D5.1 REQUIREMENTS FOR IMPACT ASSESSMENT

Primary Author(s)	Genís Mensa | Applus IDIADA Peter Wimmer | VIF Lars Schories | ZF András Bálint | Chalmers University
Related Work Package	WP5 - Safety assessment methodologies
Version/Status	6.4 | Final document
Issue date	26/02/2021
Deliverable type	Report
Dissemination Level	PU

Project Acronym	SAFE-UP
Project Title	proactive SAFEty systems and tools for a constantly UPgrading road environment
Project Website	https://www.safe-up.eu/
Project Coordinator	Núria Parera | Applus IDIADA
Grant Agreement No.	861570

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

Co-Authors

Name	Organisation
Tamara Djukic	Aimsun
Martin Östling	Autoliv
Christian Löffler	Bosch
Stella Nikolaou	CERTH
Sergio Rial	IDIADA
David Merdivan	IKA
Christian Birkner	THI
Daniel Weihmayr	THI
Stefan Kirschbichler	VIF

Reviewers

Version	Date	Reviewer (Name/Organisation)	Action (Checked/Approved)
5.0	11/02/2021	Stefan Kirschbichler, Peter Wimmer, Manuela Klocker / VIF	Checked
5.1	15/02/2021	Martin Östling / Autoliv	Checked
6.4	25/02/2021	Núria Parera / Applus IDIADA	Approved

Document Distribution

Version	Date	Distributed to
6.3	23/02/2021	Coordination Team
6.4	26/02/2021	Submission in the EC System
6.4	17/03/2022	Approved by the EC

Document history

Version	Date	Contributor(s)	Description
1.0	6/07/2020	Genís Mensa	First draft outline
2.0	30/10/2020	Genís Mensa/Stefan Kirschbichler/Peter Wimmer	List of requirements according to project demonstrators
3.0	10/12/2020	András Bálint, David Merdivan, Christian Löffler, Martin Östling, Caspar Hanselaar, Genís Mensa, Peter Wimmer, Lars Schories, Christian Birkner	Inputs for the different Demo requirements and overall impact assessment method
4.0	18/12/2020	Genís Mensa	Update the document to the new SAFE-UP template and include all the DEMO contributions
5.0	08/02/2021	András Bálint, David Merdivan, Genís Mensa, Peter Wimmer, Lars Schories, Tamara Djukic, Daniel Weihmayr	Complete document sections according to activities of T5.1 and internal review
6.0	22/02/2021	Genís Mensa, Martin Östling, Gian Antonio Daddetta, David Merdivan	Address comments and further improvements from the first review process, specially focused on the Demo 1 requirements definition section

Copyright statement

Executive summary

This report presents the basis for the overall impact assessment of the new safety technologies that will be developed within SAFE-UP. Together with the simulation of safety-critical scenarios and the research and development of new safety systems to protect vehicle occupants and Vulnerable Road Users (VRUs), the safety impact assessment methodology addressed in this report represents the three main pillars of the project.

Thus, after describing the background and objectives of the task, a literature review study on the requirements for the impact assessment is summarized, where the benefits of the simulation-based assessment methods are highlighted. Furthermore, based on the literature review and previous experiences from P.E.A.R.S. method and PROSPECT project, a preliminary impact assessment framework is detailed in later sections.

The framework for the safety impact assessment described in this report comprises several steps starting from the scenario definition on the EU level, which will be build-up from the work done in WP2 on the definition and selection of safety-critical scenarios and traffic simulation results. The geographical extrapolation of the inputs from WP2 will also be considered to set-up the baselines that will serve as a for further testing and simulation of the SAFE-UP technologies. Both physical and virtual testing activities will receive the inputs from WP3 and WP4, the work packages in charge of the investigation and development of pre-competitive safety countermeasures. Given the nature from the different technologies, those will be assessed independently and merged for the overall safety impact assessment.

The P.E.A.R.S. methodology will be considered for the evaluation of the SAFE-UP safety systems in simulation and those results will feed the calculation of the safety benefit in terms of the number of fatalities and seriously injured reduction The results from the benefit calculations will be combined with the physical testing results using the Bayesian framework approach from PROSPECT project to obtain the main output of the Work Package 5 (WP5); the benefit of the safety systems in the EU level. Results can be further updated considering the effect that factors such as the knowledge transfer and training activities, as well as the environmental conditions of the future traffic mobility, will have on the benefit calculations.

Within the description of the safety assessment method, inputs from different WPs in the project are reported. For this reason, apart from the overall impact assessment framework, the work performed in Task 5.1 (T5.1) has been focused on the requirements definition from the SAFE-UP demonstrators to ensure the correct transmission of the information needed for the benefit estimation through the whole project and guarantee the evaluation of the safety systems once the development activities are completed.

Efforts in defining requirements have focused on the evaluation objectives and establishment of the baselines for each demonstrator in order to obtain the resulting research questions. Differences in terms of maturity and the time-to-market have been observed within the SAFE-UP technologies and, thus, those are reflected in the research questions. The information provided by this report will be further enhanced and adapted during the development of the project in order to meet the objective of reducing the total number of fatalities and serious injuries in future accidents.

Keywords: safety impact assessment, Bayesian framework, requirements definition, virtual and physical demonstrators, benefit evaluation, safety-critical scenarios

Table of contents

List of figures

1. Introduction

The SAFE-UP project will define future safety-critical traffic scenarios involving vehicles with a high level of driving automation and will also propose solutions to protect both the vehicle occupants and the VRU's in the event of a possible collision in rural and highway environment and in urban environment, respectively. The new tools and technologies devoted to the protection of occupants and VRU's in future accident scenarios will include both active and passive vehicle safety systems with the aim to reduce the overall number of road fatalities through crash avoidance and the mitigation of injuries for the cases where the impact cannot be avoided.

In order to ensure the results expected for the project, the WP5 will lead and perform the impact assessment of the different technologies developed in SAFE-UP. Thus, this work package will confirm the expected improvement of road safety through the reduction in terms of fatalities and seriously injured addressing the three objectives defined in the proposal: the provision of simulation models for active and passive safety assessment, the development of methods for the safety assessment of the SAFE-UP demonstrators and the provision of an overall safety benefit of the SAFE-UP technologies through a simulation platform.

1.1 The definition of requirements for the impact assessment

The overall impact assessment of the SAFE-UP technologies will be performed at the end of the project, when the different safety systems have been proposed and validated through the activities done in the several project work-packages. However, the requirements for the impact assessment have been defined from the very beginning of the project in order to guide the inputs and outputs of the different work-packages and to ensure the correct information management for the performance of the safety assessment activities.

Accordingly, started in month 3 of the project, the T5.1 in SAFE-UP has prepared an overall framework covering all steps from accidentology to the impact assessment considering the results that will be obtained from active (WP3) and passive (WP4) safety systems, together with the baseline scenarios defined in WP2. This framework also includes the contribution from other activities in the project and the possibility to include the socio-economic benefit of the SAFE-UP technologies according to its future implementation into the automotive market. On the other hand, this task has defined a list of requirements addressed to each SAFE-UP demonstrator in order to guarantee the information needed for the impact assessment activities to be done at the end of the project. For this, several aspects such as the scenario definition and the treatment of the simulations are described in order to align the outputs from the different SAFE-UP developments and ensure the overall reduction of safety-critical scenarios and road fatalities.

In the following sections of this deliverable the activities from T5.1 are described, including the impact assessment framework and the requirements definition for each project demonstrator.

1.2 Literature review of traffic safety impact assessment requirements

There is a vast literature regarding impact assessment methods for safety systems and the corresponding requirements. The methods vary substantially depending on the type of the systems as well as the purpose of assessment. In SAFE-UP, all these approaches may possibly be of relevance, considering the different focus in WP3-4 (being VRUs in WP3 and vehicle occupants in WP4) and the overall holistic view of the project analysing the combined effects of the different safety systems involved. Therefore, instead of a comprehensive literature review, a few key references are highlighted in this section that are selected to have the highest relevance for the SAFE-UP activities.

The most relevant methods for the purposes of the SAFE-UP project are those related to prospective safety assessment, i.e., those methods that assess the real-world safety benefit of advanced driver-assistance systems (ADAS) before the relevant systems are implemented in the vehicles. There are various methods available for performing prospective safety benefit estimation. These may include, e.g., virtual assessment, based on computer simulations, driving simulator studies, real-world testing, or a combination of the various elements. For the approach in SAFE-UP, the most relevant methods are those related to virtual safety benefit assessment as well as the combination of various forms of testing, hence these aspects are detailed further below.

Virtual, entirely traffic simulation-based methods provide a safe and cost-effective way to perform safety benefit assessment. Such traffic simulations may range from multi-agent traffic simulations (Wang, 2016; Kitajima, Shimono, J, Antona-Makoshi, & Uchida, 2019), including simultaneous simulation of several road users, to counterfactual ("what-if") simulations where specific safety-critical scenarios are re-simulated under the assumption that some aspect of the situation would be different compared to how it was observed in crash data or naturalistic driving data. One such assumption could, for example, be that a safety-critical scenario is re-simulated assuming that one of the involved vehicles is equipped with a new safety system (meaning vehicle active and passive safety measures). It could then be observed in the simulation how this assumption changes the outcome of the safety-critical event (e.g., whether a collision could be avoided or mitigated, were the vehicle equipped with the safety system). More details regarding counterfactual simulations are described in Bärgman et al. (2015) and Bärgman and Victor (2020).

A very high number of simulations can be performed of the same safety-critical scenario under various assumptions; hence the results are reproducible and can be obtained in an early stage of system development. Additionally, stochastic variation of the different scenarios can also be included in the assessment (Helmer, Wang, Kompass, & Kates, 2015; Waymo, 2020; Leledakis, et al., 2021), to capture not only a reproduction of actual chains of events but also those that may have happened and would possibly need to be addressed in the future.

The several advantages of simulation-based methods detailed above can only be realized if the virtual assessment is performed in an ecologically valid way, i.e., that the simulations represent the most important elements of the relevant real-world situations.

What these elements are and how to ensure their validity is far from trivial; substantial work on these aspects has been performed in the open consortium P.E.A.R.S. (Prospective Effectiveness Assessment for Road Safety).

The corresponding work is described in detail in Section 2.1.1 below. Additionally, real-world testing (on closed test tracks or, in some cases, on public roads) is performed as an important element for verification for simulation results (Waymo, 2020; Webb, et al., 2020).

Besides verification purposes, real-world testing can also be used for the prospective safety benefit assessment by itself (Korner, 1989; Bálint, Fagerlind, & Kullgren, 2013) or in combination with simulation results to get a combined safety benefit assessment. In the EU project PROSPECT, a safety benefit evaluation framework was developed for the assessment of ADAS for VRU protection (Kovaceva, Bálint, Schindler, & Schneider, 2020). The assessed ADAS, developed in the PROSPECT project, performed autonomous emergency braking (AEB) and, additionally in longitudinal scenarios, steering (Aparicio, et al., 2017). The safety benefit assessment framework, which as its central element combines simulation results and physical testing results in the assessment, has been considered as highly relevant for the SAFE-UP purposes. Therefore, a more detailed description of the PROSPECT method is provided in Section 2.1.2.

Regarding the combination of active and passive safety aspects, an overview of relevant methods with pedestrian safety focus is provided in a doctoral thesis (Lübbe, 2015). It is pointed out that while passive safety assessment had been well established for a longer period at the time of writing the thesis, the consideration of active safety aspects and especially the integration of active and passive safety had been lacking. Therefore, an integrated method was developed in (Lübbe, 2015) assessing combinations of passive safety and the active systems of Autonomous Emergency Braking (AEB) and Forward Collision Warning (FCW).

More recently, there have been several papers addressing the possibilities to combine active and passive safety in the assessment. Several of the developed methods include elements or ideas developed during the EU project OSCCAR (Östling, Jeppsson, & Lübbe, 2019; Wågström, Leledakis, Östh, Lindman, & Jakobsson, 2019; Leledakis, et al., 2021). Other recent examples are described in the recently published white papers by Waymo (Waymo, 2020; Webb, et al., 2020; Schwall, Daniel, Victor, Favarò, & Hohnhold, 2020). The latter papers emphasize the importance of combining virtual simulation, with elements of counterfactual simulations and the generation of synthetic scenarios (i.e., artificially created scenarios representing situations that are expected to be relevant), with substantial efforts to develop a reference driver model that the performance of Connected Automated Vehicles (CAV) can be compared to.

Based on the experiences and knowledge accumulated in the research literature, a preliminary safety benefit assessment method is described in the next sections. Also, as indicated above, the PEARS and PROSPECT methods that are considered to have the greatest relevance to the SAFE-UP purposes and the preliminary impact assessment method are detailed in later sections.

2. Methodology

Based on the objectives described in the introduction of this report, the main activities within the T5.1 in SAFE-UP have been the consolidation of a common framework for the overall safety impact assessment and the definition of requirements and evaluation parameters for the different project technologies.

The safety impact assessment framework in SAFE-UP project is defined as a way to determine the benefit of the SAFE-UP technologies (described in Section 2.2) in terms of saved lives and reduced injuries. The framework has two main elements: a detailed simulation framework targeting to demonstrate the reduction of fatalities and seriously injured in 2025, utilizing and extending experience in the P.E.A.R.S. initiative (see Section 2.1.1) and the combination of simulation and physical test results targeting to evaluate the performance of the SAFE-UP safety technologies, building on the methodology developed in the EU project PROSPECT (see Section 2.1.2) to assess the crash avoidance and injury reduction performance of those technologies.

These two elements are combined with inputs from other SAFE-UP WPs merging into the overall safety benefit assessment framework, involving several elements, such as the safety-critical scenarios and traffic simulation results that will led to the baseline definition on the EU level, the simulation and physical testing activities for the technology performance evaluation and the benefit calculations from simulation and testing to derive the reduction in terms of fatalities and injuries at the end of the project. These elements as well as the connections between them are explained in the following method section of Deliverable 5.1.

2.1 The SAFE-UP overall safety impact assessment framework

Figure 1 below gives an overall picture of the safety benefit assessment framework of crash avoidance and injury reduction, planned for the SAFE-UP project from the safety-critical traffic scenarios to the benefit on the European level in terms of the reduction of injuries and fatalities in that region. The elements that are related to the base components of the assessment from P.E.A.R.S. and PROSPECT projects are highlighted in this flow-chart with a light blue surround. Each element is briefly explained under the Figure 1 and the corresponding inputs (in green) in terms of the technologies, demonstrators and different activities in SAFE-UP are specified in the later sections, where the requirements for the impact assessment are described.

Note that Figure 1 shows a preliminary framework that could potentially change and evolve through the development of the current work. The project approach came to specify an initial framework in order to determine the inputs and outputs from other activities in SAFE-UP that should be provided to the WP5 for the safety benefit assessment at the end of the project.

In this way, during its development, all the activities performed in the different WP’s of the project will consider the information gathering for the final safety benefit assessment. The framework presented in this report will be specified and detailed in T5.3 and implemented in T5.4 for the overall impact assessment of the project.

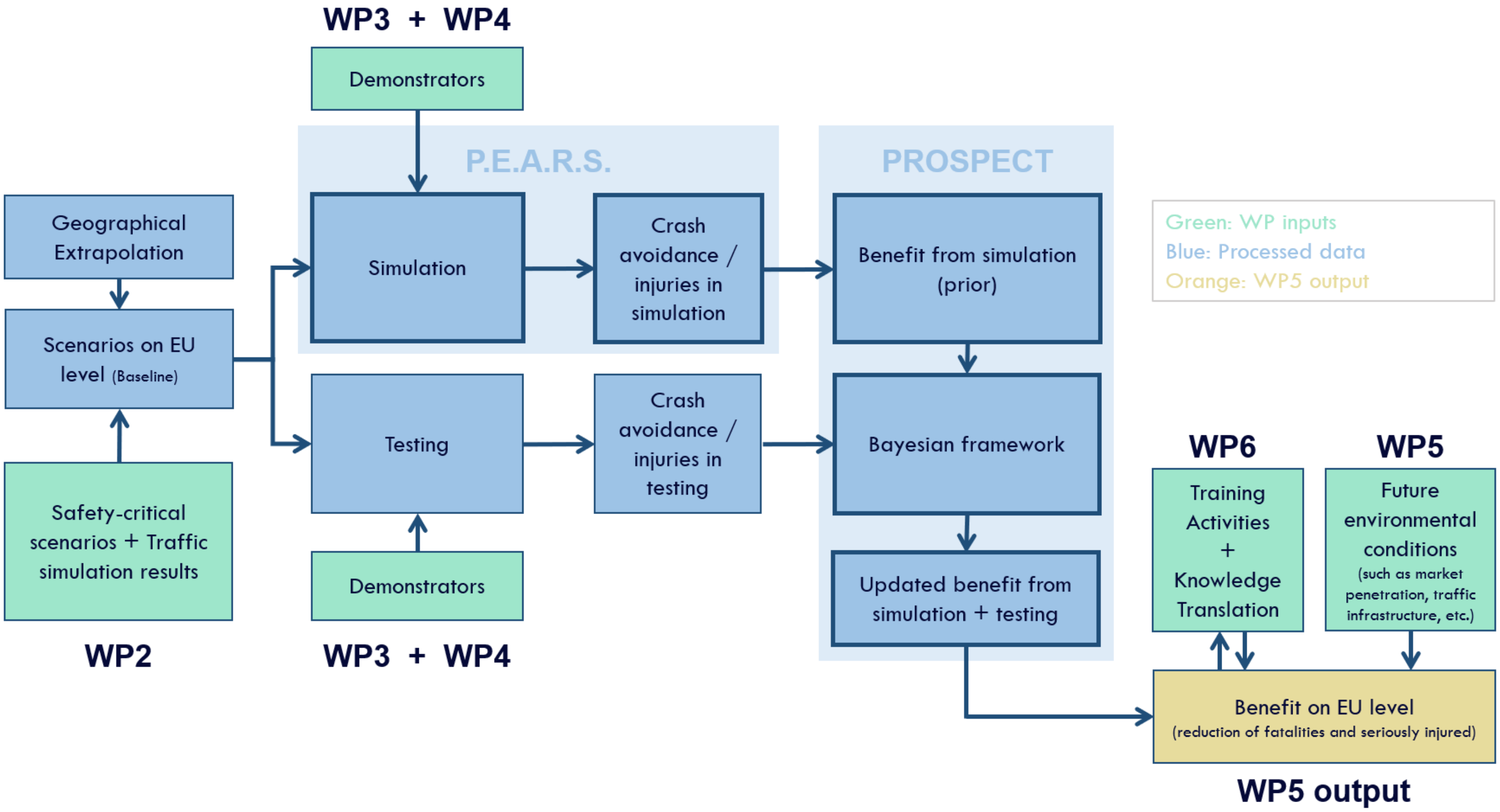


Figure 1 – Overall impact assessment framework for the SAFE-UP project

The first step to be considered in the overall assessment framework is the definition of the scenarios that the project will address. This initial process is crucial for the overall impact assessment since it will not only set the basis for the pre-competitive development of safety technologies and countermeasures during the project but will also clearly determine the scope of the benefit assessment of the project. For this, the SAFE-UP approach will consider the inputs from the work done in WP2 summarized in Deliverable 2.6 (and future updates of the document), where the different use-cases and the safety-critical scenarios involving Connected Automated Vehicles will be described.

Given the geographical limitations of the data sets with a high level of detail analysed in WP2 (e.g., the GIDAS database containing crashes in two specific regions in Germany while the scope of T2.5 is the whole EU), it is assumed that an extrapolation method will be performed in order to represent the critical scenarios in the whole European region. Addressing scenarios that correctly represent safety-critical situations at EU level (rather than addressing a potentially local issue observed at the data collection sites) ensures maximum impact of the protection principles and safety systems developed in the project.

Moreover, since the scenario definition will be relevant through all the SAFE-UP execution, the terminology used for defining concepts such as “safety-critical scenarios”, “events” or “simulations” must be clear and common for all the participants. Thus, regular meetings involving partners from WP2 and WP5 have been held in order to unify the definition of certain terms and concepts that will be important both in determining scenarios and in measuring the impact at the end of the project.

The safety-critical scenarios, which are described in the D2.6 of the project, will become the main input for the baseline of the active and passive safety pre-competitive technology developments in WP3 and WP4, respectively, and also for the assessment of those technologies in WP5. The outputs from the testing and simulation activities in those work-packages are detailed in Section 2.2 of this document, where the requirements for each of the demonstrators are defined.

The traffic safety-critical scenarios as well as the safety technologies will be represented in a virtual simulation environment following the P.E.A.R.S. framework developed for quantitative assessment of crash avoidance technologies. The general framework and the corresponding simulation and computation steps are described in Section 2.1.1. The adaptation of the framework to the SAFE-UP context will assess the crash avoidance and injury reduction performance of the SAFE-UP systems, providing thereby a preliminary (prior) assessment of the safety benefit.

Additional information regarding the safety benefit of the SAFE-UP systems will be provided by the physical testing prototypes of the investigated and developed systems. The test results would also allow an assessment of the safety benefits which could potentially be different from those obtained by virtual, simulation-based assessment.

Therefore, it is a key question how the two sets of results are combined to get an integrated assessment based on all available information. This question has been investigated in detail in the EU project PROSPECT and a method based on Bayesian statistical approaches has been developed in that project to specify how simulation-based results should be updated by test results to obtain an integrated assessment. The PROSPECT method is described in Section 2.1.2 and it is planned to adapt this method for the purposes of SAFE-UP.

Finally, the impact assessment estimations in WP5 will provide the benefit of the safety systems implementation in the European market according to the results from testing and simulation activities in the project and considering specific environmental conditions (penetration rates, infrastructures, etc.) for each of the technologies developed in SAFE-UP.

This benefit calculation is expected to be refined by considering the effects of the training and knowledge translation activities performed in WP6 together with the update of the market penetration rates according to the available data. The market penetration rates will strongly influence the overall societal benefit of the SAFE-UP systems.

Figure 2 and Figure 3 below illustrate the comparison between the new vehicle series with an AEB system and the percentage of registered vehicles with AEB in the US up to year 2016: These figures show how market penetration of a safety system changes in a 15-year period and that even when the system is available (at least optional) in essentially all new vehicles, it may take several years until the system is present in almost all vehicles in traffic.

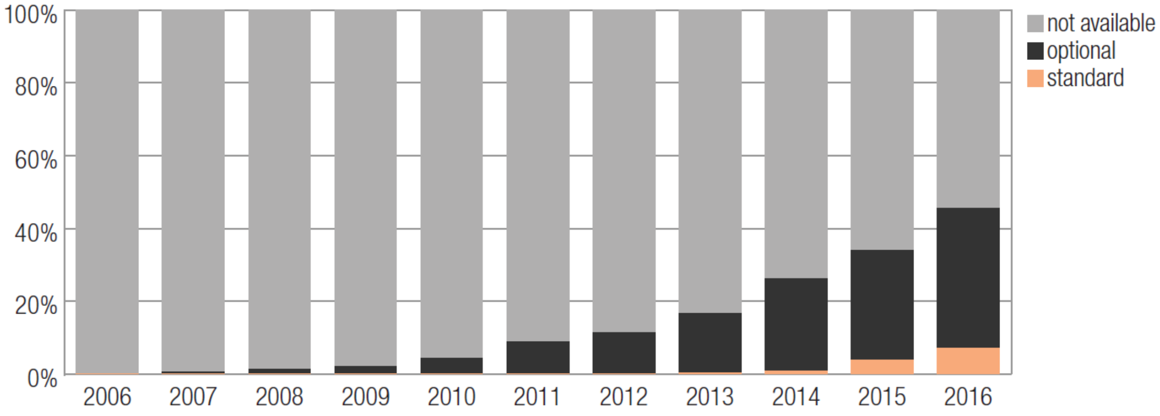


Figure 2 – Percentage of new vehicle series with AEB in the US (IIHS, 2017).

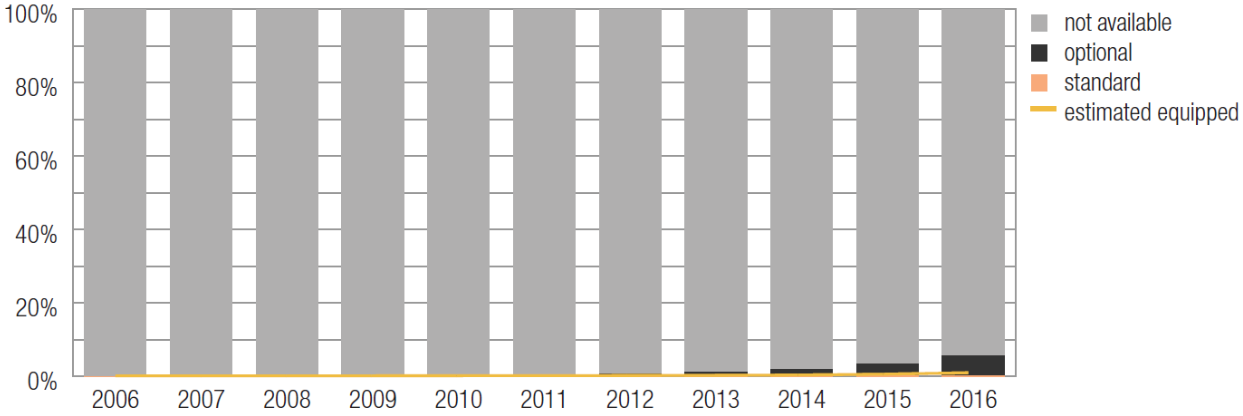


Figure 3 - Percentage of registered vehicles with AEB in the US (IIHS, 2017)

The output of the overall impact assessment framework will be expressed in terms of number of fatalities and reduction of seriously injured from the specific safety-critical scenarios in the European region.

2.1.1 The P.E.A.R.S methodology

P.E.A.R.S. (**P**rospective **E**ffectiveness **A**ssessment for **R**oad **S**afety) is an open consortium (established in 2012 as Harmonization Group) in which engineers and researchers from the automotive industry, research institutes and academia join with the objective of developing a comprehensible, reliable, transparent, and accepted methodology for quantitative assessment of crash avoidance technology by virtual simulation.

The focus of P.E.A.R.S. is on the development of an ISO standard for the prospective assessment of traffic safety for vehicle-integrated active safety technologies by means of virtual simulation. (Taken from https://pearsinitiative.com/). Further information on P.E.A.R.S. and the developed methodology can be found in (Page, et al., 2015) and (Alvarez, Page, Sander, Fahrenkrog, & Helmer, 2017).

The P.E.A.R.S. methodology was proposed to be part of the safety impact assessment in WP5 of SAFE-UP, therefore a brief overview of the methodology will be given in this section. The P.E.A.R.S. methodology mainly consists of four steps:

Step 1: Definition of Evaluation Objective / Scope

Step 2: Establishment of Baseline

Step 3: Virtual Simulation with and without Safety Technology

Step 4: Estimation of Safety Performance

These four steps will be described in more details in the following paragraphs.

Step 1: Definition of Evaluation Objective / Scope

This step consists of the definition of a precise research question and the target of the study. The research question should include the metric to be used, the technology, respectively the type of technology under study and its penetration rate, the definition of the considered scenario categories; the considered (environmental, infrastructure etc.) limitations, the considered region and time horizon of the projection, and the envisioned level of confidence in relation to the objective of the research question.

Step 2: Establishment of Baseline

The baseline sets the situation before introduction of the technology to be assessed. Several options are available for this step:

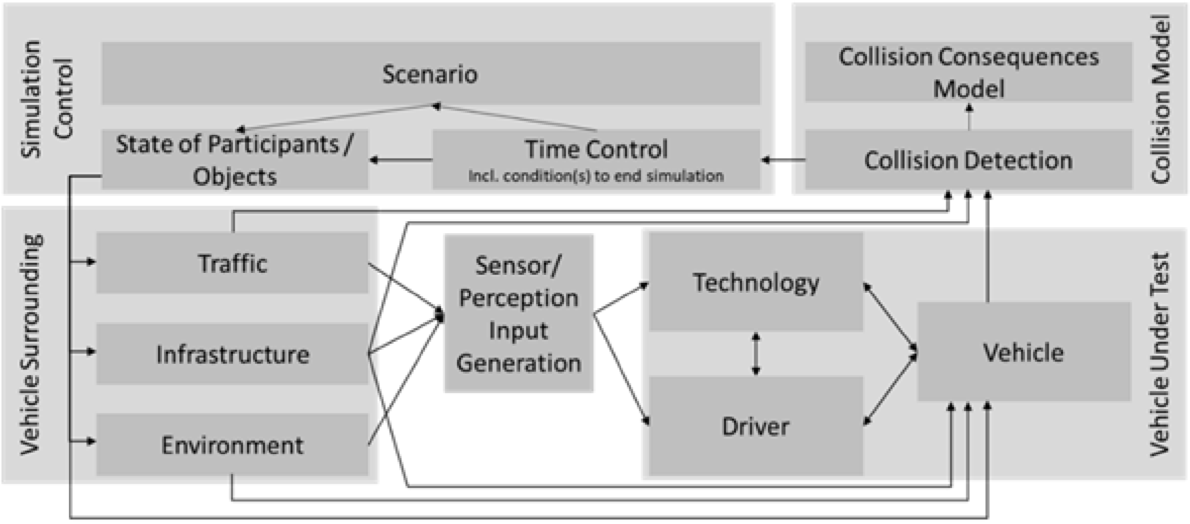
a. Baseline using single specific real-world scenarios, where real-world scenarios are used directly as baseline.

b. Baseline using modified real-world scenarios, where real-world scenarios are modified by changing or adding parameters to compensate for missing information in the original data.

c. Baseline consisting of synthetic cases, where the baseline cases are created by using simulation models capable of reproducing general crash mechanisms revealed from traffic and accident research.

Step 3: Virtual Simulation with and without Safety Technology

In this step, the actual simulations with, and, if required, without technology to establish the baseline, are carried out. The simulations with technology are called "treatment simulation". To do so, a framework as shown in Figure 4 can be used. Depending on the evaluation objective, some elements of this generic framework can be left out.



Source: ISO 21934 (20XX). "Road vehicles — Prospective safety performance assessment of pre-crash technology by virtual simulation — Part 2: Guidelines for Appliction", ISO Technical Specification under preparation

Figure 4 – Generic simulation framework for pre-crash safety performance assessment

Step 4: Estimation of the safety performance

This is the fourth and final step. Here the severity based on metric(s) defined in step 1 will be calculated for baseline and treatment simulation. The following formula can be used to calculate the safety performance for one scenario:

$$P_i = I_{Treatment,i} \times f_{Treatment,i} - I_{Baseline,i} \times f_{Baseline,i}$$

P_i… traffic safety performance for one scenario

I…. severity

f…. frequency of scenario occurrence

To estimate the safety performance of all scenarios, the following formula can be used:

$$P = \sum_{i=1}^{n} I_{Baseline,i} \times f_{Baseline,i} \times (\Delta I_i \times \Delta f_i - 1)$$

P…. traffic safety performance for all scenarios n

$\Delta I = \frac{I_{treatment}}{I_{Baseline}}$…. change in severity

$\Delta f = \frac{f_{treatment}}{f_{Baseline}}$...change in frequency of occurrence

2.1.2 The PROSPECT project

As described in Section 1.2, the PROSPECT project developed active safety systems for the protection of VRUs based on expanding the scope of scenarios addressed by the systems and advanced algorithms. To evaluate the expected safety benefit of the newly developed systems (as well as the resulting monetary benefit in terms of saved injury costs), an assessment method based on a combination of simulation results and test results was developed in the project. As SAFE-UP includes safety system development, real-world testing as well as virtual safety benefit assessment, elements of the safety benefit assessment approach in PROSPECT may give useful input regarding the requirements for safety benefit assessment. Therefore, the PROSPECT method is summarized below.

The most common crash scenarios including passenger cars and VRUs of different severity levels were identified by an extensive analysis of crash data from different sources. In several steps described in PROSPECT deliverables D3.1 and D3.2 (Stoll, Schneider, Wisch, Seiniger, & Schaller, 2016; Kunert, et al., 2016), this led to a selection of 9 cyclist demonstrator use cases (UC_DEM_1-9 in the figure below) and 3 pedestrian demonstrator use cases (UC_DEM_10-12), see Figure 5. The prototype systems integrated into four demonstrator vehicles were tested on closed test tracks in these 12 use cases. In each test it was observed whether the demonstrator vehicle avoided the collision in the test or else the impact velocity was measured.

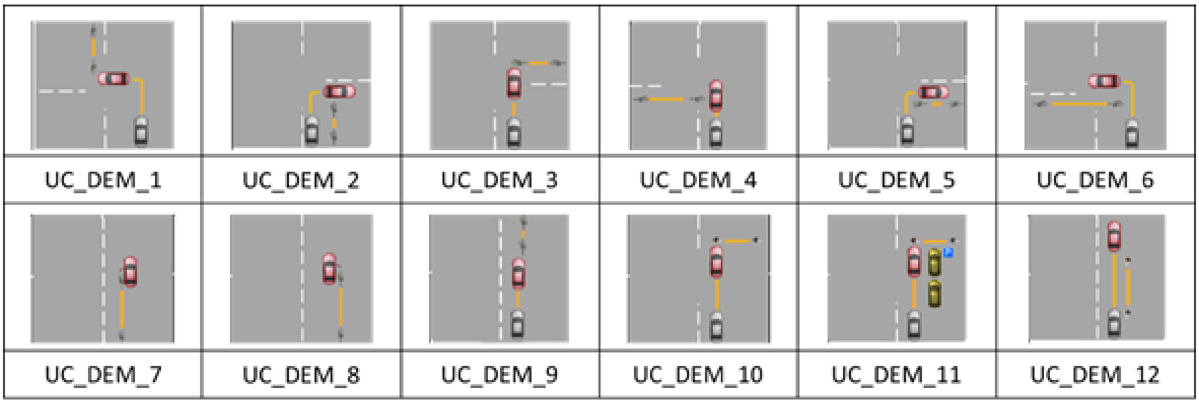


Figure 5 – Overview of PROSPECT demo use cases (Kovaceva, et al., 2018).

The developed VRU protection systems, including the new PROSPECT sensors and algorithms, were also represented in computer models. A counterfactual simulation approach was performed – that is, crashes identified in the databases that correspond to the use-cases were simulated first without and later with the modelled PROSPECT systems. The differences in the results (e.g., if the crash was avoided in the simulation with the system or if the collision speed with the system was lower than without) allowed a preliminary (prior) assessment of system effectiveness in the use-cases.

An essential input for the simulations was the detailed reconstruction of the crashes corresponding to the use-cases, including vehicle trajectories. These details were only available in GIDAS Pre-Crash Matrix (PCM), which is a subset of GIDAS. Therefore, the software-based assessment was limited to those cases where such details were available.

A key aspect of the assessment was the development of a method that can provide a combined assessment based on the integration of results from counterfactual computer-based simulations and real-world testing. Bayesian statistical methods were identified as appropriate for this purpose, based on a theorem that under reasonable assumptions, Bayesian update of available information is optimal in a mathematical sense.

In this context, simulation results could be regarded as prior information concerning the effectiveness of a safety technology and real-world test results with the prototypes can be regarded to be new information that the prior effectiveness can be updated with. The Bayesian framework then provides the posterior benefit estimate about the effectiveness in which all available information (i.e., both simulation results and test results) is integrated.

Such an update regarding the crash avoidance probability is illustrated in the Figure 6 below. The prior (dashed curve) has Beta (4,4) distribution corresponding to four simulations with collision avoidance and four when the collision was not avoided. After a successful real-world test in the corresponding scenario, the updated (posterior) curve has Beta (6,4) distribution. The updated curve indicates a higher probability of avoiding a crash in the investigated scenario and has smaller variance (indicating less uncertainty) than the prior distribution.

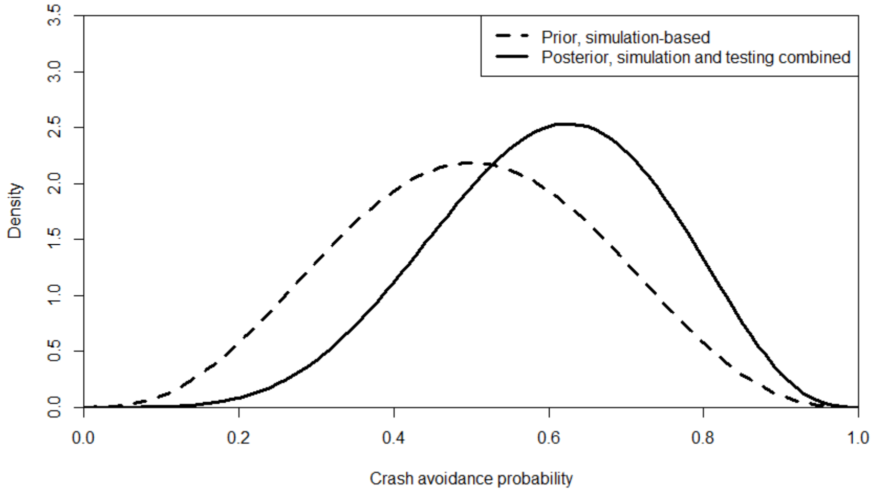


Figure 6 – Bayesian update of the crash avoidance probability.

After this step, the results were extrapolated to represent crashes on EU level with a recursive decision tree method, taking injury severity, urban or non-urban environment, daylight or not daylight and the age of the VRU into account.

This step gave an estimate of the maximum potential safety benefit of the PROSPECT technologies that could be achieved if all passenger cars were equipped with the systems and they could not be switched off by the drivers.

However, as it usually takes many years, even decades, to get close to 100% fleet penetration of a vehicle system, the maximum benefit was adjusted with previous experience on fleet penetration curves as well as a factor representing user acceptance of the system (that could influence the probability of the driver not switching off the system) to get more realistic estimates of the expected safety benefit for the period 2020-2030.

A detailed description of the method and results is provided in the PROSPECT D2.3 project deliverable (Kovaceva, et al., 2018) and an even more detailed discussion of the Bayesian information update step is available in a journal publication (Kovaceva, Bálint, Schindler, & Schneider, 2020).

2.2 Requirements definition for the impact assessment

One of the main objectives in T5.1 is the definition of requirements and evaluation parameters (e.g. signal data, simulation models, physical test results), which will be relevant for the safety impact assessment at the end of the SAFE-UP project.

Those requirements are intended to guide the different activities in SAFE-UP in terms of the inputs and outputs expected for the correct evaluation of the systems that will be investigated and developed throughout the project. Thus, in parallel to the preparation of the overall framework for the safety impact assessment, the specific requirements for each SAFE-UP technology have been defined and are presented in this Section 2.2 to ensure the corresponding benefit calculations to be performed in T5.4 of the project.

Based on the Grant Agreement initial discussions, a set of technology requirements have been prepared, in collaboration with several partners of the project, in order to get a big picture on the different SAFE-UP technologies, probable simulations and physical tests which will be relevant for the work to be done in WP5. Those technologies are tackling different areas within the field of vehicle safety, which makes it possible to assess the performance of the technologies individually.

For the requirements definition, both step 1 and step 2 of the P.E.A.R.S. methodology can already be applied, since it provides a procedure to define a precise research question. Thus, necessary boundaries were defined to discuss the data acquisitions based on the description of the activities to be performed within the demonstrators. The following sections contain the description of the SAFE-UP technologies to be investigated and developed in the project together with the definition of the main research questions and the initial set of requirements for the safety impact assessment.

2.2.1 Restraint and occupant monitoring for new seating positions

Description:

In the requirements definition for Demo 1, the passive safety systems will be identified as the occupant monitoring system and the improved occupant restraint system. Those systems for Connected Automated Vehicles (CAV) with SAE level 3 and 4 will be evaluated for crash configurations determined in T4.1. This demonstrator will be focused on vehicle occupant protection by integrating two different technologies for enabling safe new seat positions. The first technology is occupant monitoring system with the task to monitor the occupant seat position and sitting posture in relation to the interior and the occupant restraint system to adjust the restraint activation strategy.

The second technology is the improved occupant restraint system, that will be upgraded compared to current SOTA restraint systems that only address traditional upright seated occupants. This work will be done in Task 4.2. The upgrade is focused on use cases that will be likely in CAVs (will be defined in Task 4.1) such as reclined seatback and rearward positioned seats away from the steering wheel. Based on the inputs from the monitoring system the improved occupant restraint system will be adapted in terms of how it is activated.

The main objective will be the evaluation of a number of use cases defined in Task 4.1. The use cases consist of a combination of future collision scenarios involving CAVs with SAE level 3 and 4 and occupant positions of such vehicles. By using the described functionalities of the occupant monitoring system and the improved occupant restraint system a number of traffic safety-critical scenarios and occupant positions will be evaluated and compared to current situation with an upright seated occupant using human body model (HBM) simulation in Task 4.3. Key for enhancing the occupant safety of the systems and thus fostering a successful implementation will be the seamless operation between the occupant monitoring system for longitudinal seating positions and the corresponding restraint system deployment strategy. Both the occupant monitoring and improved occupant restraint systems will be identified and evaluated in three different type of demonstrators.

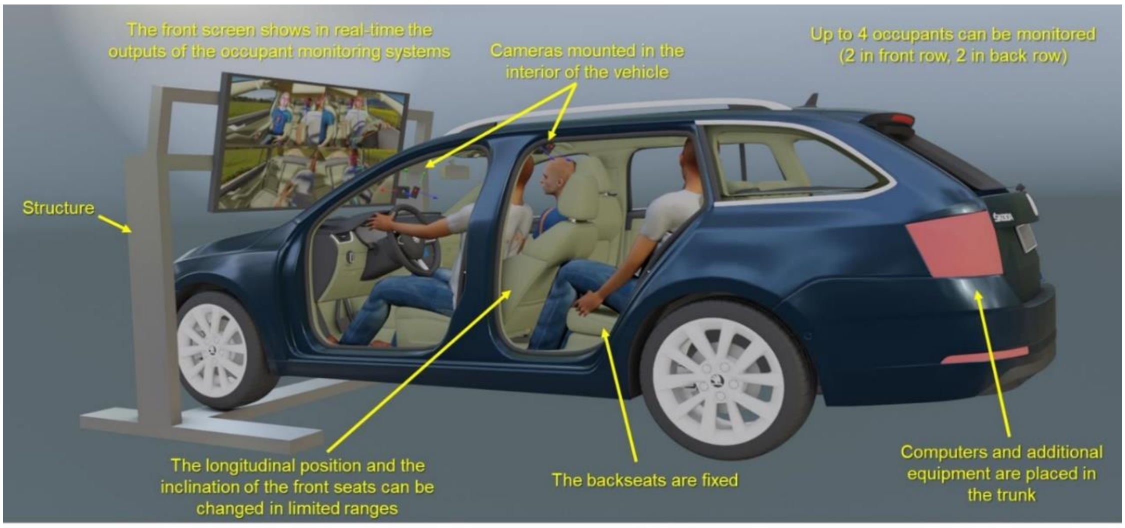


Figure 7 – Example of mock-up vehicle for occupant monitoring

First, in order to design the monitoring system, a mock-up vehicle will be purchased for the purpose of gathering necessary data. All needed elements (sensors, data acquisition, data processing, data storage and the restraint systems) will be installed in the demonstrator for a correct real-time position and posture detection of all occupants, as illustrated in Figure 7.

Secondly, occupant safety will be evaluated using HBM simulations. The defined use cases from T4.1 will be combined with the restraint system content determined in T4.2. T4.3 will then further evaluate and optimise its functionality and compared to current situation with an upright seated occupant. Example of such use case is seen in Figure 8; an occupant with a reclined seat back. The different use cases will include both pre-crash (braking and steering) and in-crash simulations.

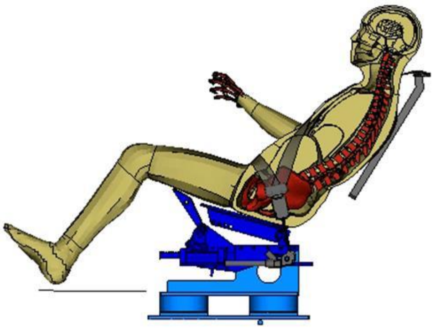


Figure 8 – Examples an HBM in reclined posture (Mroz, 2020)

Thirdly, sled tests will be performed of a selected use case based on what is found in the HBM simulations in T4.3. Therefore, a sled test rig will be built for the use of sled testing planned in subtask 5.4.2. This will be done in order to ensure the applicability of the models that is used in the HBM simulations.

Associated Deliverable(s):

All deliverables from WP 4, i.e. **D4.1 - D4.5** are relevant to refer to as they together will build up the Demo 1 details and the HBM simulation.

Basic Information:

As described in D4.1, the considered scenarios will involve future situations for SAE level 3 and 4 CAVs in peri urban and highway environments. In the short time frame, i.e. 5-10 years, it can be assumed that peri-urban scenarios will be highly relevant for SAE level 3 vehicles as stated in (Georg Doll, 2020), SAE level 4 vehicle will not be ready for peri-urban driving, whereas highway scenarios will allow further achievements on automation functions of the vehicle and thereby will be more relevant for SAE level 4 vehicles.

Assuming the considered time horizon stated in the SAFE-UP proposal it is most likely that the occupant monitoring with improved occupant restraint would be ready for its implementation in 2025. Even that occupant monitoring systems can be present in the automotive market within the scope of the project, it is still unclear if the occupant restraint system with input from occupant monitoring system will be able to reduce the expected number of fatalities and seriously injured in the future.

Resulting research questions:

> *"What are the implications in terms of head, neck, chest, pelvis and lumbar spine injuries of new seating position compared to current consumer test position with SOTA occupant protection systems in selected crash configurations?"*

> *"Can the implications of the new seating position be addressed by an improved occupant protection system including enhanced restraint functions and occupant monitoring system?"*

Treatment Simulation:

In order to assess the effectiveness of the improved occupant restraint systems with the inputs from the occupant monitoring system the simulations should be done in three steps; summarized in Figure 9.

In the first step, simulation activities will be done for an upright seated occupant to create a baseline to assess later simulations when new seat positions are included. Thus, for the baseline simulation, relevant crash configurations and occupant use cases will be selected in T4.3. Furthermore, since parameters need to be defined for quantification of the differences between several simulation stages, injury predictors for HBM will be investigated and further developed, together with the work done in T4.3 and T5.2, to assess the severity of passenger injuries. Those predictors will be also used for evaluating the simulation outcomes in WP5.

In the second step, simulation activities will be done with an improved occupant restraint system without any input from the occupant monitoring systems. Hence, the simulation for future occupant use cases will be compared to the baseline simulation. As known from other projects it can be expected that the loading on the occupant might increase just changing the seating position, sitting posture or seat configuration. Thus, the impact of new use-cases for CAVs will be evaluated.

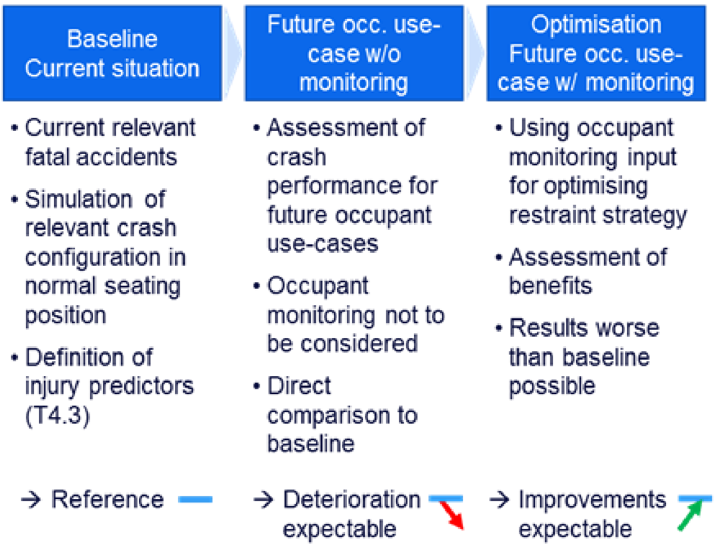


Figure 9 – Demo 1 treatment simulation approach for future occupant use-cases

Finally, the third simulation step will address the same use cases but now with consideration of the input from the occupant monitoring system. In this simulation stage the results of the research on monitoring systems e.g., collected via the mock-up demonstrator vehicle, will be implemented. As before, the simulation results will then be compared to the baseline model and the simulations for future occupant positions without occupant monitoring. In this way it will be possible to show the advantages of using continuous occupant monitoring for improving the occupant restraint systems.

2.2.2 VRU detection under bad weather conditions

Description:

Demo 2 will enhance the interaction between vehicles and VRUs under bad weather conditions by analysing the effect of bad weather on different sensor types and configurations for SOTA and future technology. Baseline tests with the actual sensor configuration will demonstrate the SOTA performance. A test-based evaluation scheme will be validated with simulative effectiveness evaluation as a comparison to physical testing. Verification tests will show the object detection limits at adverse weather conditions. The results will validate object detection as a function of weather conditions, distance, trajectory angles and speed differences.

Figure 10 – Test vehicle under increasing bad weather conditions (THI)

A demonstration car with advanced sensor configuration and VRU detection algorithms for safe object detection in all weather conditions will be used. The focus will be VRU detection in heavy rain and fog conditions with different environment objects nearby.

Demo 2 will use environmentally robust sensor concepts and innovative sensor data post-processing features for safe object detection both in the near-field area and bad weather conditions.

Associated Deliverable(s):

D3.2 and **D3.5**: Vehicle demonstrator for object detection in adverse weather conditions

Basic information:

- Metric to be used:
    - Reduced MAIS level 5+ or fatalities due to Car-VRU collisions
- Technology under assessment:
    - Detection system that can detect VRUs under adverse weather conditions
- Assumed penetration rate of the considered technology:
    - Conservative: 9.6%
    - Ambitious: 27.5%
    - Optimistic: 100%
- Considered scenarios or scenario categories:
    - Adverse weather influenced scenarios
    - Focus on VRU road crossing with (dynamic) occluding objects
    - PRELIMINARY selection reached via GIDAS/CARE database studies may be either:
        - Left-to-right pedestrian lane crossing, possibly with occlusion due to slow/stationary traffic on lane that pedestrian crosses prior to reaching ego lane (UTYP 401,431, 460)
        - Car turning left into path of VRU (UTYP 221), as this reflects a marked increase in occurring collisions in bad weather
    - It is important to define the set of scenarios that can be handled by the technical solution that is developed in the project:
        - Most important: the exact scenario that will be demonstrated in real life, including (mild) variations on scenario parameters (e.g. speed, timing, etc.)
        - For simulation purposes, other scenarios (that differ from the demo-scenario) may be considered as well, as long as they are in line with the operational design domain (ODD). For larger variations on the ODD, however, the outcome of these simulations may not be accurate/representative
- Considered (environmental, infrastructure etc.) limitations:
    - Urban regions; mild to severe rain conditions
- Considered region and time horizon of the projection:
    - Scenario covered to 2025 and projection to 2050

Resulting research question:

> "*What is the safety performance of an active safety system with an 'all-weather VRU detection system' at a penetration rate of 9.6% / 27.5% / 100% in Car to VRU collisions on urban roads in terms of MAIS 5+ injury reduction on EU level in 2025 compared to the 2016 numbers and the same safety system with SOTA VRU detection system?"*

Baseline Definition:

The baseline scenario is a (possible) Car-VRU collision, with the Car fitted with a SOTA VRU detection system as well as an AEB system, assuming the VRU detection system sees the VRU too late to activate the AEB due to the effect of the adverse weather conditions on the detection performance.

Test scenario definition:

Car-pedestrian collisions with large percentage of Killed and Seriously Injured (KSI) happen on roads outside of junctions (70 or 80%, irrespective of weather). Consequently, a scenario will be created that adheres to the following aspects:

- Has a high incidence / is disproportionally influenced by weather conditions
- Is sufficiently testable given test hall/environment available

Extension of test scenario to other relevant urban cases inside ODD:

Other scenarios (that differ from the demo-scenario) may be considered as well, as long as they are in line with the operational design domain (ODD). For larger variations on the ODD, however, the outcome of these simulations may not be accurate/representative.

Baseline Simulation:

Simulation using the same framework as for the treatment simulations (see Appendix a) on page 37) but with SOTA sensor technology and the effect of adverse weather on it using accident scenarios representative for 2016 instead of future (2025) accident scenarios.

Baseline Testing:

Baseline testing will be performed with SOTA sensor technology in adverse weather conditions.

2.2.3 Advanced intervention functions

Description:

Demo 3 will develop advanced vehicle dynamics intervention functions to avoid or mitigate critical events. The demonstrator will include a vehicle with combined trajectory control algorithm for both emergency braking and steering.

For the emergency steering functionality, electronic power steering as well as differential braking and the combination of both will be investigated and compared regarding their accident avoidance potential in the defined scenarios.

Thus, the technologies for collision-free motion / path planning, will include enhanced vehicle dynamics in dual-lane change-situations. In case of emergency, advanced intervention functions will be triggered to avoid critical events, including naturalistic crash mitigation manoeuvres, enhanced emergency functions for crash avoidance (AES, AEB), and minimisation of the sidestep distance.

Demo 3 will show the target trajectory planning and trajectory control based on the detected objects. The verification results will define the time and precision limits of trajectory generation as well as the trajectory control performance.

This will lead to values for the human factor “transversal acceleration feeling of the passengers” due to the active safety feature.

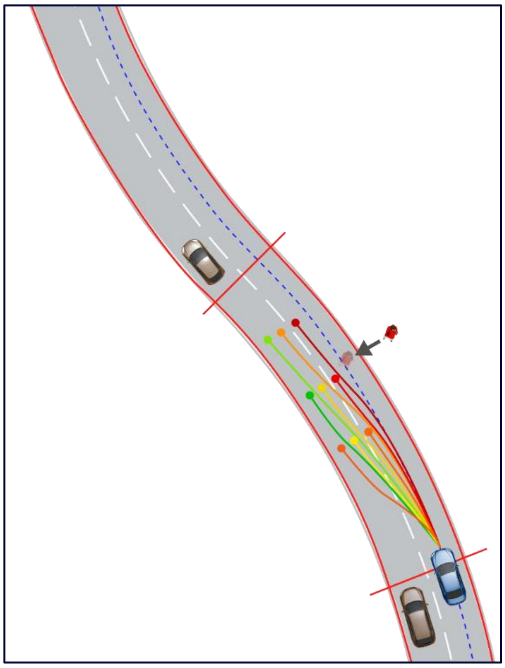


Figure 11 – Emergency trajectory planning

Associated Deliverable(s):

D3.3 and D3.6: Vehicle demonstrator for trajectory planning and control for combined automatic emergency braking and steering manoeuvres including system for VRU detection, motion planning and trajectory control to enhance real-world performance.

Basic information:

- Metric to be used:
  - Reduced MAIS level 5+ or fatalities due to Car-VRU collisions
- Technology under assessment:
  - Combined emergency braking and steering function to avoid collisions with VRUs, including sensors that can detect VRUs under bad weather conditions (“all-weather VRU AEB+S”)
- Assumed penetration rate of the considered technology:
  - Conservative: 9.6%
  - Ambitious: 27.5%
  - Optimistic: 100%

- Considered scenarios or scenario categories:
    - Adverse weather influenced scenarios
    - Focus on VRU road crossing with (dynamic) occluding objects
    - PRELIMINARY selection reached via GIDAS/CARE database studies may be either:
        - Left-to-right pedestrian lane crossing, possibly with occlusion due to slow/stationary traffic on lane that pedestrian crosses prior to reaching ego lane (UTYP 401,431, 461)
        - Car turning left into path of VRU (UTYP 221), as this reflects a marked increase in occurring collisions in bad weather

    - It is important to define the set of scenarios that can be handled by the technical solution that is developed in the project:
        - Most important: the exact scenario that will be demonstrated in real life, including (mild) variations on scenario parameters (e.g. speed, timing, etc.)
        - For simulation purposes, other scenarios (that differ from the demo-scenario) may be considered as well, if they are in line with the operational design domain (ODD). For larger variations on the ODD, however, the outcome of these simulations may not be accurate/representative

- Considered (environmental, infrastructure etc.) limitations:
    - Urban regions; mild to severe rain conditions

- Considered region and time horizon of the projection:
    - Scenario covered to 2025 with a projection to 2050

Resulting research question:

"What is the safety performance of an 'all-weather VRU AEB+S' at a penetration rate of 9.6% / 27.5% / 100% in Car to VRU collisions on urban roads in terms of MAIS 5+ injury reduction on EU level in 2025 compared to the 2016 numbers"?

Baseline Definition:

The baseline scenario is a (possible) Car-VRU collision, with the Car:

1. Fitted without assistance systems, assuming driver does NOT see the VRU
2. Fitted with AEB system, assuming the AEB does see the VRU

Test scenario definition:

What scenario is selected to represent max impact or another form of high relevance for AES as an intervention method.

Car-pedestrian collisions with large percentage KSI happen on roads outside of junctions (70 or 80%, irrespective of weather). Consequently, a scenario will be created that adheres to the following aspects:

- Has a high incidence / is disproportionally influenced by weather conditions
- AES has a likely benefit in addition to baseline
- Is sufficiently testable given test hall/environment available

Extension of test scenario to other relevant urban cases inside ODD:

Other scenarios (that differ from the demo-scenario) may be considered as well, as long as they are in line with the operational design domain (ODD). For larger variations on the ODD, however, the outcome of these simulations may not be accurate/representative.

Baseline Simulation:

Two possibilities (depending on baseline definition):

1. No simulation required as results (number of MAIS5+ injuries) can be directly taken from baseline definition
    - Relevant if the ‘no-assistance baseline is selected’

2. Simulation using the same framework as for the treatment simulations (see Appendix b) on page 39) but without technology and using accident scenarios representative for 2016 instead of future (2025) accident scenarios
    - Relevant if driver warning system / AEB system is assumed

2.2.4 VRU's safety enhanced by communications

***Description*:**

Demo 4 consists of a safety solution based on C-ITS to enable timely warning provisions establishing a communication framework for drivers and VRUs increasing the awareness of and about pedestrians, bicycles, motorcycles, etc. in the neighbourhood of other traffic participants. The demonstrator will show the communication potential between the vehicle, the infrastructure and a VRU smart device, as well as the human warning interaction for both drivers and VRUs, evaluated by technical verification of the system effectiveness and performance. The bidirectional communications allow actions to be taken not only from the vehicle side, but also from the VRUs.

The VRU system will consist of an application running on VRUs’ smart devices, which will be able to warn them on their HMI about safety-critical situations by using real-time communications. Moreover, hardware and software platforms and modules for C-ITS communication will be developed and integrated in a virtual vehicle platform. The applications will operate in a decentralized way, where each vehicle and VRU will collect C-ITS standardized messages to feed the risk evaluation algorithms running on their devices.

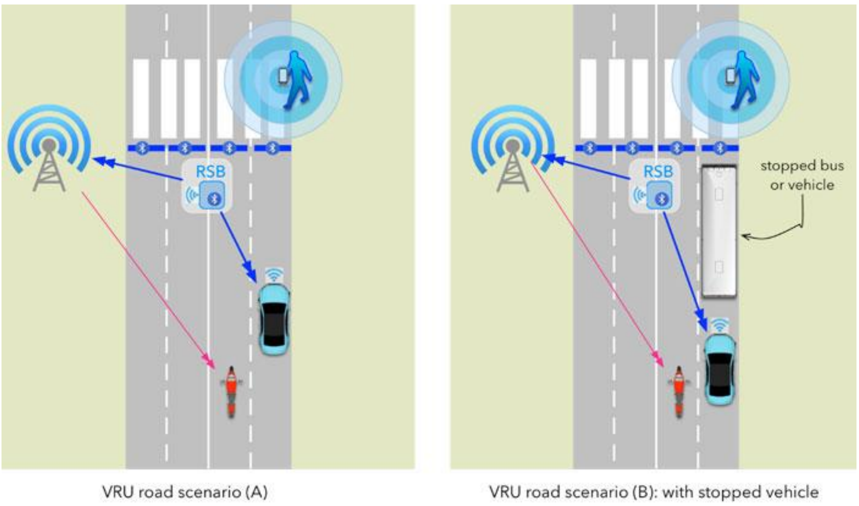


Figure 12 – VRUs warning devices based on ETSI ITS G5 (Source: SAFE STRIP)

Data from special sensors mounted on vehicles / RSUs, such as radars, lidars and cameras, will be analysed in order to increase the perceptual ability of the vehicles and the infrastructure to detect non-connected VRUs. Direct exchange of the warning messages between vehicles and VRUs will be studied. All developments will be used for the prototype demonstrator in which the applications will be validated for the different types of road users in T3.6. The advances will be assessed in WP5 from the overall safety point of view as well as included in the training schemes in WP6.

Associated Deliverable(s):

D3.4 and D3.7: Demo 4 (system for on-time warning provisions to VRUs and drivers in critical conditions). Implementation of a communication system including accident warnings for pedestrians on mobile phones and drivers of passenger cars based on C-IST-ETSI protocols. The information might also be transferred to other traffic participants using this communication channel.

Basic Information:

- Metric to be used:
    - Reduced MAIS level 5+ or fatalities due to Car-VRU collisions
    - Avoidance of crashes

- Technology under assessment:
    - Radio Access Technology (ITS-G5, LTE-V …)
        - Sensitivity >90% (i.e. detection of all true positives)
        - Specificity >85% (i.e. detection of true negatives)

- Assumed penetration rate of the considered technology:

  As stated in the proposal, the market penetration rates are taking as reference the 30% market share of Samsung in EU. Therefore, the assessment will be done between the following scenarios of adoption for this demonstrator:

  - Conservative: 75% of Samsung’s market share, resulting in 22.5%
  - Ambitious: 85% of Samsung’s market share, resulting in 25.5%
  - Optimistic: 95% of Samsung’s market share, resulting in 28.5% (optimistic)

- Considered scenarios or scenario categories:
  - Non-designated crossings for pedestrians in urban areas
  - Intersections for cyclists in urban areas
  - Urban areas related to the new interactions between VRUs and CAVs (non-engaged drivers); focus on scenarios such non-designated crossings

- Considered (environmental, infrastructure etc.) limitations:
  - Network infrastructure (latency, availability of resources)
  - Accuracy of positioning (false alarm, false detection)
  - Vehicle reaction time (late actuation, no actuation)
  - HMI warning effectiveness for VRUs

- Considered region and time horizon of the projection:
  - Scenario covered to 2025. No projection needed as this technology will evolve quickly in the upcoming years

Resulting research questions:

“What is the safety performance of a vehicle AEB enhanced by a radio signal based VRU communication and detection system in terms of MAIS5+ injury reduction in EU urban roads in 2025 compared to the 2016 numbers and the same safety system with SOTA VRU detection system?”

“What is the safety performance of a VRU C-ITS warning system, triggered by a radio signal based (OBU, VRU-smart device) VRU communication and detection system in Car to VRU collisions on urban roads in terms of MAIS5+ injury reduction on EU level in 2025 compared to the 2016 numbers?”

Baseline Simulation:

- Traffic safety-critical scenarios simulated on specific simulation software without connectivity

3. Discussion

This document describes a preliminary safety benefit assessment framework in general terms and specifies the corresponding requirements in terms of data and results needed from the various SAFE-UP tasks to enable a benefit assessment at the end of the project. The proposed preliminary framework is based on experience from previous projects and has various components. As a complex framework, it will require the specification of various assumptions during the process; some of these assumptions are discussed in the paragraphs below.

As discussed in Section 2.1, definition of the addressed scenarios will require an extrapolation step to ensure that the addressed and assessed scenarios represent EU level safety-critical situations as well as possible. There are several methods for performing such an extrapolation step and it is expected that one of these methods will be applied already in WP2 that would provide appropriate use-cases to the other tasks. However, it is important for the benefit assessment to understand how the specific extrapolation method affects the estimated safety benefit. Therefore, in T5.3, a sensitivity analysis is planned to address this question and to ensure that the most appropriate extrapolation method will be used when the final safety benefit estimates are computed.

The study presented in this report has a direct link to the kick-off and the description of the SAFE-UP project itself, meaning that several activities were in an early phase of development by the time this work has been done. This must be seen as a limitation of the T5.1 since the overall framework and the requirements for the impact assessment will strongly depend on the results from other WPs and demonstrators of the project.

This limitation has been particularly relevant for the technologies investigated in Demo 1, where 3 use-cases with different types of crash configurations between car to car and car to HGV being front-end, front oblique and rear-end with and without pre-crash braking and steering have been defined. For these use-cases, the impact of the systems will be evaluated by means of the static occupant monitoring, the HBM simulations to be performed in T4.3 and the physical testing activities to be done in T5.4. In addition, since there are no standardized injury criteria for the evaluation HBM simulations nowadays, T5.2 will define a new SAFE-UP procedure to address the benefit of the occupant protection systems investigated within the WP4 of the project.

In case of Demo 2, the interaction between vehicles and VRUs will be optimized under bad weather conditions combining new sensor technologies that will be validated through the object detection as a function of weather conditions. All the information given from the different sensors installed will be treated to enhance the effectiveness of the algorithm both in the near-field area and bad weather conditions.

In a similar way, Demo 3 will work on the vehicle dynamics intervention functions to avoid collisions given traffic safety-critical scenarios, such as the emergency steering, the electronic power steering as well as the differential braking. In both Demo 2 and Demo 3 cases, the definition of scenarios that can be handled by the technical solution developed in the project will be relevant for the final evaluation of the SAFE-UP systems.

On the other hand, given the complexity of the technology and the number of actors involved, there's a need to clearly define how the connectivity technology from Demo 4 will be assessed in order to prove the reduction in fatalities and injury reductions that the implementation of this technology would bring. Considering connectivity as another sensor in the vehicles it could provide advantages to other sensors such as camera or radars with and without the support of additional communications infrastructure. However, connectivity-based safety applications require that the rest of the traffic participants in the scenario (e.g. other vehicles, VRUs, etc…) either have connectivity or an external sensor that could position them in the space and send the corresponding information to the connected vehicle.

Additionally, for the systems developed in Demo 4, it is not only car-based safety systems that are considered, hence it may be necessary to consider the human interaction in the whole critical situation and to separate the penetration rate curves for car-based systems and, e.g. person-based systems used by VRUs related to smart devices for the corresponding systems.

Penetration rates (another relevant component in the preliminary framework) are difficult to predict and depend on the marketing strategy of the developed systems as well as legislation (e.g. making a system mandatory in new vehicles will accelerate its market penetration). It is also worth mentioning that all the penetration rates indicated in this report have been taken from the SAFE-UP proposal and, thus, are considered generic for the technologies developed in the project, but may vary in the future due to the specific use cases and requirements in the demonstrators.

In fact, the differences in the implementation time into the automotive market will play a relevant role in the impact assessment of the technologies developed in SAFE-UP. These uncertainties between the technology development and the introduction time of those ones into the market could also be affected by the current worldwide health emergency situation and mobility restrictions. Therefore, while it is planned to use all relevant information that is available when performing the safety benefit assessment, the actual benefit of the systems could deviate from the estimated amount due to e.g. differences between the assumed and actual market penetration of the systems.

4. Conclusions

The main purpose of the SAFE-UP project is the investigation and development of advanced safety systems and pre-competitive technologies to protect CAV occupants and VRU's in the mobility of the future. The success of the project will be measured, in part, by the reduction in terms of fatalities and serious injuries in the upcoming safety-critical traffic scenarios. This report presents an overall impact assessment framework that will enable the transmission of the right information through the whole project so that, in the end, the benefit of those safety systems can be evaluated. However, as mentioned in previous sections, several factors may affect the performance of the safety benefit calculations and, thus, should be considered in further WP5 tasks.

The estimation of safety benefits and relevant circumstances depend on the time point when such an estimate is to be made. Therefore, choosing the time horizon for the assessment is another critical point. This aspect affects not only the market penetration of the developed systems (as indicated in Section 2.1) but also infrastructural and other aspects. It is difficult to predict the future road environment and the further in time the forecast is made, the larger the uncertainties are concerning the underlying assumptions. It is currently planned to consider different time horizons, including near-future of 5-10 years from now, as well as attempting to address predictions for years further ahead of time, with a careful specification of the underlying assumptions as well as the known limitations of the method.

The work performed in T5.1 and the descriptions provided in this document specify requirements for other tasks that need to be fulfilled to enable a safety benefit assessment in the project. These requirements are based on the preliminary framework envisioned for the project. Note, however, that the final safety benefit assessment method will be specified and implemented in tasks 5.3-5.4 and there can be improvements in the final method compared to the status described in the current document. Therefore, it is essential to keep the discussion and information flow between WP5 and other parts of the project to ensure that the final method will be the best possible and that the other parts of the project provide appropriate information for the final method.

List of abbreviations

Abbreviation	Meaning
ABS	Anti-lock Braking System
ADAS	Advanced Driver-Assistance Systems
AEB	Autonomous Emergency Braking
AEB + S	Autonomous Emergency Braking and Steering
CARE	Community database on Accidents on the Roads in Europe
CAV	Connected Automated Vehicles
C-ITS	Cooperative Intelligent Transport Systems
D	Deliverable
ETSI	European Telecommunications Standards Institute
EU	Europe
FCW	Forward Collision Warning
FOV	Field of View
GIDAS	German In-Depth Accident Study
HBM	Human Body Models
HGV	Heavy Goods Vehicle
HMI	Human-Machine Interface
ISO	International Organization for Standardization
ITS	Information Technology
KSI	Killed and Severely Injured
LTE-V	Long-Term Evolution Vehicular
MAIS	Maximum Abbreviated Injury Scale
OBU	Onboard Unit
ODD	Operational Design Domain
RSU	Roadside Unit
SOTA	State-of-the-art
T	Task
UTYP	Unfalltyp (German); Type of accident (English)
VRU	Vulnerable Road User
WP	Work Package

References

Alvarez, S., Page, Y., Sander, U., Fahrenkrog, F., & Helmer, T. J. (2017). Prospective assessment of ADAS and active safety systems via virtual simulation: A review of current practices. *Proceedings of the 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV).* https://www-esv.nhtsa.dot.gov/Proceedings/25/25ESV-000346.pdf.

Aparicio, A., Sanz, L., Burnett, G., Stoll, H., Arbitmann, M., Kunert, M., . . . Gavrila, D. (2017). Advancing active safety towards the protection of vulnerable road users: the PROSPECT project. *ESV.* Detroit, USA.

Bálint, A., Fagerlind, H., & Kullgren, A. (2013). A test-based method for the assessment of pre-crash warning and braking systems. *Accident Analysis and Prevention 59*, 192-199.

Bärgman, J., & Victor, T. (2020). Holistic assessment of driver assistance systems: how can systems be assessed with respect to how they impact glance behaviour and collision avoidance? *Bärgman, J. and T. Victor Holistic assessment of driver assistance systems: how can systems be asseIET Intelligent Transport Systems 14*, 1058-1067.

Bärgman, J., Lisovskaja, V., Victor, T., Flannagan, C., & Dozza, M. (2015). How does glance behavior influence crash and injury risk? A 'what-if' counterfactual simulation using crashes and near-crashes from SHRP2. *Transportation Research Part F: Traffic Psychology and Behaviour*.

Georg Doll, E. E. (2020). *McKinsey & Company.* Retrieved from Private autonomous vehicles: The other side of the robo-taxi story: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/private-autonomous-vehicles-the-other-side-of-the-robo-taxi-story

Helmer, T., Wang, L., Kompass, K., & Kates, R. (2015). Safety Performance Assessment of Assisted and Automated Driving by Virtual Experiments: Stochastic Microscopic Traffic Simulation as Knowledge Synthesis. *IEEE 18th International Conference on Intelligent Transportation Systems, Las Palmas.*, 2019-2023.

IIHS. (2017, September). *Predicted availability and fitment of safety features on registered.* Retrieved from www.iihs.org

Kitajima, S., Shimono, K., J, T., Antona-Makoshi, J., & Uchida, N. (2019). Multi-agent traffic simulations to estimate the impact of automated technologies on safety. *Traffic Injury Prevention, 20:sup1, S58-S64*.

Korner, J. (1989). *A Method for Evaluating Occupant Protection by Correlating Accident Data with Laboratory Test Data.* SAE Technical Paper 890747, doi:10.4271/890747.

Kovaceva, J., Bálint, A., Schindler, R., & Schneider, A. (2020). Safety benefit assessment of autonomous emergency braking and steering systems for the protection of cyclists and pedestrians based on a combination of computer simulation and real-world test results. *Accident Analysis & Prevention 136*, 105352.

Kovaceva, J., Bálint, A., Schindler, R., Schneider, A., Stoll, J., Breunig, S., . . . Esquer, A. (2018). *Assessment of the PROSPECT safety systems including socio-economic evaluation.* Deliverable 2.3 in the EU project PROSPECT.

Kunert, M., Stolz, M., Gavrila, D., Flohr, F., Hartmann, B., & Koch, A. (2016). *Specification of the PROSPECT demonstrators.* D3.2 in the EU project PROSPECT.

Leledakis, A., Lindman, M., Östh, J., Wågström, L., Davidsson, J., & Jakobsson, L. (2021). A method for predicting crash configurations using counterfactual simulations and real-world data. *Accident Analysis & Prevention.150*, 105932.

Lübbe, N. (2015). *Integrated Pedestrian Safety Assessment. A Method to Evaluate Combinations of Active and Passive Safety Systems.* Gothenburg: PhD thesis at Chalmers University of Technology.

Mroz, K. O. (2020). Effect of Seat and Seat Belt characteristics on the Lumbar Spine and Pelvis Loading of the SAFER Human Body Model in reclined Postures. *Proceedings of the IRCOBI Conference.* München, Germany.

Östling, M., Jeppsson, H., & Lübbe, N. (2019). Predicting crash configurations in passenger car to passenger car crashes to guide the development of future passenger car safety. *IRCOBI conference 2019, paper IRC-19-92.* http://www.ircobi.org/wordpress/downloads/irc19/pdf-files/92.pdf.

Page, Y., Fahrenkrog, F., Fiorentino, A., Gwehenberger, J., Helmer, T., Lindman, M., & Wimmer, P. (2015). A comprehensive and harmonized method for assessing the effectiveness of advanced driver assistance systems by virtual simulation: THE P.E.A.R.S. initiative. *ESV.* Gothenburg, Sweden.: http://www-esv.nhtsa.dot.gov/Proceedings/24/isv7/main.htm.

Schwall, M., Daniel, T., Victor, T., Favarò, F., & Hohnhold, H. (2020). Waymo Public Road Safety Performance Data. https://waymo.com/safety.

Stoll, J., Schneider, A., Wisch, M., Seiniger, P., & Schaller, T. (2016). *The addressed VRU scenarios within PROSPECT and associated test catalogue.* D3.1 in the EU project PROSPECT.

Wågström, L., Leledakis, A., Östh, J., Lindman, M., & Jakobsson, L. (2019). Integrated safety: establishing links for a comprehensive virtual tool chain. *Proceedings of the 26th ESV conference, paper number 19-0177.* https://www-esv.nhtsa.dot.gov/Proceedings/26/26ESV-000177.pdf.

Wang, L. V. (2016). Multi-functional open-source simulation platform for development and functional validation of ADAS and automated driving. In *In R. Isermann (eds.), Fahrerassistenzsysteme (pp. 135-148). Proceedings.* Springer Vieweg, Wiesbaden.

Waymo. (2020). *Waymo safety report.* Available at https://storage.googleapis.com/sdc-prod/v1/safety-report/2020-09-waymo-safety-report.pdf.

Webb, N., Smith, D., Ludwick, C., Victor, T., Hommes, Q., F., F., . . . Daniel, T. (2020). *Waymo's Safety Methodologies and Safety Readiness Determinations.* www.waymo.com/safety.

Appendix

a) Virtual Simulation Framework for Demo 2:

Required Models:

- Vehicle under Test:
    - Vehicle Dynamics
    - Driver
    - Technology
- Sensor/Perception input generation
- Vehicle Surrounding:
    - Traffic
    - Infrastructure
    - Environment
- Simulation Control
- Collision Model

Requirements per model:

Vehicle Dynamics

- Simulation software
    - ‘Standard’ model (bicycle model or similar) will be used. Parameter sets of the used demo vehicles will be provided; model implementation can be done as preferred.
- Parameters
    - ‘Standard’ model (bicycle model or similar) will be used. Parameter sets of the used demo vehicles will be provided.
- In- and outputs (depending on who provides the vehicle model)

Technology – Sensor

- 6 high resolution prototype radars with 360° FOV (1x front, 2x corner, 2x corner-Rear, 1x rear)
- 1 stereo video front camera
- 1 360° FOV lidar (reference sensor)

Technology – Logic

The following Figure 13 is used to illustrate the developments that will be done within the activities in Demo 2:

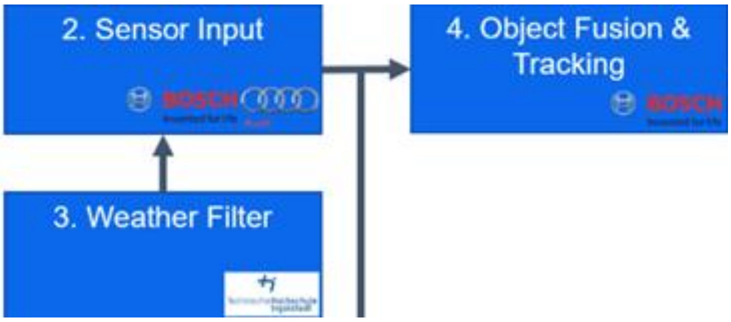


Figure 13 – Diagram showing the developments in Demo 2

Technology - Actuator(s)

- Longitudinal Braking
  - Longitudinal acceleration or wheel torques (depending on used model)

Sensor/Perception input generation

- Weather filter
  - How sensor inputs are adjusted by the bad weather filter

Traffic

- Based on test scenario
  - At minimum trajectory of VRU

Infrastructure

- Based on test scenario
  - Road layout
  - If relevant: obstructions of view

Environment

- Based on test scenario
  - Weather conditions
  - Road grip conditions
  - Light conditions

b) *Virtual Simulation Framework for Demo 3:*

Required Models:

- Vehicle under Test:
    - Vehicle Dynamics
    - Driver
    - Technology
- Sensor/Perception input generation
- Vehicle Surrounding:
    - Traffic
    - Infrastructure
    - Environment
- Simulation Control
- Collision Model

Requirements per model:

Vehicle Dynamics

- Simulation software
    - Desired type of vehicle model
        - If a ‘standard’ bicycle model or similarly standardized model (e.g. IPG carmaker model) is used, parametrization of the vehicle model suffices.
        - ‘Standard’ model (bicycle model or similar) will be used. Parameter sets of the used demo vehicles will be provided; model implementation can be done as preferred.

- Parameters
    - Specifications of vehicle model, based on vehicle used for tests in WP3T3
        - ‘Standard’ model (bicycle model or similar) will be used. Parameter sets of the used demo vehicles will be provided by Bosch

- In- and outputs
    - Depending on who provides the vehicle model
    - According to the used ‘standard’ model
    - Required inputs based on AEB/AES actuators
        - Steering angle
        - Yaw torque or wheel torques for differential braking (depending on used model)

    - Longitudinal acceleration or wheel torques (depending on used model)

Driver

- Model / actions
    - The driver model or driver actions need to be sufficiently defined for the simulation to function and play out the scenario

Technology – Sensor

- List of sensors
    - Type
    - Location
    - FOV
- Front Radar, FOV +/-60 °
- Corner Radar right, FOV +/-75 °
- Corner Radar left, FOV +/-75 °
- Front Camera, FOV +/-50 °

Technology – Logic

As the innovation in WP3T3 is described by software, the following diagram (Figure 14) is used to indicate the developments:

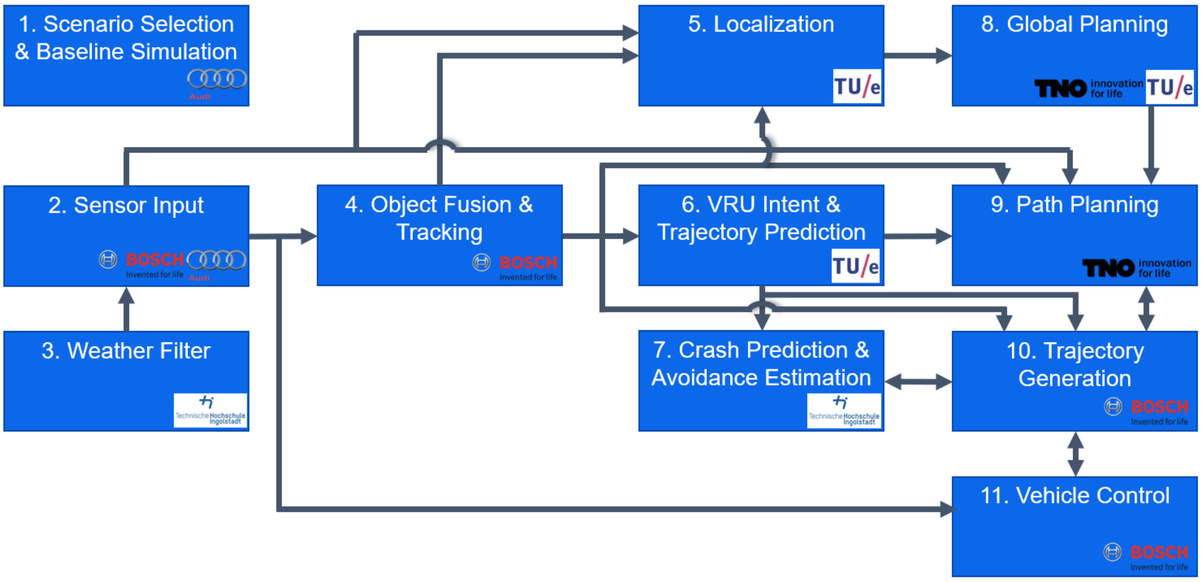


Figure 14 – Diagram showing the Demo 3 developments in SAFE-UP

A more extensive description of the intended software will be available in an architecture document from WP3T3.

Technology - Actuator(s)

- A list of relevant actuators
    - Depending on the depth of simulation model
        - Direct relation of brake percentage to torque at wheels (possibly limited by max dynamic force due to tyre envelope usage)
        - More complex ABS involved simulation where ABS characteristics are included in the tyre braking feedback
    - Electronic Power Steering model
        - Will model steering system dynamics
        - Driver model will act on steering torque as disturbance
        - Input: steering torque
        - Output: steering angle

    - Differential Braking
        - Yaw torque or wheel torques (depending on used vehicle model)

    - Longitudinal Braking
        - Longitudinal acceleration or wheel torques (depending on used model)

Sensor/Perception input generation

- Weather filter
    - How sensor inputs are adjusted by the bad weather filter

Traffic

- Based on test scenario
    - At minimum trajectory of VRU

Infrastructure

- Based on test scenario
    - Road layout
    - If relevant: obstructions of view

Environment

- Based on test scenario
    - Weather conditions
    - Road grip conditions
    - Light conditions

c) *Virtual Simulation Framework for Demo 4:*

Requirements per model:

Vehicle Under Test

- X-Position (With time Signal)
- Y-Position (With time Signal)
- Speed
- Yaw angle
- Yaw rate
- Connectivity Available (yes / no)
- Positioning accuracy
- X-/Y-acceleration
- Manoeuvre (following, lane change …)

Dynamic Objects

- X-Position (time Signal)
- Y-Position (time Signal)
- Positioning accuracy
- Speed
- Type (bike, car, pedestrian, motorcycle …)
- Connectivity Available (yes / no)

Static Objects

- X-/Y-Position visual obstruction
- Dimension visual obstruction
- Variation of x-/y-start-position
- Variation of dimension of visual obstruction

Environmental Requirements:

Environmental conditions

- Lighting (day, night …)
- Normal weather conditions

Communications

- Radio Access Technology (ITS-G5)
- Message delay
- High Channel Load
- Message outdated

Detections Requirements:

RSU (enhanced with object detection)

- Detected Objects: x-Position
- Detected Objects: y-Position
- Detected Objects: Speed
- Detected Objects: Yaw angle (Not in case of VRU)

Vehicle Under Test

- Detected Objects: x-Position
- Detected Objects: y-Position
- Detected Objects: Speed
- Detected Objects: Yaw angle (Not in case of VRU)