 Qualitative Safety impact assessment of PReVENT functions

The safety impact assessment is based on the behavioural effect approach. The method followed has been described in more detail in D16.1, section 5.3. This deliverable describes the first phase of the safety impact assessment, the qualitative safety assessment. This starts with a description of the systems and functions. These are described in the annexes D-K. This chapter describes the literature study on the safety impact of the different functions, and an analysis of the safety mechanisms (section 2.3.2.3) for the systems.

For each system, it was first explored which out of nine mechanisms are relevant. In this deliverable, these mechanisms are described qualitatively. The estimated effects and assumptions as well as the evidence from literature survey are presented with each relevant mechanism. Furthermore, possible differences between accident type, road type, vehicle type, road weather and lighting conditions are considered.

The literature searched was classified as follows:

- Empirical evidence on safety impacts (verified results e.g. experimental design)
- Expert evaluations of safety impacts (predicted results)
- Indirect evidence on safety impacts, which means more general assessment of the effects based on knowledge of driver behaviour, traffic flow, and effects of comparable systems, e.g. road side telematics (potential results). These are usually referred as "assumptions".

5.1 APALACI/COMPOSE

The APALACI and COMPOSE subprojects both deal with pre-crash functions, in particular collision mitigation. A key difference between the projects is that APALACI focuses on passenger protection while COMPOSE puts stronger emphasis on protection of other road users.

The APALACI/COMPOSE safety assessment in PReVAL will contain the following functionalities:

- Passenger protection via pre-fire and pre-set control for restraints systems
- Autonomous braking to mitigate unavoidable collision

Other APALACI/COMPOSE functionalities are being covered by eIMPACT.

5.1.1 Literature review

Two field operating tests (FOT) results and five papers have been analysed in order to exhibit assessment methods and results related to APALACI/COMPOSE functional specifications.

In FOT1 [21], 100 cars were equipped with sensors in order to collect data about naturalistic driving: 2,000,000 vehicle miles with 241 drivers provided 43,000 hours of data. Data were analysed and classified in scenarios related to events: crashes, near-crashes, incidents. In FOT2 [16], 10 vehicles were driven by 66 drivers during 4 weeks: one week without any assistance and three weeks with assistance of an Automotive Collision Avoidance System (ACAS) (forward crash warning –FCW– and adaptive cruise control –ACC).

Main crashes and near-crashes situation data for both FOTs ([21] and [16]) were as follows:

- FOT2 generated about 0.62 overall crash-imminent alert per 100 km, and 2.18 between 40 and 56 km/h (44% of alerts were due to out-of-path targets); only 3% were considered as true alerts, thus yield to 1.8 true alerts per 10,000 km.
- In FOT1, overall (real) crashes rate was 2.5 per 100,000 km and near-crashes rate was 2.4 per 10 millions km. An important result of FOT1 was that this large-scale data collection was not successful in determining a crash warning boundary: it appeared to be very difficult to detect near-crashes by quantitative methods (kinematic signature is almost the same as for many common driving situations). FOT1 exhibited 15 lead-vehicle crashes among 82 crashes.
- Both concluded that inattention is involved in a majority of conflict situations (FOT1: 78% of crashes, 65% of near-crashes and 1/3 of incidents; FOT2: 38% of crash-imminent alert episodes). In FOT1, a strong correlation has been demonstrated between inattention and increased severity for lead-vehicle rear-end events.
- The major context factor related to incidents was traffic density. Drowsiness seemed to have a dominant role (12% of crashes and 10% of near-crashes). Another interesting statement was that total crash involvement may be five times higher than police reported crashes in the US.
- In most of near-crashes situations (97%), driver braked to avoid collision (FOT1).
- In FOT2, 55% of subjects had an average reaction time of 0.5 s or less after an in-path target alert, suggesting that they were attentive or about to respond when receiving the warning.

Safety impacts of ACAS uses:

- during the first week of ACAS use, greater exposure to conflict was attributed to driver learning and experimentation;
- no subjects with ACAS enabled had rates greater than 70 conflicts per 100 km; whereas, 5% of subjects with ACAS disabled had rates greater than 70 conflicts per 100 km. ACAS positive safety impact seemed to be greater on freeways than on other highways.

Exposure effectiveness (EE) was measured as follows:

- ACAS was about 21% effective in reducing the exposure of drivers to rear-end pre-crash conflicts for the aggregate of all drivers and driving conditions.
- Using low-intensity conflicts as the metric for EE, the following results were obtained:

  - EE was highest among *female* (30%) and *older* (27%) drivers
  - EE was lowest among *male* (12%) drivers
  - EE increased with age group from *younger* (14%) to *middle-age* (23%) to *older* (27%) drivers

- Exposure effectiveness for ACAS was also positive for the different driving conditions of ambient light, road type, weather, and traffic level for *all* drivers. Again, using low-intensity conflicts as the metric for EE for *all* drivers, the following results were obtained:
  - EE for light (24%) and dark (11%)
  - EE for freeways (25%) and non-freeways (7%)
  - EE for clear (21%) and adverse (19%) weather
  - EE for low (17%), moderate (19%), and heavy (12%) traffic levels

- The analysis of exposure effectiveness by ACAS vehicle speed found that the EE for ACAS was positive only for speeds at and above 56 km/h (25%).

- It was found that freeway driving seemed to be the environment where ACAS has the highest level of EE.

- The EE results, based on driver averages, were consistently lower than the corresponding population average value of about 21 %.

Safety benefit estimation for ACAS was a potential to prevent 6% to 15% of all rear-end crashes and 10% to 20% of severe near crashes. Safety was increased through near-crashes warning to the driver, although rate of true alerts was only 3%. On 24 events, in 11 the driver was distracted, in 13 the driver was looking at the road ahead.

One drawback of ACAS was that it seemed to have an influence on headway: ACAS-enabled headway was 2.5 s versus 2.7 s for ACAS-disabled headway. Driver acceptance analysis showed that 41% of the subjects stated that they would have used an on-off switch to turn off FCW crash alerts, if it had been available.

Sultan and McDonald [22] assessed the safety effects of ACAS by examining driver's response during emergency braking situations. A series of emergency braking tests were undertaken using "real" users. The data analysis showed that drivers were likely to start their braking before the TTC reaches 4 seconds. Thereby ACAS can not rely on simple TTC thresholds for collision warning instigation. A successful ACAS has to consider dynamics of obstacle. Sultan and McDonald [22] compared TTC and headway as parameters for warning instigation. Assessment methodology is considered of interest.

Lu [18] presented a model for quantitative analysis of the effects of road traffic safety measures, based on a breakdown of the causal chain between measures and effects. The focus was on probabilities rather than on historical statistics. The model may in general contribute to clarify the mechanisms between traffic safety measures and their safety effects, allowing comparative analysis of different types of measures by defining an effectiveness index, based on the coefficients. It is particularly helpful for assessing the effects of ADAS-based measures, for which few data exist, by using existing data for infrastructure-based measures.

McLaughlin et al [20] described a method for use in evaluating the performance of collision avoidance systems (ACASs) using naturalistic driving data collected during real crashes and near-crashes. The method involved four parts: a) input of naturalistic crash data into alert models to determine when alerts would occur, b) cinematic analysis to determine when different responses would be required to avoid collision, c) translation of the time available into an estimate of the percentage of the population able to avoid the specific event, d) an evaluation of the frequency of alerts that would be generated by the ACASs. The approach was very interesting. No intervention was considered and this could be extended for a system like APALACI. The focus was on analysis of speed and acceleration and no assumptions on driver's reaction time and response behaviour was made. An analysis of balance between false and missing alarm rates was done, but the found results were not so good.

Malts and Shinar [19] evaluated the efficacy of a type of in-vehicle imperfect collision avoidance warning system under conditions of driver distraction. Distracted drivers responded to the less reliable system's alarms by increasing their temporal headway, but the warning system at the higher reliability levels led to over reliance and ultimately to maintaining shorter headways. Conclusion was, although aids may be helpful and, in many cases, the more reliable aid was preferable, in the case of distraction, drivers may misuse the aid. The results highlighted the side effects due to excessive reliability on the system ("complacency effects").

Lehto et al [17] compared two different methods for determining the thresholds of a collision avoidance warning system. Particularly, in the distributed signal detection theoretic (DSDT) model, the human operator and the warning mechanism are independent decision makers who work together as a team. The DSDT demonstrated that the optimal warning threshold, in general, differs from the signal detection theoretic threshold, which assumes a single decision maker. This prediction was tested in an experiment. The findings supported the conclusion that the DSDT model is a useful, quantitative tool that should be used by warning designers. The methodology used by the experiments in the simulator was very interesting: it was based on reward and penalties strategies for the driving subjects.

5.1.2 Safety impact mechanisms

The APALACI/COMPOSE collision mitigation functions deal with unavoidable crashes. These safety systems are not expected to have an effect on driver behaviour, and hence only modification of accident consequences (i.e. mechanism 9) is relevant.

Mechanism 9: modification of accident consequences

Changes in accident consequences:

+ The crash speed is reduced when the accident is unavoidable. This results in collision mitigation and less severe injuries.

Estimated effect:

According to the power model [4] the risk of injury in an accident increases by the second power of the mean speed, and the risk of a fatal accident increases by the forth power of the mean speed.

Table 22: Mechanism 9: Effects by circumstance.

COMPOSE Variable	Mechanisms 9 Modification of accident consequences
Accident type	No difference
Link / intersection	No difference
Road type Motor/rural/urban	The system works on all types of roads, nevertheless the effects will be directly related to the travel speed. Effect is expected to be larger on motorways than other road types
Vehicle type car/truck/bus	No difference
Adverse road conditions Good/bad weather	In adverse conditions, road friction might be lower than in other conditions. Effect is expected to be larger on good road conditions
Lighting conditions Day/night	No difference

5.1.3 Conclusions

The APALACI/COMPOSE collision mitigation functions concentrate on unavoidable crashes. They are not expected to have an effect on driver behaviour, and hence only modification of accident consequences is relevant. There were no substantial differences by circumstance. However, it is expected that the effects are larger on motorways than other road types and, compared to adverse road conditions, the effects are larger on good road conditions.

5.2 INTERSAFE (left-turn assistance)

Because eIMPACT analyses the effects of two INTERSAFE functions (Traffic light assistance and Right-of-way assistance), PReVAL safety impact assessment focuses on left-turn assistance function.

5.2.1 Literature review

The accident database of the German state Nordrhein-Westfalen (NRW) is used, where all accidents in 2001 are listed (about 100 000 accidents) [23]. The database can be seen as representative for whole Germany. For the detailed accident analysis about 200 people, which were involved in intersection accidents (especially left-turn accidents), were interviewed.

The analysis of the node accident shows that the most accidents (22.0%) occur when the driver at fault aims to turn left in a situation with oncoming traffic, followed by “traffic from right” (15.8%), “straight forward with traffic form left” 13.9%) and “turning left with traffic from left” 11.3%. Also the situations with pedestrians or cyclists from right or left are dangerous and lead to about 11.8% of all node accidents. Due to the intended assistance approach based on inter-vehicle-communication these situations cannot be considered from this kind of assistance. However, regarding only the five most dangerous situations at intersection an intersection assistant could theoretically avoid about more than 63% of all node accidents. Referred to the total number of all accidents about 22% of all accidents could be theoretically prevented.

Drivers of passenger cars are most frequently at fault. However, the accidents involving heavy trucks at fault are of higher severity that such caused by passenger cars. Also accidents with involved motorcycles and bicycles are of high severity. The motorcycles are often not detected by the drivers of passenger cars and their velocity is underestimated.

About 45% of all accidents occur at night, although at night the traffic flow is much lower than at day. At night only about 25% of the traffic flow of the daytime is reached. This shows the significance of visibility at intersections. About 50% of all accidents occur at intersections without any traffic light systems. Only about 30% of all accidents occur out of cities. Due to the higher speeds out of the city the accident severity is higher in these cases and thus also the weighted rating.

In about 55% of all situations the driver at fault (the left turner) was standing before the collision at the stop line (no stop sign necessarily). Only in about 30% he did not stop before entering the intersection. In about 20% of all cases he stopped before the stop line (e.g. behind another vehicle) and did not stop again at the stop line. In the most cases the speed level is normal, which means that the drivers did not try to pass through the intersection quickly or pass before the oncoming traffic reaches the intersection. Contrariwise, the drivers had stopped before the intersection at the stop line and accelerated after that normally. This means that either they did not detect the oncoming traffic because it was occluded by object or they were blinded by something or their attention was distracted by something else.

In about 30% of all situations the view is barred. Specifically, the view is only in 10% of situations obstructed by fixed objects like trees or houses. In other cases the view is barred by left-turning or right-turning vehicles. In case of accidents despite of free view the most drivers at faults did not notice the oncoming traffic (75%). Only 25% noticed the oncoming traffic, but misjudged the situation (e.g. incorrect speed estimation). If the oncoming traffic were not seen, this could be ascribed 75% of all cases to distraction and inattention. Only in a few situations the drivers were obstructed by optical effects or blinded (e.g. by the sun). These interview results show that not the special situation lead to the most accidents, but the “normal” situations, where the driver at fault stops first to observe the traffic and accelerates then normally. But because of distraction or dynamic occlusion he does not notice the other vehicles and an accident occurs.

In 90% of all cases the driver not at fault was not standing at the intersection but drives through the intersection, in mostly with constant velocity. Only in 25% of the situations he accelerated when approaching the intersection and in 15% he even decelerated.

Driver behaviour with intersection assistant (IA)

With IA the drivers brake in all situations earlier, on average. This effect is more substantial when the sight is occluded and the driver has to give right of way.

5.2.2 Safety impact mechanisms

Mechanism 1: Direct in-car modification of the driving task by giving information

Changes in driver behaviour:

+ The system supports the driver to perceive on-coming road users with a collision course when turning left (on an intersection without left-turn signal).
+ The system might make the driver better and earlier aware of potential collisions giving more time for brake and evasive actions, and therefore prevents collisions with other road users.
- The driving task is changed because the driver may at times glance at the display which provides the warnings. The task becomes divided attention task and might cause distraction. This also makes the driving task more complex: visual information both inside and outside the car.

Estimated effects and assumptions

- The main risk factor of intersection crashes typically deals with driver inattention, perception errors and estimation errors. Specifically, 95% of fatality accidents in Finland (between 2001–2007) in accident categories "opposing directions of travel (at least one vehicle turning)", "intersecting directions of travel", "intersecting directions of travel (at least one vehicle turning)" and "pedestrian accidents on pedestrian zebra crossing" included a risk factor such as incorrect assessment, perception error or misinterpretation [31].
- According to Larsen and Kines [33] the most common accident factor in fatal left turn accidents was attention error and the elderly drivers were over represented. The findings of Matthias et. all [34] also support the fact that elderly driver group is over represented in left turn accidents and these accidents represent a much larger proportion of total accidents for drivers over 65 years than for any other age group.

Table 23: Mechanism 1: Effects by circumstance.

INTERSAFE, Left Turn Assistant Variables	**Mechanism 1: Direct in-car modification of the driving task by giving warning**
Accident type	Effects focuses on frontal and side accidents. It is expected that there is no substantial difference between those accident types
Link / intersection	The system is effective only at intersections (also signalised if without left turn signal)
Road type	No difference between rural and urban roads.
Vehicle type: Truck/bus/car	There is no difference in the effectiveness depending on the vehicle type.
Road conditions: good/adverse weather	Since the detection as well as estimation of velocity/distance of the oncoming vehicles is more difficult in adverse road conditions (fog), the system might be more efficient in these conditions.
Lighting conditions: day/night	Since the estimation of velocity/distance of the oncoming vehicles by the driver is more difficult in dark, the system might be more efficient in these conditions.

Mechanism 3: Indirect modification of user behaviour

Changes in driver behaviour:

- A well-working system provides warnings in a reliable manner and the driver learns to trust and rely on the system, i.e., the driver delegates the responsibility to the system and becomes careless. This is a negative effect because the system may not always detect and warn in all situations.
- Drivers might learn to approach the intersections at higher speeds than before relying on the system to warn them in good time of other vehicles approaching. However, with left turn manoeuvre required, the approach speed can not be very high anyway.

Table 24: Mechanism 3: Effects by circumstance.

INTERSAFE, Left Turn Assistant Variables	**Mechanism 3: In-direct modification of user behaviour**
Accident type	Effects focuses on frontal and side accidents. It is expected that there is no substantial difference between those accident types
Link / intersection	The system is effective only at intersections (also signalised if without left turn signal)
Road type	No difference between rural and urban roads.
Vehicle type: Truck/bus/car	There is no difference in the effectiveness depending on the vehicle type.
Road conditions: good/adverse weather	In good weather, drivers tend to drive faster, if the road is free of other users. However, it is assumed that this effect on behavioural adaptation is so low that no difference is expected in various road conditions.
Lighting conditions: day/night	No difference (the rationale is the same as above)

Mechanism 4: Indirect modification of non-user behaviour

Changes in driver behaviour:

- \- The user becomes a non user when having a non equipped vehicle. Without the familiar system he may be poor in detecting other road users.
- \+ It is also possible that the system has positive transfer effects, the system may learn the driver to do adequate perceptions.

Estimated effects and assumptions

It is assumed that the magnitude of these effects is small. Consequently, no analysis by circumstance was conducted.

Mechanism 5: Modification of interaction between users and *non-users*

Changes in driver behaviour:

± If the system does not support the detection of pedestrians, the driver might not perceive them as without the system (driver has the idea of “green light, safety to turn left”). On the other hand, in complex situations the system might provide more availability/time for vulnerable road user detection.

± The driver with the system can reduce his speed earlier and he doesn't have to make a fast stop. This would reduce the risk of crashes from behind. On the other hand, the driver may relay on the system and therefore approach the system faster than without the system. This would make the behaviour more difficult to the others to anticipate. However, other road users are aware of the possibility of vehicle in front stopping if they are turning left and therefore these effects are not relevant.

Estimated effects and assumptions

- o According to Sullivan and Flannagan [35] pedestrian are 3 to 6 times more vulnerable in the dark than in daylight. However, these figures are not necessarily valid in Europe. For example, the intersection areas in Europe are frequently lighted.
- o However, it is assumed that the magnitude of these effects is small. Consequently, no analyses by different circumstances was conducted.

Mechanism 6–8: Modification of road exposure, modal choice and route choice

Changes in driver behaviour:

- \- It is assumed that the system makes car driving more comfortable and therefore increases the person car exposure.

± It is assumed that due the left-turn assistance, elderly/inexperienced drivers might select road with more complex left-turn. However, they will have a system assisting and/or training them in these situations.

Estimated effects and assumptions

It is assumed that the magnitude of these effects is small. Consequently, no analyses by different circumstances was conducted.

Mechanism 9: Modification of accident consequences

Changes in accident consequences:

+ The consequences are mitigated due to lower speeds in collisions due to earlier warnings.

Estimated effects and assumptions

It is assumed that the magnitude of these effects is small or unclear. Consequently, no analysis by different circumstances was conducted.

5.2.3 Conclusions

INTERSAFE (left-turn assistance) is expected to have direct and indirect effects on driving task. However, the effects take place at intersections only. Direct effects are more pronounced in adverse road conditions and at night. Other effects include indirect modification of non-user behaviour, modification of interaction between users and non-users, modification of road exposure, modal choice and route choice and modification of accident consequences. However, the magnitude of the effects is expected to be small and no difference by circumstance is expected.

5.3 MAPS&ADAS (Hot Spot Warning)

5.3.1 Literature review

Many studies [54], [55], [57] have aimed to specify the effect of specific traffic signs on mean driving speed under certain circumstances. Since in most cases these signs indicate a potential accident prone location the results can be used to estimate the effect of the Hot Spot Warning (HSW). Almost all studies describe tests made under adverse conditions (dark, ice). Consequently, there are no results that show the effects on driver behaviour under good or normal conditions.

5.3.2 Safety impact mechanisms

Mechanism 1: Direct in-car modification of the driving task by giving warning

Changes in driver behaviour:

+ After receiving a HSW the driver is expected to increase alertness and reduce speed (selective reduction). This is expected to reduce the number of accidents.

Estimated effects and assumptions

There is a major effect on the mean speed when drivers receive a warning. This effect is even higher if it is given in adverse conditions. In these situations a driver is frequently more attentive. As a consequence drivers will accept an advice more likely.

Table 25: Mechanism 1: Effects by circumstance.

MAPS&ADAS Variables	Mechanism 1: Direct in-car modification of the driving task by giving warning
Accident type	Driving accident resulted from the driver losing control of his vehicle, without other road users having contributed to this and all other accidents including for examples: U-turning, reversing, obstacle or animal on the carriageway are affected. Most accidents depend on non-adapted speed. Effect on accidents on non-adapted speed are expected to be biggest.
Link / intersection	The HSW system is designed to warn drivers of accident prone locations. Hence there will be no warning of accidents with third parties which often happen in link sections. The effect is expected to be biggest in link sections.
Road type	The Hot Spot Warning function is designed to work on rural roads mainly. Rural and Urban roads show more points of conflict, such as two-way-traffic, winding roads, hazard areas etc. Thus the positive effect on this type of roads might be huge if the system is reliable. This means that there have to be a high Correct Alarm rate and a corresponding low Missing and False Alarm Rate . On motorways The hot spot density is relatively low. Due to a safe design and less points of conflict motorways are the roads with the highest level of safety in terms of accidents per vehicle-km. The positive effect is expected to be biggest in rural roads. Effect in motorways is expected to be minor. In rural roads there is no effect because of a lack of information about accident prone locations.
Vehicle type	Driver of heavy vehicles are assumed to accept the advice given by the HSW if they are not that experienced in the driving task. Otherwise they are assumed to rely on the basis of their experience. Driver of cars might accept the warnings of the system more often if there is at least a medium reliability. If not user may accept the warnings first time and than get back to their own experience. In the current version the function does not consider vehicle type specific attributes. Nevertheless it can be assumed that passenger car drivers are less well trained than HGV or bus driver, who are better able to assess vehicle dynamics and street status and that therefore the HSW function deploys a higher impact on the behaviour of passenger car drivers. Effect on cars is expected to be highest.
Adverse road conditions	The HSW function considers especially adverse weather conditions like wet or probably icy roads by evaluating the rain and temperature sensors. In adverse weather conditions the warning speed thresholds are significantly lower than for normal conditions. At adverse weather conditions the safety will increase because drivers get additional information about the situation ahead. Studies show that information about slippery etc. have been considered by drivers [54],[55]. Besides it is shown that a dynamic sign, like this one used by the HSW, attract more attention than static signs [57][58]. The effect is expected to be biggest under adverse weather conditions.
Lighting conditions	In daylight the effect might be positive only at hot spots without a clear

MAPS&ADAS Variables	Mechanism 1: Direct in-car modification of the driving task by giving warning
	view. At night or dark lightning conditions the sight of drivers is reduced to the cone of the lights. Hence there might be a great effect because drivers can be warned about situations that can't be anticipated. The effect is expected to be bigger at night/dark

Mechanism 3: Indirect modification of user behaviour

Changes in driver behaviour:

− A well working system might lead to the driver relying on it in all driving situations. This is especially critical in case a system is operational only on parts of the roads and if the driver is not clearly informed about these restrictions.

+ After long term use drivers might recognize typical situations in which the HSW has shown a warning and adapt their driving behaviour accordingly by increasing their situation awareness. They might also transfer their experience to new situations or locations. Therefore it is assumed that drivers will reduce speed and possible be more aware of accident prone locations.

Additional remarks:

+ The indirect modification depends on the reliability and frequency of advice.
+ The influence of the system on the driving task depends on the reliability of the warnings. If the system gives good advice this will lead to a modification of the task.

Estimated effects and assumptions

These effects are assumed to be substantial. Tests show that driver rely on such systems after a short term of use.

Table 26: Mechanism 3: Effects by circumstance.

MAPS&ADAS Variables	Mechanism 3: In-direct modification of user behaviour
Accident type	If drivers rely on the system there are two possible consequences. First a decrease in accidents because of the warnings and second an increase because of non-adapted speed at sites not marked in the map.
Link / intersection	The HSW system addresses accidents without third parties. Therefore the effect is bigger at link sections.
Road type	The indirect modification depends on the reliability and frequency of advice. If advice are given too often driver might find it annoying. If the reliability of the system is high drivers will accept the system. As a result of a long term use drivers might learn from the system and be more attentively at all. This attention will be greater on rural and urban roads because more Hot Spots exist at this type of road. As a result users will drive slower than non-users. Hence every user might be an obstacle for non-users. This effect will be bigger on rural and urban roads because these roads are often single-carriageways and

MAPS&ADAS Variables	Mechanism 3: In-direct modification of user behaviour
	overtaking manoeuvres are more difficult. Especially on rural roads a certain behavioural adaptation might occur, because this is the main working area of the system. Nevertheless, the change from rural to urban roads might not always be clear, hence the system modus (working/ not working) might not be always clear. This effect might be very small. The positive effect is expected to be biggest in rural and urban roads. Effect in motorways is expected to be minor.
Vehicle type	The effect is expected to be equal to heavy vehicles and cars.
Road weather	The acceptance of hot spot warnings is generally better under bad weather conditions. Normally drivers don't like to drive under bad weather conditions. For example drivers might feel insecure in rain (which causes spray and limited sight). So they might be glad to become some advice while more concentrating on other parts of the driving task. Due to this fact it is obviously to the indirect modification that the HSW has a greater effect under adverse road weather. The behavioural adaptation might be even higher in adverse weather conditions, because the warning speed thresholds are lower in these conditions. In case the drive experienced a quite good system performance on these conditions, he might rely even more on it in adverse conditions. The effect is expected to be bigger in adverse conditions
Lighting conditions	Similar to the road weather the driving task will be modified most in darkness. The effect is expected to be bigger in darkness.

Mechanism 4: Indirect modification of non-user behaviour

Changes in driver behaviour:

+ Corresponding to the penetration rate there might be a learning effect of non-users. Non-user might ally the reduced speed of users with a accident prone location and will imitate this behaviour in the future.

Estimated effects and assumptions

This effect is minor. In most cases non-user won't combine the reduced speed with the awareness of a dangerous spot of users. As a consequence non-users didn't copy this behaviour.

Table 27: Mechanism 4: Effects by circumstance.

MAPS&ADAS Variables	Mechanism 4: Indirect modification of non-user behaviour
Accident type	Non-users might more often overtake users if they didn't recognize the danger. Therefore accidents with oncoming vehicle or unadapted speed will be most likely.
Link / intersection	The effect on accidents will be equal to link and intersections
Road type	Since most of the warnings are expected to be given in rural and urban roads, the learning effect is also expected to be biggest in these roads. The positive effect is expected to be biggest in rural and urban roads.

MAPS&ADAS Variables	Mechanism 4: Indirect modification of non-user behaviour
	Effect in motorways is expected to be minor.
Vehicle type	The effect is expected to be equal to heavy vehicles and cars.
Road weather	The behavioural adaptation might be even higher in adverse weather conditions, because non-users are more aware at adverse weather conditions too. The effect is expected to be bigger in adverse conditions.
Lighting conditions	Similar to the road weather the driving task of non-users will be modified most in darkness. The effect is expected to be bigger in darkness

Mechanism 5: Modification of interaction between users and non-users

Changes in driver behaviour:

– A reduction on the mean driving speed as a consequence of hot spot warnings might lead to increasing overtakings by the following drivers.

\+ In some cases users may force the non-users to drive slower than they normally would. This will enhance safety.

\+ The lower speed will contribute to an earlier recognition of other vehicles and vulnerable road users.

Estimated effects and assumptions

This effect might be substantial. On one hand non-users will attempt to overtake if a reduced speed of a user it is not obvious. This will happen even if there is a high risk. On the other hand if there is no possibility to overtake they might accept this circumstance and adapt their behaviour.

Table 28: Mechanism 5: Effects by circumstance.

MAPS&ADAS Variables	Mechanism 5: Modification of interaction between user and non-user
Accident type	Non-users might overtake more often. Therefore accidents with oncoming vehicle or unadapted speed will be most likely.
Link / intersection	The amount of overtaking will be higher on links. Normally there is no possibility for overtaking in intersections. The effect is expected to be biggest in link sections.
Road type	Depending on the penetration there is no modification in the interaction between users and non-users on motorways if the penetration is low. On rural or urban roads it is possible that drivers who generally go too fast with the flow will accept the speed limit and as a consequence reduce the average speed of the pile. On the other hand the modification might be strong on rural and urban roads. First of all there is almost only one lane so users and non-users had a permanent interaction. Beside the warning at dangerous sites may influence the interaction for example at blind corners or unclear crossings or t-junctions. At these sites drivers may probably pay more attention and react on driving faults of other road users. A road type dependent modification will probably occur, since the HSW is dedicated to rural roads.

MAPS&ADAS Variables	Mechanism 5: Modification of interaction between user and non-user
Vehicle type	Especially driver of not equipped passenger cars might tend to overtake vehicles following speed limits on roads with low speed limits more than HGV or busses. Effect is assumed to be bigger for passenger cars than heavy vehicle
Road weather	Under normal weather conditions non-users will more often attempt to overtake slower users than under adverse weather conditions. The main reason might be a poor visibility. The effect is expected to be bigger in adverse conditions
Lighting conditions	Similar to the road weather the driving task of non-users will be modified most in darkness. The effect is expected to be bigger in darkness

Mechanism 6–8: Modification of road exposure, modal choice and route choice

Changes in driver behaviour:

+ On a long-term base cautious drivers might tend to use “safer” roads more often than “unsafe” roads. This is a possibility especially for commuters or other drivers travelling the same origin-destination-connection often. But since the system is not really integrated in navigation systems for routing options the probability of this route choice adaptation is quite low.
+ Research of the accident risk shows that there is an decrease of intersections when driver use for example the least risky routes.
+ There is no information about the route choice of drivers if they are advised to take an other route as usual because of more safety.
+ It can be assumed that some amount of people would change the modal if there is a lack of safety on their route. For example travelling by train.

Estimated effects and assumptions

It is assumed that this effect is small. As the studies show there is a big potential of an increase in safety if the system can affect the route choice of drivers. By choosing a different (safe) route driver can decrease their risk exposure. Hence there is no real test reflecting this assumptions it is difficult to estimate an effect.

Table 29: Mechanism 6-8: Effects by circumstance.

MAPS&ADAS Variables	Mechanism 6-8: Modification of road exposure, modal choice and route choice
Accident type	The modal choice depends on the availability of an alternative means of transportation. If there is no choice the effect will be non-existent. On the other hand if there is a choice this will reduce all accident types similarly. Also in case of a different route choice. As a consequence all types of accidents will be reduced similarly. No type of accident is dominant
Link / intersection	Driving on less dangerous links and intersections will reduce accidents of

MAPS&ADAS Variables	Mechanism 6-8: Modification of road exposure, modal choice and route choice
	all types similarly. No type of accident is dominant
Road type	The modal choice can be seen as a function of the road type. Long distances are normally driven on motorways. For the choice of route it seems to be different. As shown, almost long distances were travelled on motorways. So most drivers didn't want to differ from this way because this will be associated with a loss of time. On rural (or even urban) roads this may be different. In most cases there is no alternative means of transportation. On the other hand in the case of route choice drivers will change their normal way based on information about speed (SLW) or dangerous sites (HSW). As the study [48] shows changing from a standard route can afford an increase in safety and beside a decrease of travelling time. Under such circumstances drivers will rely on such a system more often. The positive effect is expected to be biggest in rural roads. Effect in motorways is expected to be minor.
Vehicle type	These circumstances should be divided into two causes of travel: the commuter and the leisure traffic. In the case of leisure time is not that important. That means for this type of driver it is important to drive on a nice way to destination. This will have an great effect on cars because heavy vehicles are normally not used .for leisure traffic. In the other case time is one of the most important thing. Especially drivers of heavy vehicles have to save time. But it is also important for all employees to save time on the daily way to work. Therefore it may be that drivers try an alternative way in order to solve some speed limits or dangerous sites. Again, cautious passenger car drivers might tend to follow information of the system more frequently and might be more open to safety advises. The effect is expected to be equal to heavy vehicles and cars.
Road weather	Bad weather conditions are a possible reason for drivers to choose a different means of transportation or change the route. Especially in wintertime drivers will accept an indirect way to their destination. For example if roads are covered with snow and ice drivers would prefer motorways even it is not the direct way because maintenance on motorways will occur first. If drivers note significantly more warnings in adverse weather conditions on certain stretches of roads, the influence on the route choice behaviour might be higher in adverse weather conditions. The effect is expected to be bigger in adverse conditions
Lighting conditions	There might be no additional effect on daylight. At night drivers may choose a different route because of the possibility to be involved in an accident at sites they are warned by the HSW. In order to avoid such circumstances they will change the route to one that is more attractive. The effect is expected to be bigger in darkness

Mechanism 9: Modification of accident consequences

The seriousness of an accident correlates directly to the speed [59]. Therefore it is necessary to reduce speeding and speed in order to increase safety.

This is the most important mechanism, since correlations between driving speed and accident consequences are obvious.

Changes in accident consequences:

+ The system is especially designed to prevent accidents or mitigate accident consequences. Its focus lies on the warning at accident prone locations. This means that a well working system should "defuse" these locations and lead to fewer and less severe accidents by reducing the speed and increasing the attention of drivers.

Estimated effects and assumptions

There is a major effect on the accident consequences by the HSW if it reduces the driving speed. As indicated earlier, according to the power model [4], the risk of injury in an accident increases by the second power of the mean speed, and the risk of a fatal accident increases by the forth power of the mean speed.

5.3.3 Conclusions

MAPS&ADAS (Hot Spot Warning) is expected to have direct effects on driving task. In addition to the direct effects on driving task, it expected that there are indirect effects on driving task which results in the increase of accidents, especially at sites not marked in the maps, at link sections, on rural roads, in adverse weather conditions and at night. The modification of interaction between users and non-users as well as modification of accident consequences can be substantial. Typically, the effects are most substantial on accidents that include speeding cars, and occur in link sections of rural roads and in adverse weather conditions or at night. Other effects are expected to be minor.

5.4 SAFELANE

5.4.1 Literature review

The outcomes of the literature review are presented in this caption and split among the relevant safety mechanism chapters. A series of accident statistics (national, European and US) and analyses relevant to SAFELANE-like systems have been collected. On the basis of them, further estimations and assumptions have been made. Gaps have been detected mainly as regards in-direct long-term effects of such systems as well as behaviour of non-users and their interaction with users; further research would be valuable in these issues. In addition, not enough data have been available from real on-road and simulator trials, which make the estimations and assumptions made ambiguous in some cases (for example the Enke theory [86] on the number of accidents that could be avoided by such systems should be preferably reviewed on the basis of recent trials/experiments results).

Terminology

A simple lane departure, defined as at least one tire crossing the lane boundary, is too stringent. Many drivers, especially truck drivers, tend to touch and cross the lane boundary quite often during normal driving. Sounding a warning in these cases would annoy the driver. Instead, a “substantial lane departure” is defined as a situation in which the vehicle is more than 50% outside the lane. This may or may not result in a crash, depending on road conditions, vehicle conditions, and driver ability.

Substantial lane departures, however, are quite rare. While it is not unusual for drivers to cross the lane edge slightly, a deviation of almost a meter is uncommon, unless there are extenuating circumstances, like construction zones or debris in the road. It is also possible for lesser deviations to lead to crashes, which is better defined as a Run-Off-Road (ROR) Situation: Any state in which any part of the vehicle departs the lane. Whether an ROR situation leads to a crash depends on the extent of the departure, road state, and driver reaction time and ability.

Lane departure warning (LDW) is a driver warning system designed to reduce the number of unintended lane departures.

Accident scenarios and target accidents

The SAFELANE system provides lane keeping support in critical lane departure situations on motorways and rural roads. The system is so called Lateral Departure Warning (LDW) and it provides acoustic, visual and haptic feedback to the driver.

According to Abele et al (2004) [63], lane departure warning systems can prevent or reduce the severity of the accidents in which two vehicles collide frontally (head-on collision) and accidents in which a vehicle leaves the road without colliding with another vehicle (“left roadway” or “single-vehicle” accidents) sliding either to the right or to the left side of the road. However, according to the e-safety database, one more type of accident is also addressed, in which two or more vehicles collide laterally. Thus, these three types of accidents will constitute the main target accident groups of SAFELANE and SAFELANE-like systems.

The above classification is also in agreement with McKeever [85]:

+ 2.7% of all accidents are assumed to be “head-on” collisions accidents (3% of all accidents of the U.S.; however higher for fatal accidents); According to Finnish data (VALT), approximately 34% of all fatal accidents in Finland are head-on accidents (approximately 60% of them occur on a straight road section) and according to Gården [87] approximately 25% of fatal crashes in OECD Member countries are head-on collisions (almost 50% of these accidents were attributed to “driving left on roadway centre with no specific reason”).
+ 19.5% of all accidents belong to “left roadway” accidents category (referring to all road types; rural, urban and highways); The corresponding percentage in U.S. is 17% and these accidents are assumed to be responsible for approximately 37% of the annual highway fatalities [73]. According to a statistical

review of the 1992 (GES) and (FARS) databases, this type of crashes account for over 20% of all police reported crashes and over 41% of all in-vehicle fatalities.
+ 2.5% of all accidents belong to side–collision accidents in which the vehicles are travelling in the same direction.

These percentages appear reasonable compared with accident statistics from Germany and other studies analysing the accident avoidance capabilities of LCA and LDW ([88], [89]).. The above types of accidents constitute the main groups of accidents that can be addressed (partially) from the technical point of view by SAFELANE and SAFELANE-like systems.

Target accidents

SAFELANE and SAFELANE-like systems addressing unintentional lane departure cope with accidents associated to fatigue, sleepiness and in general driver reduced vigilance. In this context the possible SAFELANE scenarios interfering with a critical lane departure could be:

1. Driver distracted by in-vehicle situations (looking away);
2. Driver distracted by cognitive workload (looking but not seeing);
3. Fatigue driving, driver fallen asleep.

On the basis of the above scenarios, accident statistics are provided below depicting the percentage of accidents that could be addressed (at least partially) by SAFELANE-like systems. The following data in combination with the portion of relevant to SAFELANE accident groups (i.e. head-on accidents, etc.) in total accidents in several countries and the functional relationship between faster driver reaction and collision probability [86], as detailed below, Mechanism 1 assumptions have emerged.

1. In-depth analysis of Maine accident data in 2000-2002 showed that in 13% of head-on accidents inattention was the main contributing factor and in 9% fatigue/falling a sleep was the main contributing factor.
2. According to Jenssen and Moe [90], also in Norwegian accident data, fatigue is the main contributing factor in approximately 30% and distraction in about 8% of straight road head-on and single-vehicle accidents (*related also to "single vehicle" accidents category*). They also concluded that rumble strips on the road centre or edge line could very likely have reduced the accident risk in 33% of these types of accidents (counting together fatigue, asleep and inattentiveness).
3. Unlike many of the rest crash types, run-off-road crashes are resulted from a wide variety of factors. The most common contributing factor is the driver's failure to control the vehicle. Detailed analysis of 200 NASS CDS crash reports indicates that run-off-road crashes are primarily related to the following six factors :

a) Excessive speed (32.0%) - travelling too fast to maintain control.
b) Driver incapacitation (20.1%) - typically drowsiness or intoxication (possibly partially addressed by LDW systems).
c) Lost directional control (16.0%) - typically due to wet or icy pavement.
d) Evasive manoeuvres (15.7%) - driver steers off road to avoid obstacle.
e) Driver inattention (12.7%) - typically due to internal or external distraction (possibly addressed by LDW systems).
f) Vehicle failure (3.6%) - typically due to tire blow-out or steering system failure.

4. Statistics from ADAC [82] show that approximately 15% of single-vehicle accidents in Germany occur because of unintended lane departure.
5. In the USA the unintended lane departure proportion is as high as 24%. There may be a variety of factors contributing to unintentional lane departure, e.g. activities such as eating and drinking but also physical reasons such as drowsiness and fatigue. The U.S. government identifies lane departures as a major contributing factor of rollover incidents involving SUVs and light trucks. According to NHTSA, 95% of single vehicle rollover accidents are "tripped" rollovers that occur when a vehicle leaves the roadway and slides sideways into the soft soil on the shoulder of the road or hits an object such as a curb or guardrail. Though only 3% of vehicle accidents in the U.S. are rollover accidents, they account for approximately 33% of all vehicular fatalities according to NHTSA research. To reduce rollovers, some highways have "rumble strips" carved into the edge or the pavement to signal the driver that the vehicle is leaving the roadway. Rumble strips reduce unintended road departure by 30-55% according to NHTSA. On-vehicle Lane Departure Warning (LDW) systems provide similar functions for all lanes of highway travel and on roadways without physical rumble strips.
6. According to Finnish data (VALT), approximately 32% of all fatal accidents in Finland are single vehicle/loss of control accidents. There are five categories of main contributing factors related to these accidents:

   a. alcohol-related accident 49% (75% out of these accidents includes speeding as well)
   b. multi-factor accidents (distraction etc.) 22% (this could be partially addressed by LDW systems)
   c. fit (medical) 11%
   d. fatigue (falling asleep) 10% (this could be partially addressed by LDW systems)
   e. on-purpose accidents 8% (probably suicides).

7. According to Grace et al. [91] simple inattention to the driving task or drowsiness leads to about one in eight

(12.7%) road departures for both passenger cars and heavy trucks. The data shows that truck drivers who fall asleep are the single largest group of run-off-road truck crashes. However, the sampling method used to select truck crashes for study may have resulted in the number of fatigue-related crashes to be somewhat overestimated (Grace et al., 1998). Driving with hypovigilance is a significant problem for passenger car drivers but a relatively small part of the total for truck drivers [67]. Heavy duty vehicles are vehicles weighting more than 3.5 tons and up to 40 or even 65 tons. They count for less than 5% of the overall vehicle stock but more than 20% of the mileage driven. Heavy duty vehicles are involved in just a minority of the accidents on European roads. However, if a heavy duty vehicle is involved in an accident, the consequences are more substantial compared to car accidents [63].

Road departure crashes most frequently occur on straight roads (76%), on dry roads (62%) in good weather (73%), on rural or suburban roads (75%). They occur almost evenly split between day and night. However, drowsiness is frequently reported during night-time driving and in monotonous driving conditions [92], with 51% of drivers reporting that they have driven a vehicle while feeling drowsy in the past year. NHTSA data [93] shows that in recent years there have been about 100,000 crashes annually in which police cited driver drowsiness, resulting in about 1,500 fatalities [72].

Unintended steering wheel motions may lead unintended lane departure. Recent studies have shown that people who use cell phones while driving have crashes which are similar to those of drunk drivers. For instance, a driver talking on a cell phone might not notice that the vehicle is slowly drifting off the road, or may not notice an upcoming curve. A failure to properly control the vehicle in such a case could lead to a crash.

Based on a functional relationship between faster driver reaction and collision probability [86], the following assumptions were made about the percentage of accidents avoided and/or mitigated due to LDW and LCA:

a) Head-on collisions: It is assumed that LDW warning enables a driver to react, on average, 0.5 seconds earlier than he or she would without the system. This effects a collision reduction of 25% for all relevant accidents. Furthermore, in 25% of the accidents, a reduction in accident severity can be assumed.
b) “Left roadway” accidents: Time gains of 0.5 seconds can also be assumed for this type of accident using an LDW system. This translates into 25% accident avoidance and 15% accident severity reduction.

Side-collision accidents: Both analysed IVSS can contribute to accident avoidance. It is assumed that the aggregate time gain is composed of 0.5 s for the warning phase (LDW and LCA affect different accident causes and therefore the time gains are not combined) and 0.2 s for the assistance phase (LCA with haptic feedback). The cumulated time gain is 0.7 s. This leads us to expect a 60% reduction in the number of accidents and a 10% reduction in accident severity [63],[72],

5.4.2 Safety impact mechanisms

The following discussion is based on the assumption of a system with feedback (e.g. acoustic or haptic) and an active steering component, supplying a supporting torque on the steering wheel in the direction of the lane centre to trigger intuitive reaction of the driver.

Mechanism 1: Direct in-car modification of the driving task

SAFELANE supports the driver in staying in his/her own lane and takes over parts of the drivers' operational driving task, so that this activity is shared between the system and the driver.

Changes in behaviour

+ It increases users' awareness in situations when an unintended lane change is detected. This will reduce the number and duration of "out-of-lane" episodes, which means, the driver is keeping the vehicle more to the centre of his lane.
+ The driver will be supported in surpassing driving situations, e. g. in dense traffic or narrow lanes. This will lead to a reduction of workload resulting from the lane keeping task. The emerging free capacity can be assigned to other tasks, where the performance should then increase. This will also turn the system to a comfort system (i.e. lower situational demand) (see also Mechanism 3).
+ A reduced "Duration of Lateral Excursion" will heavily decrease the risk of crashing during an unintended lane change. The same is true for a reduced number of "Lateral Excursions".
– SAFELANE-like systems might induce platoon driving with bigger headway, in case road markings are masked by a vehicle driving ahead and the perception is not sufficient to keep the system operating. This will especially change the behaviour of truck drivers, who might tend to increase the headway to other vehicles/ trucks to enable the SAFELANE system (see also Mechanism 3). However, the specific system of SAFELANE operates even with no lane markings existing.

In addition to the above, assumption made in the context of Mechanism 3 should be taken into consideration.

Table 30: Mechanism 1-Effects by circumstance.

SAFELANE Variable	Mechanism 1: Direct in-car modification of the driving task
Accident type (frontal/side accidents)	SAFELANE-like systems are foreseen to have a greater positive impact in side accidents than in head-on accidents.
Link/intersection	Not relevant.
Road type (motorway/	Most of the road departure crashes occur on rural and suburban roads;

SAFELANE Variable	Mechanism 1: Direct in-car modification of the driving task
rural/ urban)	thus a positive impact is foreseen mainly for these types of roads and also in highways. According to the technical tests, the perception system had problems in the classification of bridges and big road signs ahead and sometimes classified them as obstacles ahead. Since these objects are denser on high class roads, the respective reduction of the positive safety effects may be restricted to these. However, this depends of the specific system reliability each time and should not be taken for granted without any further investigation.
Vehicle type (passenger car/ HGV/ Bus)	Although HGV accidents are not so many with regard to the total accidents, hypovigilance is the main contributing factor of run-off truck road crashes, whereas in addition the accident severity in case of a truck crash is much higher in comparison to the passenger vehicles crashes cases; thus it could be claimed that, disregarding the actual proportion, positive effects are foreseen especially for truck drivers.
Road weather (adverse/ normal)	The system tests showed that even in adverse conditions (rain) the systems performance in detecting lanes was satisfying. However, in adverse road conditions the drivers tend to pay more attention to lane keeping also without the system, so the effect might be smaller (most accidents occur in normal road conditions). Also the operational level of vehicle control is more complex in adverse road conditions (at least in low friction situations) and therefore the warning might not be as effective in fatality reduction.
Lighting conditions (day/night)	Although accidents are split between day and night, hypovigilance is a phenomenon noticed mainly in night driving and monotonous driving conditions.

Mechanism 3: Indirect modification of user behaviour

Changes in behaviour

- After a familiarisation phase, drivers might tend to shift responsibility to the system and rely on it [74]. This effect might be stronger in situations where the system shows a high reliability (probably on highways). It might even lead to increasing in-car activities, which are not directly related to the driving task, like using mobile phones or even working on documents of transport (related especially to truck drivers). In general, according to several relevant studies outcomes described ([66],[75],[76]), an increased automation leads to increased performance in secondary tasks because drivers have some mental capacity left which they can reassign to other tasks. This will likely lead to a reduced situation awareness and hence to higher accident probabilities.

Overconfidence to the systems seems to be evident even in cases that the reliability of the system is not the best possible (from the early stages of uses or progressively), as also shown in the experiments of Rudin-Brown and Noy [75] experiments.

The following ACC related aspects can be partially transferred to SAFELANE like systems:

Drivers may use any freed visual, cognitive and physical resources to engage in non-driving tasks that they perceive as improving their productivity. In reality, however, these tasks may reduce their vigilance and attention to the primary driving task, which could result in driver distraction, and a failure to detect and respond to critical driving situations ([65],[78])

+ As also analysed in SEiSS final report [63], unintentional lane departure can be caused by temporary inattentiveness of a driver busy with tasks other than driving. In such cases a well-designed warning system can certainly be effective. However, when a driver is incapable of driving, because of tiredness, or because of drugs or alcohol, a warning system may give a false feeling of security (compensation behaviour). However, if the system gives "continuous" feedback about driving path, drivers might change their optional/target lateral position while driving trying to avoid the non-necessary warnings). It was found that users increase their lane keeping performance following warnings of the system [75]. This leads to the assumption that drivers tend to adapt their behaviour, respectively their driving performance in terms of decreasing lane departures and hence they avoid receive warnings, which, in general, implies a positive effect in traffic safety.

– However, an opposite effect coming to serve the same need could be the deactivation of the system by the drivers in order to avoid receiving too many warnings. At this point, the system personalisation issues according to individual driver behaviour arise.

– Warning driver about lane departure in combination with overconfidence on the system might also lead to longer driving hour even if s/he feels drowsy.

+ Smoother driving behaviour is expected including less tailgating and unintentional lane departures, more equal distribution of speed, smoother acceleration and better use of indicators. In specific, in AIDE project [74], the long term trials results imply that the indicators use will be much more frequent than without the system, especially in case of participants who usually did not use turn signals, since the drivers will tend to avoid any unnecessary warnings, whereas the users will be better situated within lanes.

– However, according to Korse et. al. [71] and the results emerging from trials with SAFELANE-like systems, the expectation is that a part of the positive LDW effect will disappear in time (relates mainly to heavy goods vehicles or busses).

+ According to Korse [71] LDW use results in shorter reaction times and increases driver comfort.

No effect on driving speed is expected due to LDW. [67].

Estimated effects and assumptions

- After a familiarisation phase, overconfident issues may arise, leading, in some cases, to increasing in-vehicle activities, which are not directly related to the driving task which could imply reduced situation awareness and hence to higher accident probabilities.

- However, the drivers might conform to the system and increase their lane keeping performance trying to avoid continuous warnings.

Table 31: Mechanism 3 - Effects by circumstance.

SAFELANE Variable	Mechanism 3: Indirect modification of user behaviour
Accident type (frontal/side accidents)	SAFELANE-like systems affect driving behaviour mostly in the lateral axis, thus the system is expected to be especially effective for this group of accidents.
Link/intersection	Not relevant
Road type (motorway/ rural/ urban)	The positive effects might be larger in low workload driving situations more often relevant to rural roads than to motorways
Vehicle type (passenger car/ HGV/ Bus)	No evidence has been found regarding the change in driving behaviour between different types of drivers/vehicles.
Road weather (adverse/ normal)	No evidence.
Lighting conditions (day/night)	No evidence.

Mechanism 4: Indirect modification of non-user behaviour

There is no data available on the effects that SAFELANE like systems could have for non-users. Not trials/experiments results are available; thus no assumptions regarding indirect modification of non-user behaviour have been made.

Mechanism 5: Modification of interaction between users and non-users

Estimated effects and assumptions

In case of changes in platoon characteristics (increased headway between the vehicles [trucks, mainly]), non-users might increase their overtaking activities and use the increased gaps between the platooning vehicles as interstations while overtaking the whole platoon. This is an assumption and it would depend on how long headways the drivers will have when using the SAFELANE-like systems. However, not vast literature is available with regard to the modification of interaction between users and non-users; thus more research making available real long-term trials results is needed.

Mechanisms 6-8: Modification of road user exposure, modal choice and route choice

Estimated effects and assumptions

Following changes in route choice, longer paths might be selected and the respective “time in traffic” will increase. However, if the system works better on more safe (higher standard) road, this will at least partially compensate the increased accident risk caused by increased exposure. This leads to an increased user exposure. This effect is probably some kind of “playing with the system” effect of passenger vehicle drivers, will probably be very small and is not foreseen in long term use. The exposure of HGV and buses, directly related to the path length, is more a consequence of budget in terms of time and money and business planning.

Temporarily, buyers might tend to use their car/ vehicle more often due to new systems. However, the additional effect of a SAFELANE-like system will probably be marginal. Such an effect will less likely occur for trucks or buses, since modal choice will not depend on safety systems, but on time and budget constraints.

Route choice might change, depending on the preservation state of the lane markings. Roads with high quality markings might be selected more often than roads with nearly invisible markings. Following maintenance guidelines, high class roads preservation state is usually better, so these might be chosen more often than others. Hence, this will lead to higher traffic volumes on highways and consequently to lower traffic volumes on lower class roads. Since highways are the safest roads in terms of accident rates (accidents per vehicle-km), the safety effect might be noticeable.

Again, this effect will most probably be restricted to passenger cars, since the route choice of commercial trucks and busses does normally not depend on safety considerations, but on time and budget constraints as well as business planning.

Effects by circumstance

Table 32: Mechanism 6-8-Effects by circumstance.

SAFELANE Variable	**Mechanisms 6-8 Modification of road user exposure, modal choice and route choice**
Accident type (frontal/side accidents)	Not relevant
Link/intersection	Not relevant
Road type (motorway/ rural/ urban)	Road markings and system higher reliability in motorways may lead to longer exposure and relevant route choices; thus safety is foreseen to increase mainly in this type of roads (however, according to SAFELANE system description, the system operates normally even if there are no lane markings).
Vehicle type (passenger car/ HGV/ Bus)	Safety is foreseen to increase mainly for passenger vehicles, since user exposure, modal and route choice in HGV and Buses segments are not dependent on safety systems availability but more on business planning interfering with cost and time constraints.
Road weather (adverse/ normal)	Not relevant
Lighting conditions (day/night)	Not relevant

Mechanism 9: Modification of accident consequences

Estimated effects and assumptions

+ SAFELANE-like systems might suppress platoon driving, in case road markings are masked by a vehicle driving ahead and the perception is not sufficient to keep the system operating. This will especially change the behaviour of truck drivers, who might tend to increase the headway to other vehicles/ trucks to enable the SAFELANE-like system. This might bring changes in platoon characteristics (headway of the vehicles), leading to an increasing or decreasing usage of road capacity (increasing usage of capacity, because delays induced by high truck density might decrease; decreasing usage of capacity, because longer time gaps lead to increasing required space for each truck). As a side effect, longer time gaps/ increased headway will most probably lead to fewer and less sever accidents. However, the specific system of SAFELANE operates efficiently, even with no lane markings (please see system limitations).

+ As already mentioned in Mechanism 1, the potentially reduced "Duration of Lateral Excursion" as well as the reduced number of "Lateral Excursions" will heavily decrease the risk of crashing during an unintended lane change. However, apart from this, if the accident occurs, the driver will have more time for mitigating actions/manoeuvres, which might also reduce the accident consequences.
+ Changes in the trajectory of an equipped vehicle (more acute [smaller] angle) will reduce the impact/ impulse fed into the crashing vehicles. Hence the accident consequences will decrease due to lower impact speed in normal direction of both vehicles.

The above are in line with Enke [86], according to which a significant reduction in accident severity can be achieved in 25% of head-on relevant accidents, in 15% of left roadway relevant accidents and in 10% of side-collision relevant accidents.

Effects by circumstance

Table 33: Mechanism 9-Effects by circumstance.

SAFELANE Variable	**Mechanisms 9 Modification of accident consequences**
Accident type (frontal/side accidents)	The potentially reduced "Duration of Lateral Excursion" as well as the reduced number of "Lateral Excursions" will heavily decrease the risk of crashing during an unintended lane change. However, apart from this, if the accident occurs, the driver will have more time for mitigating actions/manoeuvres, which might also reduce the accident consequences, at least in the lateral fields.
Link/intersection	No specific evidence.
Road type (motorway/ rural/ urban)	No specific evidence.
Vehicle type (passenger car/ HGV/ Bus)	Longer time gaps/ increased headway foreseen especially in trucks will most probably lead to fewer and less sever accidents.
Road weather (adverse/ normal)	No specific evidence.
Lighting conditions (day/night)	No specific evidence.

5.4.3 Conclusions

SAFELANE is expected to have direct effects on driving task. Specifically, the system might reduce the number of side accidents and accidents involving trucks. Indirect modification of user behaviour can be either positive or negative. In addition, it is expected that the system may increase driving and thereby exposure, especially that of passenger cars. On the other hand, the system could lead to the decrease of accident consequences. Other effects, if any, are expected to be small.

5.5 SASPENCE

5.5.1 Literature review

Direct empirical evidence on safety impacts does not exist because SASPENCE is a future system.

Expert evaluations of safety impacts are based on the accident analyses, user tests and simulations conducted in the PReVENT project. TNO has conducted tests in Vehil Lab and simulations with the ITS Modeller. However, the results were not available in time for this study.

Indirect evidence on safety impacts. For situation 1 this can be based on studies on collision warning and – to a limited extent – ACC, keeping in mind that SASPENCE is purely advisory. For situation 2 we can use studies on advisory ISA systems and SpeedAlert.

For the literature review the scenarios are divided in three groups:

- vehicle in front, car following (scenario 1)
- vehicle in front, sudden change (scenario 2 and 3)
- speed limit advice (scenario 5 and 6)

For the latter two groups we also present some preliminary quantitative assessments.

5.5.1.1 Vehicle in front, car following

This function of SASPENCE can be compared with ACC, as long as we keep in mind the important distinction that ACC is controlling, while SASPENCE is informative. Experiments in Hoedemaeker [101] clearly demonstrate that driving behaviour with ACC reduces speed variability and initial individual differences in driving behaviour on motorways, which harmonizes traffic. A more harmonised traffic pattern can also reduce the number of accidents and thereby increase traffic safety. However, on roads other than motorways, we should be very careful with the introduction of ACC, because of dangerous overtaking behaviour and delayed reactions to traffic from the right.

Chira-Chavala and Yoo [102]analyze a hypothetical intelligent cruise control system and find that it could potentially reduce traffic accidents by up to 7.5%. Preliminary vehicle simulation results based on a 10-vehicle convoy indicate that the system could reduce frequencies of hard acceleration and deceleration, enhance speed harmonization among vehicles, and reduce incidence of “less-safe” headway.

An assessment of ACC by Hoedemaeker and Brookhuis [103] shows that merging manoeuvres were carried out more efficiently with ACC. However, low speed drivers increased their maximum braking level when they had to perform an emergency stop with an ACC. Apparently driving with an ACC forces this particular group of drivers to brake hard. Furthermore, if an Adaptive Cruise Control is explicitly meant to be effective as a safety system, the acceptability of the system to the fast drivers (who could benefit most in terms of traffic safety) needs to be greatly enhanced.

Among low speed drivers a negative effect was apparent; they drove faster and (hence) less safe with ACC than without.

A simulator study by Wilmink et al [104] shows that ACC decreases the variation in speed and acceleration.

5.5.1.2 Vehicle in front, sudden change

The following accident statistic and literature review concerns scenarios 2 and 3, where we consider the safe speed and safe headway functions of SASPENCE (Fm1 & Fm2) when a vehicle suddenly appears in front of the SASPENCE vehicle. The review discusses the following aspects:

- The relevant accident types: how many fatalities occur in accidents that correspond to scenarios 2 and 3;
- The possible effects of a headway warning system: how many fatalities could potentially be avoided by the system;
- The potential driver behaviour when this type of warning is used. We distinguish two limitations on the driver reaction:
    - How often the driver is in condition to react at all (i.e., not unconscious, etc);
    - How often the driver is willing and able to react *sufficiently* to avoid the accident. If the driver does not avoid the accident, we determine how often and by how much the accident severity is mitigated.

The statistical part concerns accidents from Finnish database (VALT) where all fatal accidents have been studied by Road Accident Investigation Teams.

In the SASPENCE Safety Assessment scenarios 2 and 3 describe the following situations:

2) Head-to-tail collisions with braking vehicle and other head-to-tail collision with moving vehicle,
3) Situations where a vehicle changes lane to the right or to the left just in the other vehicle's way.

The Finnish data show that approximately 1.4% of all fatalities occurred in situations mentioned above (data from years 2000–2003; situation 2: 1.1% and situation 3: 0.3%).

The injury rear-end accidents mainly happened to situations where the vehicle in front either braked (44%) or was stopped (34%).

Driver inattention has been identified as contributing factors in 60% of all rear-end accidents in the U.S. The distraction factor is getting more important since there is a potential to increasing driver distraction with increasing number of in-vehicle devices etc. Furthermore, the experiment of Lee et al. [105] showed that also non-distracted drivers benefit from the warning system.

Sullivan and Flannagan [106] showed that if the exposure level is taken into account, the rear-end accidents appear to be more than twice as likely in dark as in daylight.

Driver reactions and accident reduction possibilities

According to Lee et al. [105] an early warning aids drivers in avoiding accident by speeding up the accelerator release, but it does not enhance any other aspects of the response (no quicker or harder braking). However, an early warning helped approximately 80% of distracted drivers to avoid the rear-end accident. The late warning helped to avoid 50% of the accidents. This, of course, depends on the warning strategy (when the warning is given).

According to the study, both distracted and non-distracted drivers benefit from the rear-end collision avoidance system and have the possibility of greater safety margin (warning reduced the reaction time, releasing the gas pedal) with 0.6 s with both distracted and non-distracted drivers).

Sultan and McDonald [22] reported that 50% of drivers did not press the brake pedal strong enough in emergency braking and therefore also some additional braking assistance might be needed to gain the greatest safety potential in braking warning systems. However, SASPENCE has no braking assistance system and this might reduce the safety potential of the warning system. Also, in the experiments of Lee et al. [105] some driver seemed to ignore or discount the warning – drivers did not either fully understand the nature/purpose of the warning or drivers did not trust the early warning. Also some drivers failed to respond appropriately. This demonstrates that although a warning can aid drivers, it will not enhance all drivers in all situations.

According to Lee et al. [105] an early warning reduced the non-avoided accident severity by 95% (in proportional to kinetic energy). The late warning reduced the non-avoided accident severity by 80%.

5.5.1.3 Speed Limit Advice

ISA (intelligent speed adaptation) or SpeedAlert is a system that helps drivers to obey the speed limit. This is one of the functions of SASPENCE, namely Fm3.

This system can be implemented in many ways. Firstly, there can be various degrees of intervention in the driving task. One usually distinguishes between

- Informative or advisory: the system advises on the current speed limit, and/or warns when the limit is exceeded.
- Intervening: the system tries to "persuade" the driver to obey the speed limit, but the driver can ignore or override this. Usually this is implemented as a haptic gas pedal that pushes the pedal up when the limit is exceeded. The driver can override this by pressing down hard on the pedal.
- Controlling: the system controls the throttle and sometimes even the brake to prevent the driver from speeding at all.

Secondly, the system can be "always on", or the user has the option to switch it "off".

Thirdly, the system can operate for different kinds of speed limits:

- Fixed limits only. This is the simplest version that merely requires positioning equipment and digital maps.
- Fixed and variable speed limits. Variable speed limits are limits that vary over time, but in a regular and predetermined way (for example school zones, or different speed limits in summer and winter).
- Fixed, variable and dynamic speed limits. Dynamic speed limits are limits that vary by circumstance (for example depending on traffic flow, accidents, or weather). This requires communication equipment, both in-vehicle and roadside.

The HMI of SASPENCE will provide visual feedback to the driver concerning the speed limit, namely an icon that indicates the speed limit. The icon flashes when the driver exceeds the limit. Thus, SASPENCE has to be classified as an informative ISA.

As SASPENCE is a voluntary system we will assume that it can be switched off by the driver.

To decide which speed limits will be incorporated we can compare with SpeedAlert. SpeedAlert is a system for speed limit advice, which is expected to handle fixed speed limits in 2010 and dynamic speed limits in 2020. We will assume that SASPENCE can handle dynamic speed limits.

We will present a quantitative analysis of the safety impact of SASPENCE speed limit advice, supported by relevant literature. Our quantitative analysis will make use of the results obtained in road tests of ISA systems. Hence it will not completely follow the methodology used in the qualitative analysis, but rather present an overall estimate. This estimate includes the direct in-car modification of the driving task (mechanism 1 from the methodology), the indirect modification of user behaviour (mechanism 3) and the modification of accident consequences (mechanism 9), but not the other effects. We expect the remaining modifier (from mechanism 5) to be very small.

Speed reduction and accident reduction by SASPENCE Fm3.

According to the LAVIA study [110], the speed limit is violated 16.5% of the time in France without an ISA system, and 14.8% of the time with an informative system: a reduction of 1.7 percentage points or 10.3% (relative) compared to the unequipped situation. For an intervening system the relative reduction is 27.9%.

Furthermore, with an advisory system the average amount of speeding is reduced by 0.8 km/h (from 10.8 km/h to 10 km/h). This is summarized in the following table:

Table 34. Speed reduction by LAVIA.

	No ISA	Advisory ISA
speeding (% of time)	16.5%	14.8%
change (absolute)		-1.7%
change (relative)		-10.3%
excess of limit by speeders (km/h)	10.8	10.0
change (absolute)		-0.8
change (relative)		-7.4%

According to the TAC SafeCar study [114] an intervening ISA reduces the percentage of time spent at speeds that are more than 2 km/h above the speed limit by 1/3 to ½. If we consider the percentage of time spent at more than 5 km/h above the limit, then the relative reduction is even higher, at ½ to 2/3. This is quite comparable to the intervening version of LAVIA.

Three Swedish studies (in Umeå, Borlänge, Lund) show a reduction of the number of speeders with an advisory system to ½ or more on urban and rural roads, and to 2/3 on motorways. The effect is even more pronounced for an intervening system. In these studies, ”speeding” means driving at least 5 km/h over the limit, which perhaps explains why the effects are so large. The average speed is reduced by 0.75 – 2.5 km/h in all cases.

The advisory LAVIA system is closest to our situation and therefore we assume that SASPENCE speed limit advice will reduce the number of accidents caused by speed limit violation by 10.3%. For the remaining 89.7% of these accidents the effect of SASPENCE is to reduce the speed by 0.8 km/h.

Effect of speed reduction on fatalities

The effect of a 1 km/h speed change on accidents is given by [116]

Table 35. Effect of a 1 km/h speed change on injuries and fatalities.

Accidents	Speed before accident					
	50 km/h	70 km/h	80 km/h	90 km/h	100 km/h	120 km/h
Injury accident	4,0%	2,9%	2,5%	2,2%	2,0%	1,7%
Severe injury accident	6,1%	4,3%	3,8%	3,4%	3,0%	2,5%
Fatal accident	8,2%	5,9%	5,1%	4,5%	4,1%	3,3%

For simplicity we assume that a 1 km/h change in speed results in a 5% reduction in the number of fatalities. For small changes this effect can be taken as a linear function of the speed change, hence a speed reduction of 0.8 km/h leads to a reduction of 4% in fatalities.

5.5.2 Safety impact mechanisms

The functions and scenarios will be assessed in two groups: functions 1 and 2 by scenarios 1, 2 and 3 (Critical situations, vehicle in front) and function 3 by scenarios 5 and 6 (static speed advice).

5.5.2.1 Fm1&2: Critical situations (vehicle in front)

Mechanism 1: Direct in-car modification of the driving task by giving speed and headway warnings and advice

+ The system advises and warns the driver on safe headway and speed in case there is a moving vehicle in front. The warnings and advice help the driver to
    + Focus attention on the situations ahead (situation awareness, of vehicles in front), due to HMI alarms.
    + Adapt headway and speed (earlier) to the (speed of the) vehicle in front, due to distance and speed advice.
+ Heavy braking can be avoided because of early adaptation of speed or distance headway. Also suddenly changing situations are detected and driver is warned. The risk of accidents (running into a slower/braking vehicle, losing control of vehicle) will reduce, and the consequences of these accidents will reduce.

- During warnings the system diverts attention away from dangers to the side and rear of the vehicle. We assume that this is a very small effect.

Some additional comments:

- If it is assumed that the system makes the driver better and earlier aware of potential collisions (slower/braking vehicle), the system needs to give the advice/warning well before the driver can or would have detected it him/herself. It is also important that the system does not have a large number of false alarms, or give advice that excessively leans to the safe side.
- The system can be expected to make a contribution both in congested traffic and in low intensity traffic.

Table 36: Mechanism 1: Effects by circumstance.

SASPENCE Variables	**Mechanism 1:** **Direct in-car modification of the driving task by giving speed and headway warnings and advice**
Accident type	Especially rear end accidents
Link / intersection	No difference. The system is expected to give more warnings in intersections, but warnings given in link are more surprising for the driver.
Road type	- SASPENCE does not work when the ego-vehicle travels with a speed under 40 km/h. Hence it will not play a significant role on urban roads. For PReVAL we assume that SASPENCE does not operate on urban roads. - On rural roads the sight distances are shorter than on motorways, but speeds are also lower. It is unclear whether the SASPENCE system will be less or more effective on rural roads than on motorways. - On motorways speed differences between cars and trucks are larger, but this should not influence the working of the system, if speed and distance advices are tailored to the vehicle's characteristics (specific settings for passenger cars, goods vehicles and buses). - On rural roads the motorized traffic is mixed with parked vehicles, slow tractors and the like, and pedestrians and cyclists. We assume that SASPENCE will not detect stopped objects, pedestrians and cyclists, and that only moving cars and trucks with speeds over 40 km/h will be detected. No effect for urban roads. For rural roads and motorways, the effects seem to depend not on road type, but on situations encountered where SASPENCE might give an effective advice.
Vehicle type	SASPENCE is only available for passenger cars.
Road weather	- If the SASPENCE system does not differentiate between different weather conditions (if the warnings (and thresholds for the warnings) are the same in all conditions), then the normal warning may not be sufficient in adverse weather.
Lighting conditions	- In darkness a slow vehicle or an obstacle in front appears more unexpectedly without the system. The radar (and the camera?) possibly detects these obstacles earlier. The effect of this is unclear; possibly, SASPENCE has larger effects at night.

Mechanism 3: Indirect modification of user behaviour

- The warning about braking/slow/cutting in vehicle might reduce the driver situation awareness if he relies too much on the system.
- The system generally diverts driver's attention more to longitudinal situations increasing the risks related to other situations.
- Users may start to depend on the advice and warnings given by the SASPENCE system. This may result in shorter average headways, as the system will tell them when it is not safe anymore.

\+ Depending on the warning threshold and the annoyance of the warning user might also learn to avoid the warning and thereby too short headways.

+ More homogeneous speeds in platoons (a narrower speed distribution around the advised speed) may have a small positive effect on safety (this depends of course on the penetration rate). A homogenization effect was found for ACC by Hoedemaeker [101]

Table 37: Mechanism 3: Effects by circumstance.

SASPENCE Variables	Mechanism 3: Indirect modification of user behaviour
Accident type	Especially rear-end accidents (headway effects)
Link / intersection	
Road type	For PReVAL we assume that SASPENCE does not operate on urban roads. Drivers may depend more on the SASPENCE system at higher speeds, i.e. on motorways.
Vehicle type	SASPENCE is only available for passenger cars
Road weather	Unknown, lack of data
Lighting conditions	Unknown, lack of data

Mechanism 5: Modification of interaction between users and non-users

+ The non-users (drivers) in front of a SASPENCE vehicle have a reduced risk of rear-end collision with the SASPENCE vehicle (positive effect, probably small). This effect will be included in the reduction in collisions as described in mechanism 1.

+ The non-users (drivers) behind a SASPENCE vehicle have a reduced risk of rear-end collision with the SASPENCE vehicle because the SASPENCE vehicle brakes less or less abruptly (positive effect, probably small).

- Decreases the interaction between driver and vulnerable road users (the system is not able to detect pedestrians).

Table 38: Mechanism 5: Effects by circumstance.

SASPENCE Variables	Mechanism 5: Modification of interaction between users and non-users
Accident type	
Link / intersection	
Road type	No effect on urban roads. On rural roads, increased overtaking (for which the lane for traffic in the opposite direction is used) can be dangerous. Negative effects can be expected on rural roads, but on motorways the non-user can usually overtake easily and safely.
Vehicle type	Heavy vehicles are not likely to overtake on rural (or urban) roads. Negative effect of overtaking is less for interaction with a heavy vehicle.
Road weather	Unknown, lack of data. (if same advice is given in adverse weather, the system may be less effective in adverse weather)
Lighting conditions	Unknown, lack of data.

Mechanism 9: Modification of accident consequences

+ It is highly likely that the advice and warnings of the SASPENCE system lead to smaller speed differences between the SASPENCE vehicle and the vehicle in front. Hence, the consequences of accidents will be mitigated for front-to-rear collisions, due to lower impact speeds. In addition, if the SASPENCE results in lower driving speed in general, the accident consequences are lower.

5.5.2.2 Fm3: Speed advice (static)

Mechanism 1: Direct in-car modification of the driving task by giving speed and headway warnings and advice

+ The system alerts the driver to the local speed limit. The warnings and advice help the driver to
  + Reduce the amount of speeding due to limited awareness of local speed limit (unintended speeding). This effect has been observed in many experiments with advisory ISA systems, for example [114] and [110].
  + Adjust speed in accordance with the road geometry and landmarks such as curves.
+ We can assume that part of the speed-related accidents might be avoided and the remainder in some level mitigated (depending on driver reaction to the speed information/suggestion). We expect fewer road departure accidents because of the landmark warnings (especially in curves).

Table 39: Mechanism 1: Effects by circumstance.

SASPENCE Variables	Mechanism 1: Direct in-car modification of the driving task by giving speed and headway warnings and advice
Accident type	
Link / intersection	
Road type	For PReVAL we assume that SASPENCE does not operate on urban roads. Different speeding behaviour on different road types?
Vehicle type	SASPENCE is only available for passenger cars
Road weather	The current SASPENCE system does not differentiate between different weather conditions; the warnings (and thresholds for the warnings) are the same in all conditions.
Lighting conditions	The impact could be expected to be larger at night than in daytime as speeding is bigger problem in free-flow-conditions without risk of enforcement.

Mechanism 3: Indirect modification of user behaviour

- Users may begin to depend on the advice and warnings given by the SASPENCE system, especially on motorways. This may result in slightly more assertive driving, e.g. drivers choosing speeds closer to the fixed speed limit (not observing the environment himself).

+ On the other hand, more homogeneous speeds (a narrower speed distribution around the advised speed) may have a small positive effect on safety (this depends of course on the penetration rate and the flow). Homogenization has been observed in many ISA studies, e.g. [110],[114].

In addition, current trend is that camera and police enforcement is rising. This may increase the interest towards speed limiting systems. It is expected that some drivers use systems to reduce the risk of getting fines.

It is assumed that the effects by circumstance are relatively similar, except users may depend on the system especially on motorways.

Mechanism 4: Indirect modification of non-user behaviour

+ Reduced speed of equipped vehicles will influence drivers behind the equipped vehicle, especially on two-lane roads. In ISA trial in Sweden it was found that every ISA car on average influenced the speed of one other car [115], but the magnitude of this effect depends on the penetration rate.

Mechanism 5: Modification of interaction between users and non-users

± In general, mixing SASPENCE and non-SASPENCE vehicles can lead to less homogeneous traffic flow for low penetration rates and low traffic intensities (small negative effect, because of low numbers of vehicles involved). For higher penetration rates or intensities one could expect the SASPENCE vehicles to force the surrounding traffic into a more homogeneous flow pattern (positive effect) and into sticking to the speed limit. (Found in a lot of studies from ISA)

It is assumed that the effects by circumstance are relatively similar, except homogeneity is mostly relevant for motorways.

Mechanism 9: Modification of accident consequences

+ If the SASPENCE results in less speeding, more homogeneous traffic flow and lower driving speed in general, then the absolute speeds of vehicles as well as the speed differences between vehicles will decrease, and hence the accident consequences are lower for all accident types.

5.5.3 Conclusions

SASPENCE is expected to have direct effects on driving task in critical situations involving a vehicle in front. This is expected to reduce especially the number of rear-end accidents involving passenger cars and occurring at night. The system might have indirect modification of user behaviour that can be either positive or negative. Modification of interaction between users and non-users might lead to decreased safety if it increases overtaking of following car drivers on rural roads. Because the system decreases speed difference between the SASPENCE vehicle and the vehicle in front, the consequences of accidents will be mitigated.

SASPENCE with static speed advice is expected to have positive direct effects on driving task (passenger cars). In addition, there might be some indirect modification of user behaviour, but this effect can be relatively small. There can also be some indirect modification of non-user behaviour because the reduced speed of equipped vehicles will influence the speed choice of following vehicles, especially on two-lane roads. If the system results in less speeding, more homogeneous traffic flow and lower driving speed in general, the accident consequences are lower for all accident types.

6 Conclusions

The different PReVENT subprojects have developed, demonstrated and evaluated preventive and active safety functions. This deliverable gives an overview and analysis of the evaluation results of the PReVENT functions. The analysis is organised around the 3 aspects: technical performance assessment, human factors assessment and safety impact potential.

PReVENT function can be divided in three function fields, with the “time to risk” as the major differentiating parameter. The following table gives an overview of the subprojects addressed by the different analyses, discussed in this deliverable:

Table 40: Overview of PReVENT subprojects analyses

Function field	System	Technical performance assessment Chapter 3	Human factors assessment Chapter 4	Qualitative safety impact analysis Chapter 5
Tight interactions	APALACI	X		X
	COMPOSE	X		X
	INTERSAFE	X	X	X
Short interactions	SASPENCE	X	X	X
	LATERAL SAFE	X	X	
	SAFELANE	X	X	X
More distant interactions	MAPS&ADAS	X	X	X
	WILLWARN	X	X	

Technical assessment

The technical performance assessment is organised in two phases: the verification of the subsystems and the validation of the function. For all functions, Correct, False and Missed Alarm Rates were calculated. All subprojects reported good results for the scenarios and conditions tested.

A fundamental outcome from PReVENT is that each function has looked at several technologies in order to improve the performance. PReVENT subprojects make use of a large set of sensors (environmental sensing, maps, telecommunications etc) and data fusion in order to provide reliable detection and positioning inputs for the proposed assistance functions. PReVENT subproject provide a large “basket of new technologies”, which are fundamental main bricks for preventive safety systems.

The following paragraphs give a short overview of the results of the subprojects.

Function field 1: Tight and short interactions related to collision mitigation and avoidance

APALACI and COMPOSE have innovated by the use of several combinations of sensors that have been explored and tested : ultra-sonic sensors, short range radars and cameras for short distance, lidar and long range radars for long distance obstacle detection. Fusion & tracking techniques have been proved to be powerful: no missed alarms; weak rate of false alarms (2/253 situations; 0/5h18 driving); good classification rate (>98%).

INTERSAFE can be considered as the PReVENT subproject that deals with less mature technologies since collision prevention in intersections involves the development of a highly complex detection system (fusing information brought by precise maps and on-board sensors) that has to be able to locate and classify objects in the intersection. Quite good results (0% missed alarms, 7% FAR) have been obtained and demonstrated through very precise assessment tools.

Function field 2: Short interactions with other moving vehicles

SASPENCE has innovated in a reference set of optimal manoeuvers that are calculated maximizing safety margins considering various risk factors. Combined technical and HMI evaluations have pointed out good results. The validation phase of SASPENCE included the use of innovative and promising tools: digital and hardware-in-the-loop simulation (PRESCAN and VEHIL environments).

The LATERAL SAFE complements a frontal support, lateral & rear 270° bird view monitoring. At the technical level, data fusion has been proved to be powerful. Technical assessment was based on subjective perception of the driver and by on-board technicians. Reduced but actual false and missed alarm rates can be attributed partly to threshold alarm setting.

SAFELANE has innovated first in a robust lane tracker that uses data fusion (map data, radar object trails, vehicle dynamics sensors and camera) that has been developed and thoroughly tested. A second innovation of SAFELANE is the decision system that comprises a situation model based on the knowledge of different elements (driving manoeuvres, road conditions, situation characteristics). Through an extensive evaluation, the system showed very good results (~0% FAR and MAR).

Function field 3: More distant interactions

MAPS&ADAS brought mainly in the PReVENT basket of technologies, a CAN interface for map horizon data and functions capable of providing hot spot and speed limit warning. Extensive testing of all horizon providers implementations have been carried out: no errors in the CAN usage occurred, 100% of integrity of the map horizon was observed. In terms of positioning, the performance of existing positioning systems used for navigation has shown to be sufficient. In sum, the map quality governs the system performance.

WILLWARN has enriched the creation of an electronic horizon through telecommunications. The complete WILLWARN system was successfully tested and presented in various use cases with 4 cooperating cars and a road side unit on public roads. One should point out the contribution of WILLWARN to the position relevance check that verifies if the host vehicle is concerned by the receiving message. Moreover, further tests are needed to study the effects of more communicating partners through ad-hoc networks.

Additional Remarks:

PReVENT subprojects addressed very new and innovative concepts and technologies, for which no well established standard assessment procedures exist So, besides of the challenge to build such innovative concepts, the evaluation procedure in itself is innovative. Since PReVENT is not an assessment dedicated project, the evaluation procedure has been constrained to a tight schedule. Due to this fact, there has been in general a limitation on the number of repetitions for each scenario, fact that plays a role on the related statistical confidence intervals.

Human factors evaluation

Since the functions are proof-of-concept, the HMI has not received the major scope. Table 21 gives an overview of the human-factor-related results across subprojects. All the analysed sub projects report positive results on driving performance and driver behaviour, as well as for acceptance and usability, however with a variation in the significance and distribution of the results.

Most projects emphasize the need for further experiments with a larger amount of scenarios and a larger group of test subjects for achieving statistically significant results. Also further tests for optimising the HMI solution is mentioned in some projects. There is also a need for assessing the long term behaviour of the driver.

Safety potential assessment

Safety potential assessment focused on the impact mechanisms evaluating first how the functions affect driver behaviour and travel behaviour. The functions were selected so that they cover the whole scope of functions when the analyses conducted by the eIMPACT project are taken into account. The PReVAL functions analysed were:

- Safe speed and safe following: SASPENCE, MAPS&ADAS
- Lateral support: SAFELANE
- Intersection safety: INTERSAFE left turn
- Collision mitigation: APALACI-COMPOSE (autonomous braking, pre-fire and pre-set)

Based on the state of the art knowledge, the relevant safety impact mechanisms for each PreVENT system were defined in qualitative terms. In addition to the overall analyses, the expected effects were assessed by circumstance (i.e. type of accident, road type, vehicle type, weather conditions etc.).

The main results by system were as follows:

The APALACI/COMPOSE collision mitigation functions deal with unavoidable crashes. These systems are not expected to have an effect on driver behaviour, and only modification of accident consequences is relevant. There were no substantial differences by circumstance. However, it is expected that the effects are larger on motorways than other road types and, compared to adverse road conditions, the effects are larger on good road conditions.

INTERSAFE (left-turn assistance) is expected to have direct and indirect effects on driving task. However, the effects take place at intersections only. Direct effects are more pronounced in adverse road conditions and at night. Other effects include indirect modification of non-user behaviour, modification of interaction between users and non-users, modification of road exposure, modal choice and route choice and modification of accident consequences. However, the magnitude of the effects is expected to be small and no difference by circumstance is expected.

MAPS&ADAS (Hot Spot Warning) is expected to have direct effects on driving task. In addition, it expected that there are indirect effects on driving task which results in the increase of accidents, especially at sites not marked in the maps, at link sections, on rural roads, in adverse weather conditions and at night. The modification of interaction between users and non-users as well as modification of accident consequences can be substantial. Typically, the effects are most substantial on accidents that include speeding cars, and occur in link sections of rural roads and in adverse weather conditions or at night. Other effects are expected to be minor.

SAFELANE is expected to have direct effects on driving task. Specifically, the system might reduce the number of side accidents and accidents involving trucks. Indirect modification of user behaviour can be either positive or negative. In addition, it is expected that the system may increase driving and thereby exposure, especially that of passenger cars. On the other hand, the system could lead to the decrease of accident consequences. Other effects, if any, are expected to be small.

SASPENCE is expected to have direct effects on driving task in critical situations involving a vehicle in front. This is expected to reduce especially the number of rear-end accidents involving passenger cars and occurring at night. The system might have indirect modification of user behaviour that can be either positive or negative. Modification of interaction between users and non-users might lead to decreased safety if it increases overtaking of following car drivers on rural roads. Because the system decreases speed difference between the SASPENCE vehicle and the vehicle in front, the consequences of accidents will be mitigated.

SASPENCE with static speed advice is expected to have positive direct effects on driving task (passenger cars). In addition, there might be some indirect modification of user behaviour, but this effect can be relatively small. There can also be some indirect modification of non-user behaviour because the reduced speed of equipped vehicles will influence the speed choice of following vehicles, especially on two-lane roads. If the system results in less speeding, more homogeneous traffic flow and lower driving speed in general, the accident consequences are lower for all accident types.

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Annex A Keywords

Active Safety System, ADAS, Advanced protective safety, Integrated safety systems, Preventive safety applications, Evaluation, Assessment, Validation, Safety impact analysis, Human-Machine Interface, Technical Performance Assessment

Annex B Glossary

Abbreviation	Explanation
ABS	Antilock Braking System
ACAS	Automotive Collision Avoidance System
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ANOVA	Analysis of Variance
BSD	Blind spot detection
CAN	Controller Area Network
CAR	Correct Alarm Rate
CPU	Computer Processing Unit
DWS	Driver Warning System (MAPS&ADAS)
EE	Exposure Effectiveness
ESC	Electronic Stability Control
FAR	False Alarm Rate
FCW	Forward Collision Warning
FCW	Forward Collision Warning
FN	False negative rate
FOT	Field Operational Test
FP	False positive rate
H/W	Hardware
HDM	Hazard Detection Module (WILLWARN)
HF	Human Factor
HGV	Heavy Goods Vehicle
HIL	Hardware-in-the-Loop
HMI	Human Machine Interaction Human Machine Interface
HR	Hit Rate
HSW	Hot Spot Warning (MAPS&ADAS)
HWM	Hazard Warning Module (WILLWARN)
IA	Intersection Assistant (INTERSAFE)
ISA	Intelligent Speed Adaptation
ITS	Intelligent Transport Systems
I-TSA	INVENT Traffic Safety Assessment
IVIS	In-Vehicle Information Systems
JDVS	Joint Driver-Vehicle System
LCA	Lane Change Assistant (LATERAL SAFE)
LCW	Lateral Collision Warning (LATERAL SAFE)
LDW	Lane departure warning (SAFELANE)
LRM	Lateral and Rear Area Monitoring (LATERAL SAFE)
LTA	Left Turn Assistant (INTERSAFE)
MAR	Missed Alarm Rate
NASA-TLX	NASA Task Load indeX
OEM	Original Equipment Manufacturer
ROR	Run-Off-Road
RT	Reaction Time
SLW	Speed Limit Warning (MAPS&ADAS)
SRR	Short Range Radar
SVIP	Synthesized Vision Image Processing
TCA	Turning/Crossing Assistant (INTERSAFE)
TEM	Trajectory Estimation Module (SAFELANE)
TLA	Traffic Light Assistant (INTERSAFE)
TLC	Time to line crossing
TN	True negative rate
TP	True positive rate
TTC	Time to collision
V2I	Vehicle to Interface
V2V	Vehicle to Vehicle

Abbreviation	Explanation
VVC	Vehicle2Vehicle Communication (WILLWARN)
WLAN	Wireless LAN (Local Area Network)
WMM	Warning Message Management Module (WILLWARN)

Term	Definition	Comment	Source
Acceptance	The degree to which drivers consider a function to be useful and satisfactory.	Acceptance may be influenced by the technical performance as well as the usability of the system.	Original definition
Application	A program (such as a word processor or a spreadsheet) that performs one of the important tasks for which a computer is used		AIDE Glossary
Assessment	The process of determining the performance and/or impacts of a candidate application, usually in comparison to a reference case (existing situation or alternative applications), and usually including an experimental process based on real-life or other trials, often involving users.		CONVERGE
Assessment objectives	A precise statement of an individual objective which an application should be judged against. It should be associated with a precise definition of the associated indicator(s) and definition of success.		CONVERGE
Control	Achieving and/or maintaining a consistent goal state		Original definition
Dependability	The trustworthiness of a computer system such that reliance can justifiably be placed on the service it delivers.		EAST-EAA, AIDE Glossary
Driving performance	The degree to which the goals associated with the driving task are attained		AIDE glossary
Driving task	All aspects involved in mastering a vehicle to achieve a certain goal (e.g. reach a destination, including tracking, regulating, monitoring and targeting)		AIDE glossary
Evaluation	The process of determining the value of an application in comparison to alternative applications and/or to a "base case", and deriving recommendations for decision makers based on identifying requirements on and analysing results of related experiments.		CONVERGE
Function	A description of what something does or is used for		RESPONSE (option a)
HMI- Human Machine Interaction	All the possible modes by which interaction (direct or indirect) between the driver and one or more vehicle systems takes place.		Response Glossary

Term	Definition	Comment	Source
HMI- Human Machine Interface	A set of components that govern the interaction between the user and one or more systems.		AIDE Glossary
Human factors evaluation	Assessment of a function taking into account driving performance, driver behaviour, usability and acceptance.		Original definition
Impacts	Changes or effects brought about by an application resulting from its use in an experimental or real application.		CONVERGE
Indicator	Parameter that is used for estimating the performance (or impacts) of a function.	Indicators form subsets of parameters. They are usually measured or can be derived from measurements and operationally defined in terms of metrics. When simulation is used instead of measurement, indicators will usually be outputs of the simulation. It may be necessary to use more than one indicator for each assessment objective.	Original definition
Intended effects	Effects of a function that are intended by the designer of the function.	Intended effects are normally (explicitly or implicitly) implied by the functional specifications. For instance, an intended effect of a Forward Collision Warning function is a reduction in brake response time to a sudden unexpected front obstacle. This corresponds to the term "direct effect" in the AIDE glossary.	Original definition
Joint Driver-Vehicle System (JDVS)	The system comprised of the driver and the vehicle.		Based on Hollnagel and Woods (2005)
Long term testing	Assessment of effects that appear on a time scale of days or longer.		Original definition
Metric	Operational definition of an indicator.	A metric defines how an indicator is measured or derived from measurements. It gives clear advice about the techniques and technologies to be used during the measurement and, if the indicator is derived from direct measurements, the metric describes the respective mathematical operations; the process how to get values of the indicator.	Original definition
Parameter	An independent variable used to express the coordinates of a variable point and functions of them	Parameters are measurable quantities that, for the purpose of safety system assessment, represent properties of the driver, the vehicle and/or the environment. Parameters can be used to describe situations.	EAST-EAA (Webster)

Term	Definition	Comment	Source
Short term testing	Assessment of effects that appear on a time scale of hours or less.		Original definition
Situation	A set of relevant driver-, vehicle and environment elements within a volume of time and space.	A situation can be described in terms of parameters and their temporal evolution.	Original definition, based on the existing definition of situational awareness by Endsley.
Situational control	The degree of control that a Joint Driver-Vehicle System (JDVS) exerts over a specific situation.		Original definition
System	A collection of components organized to accomplish a specific function or set of functions.		AIDE (EAST-EAA) + RESPONSE
Target situations	The situations where a function has its intended effects.	In the case of active safety functions, target situations are often, but not necessarily,, critical.	Original definition
Technical evaluation	Assessment of the technical performance of a function or system		Original definition
Technical performance	The degree to which a system meet functional and technical specifications.	Technical performance can, for example, be quantified in terms of false alarm rate, missed alarm rate, etc. It also involves aspects related to system dependability. Technical performance is directly related to situational control for fully automated functions, i.e. functions without the driver in the loop. However, whenever the driver is in the loop both technical and human factors testing are needed to assess the impact on situational control e.g. in terms of reliability, time accuracy, missed alarm rate, false alarm rate etc.	Original definition
Unintended effects	Effects of a function that are not intended by the designer of the function.	Unintended effects are not implied by the functional specification. They can be either positive or negative with respect to safety. This corresponds to “indirect effects” in the AIDE Glossary	Original definition
Usability	The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.	In the case of warnings, comprehensibility is a key aspect of usability.	ISO 9241-11
Use-case	An intended or desired flow of events or tasks that occur within the vehicle and are directed to or coming from the driver in order to accomplish a certain system-driver interaction		AIDE Glossary

Term	Definition	Comment	Source
Validation	The process of evaluating a system or component during or at the end of the development process to determine whether it satisfies the expectations.		RESPONSE
Verification	Assuring, e.g. by testing, that a component, a subsystem, a system or a process is working as required and specified.		RESPONSE

Annex C Common System Description and evaluation results description template

This document provides a common system description for workpackages 16.300 (Technical Evaluation), 16.400 (Human Factors evaluation) and 16.500 (Safety Potential) of the horizontal PReVAL subproject of IP PReVENT.

Its objective is to describe systems and functions so that all three workpackages gain a common understanding of the subproject developments and to provide a starting point for deeper analysis. Its purpose is *not* to provide an extensive description of algorithms, sensors, displays, mechanisms etc. to allow an in-depth analysis for all three workpackages. The necessary information for such an in-depth analysis has to be provided by themselves.

The document is organized as follows:

Section C.1 comprises a general system description for identification purposes, as well as functional specifications and the circumstances in which the system is supposed to work.

Section C.2 gives a technical description providing the basis for the technical evaluation of the system, it includes descriptions of sensors, actuators, additional sources of data and short description of algorithms, as far as this is necessary to understand the main aspects of the system.

Section C.3 contains the verification results of subsystems, and Section C.4 the validation results of the functions.

Section C.5 comprehends the Human Factors related information about the system. It includes descriptions of the HMI, that is about displays, information channels (optic, acoustic, haptic), etc., but also information about the hypothesis addressed by the user tests and the related indicators and metrics, where applicable.

Section C.6 includes additional necessary details about safety relevant aspects of the system to allow for the safety evaluation of the systems following the behavioural effect approach proposed by Draskoczy et al. [3].

C.1 Function description

The function description provides specifications to which validation will refer.

C.1.1 General - Identification

Name: **A one line description for identification purposes**

General function: **A brief "headline" description of the function performed by the system**

Contact point: **Name and contact points to get further information if necessary**

C.1.2 Description

Short and **accurate** description of the function. It answers the following questions:

- what are the triggering events?
- what does the function perceive?
- what are the decision criteria (for instance, TTC<1s)?
- in what way does the function react (warning, action) and when?

The types and numbers of accidents should be described in a few words. Summary use cases may be described.

Limitations of the function specifications should be detailed (for instance, specify if function activate above a threshold speed, does not work by night or dense traffic, etc.)

Time schedule of function activation should be clearly described (for instance: action takes place 0.5s before collision, perception of obstacle should occur 0.5s before action, delay for validation of obstacle detection is 1s after triggering event occurs).

This short description should be repeated for each part of the function.

In this section, the description of the function has to be detailed enough to enable the reader to understand quickly how it performs, and to compare specifications to validation results detailed in section C.3. Thus all assumptions should be quantified when relevant.

The following summary table should be completed by putting all relevant categories in bold font:

Vehicle type concerned	Passenger car/Heavy duty/Bus
Target considered (when relevant)	Pedestrian/Two-wheels/Car/Heavy duty
Road type	Rural/Urban/Highway
Weather conditions	Normal/Adverse
Light conditions	Day/Night
Level of cooperation	None/Veh. to infra./ Veh. to Veh.

Summary conditions of function specifications

C.2 Technical description

The technical description provides function subsystems specification to which verification results will refer.

The technical description should provide specification of “technical” parts of the function implementation:

- sensors (with range, latency, refreshing rate, field of view, etc.);
- databases;
- fusion algorithms (what are inputs and outputs);
- decision algorithms (what are inputs and outputs);
- actuators or warning displays

This description should be detailed enough for the reader to understand how the function works, and what is part of each subsystem in the action process. Limitations should also be mentioned. Time schedule specification of workflow should be detailed.

C.3 Verification

C.3.1 General considerations

Test results should be described for all subsystems. General considerations about verification should be made in first section (for instance, description of common test scenarios).

C.3.2 Subsystem 1

Describe briefly the way subsystems have been assessed: targets, test roads, use of simulation, etc.). Verification only refers to subsystems. The way the whole function is assessed should be described in next section.

Verification results should refer to all specifications of subsystems. When some specifications are not tested, this should be mentioned and discussed. For instance, if all verification tests of a video sensor have been made by daytime and function should also perform by night, then night influence on perception results should be discussed.

Statistical confidence of assessment results have to be discussed.

C.3.3 Subsystem 2

…

C.4 Validation

C.4.1 Validation methodology

Only general outlines of evaluation plan have to be described. Tools and scenarios that are used to perform evaluation are listed in this section.

C.4.2 Assessment results

Validation results should be detailed in this section. They are related to function evaluation. It should be specified whether overall function evaluation is performed in a whole or is declined from verification results.

All results related to validation should be described, comprising time process and limitations.

Statistical confidence of assessment results have to be discussed.

C.4.3 Conclusion, discussion

All validation results have to be discussed and compared with specifications. An opinion should be exposed on achievement of function and ways to improve its performances.

C.5 HMI Specifications and HF evaluation

HMI Provide information about the HMI of the system, if there is any. Include pictures of the HMI or other descriptions to show the main aspects of the HMI.

Hypothesis Provide information about the hypotheses addressed in the Human Factors evaluations. Also mention indicators and metrics.

Table 41: Hypotheses: expected Impacts on Traffic Safety of the Driver Warning System functions.

ID	expected Impacts	Functions	Magnitude of expected Impact*
Imp 1			
Imp 2			
…			

* ++ very positive; + positive; o neutral/ uncertain; - negative; -- very negative

Table 42: Impacts and Indicators of the Driver Warning System applications

ID	Indicator	Related Impacts
Ind 1		
Ind 2.1		
Ind 2.2		

Table 43: Indicators and methods

ID	Indicator	Method/ Tool
Ind 1		
Ind 2.1		
Ind 2.2		

Subjects Provide data about the subjects that participated in the tests

	Control Group	Experimental Group
Number of subjects		
Age range		
Gender distribution		
Driving experience (km/a)		
Private/professional drivers		

C.6 Safety Aspects

Target scenarios and accidents

What are the scenarios (traffic situations) where the system is likely to be most potential? In what kind of accidents (CARE database+ specifications+ limitations) the system is expected to have safety benefits?

Target behaviour What is the desired reaction of the driver with the system. How the driver is expected to behave and how does this link to safety.

Behavioural adaptation Is there some other changes in driving behaviour that could be expected?

Measured driving behaviour

Results from PReVENT studies related on safety relevant driving behaviour.

Annex D APALACI

It is very important to understand that the information reported in the following regard only the CRF APALACI demonstrator.

General function: APALACI subproject covers the functional area of Collision Mitigation in order to improve the protection of the driver and the passengers of the equipped vehicle. The APALACI system is based on reliable sensor fusion techniques to capture obstacle dynamic data before an imminent crash. The general objective is to mitigate a possible unavoidable collisions by two types of action:

- intervention on the brake in order to optimize the braking manoeuvre and reduce the energy of impact;
- optimization of advanced restraint systems to improve the protection of passengers.

The final outcome is therefore a reduced risk of fatalities and severe injuries for both the vehicle occupants.

Benefits: The first address of the APALACI system is to keep the best and appropriate braking actions, in order to reduce the damages and the injuries of equipped vehicle occupants. In this way the speed and the kinetic energy at the impact point are considerably reduced. Another goal is to improve the control of restraint systems, to mitigate the effects of unavoidable collisions and to protect the car passengers. The main benefit of the system use should be a considerable reduction of the big social costs due to road accidents.

D.1 Functional Specifications and Context

The functions developed by CRF APALACI demonstrator system are:

- Collision Mitigation;
- Pre-Fire;
- Pre-Set.

These functions have the goal to reduce the damages and the injuries for the people inside the equipped vehicle, derived from a possible unavoidable frontal collision. The functions are described briefly in section 3.2.1.1.

Vehicle:

Vehicle Type	ADAS works in/ is designed for
Passenger car	x
Bus	
Truck	

For the CRF APALACI demonstrator only a passenger car has been considered and tested, but there are not particular restrictions about the vehicle within which the ADAS is intended to be used.

The vehicle used by CRF for APALACI functions is a normal car production Fiat Stilo equipped with the following additional sensors and physical devices:

- 1 additional and dedicated PReVENT CAN bus;
- 2 Medium Range Radar (MRR) and Radar ECU;
- Camera and Image Processing Unit;
- Belt tension device;
- Active Booster;
- Yaw Rate sensor;
- Central Control Unit.

Driver: No restrictions or special driver skill requirements are required.

Road:

Road type	ADAS works on/ is designed for
Urban	x
Rural	
Highway	x

Following the before mentioned statistics and in order to achieve the APALACI project objectives, the application scenarios should consider all road types (focussing on urban and extra-urban roads, in particular) and in general, it is requested to be operable in all traffic situations.

Considering the three different functions implemented on the CRF prototype the system is expected to cope the following requirements:

- the application should be able to work on urban and extra-urban scenarios;
- useful in all traffic situations but mainly focused on speeds lower than 70 km/h;
- able to deal with different kind of obstacles: vehicles, vulnerable road users, generic barriers, trees, poles etc, and distinction between different objects should also be possible in the defined field-of-view. The system should have the ability to detect these objects both in moving and standing conditions. Objects have to be detected when closer than 50 m;
- the system has to detect approaching, leaving and standing objects;
- any crash in front of the vehicle as well as critical passing of objects have to be detected;

The system should not react during normal and uncritical driving conditions.

Traffic: In general is requested to be operable in all traffic situations.

Environmental:

Weather Condition	ADAS works in/ is designed for
Normal	
Adverse	

Light Condition	ADAS works in/ is designed for
Light	
Dark	

About weather and light conditions the system should be operative in all kinds of conditions but principally in case of normal visibility, where the majority of accidents occur.

The performance of the system has to be ensured under all environmental conditions (daylight, night, temperature) but principally in case of normal visibility, where the majority of accidents occur, and must not be influenced by adverse weather conditions (rain, storm, fog..).

Infrastructure:

Level of Cooperation	System
None, stand alone system	x
V2V	
V2I	

There are not any infrastructure or external information which are requested.

Other limitations: There are not particular limitations for the system.

D.2 Technical Specification

Time frame (sensor, decision, actuator) :

Generally is used the Time To Collision (TTC) like a simple parameter in order to put the various applications in a common perspective and to explain how the different functions evolve. TTC is defined by the distance between the equipped vehicle and an obstacle, divided by the relative speed.

Collision mitigation.

The TTC is in the range 1,5 - 0,5 s (the upper limit is extended to 2 seconds when warning to the driver is considered).

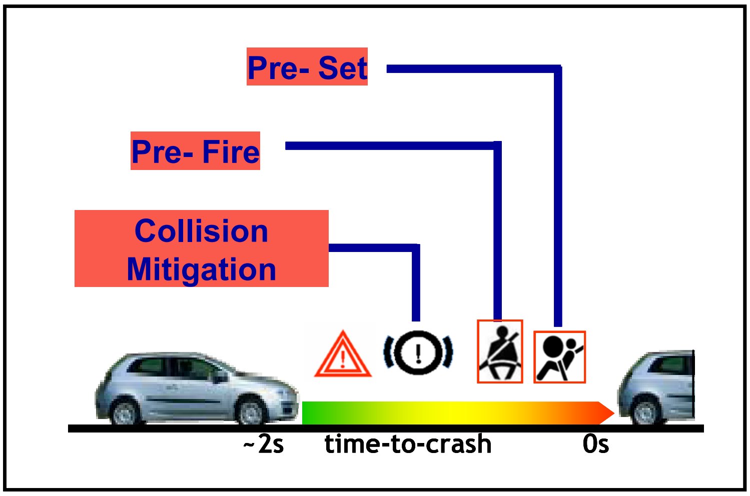
Pre-Fire.

A TTC between 0,3 and 0,1 s is considered for this function, in relationship with the activation time of typical smart restraints.

Pre-Set.

An even shorter TTC, down to 0,02-0,01 sec, is characteristic of the Pre-set function.

The picture below summarize the different TTC for the different functions.



During the test performed with the CRF APALACI demonstrator the verification of the TTC accuracy has been one of main issue for the evaluation system.

Sensors:

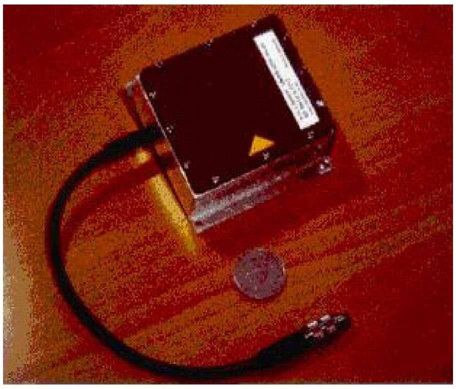
In order to realize the three different functions CRF has installed on the vehicle the necessary sensors, components and actuators.

For the reconstruction of the external situation in front, on the vehicle are installed:

- two medium range radars (frequency 24 GHz) positioned behind a bumper penetrable for radar pulses with these properties:
  - Development state, available on the market as prototype;
  - Supplier SMS;
  - Operative frequency of 24÷ 24.250 GHz;
  - The provided data are the target position(X,Y) and the speed vector (Vx and Vy, traking is included);
  - Distance range of 0.75-70 m;
  - Speed range of ± 250 km/h;
  - Horizontal FOV of ± 30 deg;
  - Angular accuracy < 0.5 deg;
  - Cycle time of 30 ms;
  - Tested sensitivity for pedestrian detection at least up to 30 m;
  - CAN interface.

  In order to do the tracking and associate the two object lists coming from the two medium range radar sensors, a dedicated radar ECU compliant with the automotive standard regarding the operating voltage and communication line will be installed on the demonstrator car.

  The pictures below show the radar sensor and the relative ECU.



- a digital monocular grey level camera that will be installed in the driver compartment behind the central mirror in the windscreen with these characteristics:
  - Horizontal FOV: 60 deg;
  - Vertical FOV: 40 deg;
  - Resolution:1280 x 1024;
  - Interface: Fire-wire (IEEE 1394a);
  - Frame rates > 10 Hz

  The picture below shows the camera installed on the vehicle.

The data acquired by the digital video camera inside APALACI will be processed by a dedicated image processing unit.

A real-time control unit (named Central Control Unit) has been used for post processing of sensor data and for controlling the actuators and the complete system. This Central Control Unit among other things, done the sensor data fusion of multiple sensors, evaluated the impact risk level and calculate the required crash data. Based on the decision taken, appropriate signals are transmitted to the active booster and to the Belt Pre-tensioners.

For development purpose, the Central control unit allows:

- to run under real time constraints;
- a rapid prototyping of the algorithms;
- the flexibility to modify and test different algorithm solutions with an easy and quick upgrading procedure of the embedded software;
- the robustness to the automotive environmental conditions;
- a reduced start-up time;
- to control also digital and analogical device (e.g. buttons, led, relè), for instance to activate/deactivate the sensors and the functionalities;

For this purpose, a dSPACE microautobox (see the picture below) processing unit has been used on the vehicle.

Additional Sources No additional sources are necessary for the system.

Decision system Different active areas are identified on the plan opened up by relative speed and distance:

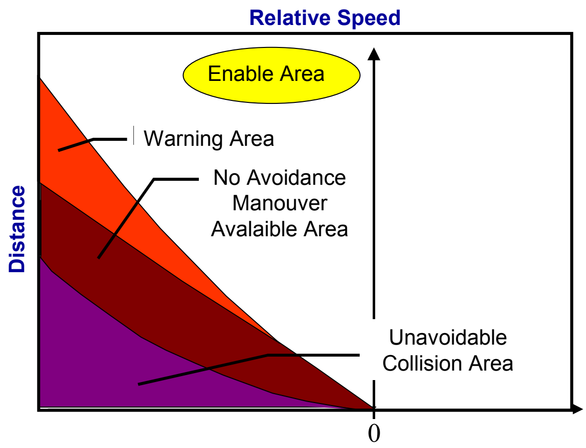
warning area: is the area within that the warning distance is reached;

no avoidance area: is the area within that it is very hard (for a normal driver) to execute an avoidance manoeuvre, only longitudinal dynamics are considered;

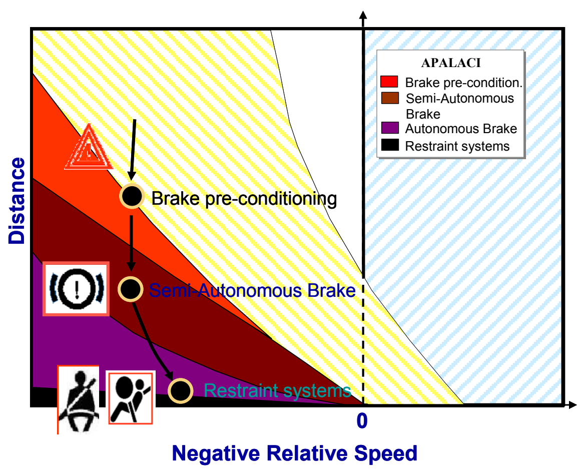
unavoidable collision area: is the area within that a collision is unavoidable.

restraints area: is the area within that the restraint (seat-belt and/or airbag) are activated.

The following figure shows these active areas:

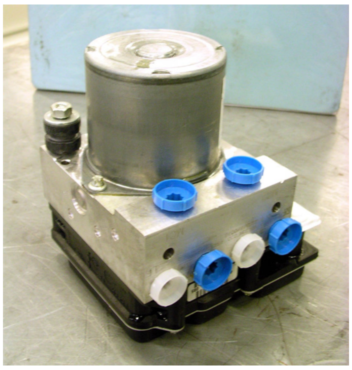


The following figure shows the same graphic by pointing out the different functions implemented by the CRF APALACI in the own field of operability.



Actuator:

In order to perform the collision mitigation application on the demonstrator is installed an active booster for the braking system (see the following picture), equipped with a CAN interface to drive the brakes by computer control. An integration of manual and automatic brake actuations has been implemented, according to the requirements of the semi-autonomous mode for the collision mitigation function.



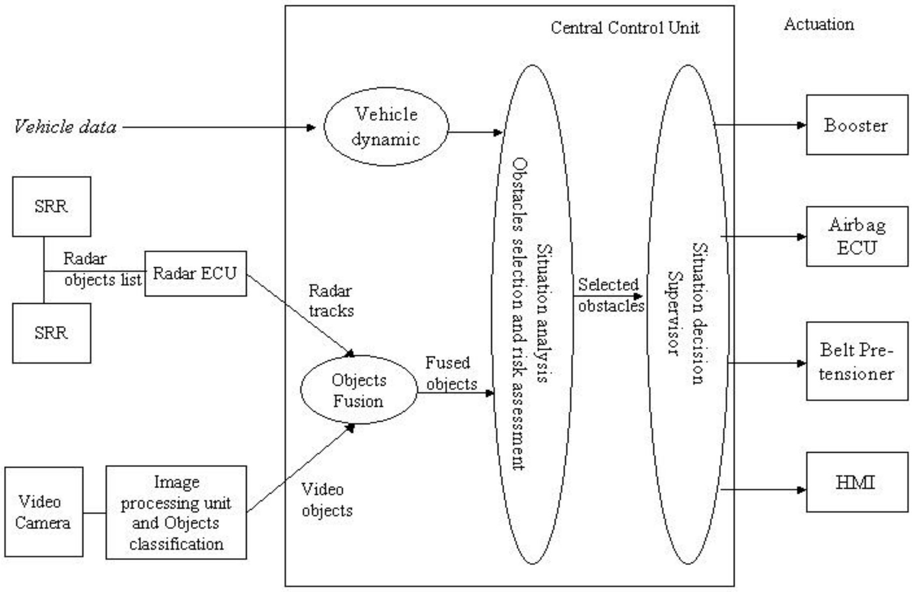
The maximum deceleration provided by the active booster is about 10 m/s^2.

For the actuation of the Pre-Fire function, on the vehicle is installed, both on the driver and the passenger seat, a reversible belt pretensioner receiving trigger from the APALACI dedicated CAN. The picture below shows one of the belt pretensioner mounted on the vehicle.

The forces performed by the belt-pretensioner are about 50 N for the warning modality and a very strong of 160 N during the Pre-Fire actuation.

Algorithms:

The functionality architecture, represented in the pictures below, shows the main processing modules in the data-processing flow for the specific cases implemented in the APALACI experimental vehicles .



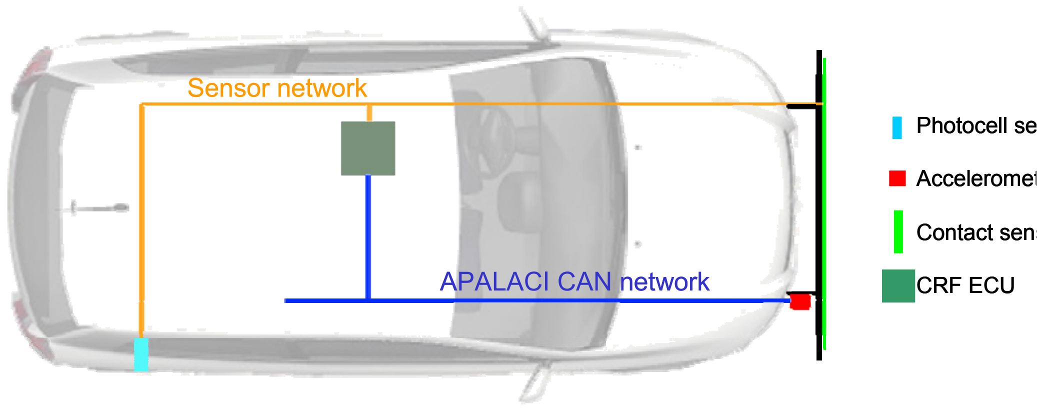
D.3 Reference measurement

For the validation of the three functions implemented on the CRF APALACI demonstrator (Collision Mitigation, Pre-Fire and Pre-Set) are considered the key indicators reported in Table 4 (p. 14).

In order to calculate the parameters for the quality of the measurement and to evaluate the APALACI applications implemented in the CRF demonstrator vehicle a specific H/W system has been designed and integrated in the car. On the front bumper a robust metallic buffer has been added to protect the body car from the impacts against dummies obstacle (tests at speed > 50 km/h have been also conducted). Moreover, in order to compare the measurements provided by the APALACI perception system with reference values (e.g. for the time to impact estimation, obstacle distance…) an additional subsystem has been installed in the car:

- a photoelectric cell;
- a contact sensor on the metallic buffer in front;
- an accelerometer on the metallic buffer in front.

The picture below shows the sensors position on the vehicle.

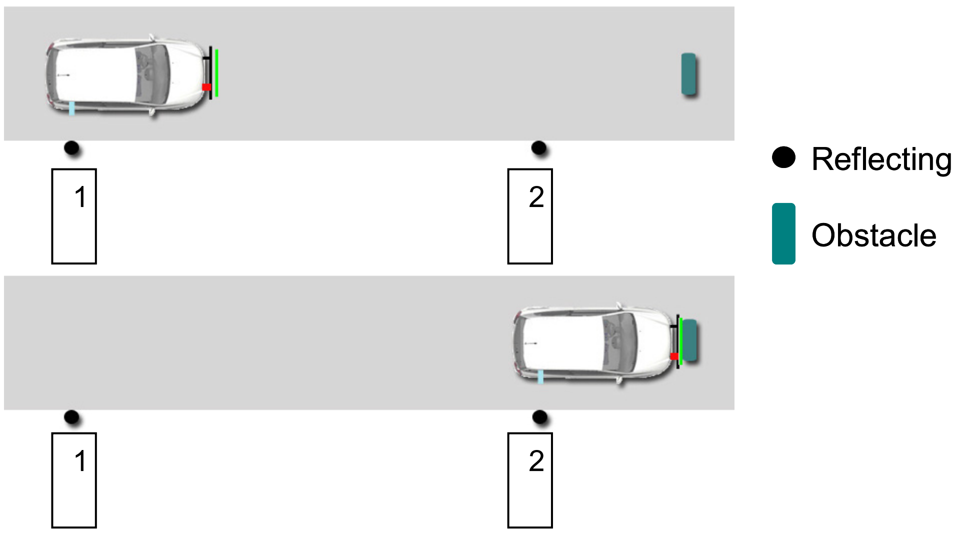


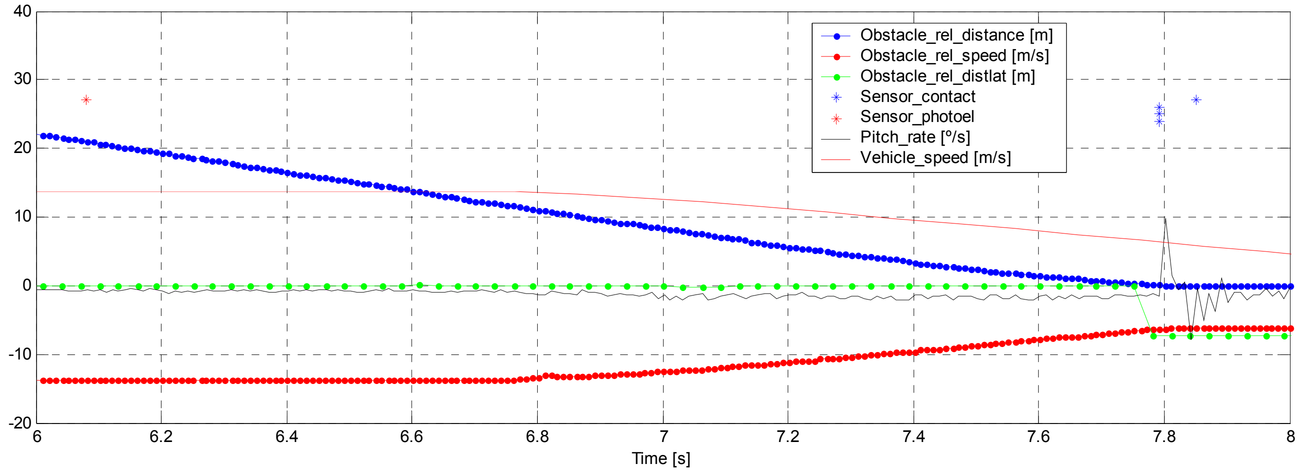
The added systems allow achieving additional and independent measurements about the impact and the distance from the obstacle. In particular:

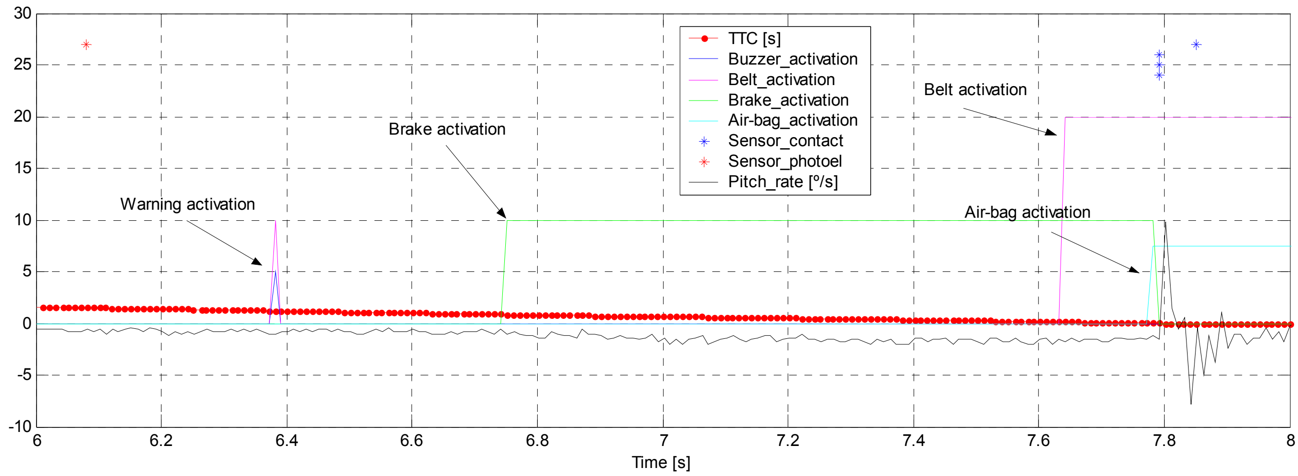
- the photoelectric cell provides a signal when the car passes at certain defined distances from the dummy obstacle where appropriate reflectors have been located and at the impact point;
- the contact sensor and the accelerometer provide a clear signal at the impact time against the dummy obstacle.

All signals generated from the independent subsystems above mentioned are acquired from a laptop together with all synchronized vehicle and APALACI data. The data post-processing allows to compare the different measurements and to evaluate the APALACI perception system accuracy.

The picture below shows an overview of this experimental set-up.







The pictures above show two graphics regarding a test (approaching and collision of the CRF APALACI demonstrator with a fixed dummy obstacle) performed during the CRF APALACI test phase.

The first reflecting indicated with the number 1 is positioned at 20 m (reference distance) from the dummy obstacle. When the vehicle pass near it the photocell gives a signal (see the red asterisk in the first graphic) so it's possible to compare the obstacle relative distance measure performed by the APALCI system (see the blue points in the first graphic) at the same time with the reference distance of 20 m. This allows calculating the key indicator position accuracy.

The contact sensor (see the blue asterisk in the graphics) and the accelerometer (see the black line in the graphics) provide a clear signal at the impact time against the dummy obstacle. So it is possible to have:

- an other indication of the position accuracy at different distance vehicle-dummy;
- and calculate the key indicator TTC accuracy, by comparing the TTC calculated and provided by the CRF APALACI system (see the red points in the second graphic) for example during the activation warning signal (see the magenta line in the second graphic), with the real TTC

calculated like time gap between the impact signal time and the signal activation warning time. The same procedure it is possible also to perform for the other TTC with the brake activation signal, the belt activation signal and a possible air-bag activation signal (see the second graphic).

The impact speed accuracy is evaluated during the test with fixed obstacle by comparing the relative speed vehicle-obstacle given by the APALACI system with the vehicle speed.

D.4 HMI Specifications and HF evaluation

The CRF APALACI vehicle has no a specific HMI. The only interface system/driver is an acoustic message and a soft restrain to the belt-pretensioner used like warning in order to advise the driver of the obstacle presence in the area in front the vehicle.

Annex E COMPOSE

E.1 Objectives, functionalities, accident scenarios and expected driver behaviour

APALACI/COMPOSE is developing, integrating and validating a pre-crash safety applications for passenger and vulnerable road user protection as well as collision mitigation by autonomous or semi-autonomous braking for trucks and passenger cars. These applications significantly reduce the kinetic energy at the impact. Four systems are developed:

1. Pre-crash systems
2. Road user protection systems
3. Collision mitigation systems for cars
4. Collision mitigation systems for trucks

The COMPOSE subproject deals with pre-crash functions, in particular collision mitigation. Opposed to APALACI, that focuses on passenger protection, COMPOSE puts stronger emphasis on protection of other road users.

These systems are based on reliable sensor fusion techniques to capture obstacle dynamic data before an imminent frontal crash. Starting from this information, the following objectives are mainly addressed:

- To mitigate unavoidable collisions by intervention on the brakes to reduce the energy of impact;
- To protect road users in the direction of the host car

The functions developed are summarized in the following and the time to collision (TTC) is used as a simple parameter allowing to put the applications in a common perspective, and also to relate them with the other areas of the integrated project. TTC is defined by the distance between the equipped vehicle and an obstacle, divided by the relative speed.

Collision Mitigation

The application aims at reducing the energy of impact when a crash is unavoidable, first of all enhancing the braking action started by the driver after a collision warning (semi-autonomous modality) but also activating the braking system when the crash is unavoidable (autonomous modality), if the driver doesn’t react to the warning and an evasive manoeuvre is not suitable.

The initial TTC is in the range 1,5–0,5 s (the upper limit is extended to 2 seconds when warning to the driver is considered).

1) If obstacle is seen in advance, then in a specific TTC (is this TTC chosen so that the accident can be avoided or it is chosen supposing that the accident will happen and then all can be done (by driver or system, or both) is reduce its consequences, the system gives an alarm anyway.

2) Following this alarm, 2 situations can happen:

- driver brakes optimally (no system intervention)

- driver brakes too lightly (system improves driver braking)
- driver is inattentive and does not brake (system waits until the last moment to see if driver has reacted) and system brakes in the last moment to reduce accident severity (precise TTC)

3) Obstacle appears suddenly in front of the vehicle: autonomous mode is activated.

Scenarios:

Scenario 1: Rear-end collision

Vehicle in front brakes suddenly: in this case, driver is not able to brake in time - autonomous mode is activated.

Scenario 2: Collision with stationary objects

Obstacle appears suddenly in front (bicycle, animal etc.): in this case also, driver is not able to brake in time - autonomous mode is activated.

Scenario 3: Collision with pedestrians or vulnerable road users

Obstacle or vehicle in front exists already. Driver is inattentive. An alarm is given and the accident, under the condition that driver reacts, can still be avoided. If driver does not react, autonomous mode reduces accident severity.

Annex F INTERSAFE

F.1.1 Objectives, functionalities and expected driver behaviour

Objectives

Intersection safety contains a variety of subsystems which all aim to assist the driver in avoiding common mistakes which may lead to typical intersection accidents (traffic light violations, yielding or turning left). The system does not take control over from the driver, but gives information and warnings.

Functionalities, HMI and scenarios

INTERSAFE system has two main functions: Intersection Assistant and Traffic Light Assistant. The latter one is dependent of infrastructure equipments (based on the communication with traffic lights (V2I) whereas the first one is not dependent on infrastructure. For the left-turn assistance, the vehicle has to be equipped with video camera and laser scanners for the localisation and detection of other road users. This section will only describe the Left turn assistance, for which a safety assessment is performed.

Left-turn assistance (as a sub-function of Intersection Assistant including also yielding situations) warns the drivers about potential collision with other vehicles with crossing path. The left-turn assistance pays special attention to oncoming traffic during the left turn.

According to speed and distance to conflict area of both vehicles, the controller checks the risk of the situation and presents visually a risk level (green, yellow, red) to driver. The risk level is presented with a continuous manner for the time of an identified risky situation. It supports the driver in finding an acceptable gap between vehicles in order to cross the intersection safely. Also an acoustic warning is given if the situation is dangerous (no safe left turn). Visual information on the screen and in the end acoustic warning shall support the driver in his decision making (e.g. warning that gives an assessment of the gap to the on-coming vehicles) and the system might also be able to prevent accidents that occur because of inattention or occluded field of view of the driver.

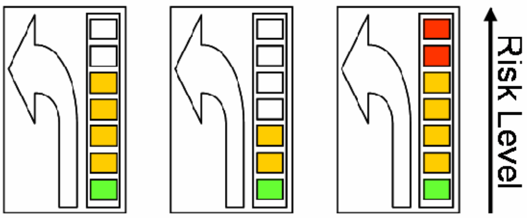


Figure 8. HMI Display in VW demonstrator vehicle, left-turn assistance.

Expected driver behaviour

The risk level information is shown in all intersections, but the warning of INTERSAFE system comes only, when there is a potential dangerous situation. Therefore driver is expected to assess the situation based on risk level and own perceptions, but to react on the warning (namely braking) immediately.

In traffic light assistant, additional to warning, a recommended speed is also shown in the displays. This is only a recommendation, driver can follow it or even not. If he follows it, he can pass the intersection with traffic light in green without stopping his car.

F.1.2 System limitations

The INTERSAFE system does not detect vulnerable road users, if they are occluded.

The INTERSAFE Traffic light assistant needs the intersection to be equipped with communication module as well (equipment rate of intersections).

If vehicles are occluded, they can only be detected when equipped with communication module (equipment rate of vehicles).

A detailed digital map containing registered landmarks and road markings must be available for the application and transmitted to the approaching vehicles by I2V (equipment rate of intersections).

The BMW traffic light assistant could have problems with the localisation, in case of D-GPS shadowing effects (e.g. in cities with high buildings) .

F.1.3 Context

Table 44: Summary conditions of function specifications

Vehicle type concerned	**Passenger car**/Heavy duty/Bus
Target considered (when relevant)	Pedestrian/**Two-wheels**/**Car**/**Heavy duty**
Road type	**Rural**/**Urban**/Highway
Weather conditions	**Normal**/**Adverse**
Light conditions	**Day**/**Night**
Level of cooperation	**None**/**Veh. to infra.**/ Veh. to Veh.

F.2 Technical specifications

The following sensors are operated:

Vehicle to Infrastructure Communication (V2I) must be available to get the phase of the traffic light with fixed phases.

Laser scanner to detect other road users in the area of the intersection and can also be used for localisation of the vehicle in the intersection. The requirements of the Laser scanner lead to a necessary angular field of view of approximately 250° horizontally and a range of about 190 m. The vertical detection range is not specified in the project and therefore not tested.

Image Processing System to localise the vehicle position at the intersection.

(D)GPS and digital map to localise the vehicle and intersection position. For the localisation, not only the intersection location but also the positions of landmarks at intersection should be included in the digital map.

Sensor fusion of video and laser scanner in combination with detailed map of the intersection, to achieve high precision vehicle localisation.

The system uses also the vehicle speed, the status of the brake, indicator and gear information as input.

Annex G LATERAL SAFE

G.1 Description

G.1.1 General information

LATERAL SAFE is designed to prevent collisions with vehicles and objects to the side of or behind the ego vehicle. This is achieved through implementation of three information and warning systems which alert the driver to a number of lateral and rear risk situations.

G.1.2 Functional Description

The LATERAL SAFE applications are Lane Change Assistant (**LCA**), Lateral Collision Warning (**LCW**) and Lateral and Rear Monitoring (**LRM**): A more detailed description is found in section 3.3.2.1 (p. 24)

Lane Change Assistant (LCA) aims at reducing risk of accidents between vehicles when changing lanes on roads with more than one lane (tactical level).

Lateral Collision Warning (LCW) aims to reduce risk of accidents between ego vehicle and obstacle to the side of the vehicle (operational level).

Lateral and Rear Area Monitoring (LRM) aims to reduce risk of collision between ego vehicle and other vehicles both in the lateral and rear area around the ego vehicle (tactical level).

Table 45: Summary of conditions concerning the function.

Vehicle type concerned	**Passenger** / **Truck** / ~~Bus~~
Target considered (when relevant)	~~Pedestrian~~ / Two-wheels / Car / Heavy duty
Road type	**Rural** / **Urban** / **Highway**
Weather conditions	**Normal** / **Adverse**
Light conditions	**Light** / **Dark**
Level of cooperation	**None** / ~~Veh. to infra.~~ / ~~Veh. to Veh~~.

G.1.3 Function limitations

Lane Change Assistant:

Ego vehicle speed has to be above 60 km/h for system activation, and lane markings are necessary.

Minimum target size for LCA is a highway-legal motorcycle with a rider.

The system may be activated based on the ego vehicle turn signal status. For instance, if the left turn signal is on, the system may be activated on the left side of the ego vehicle, while remaining inactive on the right side.

The system may be activated based on the steering input by the ego vehicle driver. If, for instance, the system determines that the driver is initiating a lane change to the left, the system may be activated on the left side of the ego vehicle, while remaining inactive on the right side.

The system may be activated based on the ego's vehicle position and/or lateral motion within its lane. If, for instance, the system determines that the ego vehicle is moving toward or into the lane to the left, the system may be activated on the left side of the ego vehicle, while remaining inactive on the right side.

Lateral Collision Warning:

The function is only active in case of a certain ego vehicle velocity of above 15 km/h. Warning shall not be triggered if the ego velocity is below 15 km/h, meaning standing and parking scenarios are not addressed. These situations are not considered to be critical and are therefore no use-cases for the intended functionality.

The function is only active in case of targets approaching with a limited relative velocity and at a sufficient lateral distance.

According to the documentation, the background is that the driver needs enough time to react after he is warned (a few seconds before a likely accident). The warning intends to prompt the driver to evade the critical situation and therefore it should not be triggered if the calculated time to collision is below a certain threshold. It does not mention how large this threshold is however.

The warning is not activated for collisions with small objects on the lane like cans, animals, road debris, drainage pits, etc., since collision with these objects are not fatal.

The addressed relative speed range is 50-120 km/h

Lateral and Rear Area Monitoring (LRM)

No limitations.

G.2 Technical specifications

LATERAL SAFE functions make use of the following sensors:

- Long Range Radar (LRR, rear looking) - The Bosch Long-Range-Radar-Sensor second generation (LRR2) is a 77 GHz frequency modulated type radar (FMCW). It detects objects in from 2 m up to 200 m. The field of view is +/- 8°.
- 2 triplets of Short Range Radar (SRR, along each side of vehicle). The SRR from M/A-COM / Tyco Electronics is an 24 GHz ultra wide band (UWB) pulse. It detects objects from 0.2 m up to 30 m. The angular detection range is +/-65° in azimuth.
- 3 cameras (2 in the side mirrors and 1 in the rear mirror). The INKA camera from Aglaia GmbH Germany is black and white with VGA-resolution, 45° FOV and has an automotive HDR CMOS (Kodak LM9618) with High Dynamic Range (HDR, 12 Bit/Pixel++, 110 dB++)

Coverage for LRM is supposed to be 270° (below, red areas marked most important, grey areas less important).

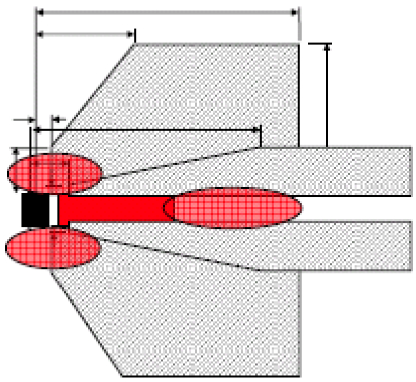


Figure 9: LRM coverage

Sensor coverage for LCW is expected to be as below:

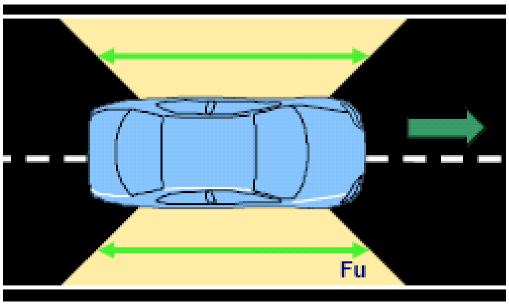


Figure 10: LCW coverage

Figure below shows the precise ranges for LATERAL SAFE functions sensors.

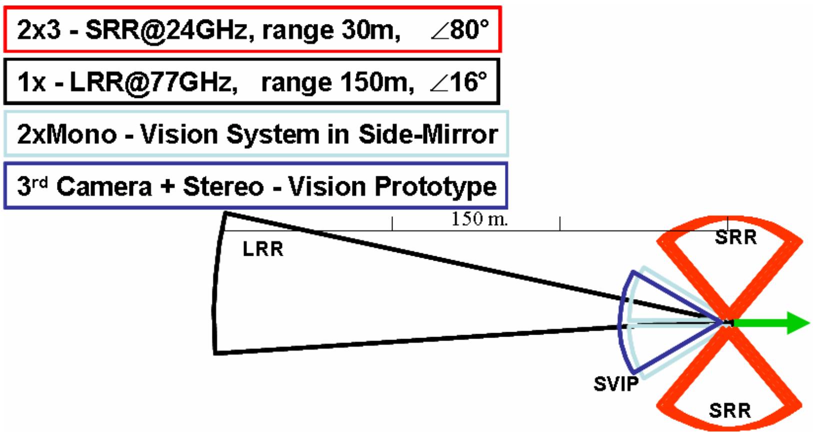


Figure 11 : Ranges of LATERAL SAFE functions sensors.

The HMI solution for the LCA application is the following:

1st level: An orange ISO symbol lights up in the left or right side mirror, when a vehicle is approaching in the left or right adjacent lane respectively (TTC≤3 sec).

2nd level: A red ISO symbol lights up in the left or right side mirror , when a vehicle is occupying the left or right blind spot area of the car and the system has determined that there is a critical danger if the driver decides to change lane.

3rd level: A red ISO symbol is flashing in the left or right side mirror in combination with a directional, left or right, Wierwille sound, when a vehicle is approaching in the left or right adjacent lane respectively or when a vehicle is occupying the left or right blind spot area of the car, the driver has activated the corresponding turn indicator signalling a lane change manoeuvre.

The HMI solution for the LCW application is the following:

One level: A flashing red warning triangle above ISO symbol K17B, in combination with a directional sound cue (1beep.wav, similar to Wierwille), if and when the system determines that there is a risk of collision (TTC≤2sec) at the left or right side of the vehicle, respectively.

The HMI solution for the LRM application for trucks is the following:

Objects behind truck (same lane)

Normally yellow, but red if object is very close behind the truck (headway < 0.3s).

Objects in adjacent lanes

Yellow objects, except if highlighting is made according to any of the lateral highlighting conditions below.

Lateral highlighting conditions

Even if an objects is two or more lanes away, it is presented if is closing the truck rapidly (TTC< 3s), yellow if TTC is between 1.5 and 3s and red if TTC is < 1.5s. At the same time as the object turns red, an LCW acoustic warning is issued.

If the driver intends to change lane (use of turn indicator) with an object that is or within 1.5 s will be to the side of the truck, an acoustic LCA warning is issued and the object turns red.

If an object is extremely close laterally (< 0.25 m) to the ego vehicle, it is highlighted by turning red.

The acoustic warnings regarding the lateral regions correspond to the LCW and the LCA applications.

Logic for hysteresis of warnings and highlighted objects is also implemented (minimum time 4 s between acoustic warnings of the same type and minimum 2 s for highlighting of objects). Objects not presented at all if moving away with relative speed > 1 s (object driving slower than truck).

Annex H MAPS&ADAS

H.1 Function specifications

H.1.1 Functional Description

The Driver Warning System consists of two functions and a dedicated electronic map. The applications are the so called Speed Limit Warning (SLW) and the Hot Spot Warning (HSW).

Speed Limit Warning

The concept of the Speed Limit Warning function (SLW) is to inform the driver in case the vehicle speed is higher than the speed limit. This is done by comparing the speed of the vehicle with the current static speed limit stored in the ADAS map. Speed limits may also depend on weather conditions, vehicle type, period of the year, etc.

Hot Spot Warning

The Hot Spot Warning function provides an anticipatory warning of (potential) dangerous sites in the road network depending on environmental influences and current driving dynamics [1, chapter 2.2, 2, chapter 1.2.1]. This corresponds to accident prone locations identified from accidentology data.

A hot Spot for the HSW application is defined as a road segment or a specific place on the road, which represents an increased risk of accident to a driver.

The Hot Spot Warning function offers a warning to the driver in case the light und weather dependent speed thresholds of the Hot Spots are exceeded. This warning is given with information about the nature of the potential accident prone location, e. g. sharp curves, high slopes, accident prone intersections.

The map is a commercial electronic map commonly used for navigation purposes, enhanced with ADAS specific attributes like speed limits and hot spots.

If a “Hot Spot” is provided along the path and speed, lighting, and weather conditions match the “Hot Spot” characteristic the system provides a warning to the driver 5 seconds before reaching the spot.

In addition to the speed icon shown by the speed limit warning an acoustic warning and a dedicated hot spot warning sign is presented to the driver on the onboard screen.

H.1.2 System limitations

The system is based on an electronic map commonly used for navigation purposes, enhanced with specific attributes like speed limits and hot spots. Hence the system can only warn if a hot spot is listed in this map. Besides the system should be installed with a temperature sensor and optional with a rain sensor. If this sensors give false information about weather conditions system may give false or in this case no warnings.

If the information of the map has a high quality in terms of accuracy and up-to-dateness, the reliability of the system will be high.

Table 46: Summary conditions of function specifications

Vehicle type concerned	**Passenger car** / Heavy duty / Bus
Target considered (when relevant)	Pedestrian/Two-wheels/Car/Heavy duty
Road type	**Rural / Urban / Highway**
Weather conditions	**Normal / Adverse**
Light conditions	**Day / Night**
Level of cooperation	None/Veh. to infra./ Veh. to Veh.

H.1.3 Target accidents

The Hot Spot Warning function is designed to work on rural roads mainly and only secondary on motorways. It is not a system to prevent accidents in urban areas, since it addresses accidents without third parties. Hence its focus is on accidents caused by unadapted speed and insufficient alertness/ attention, often in demanding driving situations like curvy roads, high slope or in woodland. On motorways Hot Spots occur more rare, therefore the main field of the system are rural roads. The concept does not include hot spots in urban areas, since the related accidents are often influenced by the surrounding traffic and can be avoided more efficiently by systems which monitor traffic and objects around the car. Therefore the HSW is mainly an inter-urban system.

The HSW application based on an ADAS map will be able to avoid accidents which follow a specific pattern of previous accidents linked on characteristics of the digital map.

The type of accident describes the conflict situation which resulted in the accident, i. e. a phase in the traffic situation where the further course of events could no longer be controlled because of improper action or some other cause.

For the HSW two types of accidents have been identified:

- Driving accident: The accidents was caused by the driver losing control of his vehicle (due to unadapted speed or misjudgement of the course or condition of the road etc.), without other road users having contributed to this.
- Other accidents: This includes all accidents that cannot be allocated to any other type of accidents. Examples: U-turning, reversing, obstacle or animal on the carriageway.

Besides this two types of accident there are over all five kind of accident:

- Collision with another vehicle moving laterally in the same direction in combination with accident caused related to overtaking

- Collision with another oncoming vehicle in combination with accident caused related to overtaking
- Collision with another vehicle which turns into or crosses a road in combination with priority related accident causes
- Collision with an obstacle in the carriageway. This reflects accidents with game.

H.2 Technical specifications

The system should provide a warning well before entering a critical situation.

Position is continuously matched to the digital map. The current position and the most probable driving path are provided via the horizon provider to the warning system. Depending on the length of the horizon, the time varies when the warning system gets information about “Hot Spots” and speed limits.

The system decides to give “Hot Spot” warning at a distance defined by the vehicles speed multiplied with a fixed time of 5 seconds. It decides to give a speed warning if the current speed exceeds the valid, stored legal speed limit by 6 km/h (blinking) or 20 km/h (acoustic warning).

Due to the fact, that the system provides warning well before entering a dangerous situation, the decision is not time critical.

Annex I SAFELANE

I.1 Function description

I.1.1 General information

SAFELANE lane keeping support systems; Providing warnings and intervention to avoid lane departure. The goal is to support drivers on tactical (warning) & operational (intervening) levels to avoid lane departure.

I.1.2 Functional Description

SAFELANE develops an enhanced and model-based lane keeping support system which is mainly characterized by an enhanced environment perception, a model-based adaptive decision component and an active steering component.

One of the main original safety features of SAFELANE keeping systems is the conception of a multi sensors situation model based decision system. This situation model builds a model of the current situation from the sensor data. With map data, radar or obstacle detector data and vehicle sensors, we get much more input than traditional lane keeping systems. This situation model is described in more details below.

Depending on the prototype implementation the system provides different warnings or actions:

1. Visual (information) warning
2. Acoustic warning
3. Haptic warning (symmetric wave forms)
4. Haptic action suggestion warning (dissymmetric waveforms in to suggest direction of correction by the driver)
5. Corrective action (automated correction)
6. Constant lane keeping

The functions 3 to 6 are implemented through an action in the steering wheel (warning (3,4) and intervening (5,6))

The definition of success for test of the systems behaviour has been a minimum of either TLC<[0.5..2s] or a lateral distance of .2 m from the edge of the vehicle to the closest lane border. The system has been implemented in demonstrator from VTEC and CRF (both trucks) as well as in a car from Fraunhofer Gesellschaft and one test vehicle from LCPC. Different ways of giving feedback to the driver have been installed in the four demonstrator vehicles (cp. Table 47), a list of perception technologies is presented in Table 48.

Table 47: Properties of demonstrator vehicles.

Demonstrator	Vehicle type	HMI channel			Active steering
		acoustic	optic	haptic	
VTec	Truck	optional rumble strip noise		vibrations in steering wheel	torque in direction of lane centre
CRF	Truck	rumble strip noise	X	vibrations in steering wheel	
FhG	Car	X			
LCPC	Car	rumble strip noise		vibrations in steering wheel (asymmetric, directed towards lane centre)	

The systems are based on vehicle-side technologies. The basic input comes from cameras monitoring the road in front of the vehicle. They detect lanes, if necessary in consideration of infrastructure elements and road traffic. The cameras are supplemented by existing vehicle CAN bus data, digital road maps and a precise vehicle positioning. ACC systems or other forward looking active sensors provide supplementary information as well. The system reaction in critical lane departure situations involves the control of an acoustic or haptic warning actuator and an active steering actuator, depending on the demonstrators.

The essential quality enhancement of the approach comes from a decision component that analyses the incoming sensor data, detects the lanes, determines the relevant situation, predicts vehicle paths, computes the most likely vehicle trajectory and synthesises data for controlling the system actuators. For this, a flexible model based technology is used It allows the system to be adaptive to several situations and to be configured to different sensors or actuators. An essential feature is a self-assessment module that informs the driver in each situation how reliable the support is.

Table 48: Perception Technologies of the four demonstrators.

Demonstrator	Vehicle Type	Perception Technology
VTec	Truck	Lane Tracker camera and image processing PC MAPSENSOR electronic horizon system (MAPS&ADAS System) providing geospatial data like position, driving direction, map position, ADAS attributes from the map ACC radar sensor, providing object information of the vehicles ahead All onboard information available on the CAN
CRF	Truck	a vision system providing lane marking information an electronic horizon system (MAPS&ADAS system) ACC radar sensors (“Active Sensors”) providing a list of objects of the vehicles ahead. All onboard information available on the CAN Two additional Lane Detection Systems as reference systems
FhG	Car	A camera and an image processing IR radar
LCPC	Car	All data on the vehicles CAN bus Lane detection camera plus image processing

Accidents

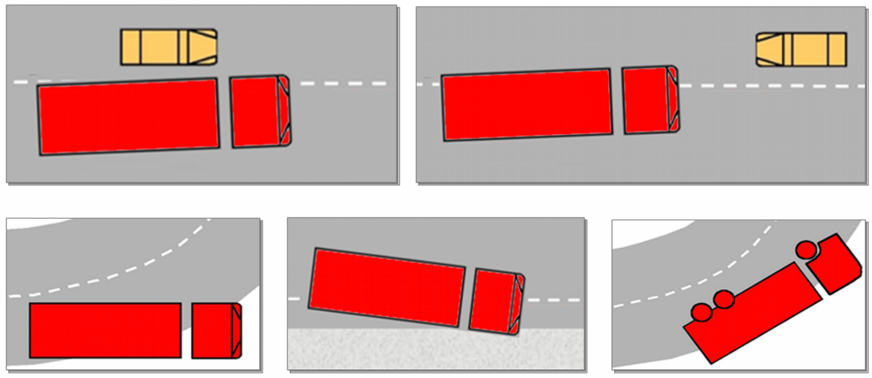


Figure 12: Typical Accident Scenarios targeted by SAFELANE

Within SAFELANE accidents caused by some form of driver inattention (e.g. drowsiness, fatigue and distraction) are of special interest since the developed SAFELANE system is aiming to prevent accidents resulting from poor lateral control and caused by one or the other form of driver inattention.

I.1.3 Functional Specifications

The system should handle road segments with *one lane, one lane for each direction, several lanes for each direction.* It should especially be able to work under the condition of *small lane width*.

All usual kinds of road surface have to be considered: concrete, bitumen, stones, corrugation, dirt, water.

The following lane markers are considered: *dashed, permanent, and combined*. The distinction between white and yellow markings is optional if colour images are available. Country-specific markings should be considered, too.

The system should also give some support if lane markings are not or only partially available (e.g. information warning for example since reliability might be not high in this case). Especially, the cases if only left or right markings are available or if there are several or ambiguous markings have to be handled.

The system should work in normal/adverse weather conditions and day/dark light conditions.

The task of the system is to minimize environmental influences on the situation detection rate and to regard them in the decision process for certain actions.

The system reaction time is less than 250ms (this includes the time from issuing a warning/steering request until the overall system reacts by e.g. steering). The system update rate should be at least 20Hz (this includes all time from image processing (30Hz) to the actuator).

I.1.4 System limitations

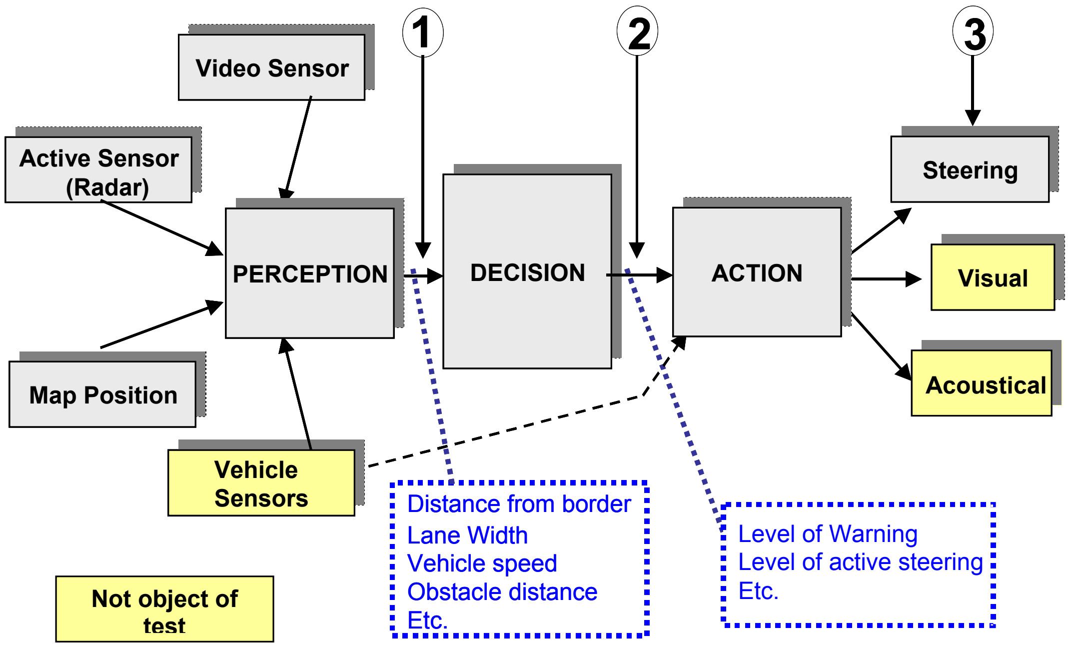
In spite of the fact the curvature and the curvature rate can be recovered by lane data fusion, lateral offset, a fundamental variable for lateral assistance, is dependent on vision. This is however an actual known limitation in lateral assistance.

Table 49: Summary conditions of function specifications

Vehicle type concerned	**Passenger car** / Heavy duty / **Bus**
Target considered (when relevant)	Pedestrian / Two-wheels / Car / Heavy duty
Road type	**Rural** / Urban / **Highway**
Weather conditions	**Normal / Adverse**
Light conditions	**Day / Night**
Level of cooperation	**None** / Veh. to infra. / Veh. to Veh.
Speed	Not available, but designed for highway and rural road speeds
Limitations (e.g. road markings necessary)	System works even if lane markings are missing or ambiguous or the visibility is restricted.

I.2 Technical specifications

Radar, video sensor, GPS with map positioning (needs map data), vehicle sensors (torque, steering wheel angle), inertial sensor



The decision system determines

- whether the system is able to furnish an assistance. It determines as well which type of assistance it is able to furnish (both are self-assessment) (see table below – red means no action);
- which type of assistance it must be furnished as a function of the danger in lane and road departure and intention (blinkers, estimated overtaking, curve cutting). It splits in 6 modules.

The decision system consists of 6 modules:

- Most likely path (MLP): predicts the most probable route that the driver will take. Objective: map attributes within the electronic horizon are then searched only in the MLP. Method : done with past experience, destination input, sensors
- Lane data fusion (LDF): fusing the lane data from different sensors to one lane model (see figure below). It is made to increase availability and robustness of lane geometry.
- Trajectory estimation (TEM): estimate the future trajectory of the vehicle in relation to the lane model. Computes the TLC variable (time to line crossing).
- Situation model: builds a model of the current situation from the multi-sensor data (with map data, radar or obstacle detector data and vehicle sensors in addition to the vision system).

  It is one goal of the SAFELANE system to use this additional data and adapt the lane keeping support to the current "driving situation".

  Situation model extracts an abstract situation description (sub-models) from the mass of input data.

  Sub-models are driving manoeuvres (overtaking, cut a curve), lane and road conditions (lane width, curvature, velocity), lane departure class with different levels of danger (function of lateral offset and TLC - computed from TEM module), driver attention, urban area, environment, inhibition, intention (function of indicator, curve cutting, overtaking, etc) (see Figure 13).

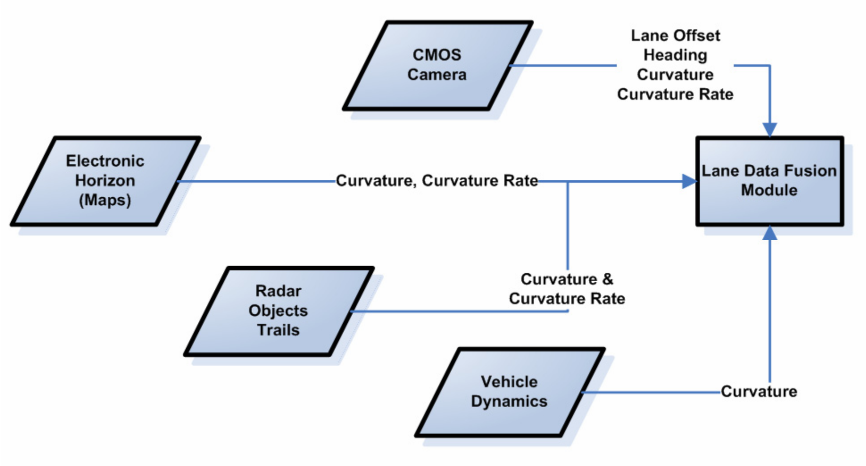


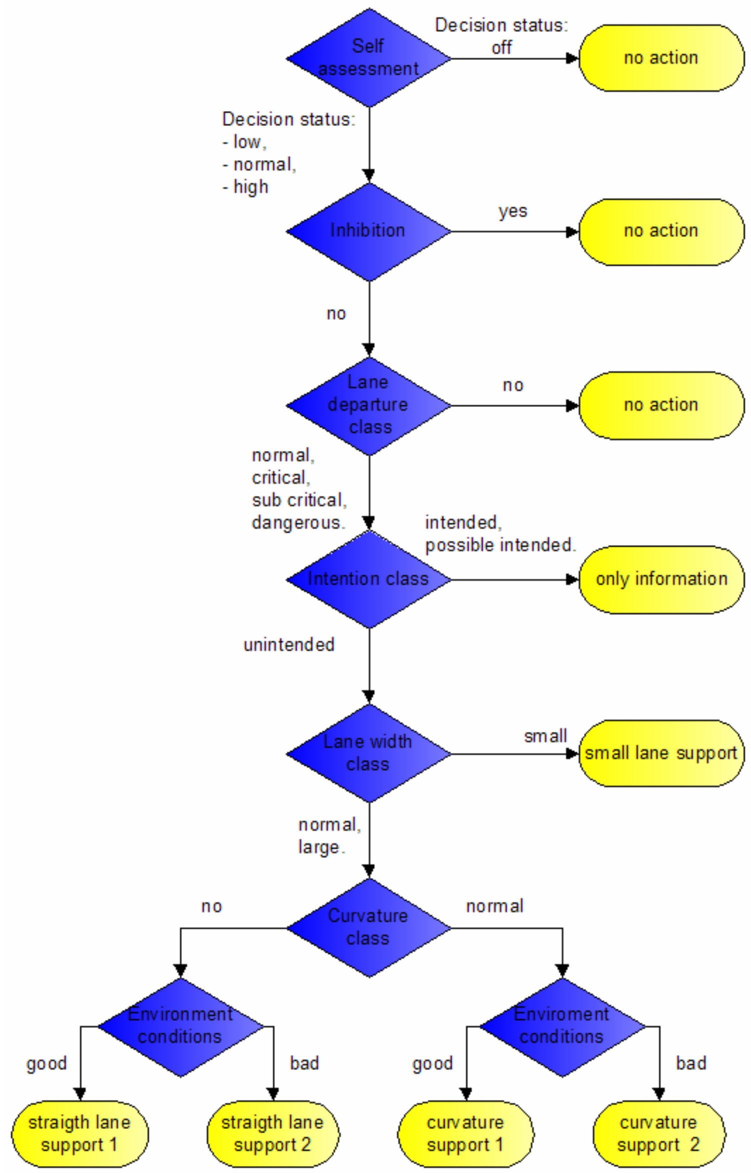
Figure 13: Lane data fusion.

- Self assessment: estimate the reliability of the system. See table below. All decisions from the decision system will be limited to the allowed actions. There are 3 main sources to estimate the system reliability :
  1. Failures of system components or a lack of sensor data,
  2. Predefined situations like travelling in urban roads or if a curvature exceeds a certain amount,
  3. The statistical reliability of the lane estimation model.

Table 50: self assessment results (red means no action)

Decision status	Warning level			
	no warning	information	warning	automatic control
high	✓	✓	✓	✓
normal	✓	✓	✓	not allowed
low	✓	limited	limited	not allowed
off	✓	not allowed	not allowed	not allowed

- Decision model: decide what kind of action should be taken from the current lane departure and situation.



Annex J SASPENCE

J.1 Description

J.1.1 General information

SASPENCE (= SAFE SPEED and SAFE DISTANCE) system is an assistance system that provides suggestions (warnings or advices) to the driver, related to maintain the safe speed and safe distance, depending on external scenarios and conditions (potential dangers - in front of the host-vehicle). The information are given in an optimal way, by an appropriate HMI.

J.1.2 Functional Description

Objectives:

The objective of the SASPENCE system is to assist drivers to keep a Safe Speed and a Safe Distance relative to potential dangers on his / her lane, to keep an appropriate speed in accordance with the road legal speed limits, to keep a safe speed in accordance with the road (and weather) conditions.

Functionalities

SASPENCE allows the driver to have a safe and comfortable driving experience by measuring environment and vehicle parameters and warning the driver in case of unsafe speeds or distances to obstacles in front (e.g. predecessors).

SASPENCE covers the following functionalities:

- Safe speed w.r.t. vehicle in front (Fm1 in the system description).
- Safe headway w.r.t. vehicle in front (Fm2 in the system description).
- Appropriate speed w.r.t. the speed limit (Fm3 in the system description).
- Appropriate speed w.r.t. road and weather conditions (Fm4 in the system description). N.B. no information is available as to how road and weather conditions are taken into account.
- Safe and comfortable driving by measuring environment and vehicle parameters (Fm5 in the system description). N.B. it is not clear how this function adds something to Fm1&2.

The first two functions of the SASPENCE system provide advice regarding moving or stationary objects/obstacles in front that are considered to be a hazard to the driver. The third function advises about the appropriate speed given the local speed limit. The fourth function gives warnings in case the speed is considered excessive for the circumstances, e.g. when approaching a sharp curve or in adverse weather. However, as weather is not a part of the SASPENCE development system at the moment, we will not consider it in this PReVAL safety assessment. Our investigation has not shown any additional safety effect for Fm5 beyond those of Fm1 and Fm2, and hence we do not consider it in this analysis.

J.1.3 Accident scenarios and expected driver behaviour

Scenarios

In the safety assessment we will consider two situations:

- Situation 1 deals with the case where the speed or headway is not appropriate to the vehicle in front. This covers SASPENCE sub-functions 1 and 2.
- Situation 2 deals with speed behaviour in all driving situations (i.e. not only in car-following situation). This covers SASPENCE sub-functions 3 and 4.

The driver behaviour might be different, depending on the situation where the speed and headway advice is given. Each situation contains a number of relevant traffic/accident scenarios. For each of these scenarios the expected driver behaviour needs to be specified. This is the driver's response to information, advice or a warning issued by SASPENCE.

We now describe the scenarios and for each scenario we mention the potential effect of SASPENCE and what the driver needs to respond to:

Situation 1: Risk of rear-end collision. SASPENCE suggests safe speed and headway, or gives a warning about the headway compared to vehicle travelling in front.

Scenarios:

1. Ego vehicle is approaching or following too close a vehicle ahead: advice or warning is provided to the driver. Three different warning levels are provided, depending on the severity of the situation.

   Potential effect of SASPENCE: The driver will always be made aware of unsafe following situations and can adapt speed and headway before really critical situations occur.

   Driver has to respond to advice about the safe speed and/or headway when following a vehicle closely;

2. Ego-vehicle is approaching an obstacle ahead, e.g. a vehicle that drives slowly, or slows down, or brakes very hard. Three different warning levels are provided, depending on the severity of the situation. The difference between scenarios 1 and 2 is that scenario 2 is about a *sudden* change, like approaching the tail of a traffic jam, while scenario 1 is about a *continuing* situation, like travelling in a platoon.

   Potential effect of SASPENCE: The driver will be made aware of slow moving vehicles ahead and can decelerate in time; hard braking can be avoided.

   Driver has to respond to advice about the safe speed and/or headway when approaching an obstacle (usually a slower vehicle) and slowing down or braking is needed;

3. Ego-vehicle is travelling and another vehicle is entering or departing on the host-path and a warning has to be given in time to the driver.

   Potential effect of SASPENCE: If the relative speed or the following distance becomes critical, the driver can be warned and he can adapt speed and/or headway.

   Driver has to respond to a warning when a vehicle cuts in (or cuts out, in that case it may be possible for the ego-vehicle to accelerate);

4. Ego-vehicle is travelling on a one-lane rural road and another vehicle is approaching in opposite direction: info to the driver for caution: potential critical situation. In the future vehicles approaching from the opposite side may be detected; however, this is not part of the current SASPENCE system, due to its limited detection range. Hence we will exclude this scenario in the safety analysis.

Situation 2: General traffic situation, not tied to a vehicle in front. SASPENCE suggest an appropriate speed in accordance with the speed limit on the road, road features and weather conditions.

Scenarios:

5. Ego-vehicle is travelling on a free road: info on speed limit

   Potential effect of SASPENCE: The driver will be advised on the legal fixed speed limit and warned of speeding (whenever his road is covered by the digital map and his position is determined accurately). The system does not intervene. SASPENCE does not have a communication module and hence is not expected to deal with short-term speed limits (road construction etc.) or variable speed limits.

   Driver has to respond to advice about the appropriate speed based on the fixed speed limit;

6. Ego-vehicle is approaching a sharp curve or a particular landmark: warning levels are provided, depending on severity of the situation; proper speed to keep is suggested, and the cause of the speed advice is indicated

   Potential effect of SASPENCE: Geometry related hazards are derived from the map data (and road curvature also from the camera) and are therefore detected whenever they are covered by the digital map and the vehicle position is determined accurately. The driver will be made aware of such special situations and will be provided with appropriate speed advice and information on the cause of the speed advice.

   Driver has to respond to advice about the safe speed when approaching specific spots where a lower speed than the speed limit is advised (curves, pedestrian zones etc.);

7. Ego-vehicle is travelling on a road in a bad-weather situation: info on the proper speed to keep. As weather is not a part of

the SASPENCE development system at the moment, we will not consider this scenario.

Remarks:

- The headway advice supports the driver to estimate the distance between the two vehicles and reminds him of the safe distance, taking the current speed into account.
- In vehicle-following situations where a sudden change of situation happens, SASPENCE acts as a warning function and may help driver to detect sudden changes in situations, so that proper action can be taken. However, in the case of sudden changes, the question is how much support SASPENCE really gives, especially in cut-in situations – when does the radar notice the vehicle cutting in? How often would a driver not notice this in time?
- In the case of speed advice based on (fixed or flexible) speed limits, SASPENCE advises a safe speed and it is the drivers' decision how to react to this suggestion. Based on previous research it might be assumed that the drivers will better comply with the suggested speed based on dynamic information (Finnish VMS studies, for example). This might be the case also with hot spots speed suggestions, but the type of information the suggestion is based on might have a substantial effect on drivers' response (i.e. speed reduction). In addition, strong effects are expected for hot spots with low subjective risk or workload (i.e. hidden objective risks) but not for hot spots with high subjective risk or workload (such as…?). Also, speed suggestions in urban area might be taken more seriously than in rural areas (the ISA studies might give indications regarding this effect).
- We observe that scenario 6 differs from the MAPS&ADAS "Hot Spot Warning" because the MAPS&ADAS hotspots are accident-prone locations, while SASPENCE looks at road geometry and landmarks like school zones.

J.1.4 System limitations

Conditions under which SASPENCE is expected to function

The SASPENCE system is expected to provide assistance in a multitude of circumstances, but not always and everywhere. The following should be taken into account when assessing the impacts:

Vehicle types

Currently SASPENCE is being developed for passenger cars only. In the future it may also be developed for trucks, but for PReVAL we will assume the system is available only for passenger cars.

Road types

SASPENCE is dedicated to motorways and rural roads. Among the operational requirements are that the speed of the ego-vehicle is between 40 km/h and 140 km/h. At speeds outside this range the system goes in “pause” mode. The mode is indicated by a visual signal. Usage in urban roads is questionable.

Detection of weather

As mentioned before, this is not considered in PReVAL.

General limitations

Technically the system is able to detect cars (of various kinds: trucks, passenger cars, etc), motorbikes, bicycles, and stationary obstacles, but not pedestrians. However, there is no obstacle classification, and in practice the detection of small or stationary obstacles suffers from a large number of false alarms. Hence, for PReVAL we will only consider the detection of *moving* cars.

Technical constraints and limitations are:

- The intervention range, which depends on
    - The maximum braking power of the equipped vehicle
    - Road surface (related to weather condition as well)
    - Maximum detection range of the long ranger radar
- The relative velocity: the maximum relative speed at which a warning can still be provided in time;
- General limitations of data acquisition on environment always available with the necessary precision (accuracy, resolution, field of view (FOV):
    - Horizontal FOV (HFOV);
    - Detection of obstacles in a curve;
    - Lateral position and extension of an object;
    - Angular resolution and accuracy;
    - Vertical FOV (VFOV);
    - Detection of overhead objects (and regarded as it is);
    - Vertical resolution.
- Prediction limitations: To predict the host-vehicle trajectory and the obstacles dynamics in scenarios which are not-well or not-at-all structured (urban, low-speed conditions, etc.)

Limitations per scenario

Per scenario, the following limitations have been identified or should be analysed:

Scenario	Limitation
1. Following behaviour	None (if radar functions well)
2. Obstacle ahead	Which obstacles that the ego-vehicle shares the road with cannot be detected (cars and trucks driving at speeds below 40 km/h? cyclists, pedestrians?).
3. Cut-in situation	Can the system give an advice in time for the driver to react to critical situations? When does the system detect the vehicle cutting in (angle)?
5. Information on speed limit	None
6. Speed advice due to landmark	The availability of correct data to base the warnings on.

Accident types

In total 8 traffic scenarios (use cases) have been described:

- Vehicle is travelling on the road, no obstacles appear
- Vehicle is travelling on the road, no obstacles appear, critical weather conditions are present
- Vehicle is travelling on the road, obstacle appears ahead, but not on the ego-path
- Vehicle is travelling on the road, obstacle appears ahead, on the ego-path, without being dangerous
- Vehicle is travelling on the road, obstacle appears ahead and it could be (or become) dangerous
- Vehicle is travelling on the road, obstacle appears ahead suddenly
- Ego vehicle is travelling on a rural road with on-coming vehicles approaching
- Host-vehicle is approaching some particular landmarks at too high speed

In addition also information is provided on relevant parameters and operation conditions.

Vehicle:

Vehicle Type	ADAS works in/ is designed for
Passenger car	X
Bus	Not implemented, but possible with adaptations
Truck	Not implemented, but possible with adaptations

Sensors:

The following sensors (and information sources) are used on the SASPENCE system:

long range obstacle detection radar;

front looking camera for lane recognition;

differential GPS;

enhanced road map (from MAPS&ADAS);

vehicle-to-vehicle communication by wireless LAN (as possible extension).

[d20.35]

Road:

Road type	ADAS works on/ is designed for
Urban	x
Rural	x
Highway	x

Note: the system was not defined for urban roads, but works if the minimum ego vehicle speed exceeds 40 km/h.

Road Conditions	ADAS works in/ is designed for
Straight roads	x
Curved road sections	X > 30m
Intersections	X
Junctions	X
Dry road	X
Wet road	X
Slippery road	X

Note: the system is designed for wet and slippery road, but the road friction is not measured.

Traffic:

Traffic Context	ADAS works in/ is designed for
Accident	x
Traffic Jam ahead	x

NOTE: traffic jam ahead can be critical, due to the presence of stationary obstacles, which can cause false alarms

The system performance increases when the vehicle-to-vehicle communication option is included.

Environmental:

Weather Condition	ADAS works in/ is designed for
Normal	x
Adverse (rain, fog)	x

Light Condition	ADAS works in/ is designed for
Light	x
Dark	x

The vision system performance is limited in dark conditions.

Infrastructure:

Level of Cooperation	System
None, stand alone system	x
V2V	Present ((even if not fundamental)
V2I	Optional

Other limitations:

Minimum vehicle speed: 40 km/h

Maximum vehicle speed: 140 km/h

Other vehicles: ranges of speed: unclear [D20.33, P 47]

The system is designed for several road conditions (dry, wet, slippery), but internal models are optimised for dry road, and road condition is not measured by the system.

The system is done for different types of conditions and situations, based on the fact that it is needed to have the related information. If from communication or other source we get such information (i.e. the slippery road), strategies could be modified accordingly).

J.2 Technical Specification

Time frame (sensor, decision, actuator):

Depends on speed and environmental factors

The cycle time of the system is 100- 300 ms and depends on the complexity of the situation. Mean value is 150 ms.

Sensors:

TRW Image Processing Unit, comprising a processing unit and a camera (30 frames/s, horizontal field of view 54° and vertical field of view 22°).

Fujitsu Ten Long Range Radar: max. range 120 m, min. range 4 m, horizontal field of view 16°, relative speed range 200 km/h, update frequency 10 Hz

NAVTEQ Sensor Box consisting of GPS receiver (10 m accuracy), gyro and other electronics to provide positioning info.

UBLOX differential GPS for global positioning (2-2.5 m accuracy)

[D20.35, p19 and following]

Additional Sources

Enhanced (digital) map data.

WLAN for vehicle-to-vehicle communication (optional)

Actuator

No actuators are present, but information is given to the driver by several HMI channels, one of which is a hap-tic accelerator pedal. This is common to the two demonstrator vehicles (done by CRF and TRW). On the TRW car there is also an active seta-belt (pre-tensioning or vibrating) as a redundancy HMI channel.

Algorithms

Sensor data is fused at multiple levels to provide an enhanced view of the environment, resulting in estimations of the host global state, the road course ahead and the relative position of other vehicles to the host vehicle and their predictive paths (Figure 14)

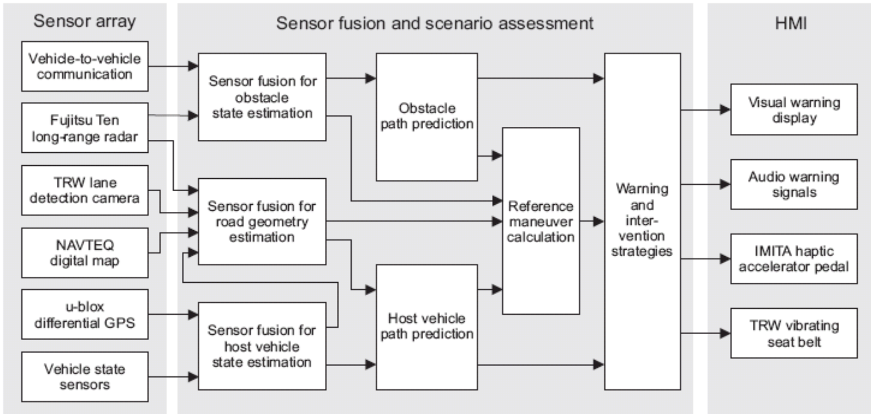


Figure 14: System architecture of SASPENCE system

The results of the sensor fusion and road geometry estimation modules are used to compute an optimal reference manoeuvre. The optimal reference manoeuvre is the manoeuvre with the lowest risk level when the safety margin is considered. This is based on the maximum friction potential, but the precise calculation is not clear. The reference manoeuvre is then compared to the predicted path of the host vehicle allowing the SASPENCE system to compute an appropriate speed and safe distance to the preceding vehicle, as well as to consider speed limits and weather conditions.

If the difference between the calculated reference manoeuvre and the predicted host vehicle crosses a threshold, the system intervenes by giving information and/or warnings to the driver. The warning and intervention modules compute the appropriate warning type and level; then, it selects the proper and optimal HMI channels. [98]

Annex K WILLWARN

K.1 Description

K.1.1 General information

Generation of hazard information by standard vehicle sensors, distribution of information in a car-to-car wireless network, early danger warning to the driver.

K.1.2 Functional Description

WILLWARN supports the driver in safe driving by inter-vehicle communication based on the creation of an electronic horizon that enables foresighted driving which is an important part of the PReVENT scope. WILLWARN warns drivers early whenever a safety related critical situation occurs ahead, especially of obstacles, adverse road and weather conditions, and hazardous construction sites, even if it happens outside their field of view.

The main project goal is the reduction of accidents by early warning. Nevertheless, this cannot be evaluated within the WILLWARN project. The evaluation scope was to prove if the system approach was correct, if the assumptions on drivers' expectance and drivers' behaviour were correct, and if the requirements and specifications for the system modules were justified. Consequently, the validation scheme was approached on a qualitative level.

Foresighted driving and early detection of hazards is a key for safe driving and accident avoidance. Vehicle communication in PReVENT is focused on the major accident reasons shown in the German accident statistics. This brings a benefit for 39.6% of the accidents as table Table 51 shows.

Table 51: PReVENT scope of communication based safety

Reasons for driver caused accidents	%	PReVENT system
Too fast	16.3	WILLWARN, SASPENCE
Too close	10.5	WILLWARN, SASPENCE
Right of way violation	12.8	INTERSAFE

PReVENT WILLWARN based the categorization of the use cases on the major accident reasons shown in the German accident 2004 statistics, limiting the use cases related to accidentology to speed or inadequate following distance and bad weather. In 88.2% of the accidents with damage to persons (killed or injured) the driver is responsible for the accident. The classification of accidents is done by the police. The remaining 11.8% are caused by vehicle problems (mainly tires and brakes), pedestrians and bad road status.

The 88.2% of accidents where drivers are responsible are classified as Figure 15 shows. Accident reasons which are marked in red are potential candidates which can be improved by warning or manoeuvring information coming from the communication channel.

Driving too fast and too close to preceding vehicles is the reason for 26.8% of the accidents caused by drivers. This means that in the situation where an accident occurred, lower speed and a greater headway could prevent an accident. The next big reason for accidents is manoeuvring mistakes. Right of way problems at intersections, merging at entry or exit lanes, and passing and overtaking errors lead to 30.2% of the accidents (Figure 15)

This means that 57% of the accident reasons caused by drivers can be positively influenced by earlier, more and better information through communication.

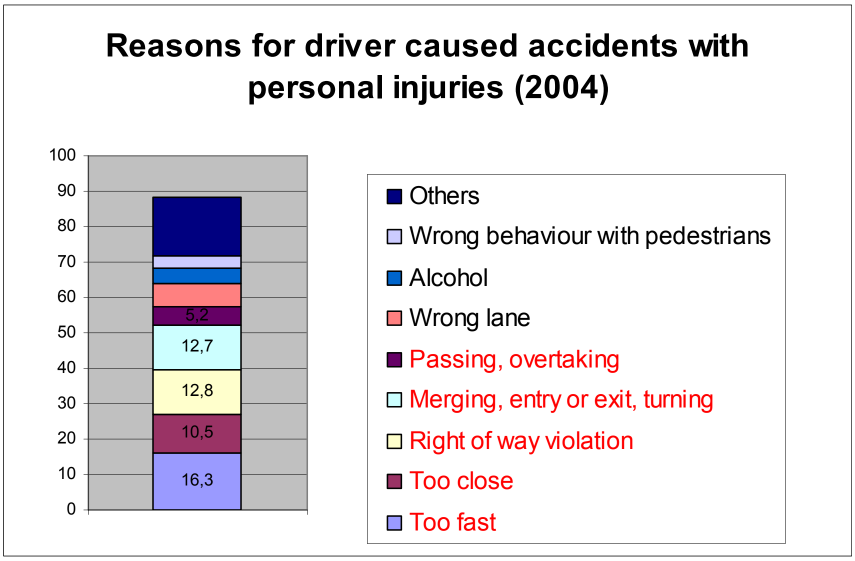


Figure 15: Shares of accident reasons in Germany (2004)

The WILLWARN system assistance type is mainly:

- Detection and warning of obstacles on the road
- Warning of emergency vehicles or slow vehicles
- Detection of reduced friction or reduced visibility through bad weather
- Warning of dangerous spots like construction zones through electronic beacons

Table 52: Summary conditions of function specifications

Vehicle type concerned	**Passenger car/Heavy duty/Bus**
Target considered (when relevant)	Pedestrian/Two-wheels/Car/Heavy duty
Road type	**Rural/Urban/Highway**
Weather conditions	**Normal/Adverse**
Light conditions	**Day/Night**
Level of cooperation	None/Veh. to infra./ **Veh. to Veh.**

K.2 Technical specifications

WILLWARN has the following main functionalities:

- on-board hazard detection (obstacles, reduced visibility, bad road conditions, construction sites) by the Hazard Detection Module
- in-car warning management (application based routing, store and forward) by the Warning Message Management module
- decentralized warning distribution via communication performed by the Vehicle2Vehicle Communication Module in cooperation with the Warning Message Management module
- position based relevance check and driver warning performed by the Hazard Warning Module in cooperation with the Warning Message Management module.

The WILLWARN system comprises (see also section 3.4.2)

- Vehicle2Vehicle Communication module (VVC).
- Hazard Detection module (HDM).
- Hazard Warning module (HWM).
- Warning Message Management module (WMM) and a database.

In-car Message Management and warning dissemination (application based routing) was developed within WILLWARN, decoupling the application functionality from the underlying communication technology, making WILLWARN independent from specific communication solutions. This was the reason, why an application based routing established in the application layer was chosen. For low penetration rates the warning dissemination is done by store and forward. Messages have to be checked regarding their relevance of space and time. Redundant messages have to be identified to avoid long message lists. To enable ad-hoc networking in a scalable network with many participants and ensure the interoperability with other cooperative telematics services, WILLWARN has integrated and consolidated the routing functionality from the German Network on Wheels project (NoW) in the network layer of the communication system.

As soon as the VVC module is available for sending WILLWARN hazard messages, the new hazard message is forwarded to VVC “send queue” and transmitted through the VVC communication module. It should be noted that a message is kept in the databases and is forwarded to neighbour vehicles until it becomes temporal and spatial invalid or redundant. Received hazard messages are checked for relevance with respect to own vehicle position and forwarded to the HWM for driver warning only after they are proved relevant.

The HDM module provides negative information, i.e. information about hazards that can not exist at the current position, to the WMM. Based on this the WMM can detect and discard invalid hazards that have been reported by neighbour vehicles. Finally, a positioning system (GPS, Galileo etc) is used for the moving vehicles for hazards relevance checks and for hazard message forwarding and dissemination.

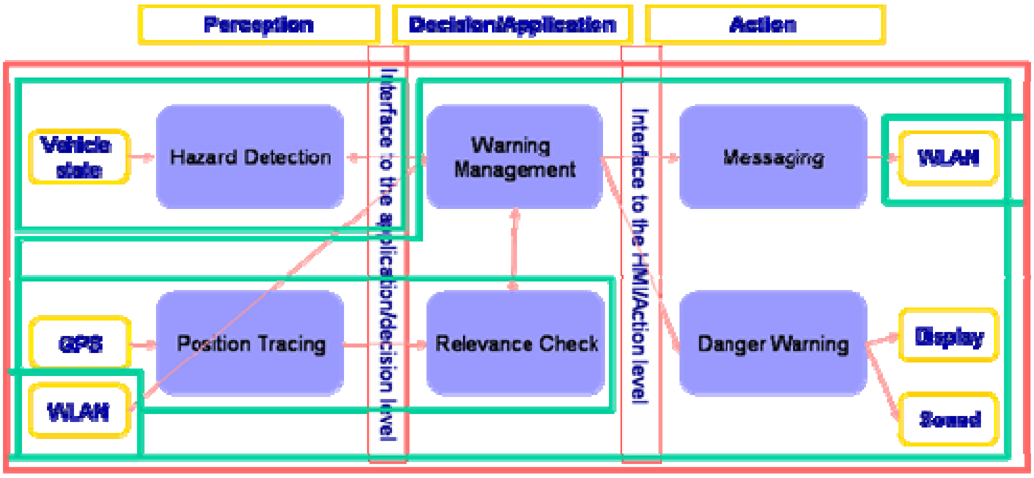


Figure 16: WILLWARN: perception, decision/application and action parts.

Spatial characteristics :

The timing of warning depends on speed and driver's reaction time, and is presented to the driver a few hundred meters from the dangerous spot using a display, and a speaker/beeper.

Temporal validity of data depends on the equipment rate, traffic, and hazard type. They must be assigned dynamically.

The maximum possible range depends on the radiated power, antenna gain, the sensitivity of the receiver as well as losses caused by cables and connectors. Since there was no rain at the time of the measurements the rain attenuation can be neglected. The atmospheric attenuation can also be neglected for the used frequency. Following a mathematical formalism (available in WILLWARN deliverables) the computed value for this distance is 0,518Km.

Other system characteristics:

- Detection of hazard with suitable danger classification is mandatory. Detection of position with GPS accuracy of 10-25m is needed.
- Broadcast, information hopping or ad-hoc networking scalable from low to high equipment rates is used to disseminate the warnings. A message management for outgoing and incoming messages should be a part of the application.
- Relevance check through trace point matching with high reliability is needed for high system reliability
- WLAN communication hardware from the shelf should provide a direct communication range of about 400m. A frequency band at about 5.9 GHz with enough bandwidth is needed (at its present state).
- Hazards can only be detected if a WILLWARN car detects a hazard or if the driver generates a message through an emergency button. Other cars can only be warned if this message is transported by cars and message forwarding through communication. Thus WILLWARN cannot guarantee

that every hazard is detected and reported by other cars. This depends on the equipment rate and the traffic density.

- To ensure an optimal spatio-temporal validity of warnings, the following requirements have to be fixed:
  - Temporal validity of data: minutes to hours
  - Spatial validity of data: m to km,
  - Stored geo-cast routing must ensure a scalable routing from physical message transport through oncoming traffic to networking of many cars without jamming the communication channel.

  These values depend on the equipment rate, traffic, and hazard type. They must be assigned dynamically.