

IMPROVING THE EFFECTIVENESS OF ACTIVE SAFETY SYSTEMS TO SIGNIFICANTLY REDUCE ACCIDENTS WITH VULNERABLE ROAD USERS - THE PROJECT PROSPECT (PROACTIVE SAFETY FOR PEDESTRIANS AND CYCLISTS).

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ABSTRACT

Accidents involving Vulnerable Road Users (VRU) are still a very significant issue for road safety. 'PROactive Safety for PEdestrians and CyclisTs' is a collaborative research project funded by the European Commission. The objective of PROSPECT was to improve significantly the effectiveness of active VRU safety systems compared to those currently on the market by: (i) expanding the scope of urban scenarios addressed (ii) improving the overall Autonomous Emergency Braking (AEB) and Autonomous Emergency Steering (AES) system performance (iii) proposing extensive validation methodologies for consumer testing, simulation and acceptance studies with tools for testing. Concepts for sensors and control systems were shown in three vehicle demonstrators and a mobile driving simulator and tested with novel VRU dummy specimen. Those systems address the well-known barriers of current AEB systems such as limited sensors field-of-view, fuzzy path prediction, unreliable intent recognition and slow reaction times for the actuation. User acceptance tests with the participation of drivers were also crucial in PROSPECT for the success of all active safety systems. Driving simulator studies were then used in a controlled and repeatable environment for the collection of data regarding the interaction between the driver and the safety function. Finally, project consortium implemented a novel benefit estimation methodology that includes an assessment of the combined effect of active and passive safety measures of PROSPECT-like systems.

Keywords: Active safety; Advanced Driver Assistance Systems (ADAS); Vulnerable Road Users (VRU); Autonomous Emergency Braking (AEB); video and radar technology.

1. INTRODUCTION AND MOTIVATION FOR PROSPECT PROJECT

Considering the countries in the European Union (EU) and the latest year of data availability for 2017, according to the accident data published by the EU [1], about 1.3 million people die each year on the world's roads, of which 25.300 lost their lives in the EU. In 2017, vulnerable road users (VRU) accounted for almost half of the road victims, where 21% of all people killed on roads were pedestrians and 8% were cyclists. These percentages show the magnitude of the problem and the need to take action in order to reduce these figures (see Fig. 1).

The White Paper (Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System) contains European Union goals on the area of traffic safety [2]: „By 2050, move close to zero fatalities in road transport. In line with this goal the EU aims at halving road casualties by 2020.”

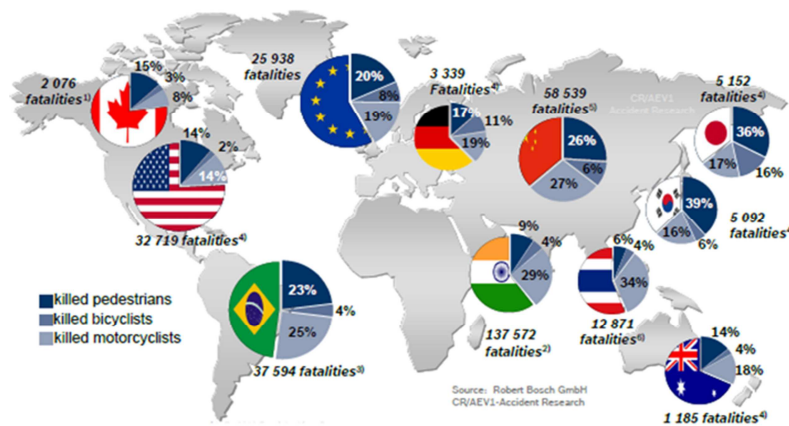


Figure 1. Road traffic deaths by type of road user in Europe and world (Source: Robert Bosch, 2015)

Nowadays, Advanced Driver Assistance Systems (ADAS) are the basis for the development of automated cars. The last decade has seen significant progress on active safety, as a result of advances in video and radar technology. Nevertheless there is still high potential for improvement in this field.

In particular, a study by Euro NCAP and NCAP concluded in 2015 (Author's Note: the independent safety bodies for Europe and Australasia) confirms high effectiveness of Autonomous Emergency Braking systems (AEB) which lead to a 38% reduction in real-world rear-end crashes at low speeds [3]. Further on, according to estimates by the European Commission, AEBs could save more than 1,000 lives every year within the EU only [4].

At this stage AEBs are already available for some car models in the EU countries, but up to date there were no standard technical requirements guaranteeing the effective performance of such systems. What is already under way, the introduction of AEB functions will be a must for vehicles sold in the United States and in the European Union by 2020-2022, since AEB Systems have the potential to increase safety for drivers as well as for VRU.

Currently around 40 countries have agreed on a draft United Nations Regulation for Advanced Emergency Braking Systems for cars. The draft of the United Nations Regulation, adopted at United Nations Economic Commission for Europe (UNECE), will lay down the technical requirements for the approval of vehicle-to-pedestrian and vehicle-to-vehicle AEBs fitted on cars. The new Regulation sets out test requirements for the deployment of AEBs at a range of different speeds, from 0-60 km/h. When this Regulation will enter in force, most of existing systems fitted into cars will have to be updated to meet stricter requirements. This would finally mean that over 15 million new cars in the EU would be equipped with the lifesaving AEBs technology every year [5].

To improve the effectiveness of active safety systems fitted into cars, the consortium of 17 partners: top automotive manufacturers, suppliers and test labs proposed the 'PROactive Safety for PEdestrians and CyclisTs' (PROSPECT project). The main objective was to significantly reduce accidents with Vulnerable Road users (VRU).

PROSPECT is a collaborative research project funded by the European Commission. The project pursues an integrated approach comprising in-depth and multiple European accident studies involving VRUs, combined with results from urban naturalistic observation. A vast variety of data collected at European level, where vehicles and VRU interact in real traffic situations, helped to understand critical situations, identify factors that lead to conflicts and better anticipate possible accidents. As the output, the Accident Scenarios were identified for pedestrians and cyclists with a special focus on urban environments, where indeed the majority of accidents involving VRU occur. Further on, the most important Use Cases were derived as basis for the development of Test Scenarios for the ADAS systems. Proposed test cases are more detailed than the defined use cases - they are a description of how to reproduce a specific use case on test tracks.

Finally, this accident analysis represented a key input for the system specifications, integration and demonstration to the public in three project prototype vehicles. These demo-vehicles were extensively tested in realistic scenarios. Proposed by the PROSPECT team a broad testing methodology went beyond what has currently been used: VRU intention detection (dummies with additional degrees-of-freedom), intersection driving style (natural driving style using robots by analysis of human driving) and transferability to real life (testing in realistic traffic scenarios, user acceptance tests).

What is novel is that the project consortium implemented the benefit estimation methodology that includes an assessment of the combined effect of active and passive safety measures (i.e. integrated safety). The results from this analysis depended strongly on testing activities within the project and were extrapolated to the EU-28 level. Finally, the expected fleet penetration rates for 2020-2025 were analysed. The PROSPECT project technical approach is presented herein below (see Fig. 2).

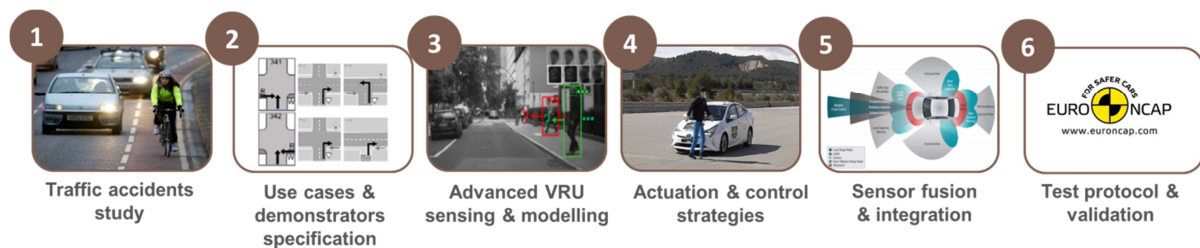


Figure 2. The PROSPECT project technical approach

In PROSPECT, just like other functions implemented in automated driving, vehicle-based sensors (i.e. video, radar) survey the vehicle surroundings, advanced algorithms enable safety related decision-making, and the system acts actively when necessary. Being active safety solutions focused on VRU, the systems developed in PROSPECT take action when a critical situation with a VRU occurs. Moreover, each of the demonstrators completed within the project has its unique focus:

- I demonstrator is equipped with stereo vision camera and high resolution radars, featuring a high dynamic brake system combined with a power assisted steering actuator.
- II demonstrator features improvements in earlier, accurate and more robust detection of VRUs where sensor fusion with radar / lidar technologies is planned to extract VRU intention-related features.
- III demonstrator integrates enlarged FOV radar sensors including side and rear coverage and avoids critical situations or collisions by steering and/or braking in complex urban scenarios.

- Additionally, one driving simulator included advanced warning/HMI and control strategies to evaluate interaction between the driver and the vehicle inside PROSPECT.
- Advanced realistic pedestrian and cyclist dummies including a platform propulsion system improves realistic testing by extending dummy trajectories, organic materials, kinematics and physical behaviour.

AEB Systems have the high-potential to improve VRU safety. The findings within PROSPECT contributed not only to the generation of state-of-the-art knowledge of VRU-vehicle behaviour but as well to technical innovations i.e. assessment methodologies and tools for testing of next generation VRU active safety systems. Besides, in terms of the impact, the introduction of a new generation safety system in the market will enhance VRU road safety in the 2020-2025 timeframe, contributing to the ‘Vision Zero’ objective of no fatalities or serious injuries in road traffic set out in the Transport White Paper. Test methodologies and tools shall be considered as well for 2022-2024 Euro NCAP road-maps [6].

2. ACCIDENT ANALYSIS: ACCIDENT SCENARIOS, USE CASES AND TEST CASES

The first stage of the project included macro statistical and in-depth accident studies involving VRUs, performed in Europe and focused mainly in pedestrians and cyclists. An overview and an in-depth understanding of the characteristics of road traffic crashes involving vehicles (focus on passenger cars) and VRUs (i.e. pedestrians, cyclists, riders of mopeds, e-bikes or scooters) was provided for different European countries.

The in-depth understanding of the crashes includes the identification of the most relevant road traffic “accident scenarios” and levels of injury severity sustained, as well as the transport modes that represent a higher risk for VRUs. Besides extensive literature studies, comprehensive data analyses have been performed including information from recent years.

Several crash databases have been analysed: CARE database (Europe), the German, Swedish and Hungarian national road traffic statistics as well as the in-depth databases IGLAD (Europe), GIDAS (Germany), from Central Statistical Office (Központi Statisztikai Hivatal – KSH) and the Volvo Cars Cyclist Accident Database (Sweden).

Accident type	UTYP Pictogram	PROSPECT pictogram (basic version)
(I) Car straight on, cyclist from near-side		
(II) Car straight on, cyclist from far-side		
(III) Car turns		
(IV) Car and cyclist in longitudinal traffic		
(V) Others		

Figure 3. Most relevant car-to-cyclist scenarios

PROSPECT_UC_PD_x (x=1...8)	Pictogram	in %	Description
PROSPECT_UC_PD_1 PROSPECT_UC_PD_2		23% 22%	Crossing a straight road from near-side / off-side; No obstruction
PROSPECT_UC_PD_3a PROSPECT_UC_PD_3b		5,5% 5,5%	Crossing at a junction from the near-side / off-side; vehicle turning across traffic
PROSPECT_UC_PD_4a		4%	Crossing at a junction from the near-side / off-side; vehicle not turning across traffic
PROSPECT_UC_PD_5 PROSPECT_UC_PD_6		10% 7%	Crossing a straight road from near-side / off-side; With obstruction
PROSPECT_UC_PD_7a PROSPECT_UC_PD_7b		3%	Along the carriageway on a straight road away from vehicle / towards vehicle; No Obstruction
PROSPECT_UC_PD_8	No Pictogram	6%	Driving Backwards
Others		14%	Others

Figure 4. Pedestrian accident scenarios

The focus of the project was on crashes with two participants. Regarding the injury severity of the vulnerable road users two groups were considered: first “slightly, seriously injured and killed (SSK) VRU” and second “killed and seriously injured (KSI) VRU”. Early investigations have shown that the crashes between passenger cars and pedestrians or cyclists are from highest relevance for Europe. Fig. 3 shows a summary of the most relevant accident scenarios related to car-to-cyclist crashes were generated from this study.

From the most relevant accident scenarios, detailed car-to-cyclist crash analyses have been performed focusing on the causation of crashes: car-to-cyclist accidents have been analysed from the car driver’s point of view. With this approach deeper insight can be gained about the situations faced by the drivers especially why they sometimes failed to manage these crash situations [7].

In the analysis of car-to-pedestrian accidents, the Accident Scenarios introduced in the European project AsPeCSS [8] were considered as basis. Regarding crashes between cars and pedestrians, all databases confirmed that the Accident Scenario 1 “Crossing a straight road from nearside; no obstruction” was ranked highest regarding killed or seriously injured pedestrians, and the Accident Scenario 2 “Crossing a straight road from the offside; no obstruction” was ranked highest regarding all pedestrian injury severities. An additional Accident Scenario “Driving backwards” has been considered. The car-to-pedestrian accident scenarios can be seen in Fig. 4.

The ‘Accident Scenarios’ obtained from the studies describe the type of road users involved in the accident, their motions (e.g., the motion of the cyclist or pedestrian relative to the vehicle) expressed as ‘accident types’ and further contextual factors like the course of the road, light conditions, weather conditions and view obstruction. More information is available on the project deliverable “Accident Analysis, Naturalistic Driving Studies and Project Implications” [9]. The most relevant accident scenarios have been clustered in “Use Cases” or “target scenarios” addressed by the project.

The final goal was to define representative ‘Test Scenarios’ from available Use Cases, taking into account relevant parameters and representative values for the selected parameters based on accident potential and system analysis. Constraints taken into account are a limited and feasible number of test runs, durability (e.g. maximum impact speed) and the feasibility of the test tools (Fig. 5).

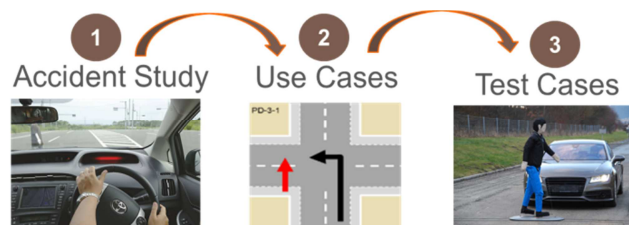


Figure 5. From accident analysis to test cases

Complementary to accident studies which have derived the most relevant use cases to study, naturalistic observations have been carried out to provide information that cannot be inferred from accident data bases, since these usually do not contain detailed information about the time before the accident happened (the so-called “pre-crash phase”). The first goal has been to acquire data about indicators of VRU’s behaviours that sign their intent in the near future. Naturalistic observations were also used to look for correctly managed situations by the road users that could have led to false alarms for an active safety system.

As seen in Fig. 6, two types of naturalistic observations were carried out in four countries. A first data set (France and Hungary) was collected from on-site observations by infrastructure-mounted cameras. A second data set was collected by cars equipped with sensors and cameras (Hungary and Spain) to observe interactions with surrounding VRUs. The additional study was performed in the final stage of the project in city of Leuven (Belgium) to annotate data samples and to validate final Vehicle under Test (VUT) trajectories for testing.

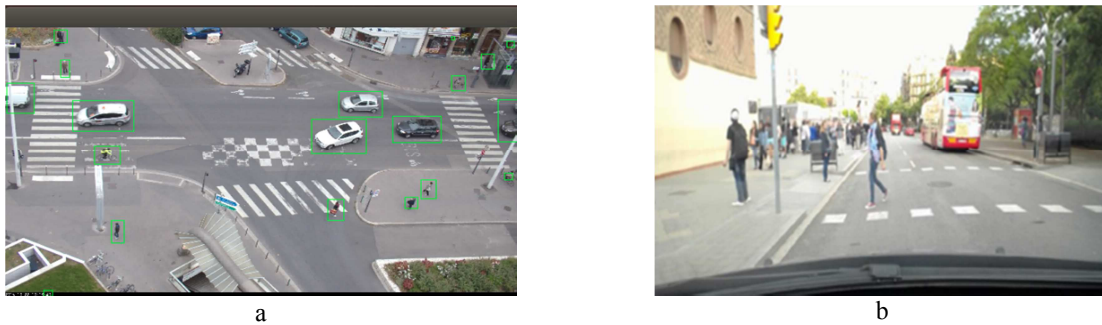


Figure 6. Two types of naturalistic observations carried out in PROSPECT: (a) View from infrastructure-mounted cameras, (b) Video data from in-vehicle camera

3. HUMAN FACTORS AND HUMAN MACHINE INTERFACE (HMI) STUDIES

Human Factors (HF) as a discipline is concerned with understanding the characteristics and capabilities of people, and their interactions with technology and systems, to ensure safe, effective and engaging performance. HF has therefore been applicable at each stage of the PROSPECT project and across multiple partners, activities and work-packages.

In the context of PROSPECT, HF activities have included literature reviews, focus groups, expert evaluations, simulator studies, text track evaluations and video analyses. These have been used to help understand and specify user needs and requirements, inform the design of the PROSPECT system, evaluate HMI and control strategies, assess drivers' reactions and responses, and determine acceptance (i.e. likely uptake) of the final product.

At the start of the project, focus groups involving cyclists and car drivers were conducted by the University of Nottingham, in collaboration with TNO, in the UK and Netherlands. The focus groups aimed to uncover the cues (e.g. hand signals, head movements) that indicate a cyclist's future path and the characteristics of the environment/contextual variables that may affect their choice, to inform the design of the system. Cues and characteristics were identified and categorised into themes: cyclists' appearance, communications and signalling, movement and position of bicycle, and environment and conditions. Results indicated consistency between groups of cyclists and drivers, but were tempered by a cultural perspective, reflecting the higher social status afforded to cyclists in the Netherlands [10].

Functional requirements were also explored by investigating the relationship between false alarms and driver acceptance during a medium-fidelity driving simulator study conducted at the University of Nottingham. By varying urgency ('when') based on the time-to-collision (TTC) at which the warning was presented, and modality ('how') by presenting warnings using audio-only and audio combined with visual alerts presented on a head-up display (HUD), the study explored the effect of false-alarms and HMI modality. False-positive alarms (the system warned, when no hazard was present) corresponded with TTC, in so far as a higher proportion of false alarms occurred at longer TTCs, although there were no false negatives, or 'misses'. Overall, the study indicated a greater margin of safety associated with the provision of earlier warnings, with no apparent detriment to acceptance, despite relatively high false alarm rates at longer TTCs. It was also evident that drivers felt more confident with a warning system present, especially when it incorporated auditory and visual elements, even though the visual cue did not necessarily improve hazard localisation or driving performance beyond the advantages offered by auditory alerts alone [11].

In addition, PROSPECT partners TME and Chalmers University and associated partner Autoliv collaborated to explore and identify driver comfort boundaries. Experienced drivers negotiated an urban scenario in which they approached a road intersection. As they approached the intersection, a pedestrian appeared and then crossed the road ahead. The drivers were instructed to drive as normal as they would have done in the same situation in real life, to gain an understanding of where the driver would naturally ('comfortably') brake. Results indicated that car speed,

pedestrian size, crossing entry and lane width had a significant effect on TTC at brake onset for all drivers – increased car speed was associated with shorter TTC at brake onset, whereas as longer TTC were associated with adult compared to child pedestrians, and wider lane width. There was also evidence of learning and adaptation effects for frequent drivers [12].

To support initial HMI choice by car manufacturers for the PROSPECT demonstrator vehicles, the University of Nottingham in collaboration with IFSTTAR developed HMI taxonomy. The taxonomy was based on the literature review and expert analysis from HF's experts in consortium. It provided a novel framework for the assignment of appropriate feedback modes to different actions of an active safety system. Elements included a classification of possible HMI feedback modes, an identification of active safety system actions at different levels of automation, a set of heuristics to guide HMI design, and taxonomy of action-mode assignment supported by examples.

A number of HF activities were also conducted as part of the acceptance testing later in the project. Partners Toyota and Audi conducted simulator studies that aimed to identify and tune user acceptance of the PROSPECT functions. The 'comfort boundaries' model developed at the start of the PROSPECT project was used to select warning times for a forward collision warning (FCW) system, with the expectation that the system would react in a more 'natural' way if it were based on what an attentive human driver would do (i.e. their 'comfort boundary'). Using a 'vehicle-in-the-loop' simulator, whereby participants drove around a test track in a real vehicle while wearing a VR headset to provide the visual stimuli, warnings were provided either inside or outside the identified comfort limits based on the responses of 95% of the population in a between-subjects design. In addition to exploring issues associated with acceptance (to validate the models), the study also investigated when people actually decided to brake following the warning, with the aim of providing an indication of how the PROSPECT system should behave. Audi also conducted experiments to investigate the interaction of the driver, system and VRU in critical situations in a real-car environment using its mobile driving demonstrator. The aim of this study was to examine the role of sensory conspicuity of cyclists within the drivers' detection of cyclists in specific scenarios.

Finally, Volvo and VTI conducted test track and simulator studies to assess drivers' reactions to warnings and automatic steering interventions in critical longitudinal VRU scenarios. The studies aimed to evaluate ADAS performance with a forward collision warning (FCW), both with and without intervention while the driver was distracted (engaged in a secondary task on a touchscreen). In a novel approach, the same study was conducted by VTI in their driving simulator, and by Volvo on the test track, thereby also allowing issues of simulator validity to be explored. The FCW HMI included auditory (alarm), visual (blinking LED) and haptic (brake pulse) elements, in conjunction with an automatic steering intervention.

4. SYSTEM SPECIFICATION AND DEMONSTRATORS - CHALLENGES AND GENERAL METHODOLOGY FOR ADDRESSING BARRIERS OF CURRENT ADAS SYSTEMS

Based on the derived Use Cases, the sensor specification was achieved including hardware characteristics (e.g. stereo vision base line, image resolution, microwave radar sensitivity/accuracy, field of views) and items that relate to the sensor processing e.g. VRU detection area, correct vs. false recognition rates, localization accuracy, and computational latencies.

PROSPECT focuses on active safety solutions, where the vehicle surveys surroundings based on video and radar sensing. The developed sensors intend to support a larger coverage of accident scenarios by means of an extended sensor field of view (e.g. frontal stereo vision coverage increased to about 90°, radar coverage increased up to 270° covering vehicle front and one side), high-resolution and sensitive microwave radar sensors with enhanced micro-Doppler capabilities for a better radar-based VRU classification. For automated driving however, the system should not only detect VRUs, but also predict their trajectories to anticipate and avoid potentially dangerous situations. In

this case, advanced algorithms enable safety related decision-making and the systems developed within PROSPECT take action in case of a critical situation with a VRU, increasing the effectiveness of current active safety systems.

Improved VRU sensing and situational analysis functions (enlarged sensor coverage; earlier and more robust VRU detection and classification; sophisticated path prediction and reliable intent recognition) were shown in three vehicle demonstrators at the final project event at IDIADA proving ground (Spain) in October 2018. All vehicles are able to automatically steer and / or brake to avoid accidents. Special emphasis is placed on balancing system performance in critical scenarios and avoiding undesired system activations. Information about the demonstrators developed in the project is available in the related PROSPECT deliverables [13]. This section provides an overview of the applied methodology pursued in this project in relation to PROSPECT car demonstrators.

Demonstrator car I

Demonstrator car I is able to quickly detect and classify VRU from -90° to 90° with respect to the vehicle center line with three RADAR sensors, additionally detect the lane markings with a lane camera. There are actuators for the steering and the brake. Especially the brake actuator can increase brake force much quicker than current production brake systems (approx. 150 ms from start of braking to fully cycling ABS). Due to shorter reaction time a prediction horizon can be reduced and the prediction error is lower. The reduction of false activations improves overall driver acceptance and usability. Fig. 7 shows the addressed use cases and utilized sensors of the demonstrator.

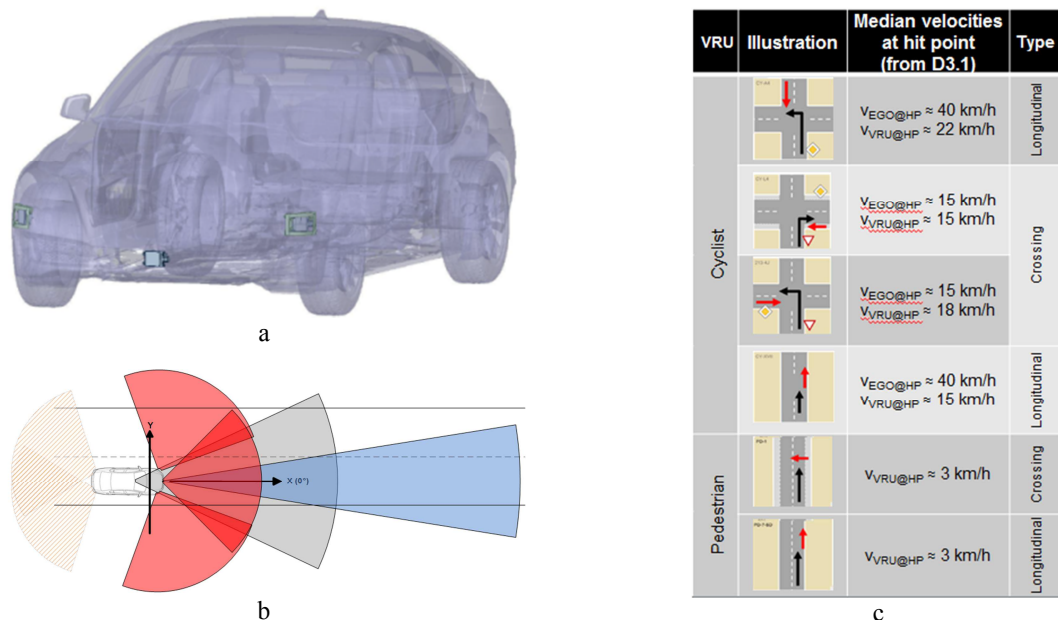


Figure 7. The Demonstrator car I - vehicle with functional setup and addressed use cases: (a) Sensors integration site RADARS, (b) Overview Radar sensor setup, (c) Use Case selection

Demonstrator car II

To handle the defined use cases (e.g. car moving straight with VRU crossing/moving straight, car turning right/left with VRU crossing) the II demo-car is equipped with a front facing stereo camera and two side-mounted cameras. By this camera setup a horizontal FOV of approx. 210° is covered, which is suitable for most of proposed use cases (see Fig. 8 with the sensor setup). In the near range (longitudinal distance up to ~ 40 m) a more detailed analysis of the VRUs will be executed. Based on this detailed information intention recognition can be performed. The correct estimation of VRU's intention helps to increase the possible prediction time horizon, allowing much earlier warnings and interventions without increasing the false-positive rate.

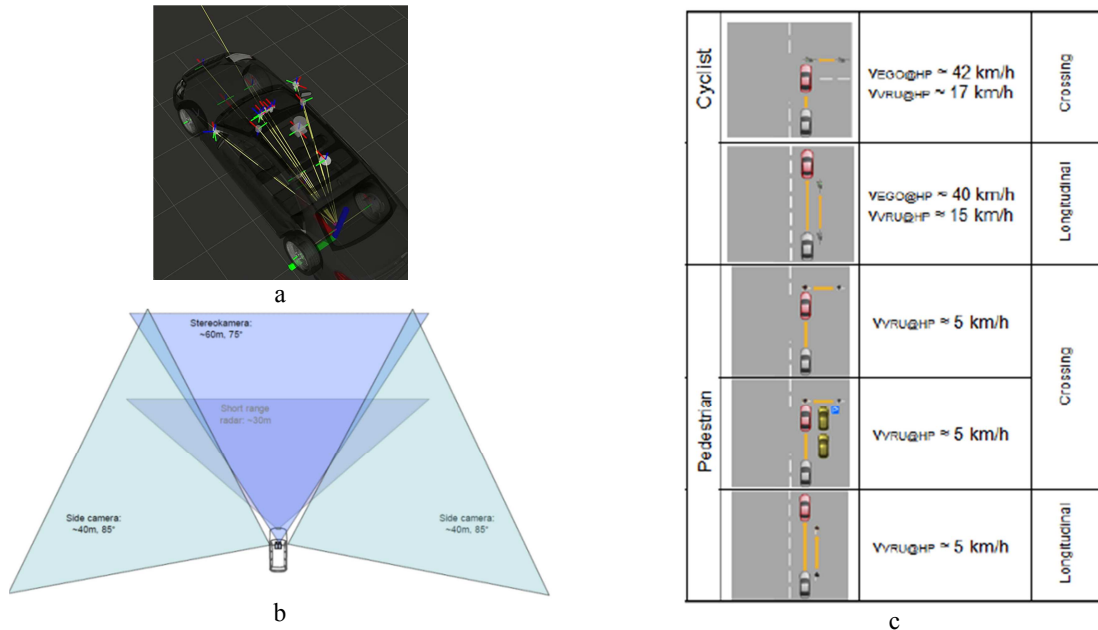


Figure 8. Demonstrator car II - calibrated and synchronized stereo camera and lidar system and addressed use cases: (a) Calibrated and synchronized stereo camera and lidar system, (b) Sensor setup consisting of one front facing stereo camera and two side-oriented cameras, (c) The addressed use cases

Demonstrator car III

Demonstrator car III focuses on high resolution RADAR sensors with a coverage of the regions in the front, rear and at least at one side of the vehicle: especially accidents with crossing or rewards approaching, quick-running bicycles in combination with a relatively slow or stopped car require a sufficient large field-of-view zone for a sound detection and appropriate vehicle action (e.g. for a stopped car in a parking lot and an approaching cyclist from the rear a warning or even the blocking of the door is needed to avoid an accident). See Figure 9 for more details.

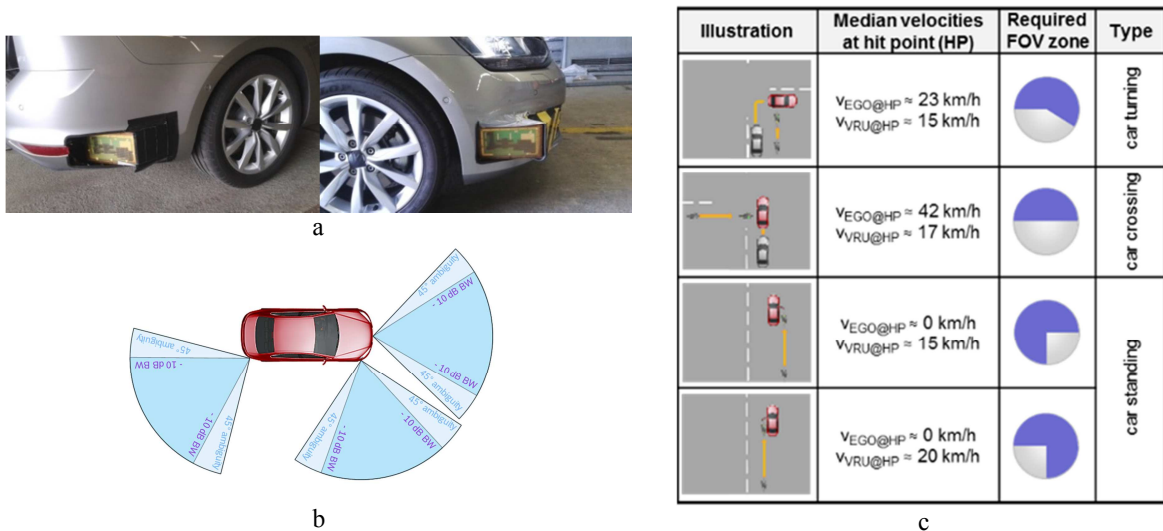


Figure 9. Demonstrator car III - high resolution radar sensors and addressed use cases: (a) The demo-car equipped with radar sensor, (b) Radar sensor mounting positions and FOV, (c) The addressed use cases

5. NEXT GENERATION TESTING

A sound benefit assessment of the prototype vehicle's functionality required a broad testing methodology which goes beyond what has currently been used. A collection of 'test scenarios', representative for all accident scenarios, was required to be defined and specified within the project, resulting in a test protocol **¡Error! No se encuentra el origen de la referencia.** A key aspect of the test methodology was the provision of naturalistic driven trajectories on the test track with driving robots. For this task, data from real driving studies with subjects in a suburb of Munich, Germany; Leuven, Belgium and from Barcelona, Spain were used.

Test methodologies and assessment protocols

Apart from technology demonstrators that will help to maintain and extend the leadership of European car manufacturers in intelligent vehicles and for autonomous driving, PROSPECT took a step forward in defining test and assessment methods for Euro NCAP consumer testing AEB VRU systems. Euro NCAP assessment programmes provide truthful, accurate and independent comparative safety information on vehicles. This programme encourages manufacturers to exceed the minimum legal requirements and promote safety innovation.

Euro NCAP directly benefited from the project's findings and results, especially by being supplied with deliverables including test protocol as a proposal for consumer testing, the dummies prototypes and verification testing. Since Euro NCAP is the leading NCAP in the world regarding active vehicle safety, this helps to keep the European automotive industry in the pole position of active safety.

At this stage, Euro NCAP has published a roadmap document that outlines the strategy for the timeframe 2020 to 2022, which announces several requirements for e.g. steering intervention and cross-junction AEB systems that need specifically conditioned VRUs. PROSPECT results were an early input for the definition of all these requirements (see Fig. 10).

PROSPECT testing results gave deep insight not only in braking but especially for steering strategies. In PROSPECT radar perception was conducted on feature level with static and dynamic grid-maps. Moreover, free space detection and critical objects monitoring for evasive path planning task was performed by developed systems. Evasive steering opens many more possibilities with respect to VRU collision avoidance, but provokes also new challenges and the need of innovative, advanced control and perception performance. In final PROSPECT protocol, evaluation of the improvements and benefits of additional steering for Euro NCAP AEB systems is elaborated.

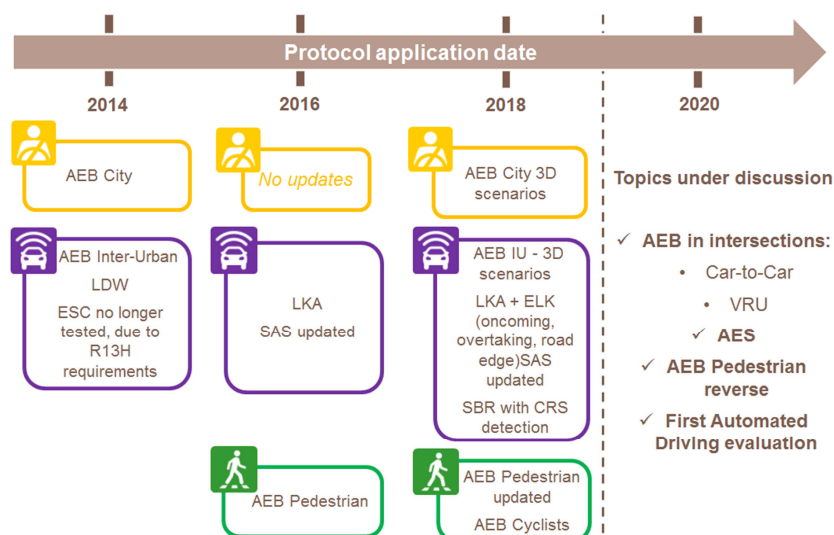


Figure 10. Euro NCAP roadmap for active safety (Source: Euro NCAP, 2018)

Testing tools

PROSPECT focuses on functions that avoid collisions with vulnerable road users, so at least one other traffic participant was a part of the test. Active safety functions might or might not be able to avoid a collision, so the “other” traffic participant needs to be an impactable dummy, a surrogate either for a bicycle or a pedestrian. Both objects (Vehicle-Under-Test (VUT) impact partner) are moved on a predefined track and with predefined speeds so that a critical situation develops. Active safety functions in the VUT might intervene and avoid the collision.

In the context of testing tools development, advanced articulated dummies - pedestrian and cyclist - prototypes were completed by partner 4activeSystems to obtain higher degrees of freedom (head rotation, torso angle, pedaling, side leaning, etc.) and an improved behaviour during the acceleration- and stopping-phase (see Fig. 11). The demonstrator vehicles made use of novel realistic VRU dummy specimen features for a better object classification and prediction of intended VRU movements. The dummies were mounted on fully self-driving platforms to take into account even complex test scenarios with different arbitrary movements.

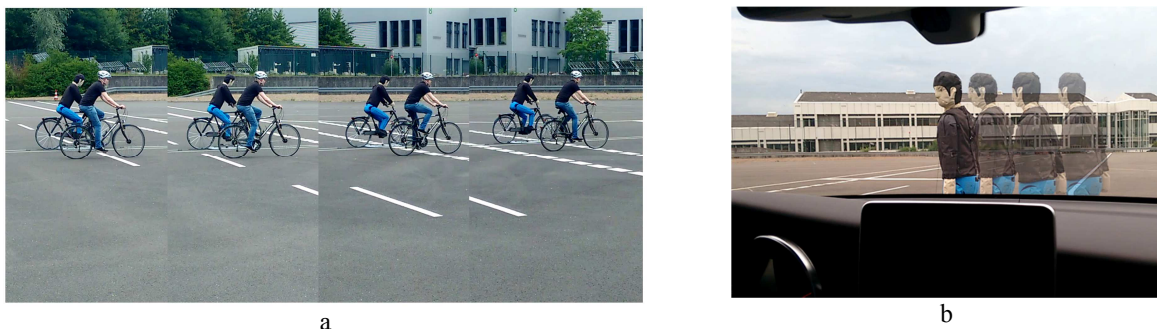


Figure 11. Examples of advanced dummy features: (a) Pedaling cyclist dummy with rotating wheels, (b) Pedestrian dummy full stop and rotate head towards approaching car

Further elements of the PROSPECT test methodology were a standard intersection marking to be implemented on the test track which allows the efficient testing of all PROSPECT test cases and a concept for tests in realistic surroundings. The proposed intersection is in compliance with the German recommendations for road construction for urban intersections (see ERA, 2010 for bicycle lanes, EFA, 2002, for pedestrian crossing definition, and in General RASt, 2016 for street design in cities). It was adopted for the purpose of PROSPECT test cases on the IDIADA and BASt test tracks.

Since the exactly same test tools were used on a test track and in realistic surroundings by BASt and IDIADA, all tests were repeatable (test results measured in the same condition are comparable) and test results from a test track were reproducible (test results from different test tracks, but same vehicle and test setup are comparable). Test results on real city streets however are not reproducible (they cannot be reproduced on another intersection, in another city etc.). The Deliverable D7.1 shows the defined test cases. Speed ranges and behaviors have been selected according to what has been found within the use case generation [15].

Proving ground test results

What was completed within PROSPECT test campaigns, were the baseline tests according to the PROSPECT test methodology that started in September 2017 with four most advanced production vehicles from the market. These tests represent the baseline for the state-of-the-art of AEB/AES systems and focus on testing dummy-vehicle interactions. The other objectives of testing production vehicles against the first PROSPECT draft test program were to generate not only baseline data but as well to refine the test procedures. In the final stage of the project, these results were compared with the prototype performance. The hypothesis that was deeply studied was that current vehicles from the market are able to address only a limited number of PROSPECT scenarios. The final tests of the three prototype vehicles developed within PROSPECT were conducted in the first half-year of 2018; in

surroundings and conditions as realistic as possible to real urban roads. The results from consumer testing are summarized in the deliverable D7.1 'Report on vehicle-based functional tests' [15] and show great improvements on the car safety when PROSPECT-like AEBs systems are fitted on cars.

Acceptance testing

Acceptance testing was an important part of the project since it provides knowledge on the user perception of the proactive systems that were developed, and an indication of their likelihood to purchase such systems. Fundamentally, it is crucial for the success of active safety systems that they are acceptable for the drivers (e.g. useful and trusted). If not, they could be permanently turned off and would then have no effect on traffic safety. Moreover, interventions of active systems being rare, they may lead to unpredictable reactions from non-aware drivers being potentially frightened or startled when activated.

In this context, a specific acceptance methodology was developed based on existing questionnaires [16], [17], [18]. It integrates acceptance of false positive (warnings and/or interventions occurring at inappropriate times) and false negatives (no warning or activation when needed) and evaluates their influence on the drivers' acceptance. By using common questionnaires, this work enabled an overall evaluation of the acceptance of the developed functions. Collecting them in such a way ensured data being acquired in the same format and thus be easily compared. The questionnaires were chosen with the objective to make acceptance evaluation not too invasive during the tests, and to disturb the test participants as little as possible.

Results show a high likelihood of acceptance of PROSPECT systems, whatever the experimental conditions or the system investigated (UoN, IFSTTAR, VTI). However, ISFTTAR experiment showed that the more participants are aware of the risks associated with VRUs the more they give high acceptability values, which substantiates Choi and Ji (2015) findings on the influence of the perceived risk on acceptability.

The participants also expressed high confidence in the systems (UoN, IFSTTAR). Indeed, trust in the systems increased after having experienced situations where PROSPECT functionalities could help to avoid accidents. An interesting point from IFSTTAR experiment was the influence of drivers' attitude towards in-car technologies in their confidence in the systems. As a result, drivers ready to drive highly automated car would rely more on PROSPECT systems.

Participants were most positive towards the warning function, but nevertheless they indicated also a high likelihood of using the braking and steering functions (UoN, IFSTTAR, VTI). It is interesting to note the influence of the driving environment. The participants declared to be more ready to use all functionalities in urban areas. Regarding highway and express road, only warnings seem to be acceptable, since braking and steering functionalities obtain quite low values of intention of use.

Willingness to buy was influenced by various factors, such as: the situation experienced (VTI: dummy versus bike), and the time at which the warning occurred (TME). Participants' willingness to buy increased after they were presented with 'critical' situations (IFSTTAR). A significant correlation was also found between the willingness to buy a car equipped with a PROSPECT system and acceptability and trust in the systems. Participants who expressed a high level of acceptability were those who declared being the more inclined to buy such systems, which is consistent with acceptability models.

These studies, that were complementary to testing activities at the proving ground, show improvement of PROSPECT technologies comparing to the current state of the art and their benefits/challenges. Results of both, simulator and acceptance studies are included in Deliverable D7.3 [19].

6. SAFETY BENEFIT ASSESSMENT

The test results were used for benefit estimation of the PROSPECT systems. An important aspect of the project was to estimate the real-world benefit of the developed systems, i.e. the improvement for traffic safety in terms of saved

lives or serious injuries and the resulting overall benefit - not only the system performance measured in terms of detection rate or speed reduction.

A new methodology has been proposed for safety benefit assessment of real-world benefit of the Advanced Driver Assistance Systems (ADAS) in terms of saved lives and prevented injuries as well as the resulting monetary benefit for society (Fig. 12) . This methodology was demonstrated and applied to PROSPECT systems that address potential crashes of passenger cars with vulnerable road users (VRUs) such as pedestrians and cyclists [20].

Pre-crash kinematics data from crashes between passenger cars and VRUs from the Pre-Crash Matrices (PCM) based on the German In-Depth Accident Study (GIDAS) have been analysed with respect to twelve use cases [21]. Counterfactual simulations using relevant models for PROSPECT sensors and algorithms have been performed on car-to-cyclist and car-to-pedestrian crashes corresponding to the use cases. The counterfactual simulation is a method that has been used to analyse crashes amenable to the technology and assess what the crash outcome would have been had the vehicle been equipped with the investigated technology [22], [23]. Four algorithms of the PROSPECT systems have been modelled and implemented in the counterfactual simulation tool.

The simulation results were updated with the results from vehicle-based testing on closed test tracks for each use case. A key aspect in the benefit methodology was the combination of results from different sources concerning the effectiveness of the PROSPECT systems in different use cases, e.g. simulation results and test results. For this purpose, Bayesian statistical methods [24], [25] were proposed as an appropriate mathematical framework.

Injury Risk Functions (IRF) for all cyclist use cases as well as for all pedestrian use cases per severity were developed based on the police coded injury severity and the collision speed. The computation of the local safety benefit of the PROSPECT systems was based on a combination of models for crash avoidance probability and collision speed in case of a crash (resulting from the Bayesian analysis combining simulation results and test results) with the developed IRFs, using a variant of the dose-response model.

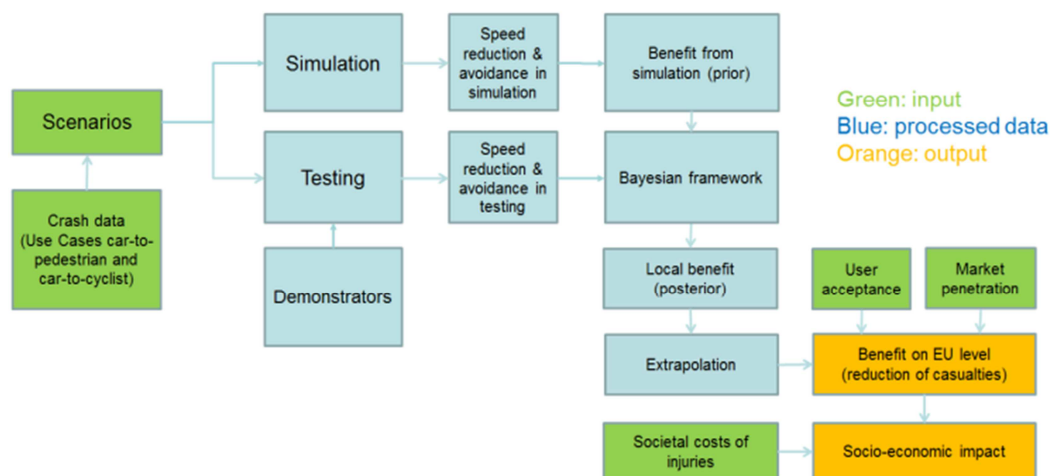


Figure 12. PROSPECT Assessment framework

The local benefit regarding fatalities, serious and slight injuries showed 55%-98% benefit of the algorithms, depending on the use case. The system gives a somewhat greater overall fatality reduction (82-86%) for all cyclist use cases combined than for pedestrian use cases combined (69-76%, depending on the algorithm). These use cases are addressing 86% of car-to-cyclist fatalities and 39% of car-to-pedestrian fatalities in GIDAS PCM data, hence the reductions within the use cases correspond to an overall estimated local reduction of 70-74% within car-to-cyclist fatalities and 27-30% within car-to-pedestrian fatalities.

The reduction for serious injuries is somewhat lower than for fatalities, especially for pedestrians. The results are in the range of 53-93% for cyclists and 23%-58% for pedestrians depending on the use case and yielding an overall reduction of 71-76% for cyclists and 36-44% for pedestrians within the use cases for the different algorithms. This corresponds to an overall reduction of 53-56% for seriously injured within car-to-cyclist and a 19-23% decrease of seriously injured within car-to-pedestrian crashes. The reduction of slight injuries is generally smaller than the reduction for serious or fatal injuries, especially for pedestrians.

This local benefit was extrapolated to EU-28 by using the community database on road accidents (CARE - European centralised database on road accidents which result in death or injury across the EU) and a decision tree method [26], [27], [28]. It was assumed that market penetration and user acceptance of the PROSPECT systems gradually increase, from 5.8% and 84.5% in 2025 to 20% and 87% in 2030. Due to the assumed increasing market penetration and user acceptance, the annual number of lives saved in EU-28 increases from an estimate of 79-95 in 2025 to 280-336 in 2030, while the corresponding estimates for the reduction of seriously injured are 439-697 in 2025 and 1558-2474 in 2030. Accordingly, the socio-economic benefit of PROSPECT systems increases from 203-296 million euros in 2025 to monetary values exceeding 878-1280 million euros from 2030 on. The results have potential implications for policies and regulations in understanding the real-world benefit of new ADAS.

7. CONCLUSIONS

The proliferation and performance of ADAS systems has increased in recent years. PROSPECT's primary goal was the development of novel active safety features to prevent accidents with VRUs such as pedestrians and cyclists in intersections. The know-how obtained in the accident analysis and the derivation of the PROSPECT use cases enable the development of improved VRU sensing, modelling and path prediction capabilities. These facilitate novel anticipatory driver warning and vehicle control strategies, which will significantly increase system effectiveness without increasing the false alarm/activation rate.

Multiple PROSPECT demonstrators (three vehicles, one mobile simulator, dummy specimen) integrated the different technologies including sensor setup position and orientation, sensor fusion, environment information evaluation and processing, actuators and HMI required covering the selected relevant use cases. Disruptive AEB/AES systems were finally demonstrated to the public in prototype vehicles with the use of realistic dummy specimen during the final PROSPECT event in 2018 at IDIADA testing tracks, Spain.

Full motion driving simulators were used for the collection of data regarding the interaction between the driver and the safety function. The driving simulator studies aimed specifically to evaluate HMI/warning in combination with automatic intervention by braking and/or steering with the driver in the loop. Finally, simulator studies helped to evaluate acceptance of PROSPECT-like systems - if the systems are unacceptable for the drivers (e.g. annoying), they could be permanently turned off and would then have no effect on traffic safety. Moreover, interventions of active systems being rare, they may lead to unpredictable reactions from non-aware drivers i.e. being potentially frightened.

What is known is that the European New Car Assessment Program (Euro NCAP) will include the testing of Cyclist-AEB systems from 2018 onwards in their safety assessment [29]. With respect to PROSPECT, more complex car-to-cyclist scenarios were implemented in demonstrators and assessed through testing activities. The test methodologies generated in this project were proposed to Euro NCAP for standardization on a regular basis.

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