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Improving safety of Vulnerable Road Users by addressing barriers of current Autonomous Emergency Braking (AEB) systems. The project PROSPECT (PROactive Safety for PEdestrians and CyclisTs)

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Abstract

Accidents involving Vulnerable Road Users (VRU) are a very important issue for road safety. The objective of the PROSPECT project is to improve significantly the effectiveness of active VRU safety systems by: (i) expanding the scope of urban scenarios addressed (ii) improving the system performance (iii) proposing extensive validation tools and methodologies for consumer testing, simulation and acceptance studies. Concepts for sensors and control systems were shown in three vehicle demonstrators and a mobile driving simulator and tested with novel VRU dummy specimen. User acceptance tests with the participation of drivers were crucial in PROSPECT for the success of all active safety systems. Driving simulator studies were used in a controlled environment for the collection of data regarding the interaction between the driver and the safety function. A benefit estimation methodology was developed and 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).

Introduction and motivation

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, VRUs 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 **¡Error! No se encuentra el origen de la referencia.).** 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."*

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 ANCAP 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.

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 VRUs.

Just like other functions implemented in automated driving, vehicle-based sensors (i.e. video, radar) survey the vehicle surroundings, advanced algorithms will enable safety related decision making and the system will act actively when necessary. Being an active safety solution focused on VRU, the system developed in PROSPECT will take action when a critical situation with a VRU occurs. The PROSPECT project technical approach is presented herein below (see Figure 1).

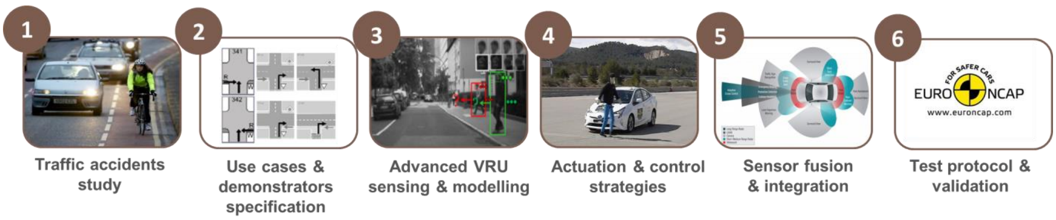

Figure 1 - The PROSPECT project technical approach

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 [5].

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	371	
(II) Car straight on, cyclist from far-side	372	
(III) Car turns	224	
(IV) Car and cyclist in longitudinal traffic	601	
(V) Others		

Figure 2 - Most relevant car-to-cyclist scenarios

PROSPECT_UC_PD_x (x=1...8)	Pictogram	in %	Description
PROSPECT_UC_PD_1 PROSPECT_UC_PD_2	PD-1 PD-2	23% 22%	Crossing a straight road from near-side / off-side; No obstruction
PROSPECT_UC_PD_3a PROSPECT_UC_PD_3b	PD-3-1 PD-3-2	5,5% 5,5%	Crossing at a junction from the near-side / off-side; vehicle turning across traffic
PROSPECT_UC_PD_4a	PD-4-1 PD-4-2	4%	Crossing at a junction from the near-side / off-side; vehicle not turning across traffic
PROSPECT_UC_PD_5 PROSPECT_UC_PD_6	PD-5 PD-6	10% 7%	Crossing a straight road from near-side / off-side;With obstruction
PROSPECT_UC_PD_7a PROSPECT_UC_PD_7b	PD-7-SD PD-7-OC	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 3 - Pedestrian accident scenarios

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 2.1 [6]. The most relevant accident scenarios have been clustered in "Use Cases" or "target scenarios" addressed by the project.

System specification and demonstrators - challenges and general methodology for addressing barriers of current ADAS systems

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 can 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 deliverable 3.2 [7]. This section provides an overview of the applied methodology pursued in this project in relation to PROSPECT car demonstrators.

- 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 behavior

Mobile driving simulator

Within the project, a mobile driving demonstrator was used to present and evaluate the results of PROSPECT in a realistic setting applying a real car as a mock-up. Based on the results of the accident analysis it was possible to integrate common accident scenarios between car drivers and cyclists into the Audi driving simulator in order to demonstrate the circumstances of car-to-cyclist-accidents. Moreover, the results of the accident analysis contributed fundamentally to the establishment of hypotheses which outlined why car drivers fail to manage these common crash situations with cyclists. As a next step, studies were carried out with Audi driving simulator in order to evaluate these hypotheses. One of the planned studies dealt with the role of sensory conspicuity of cyclists within the detection of cyclists in specific scenarios by car drivers. The results of these studies account for a better understanding of possible reasons why car drivers often fail to handle such situations properly.

Figure 4 shows the Audi driving simulator, which was equipped with two additional monitors (for a better side view in order to improve the demonstration of crossing cyclists) with Audi Simulation Tool (side view and drivers view).

Figure 4 - Audi Mobile driving simulator presentation Two additional monitors mounted (above) Driver and VRU perspective (below)

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 4. 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. In final PROSPECT protocol, evaluation of the improvements and benefits of additional steering for Euro NCAP AEB systems is elaborated.

Testing tools

PROSPECT focuses on functions that avoid collisions with VRUs, 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 driven on a predefined trajectory 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 Figure 5). 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 allow reproducing complex test scenarios with different arbitrary movements.

Figure 5 - Examples of advanced dummy features: Pedaling cyclist dummy with rotating wheels (left) Pedestrian dummy full stop and rotate head towards approaching car (right)

A reproducible movement of the VUT was achieved by using driving robots that can follow a path with a lateral tolerance as low as 5 centimeters. The use of driving robots is standard in active safety tests. On the other hand, the opponent (bicycle or pedestrian) is controlled completely with a time-synchronized propulsion system.

In various accidents that had been analyzed for the use case definition, the VRU (bicycle or pedestrian) was hidden to the VUT's field of view for a significant amount of time. To reflect this, some test cases were defined with an obstruction that initially hid the pedestrian or the bicycle to the VUT, and it was necessary to have an appropriate obstruction tool for these test cases.

The principle concept for the obscuration objects and a versatile intersection layout allows the conduction of all defined intersection test cases. For this type of tests, laboratories used market ready solution. The obstruction wall represents a permanent full view blocking obstruction from the ground up between vehicle and bicyclist, running parallel with the bicyclist path.

Figure 6 - Structure of the mobile obstruction panel for the VRU in PROSPECT

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 follows 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 both test tracks 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 [8] shows the defined test cases. Speed ranges and behaviors have been selected according to what has been found within the use case generation. As each of the demo-vehicles has its own unique features, different use cases were assigned (see Figure).

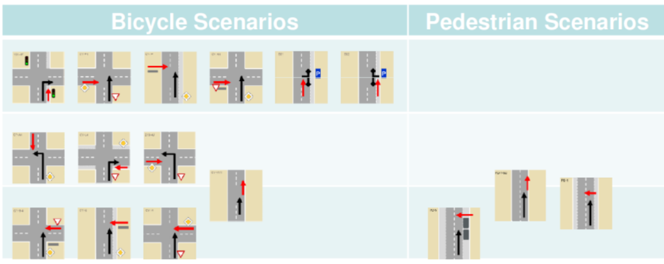

Figure 8 - Test Cases assigned to demo-vehicles within PROSPECT

Types of testing activities

PROSPECT considered of special relevance the following testing activities:

- Vehicle-based functional tests: the actual conduction of the tests on appropriate test tracks and locations and the deployment of appropriate test tools (in particular bicycle dummy and propulsion system).
- Simulator testing: testing the designed safety measures in real traffic with normal drivers induces risks that cannot be afforded at such early stages of the system development. The driving simulator studies aim 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.

- User acceptance: it is also crucial for the success of all active safety 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.

PROSPECT partners investigated different types of PROSPECT actuations (warning, braking and steering), different criticality of the situations (critical scenarios / possible critical) and different types of activations (true positive and false positive), among others. 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 [9].

Moreover, the test results were used for benefit estimation of the PROSPECT systems. 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.

Proving ground test results

Vehicle-based functional tests started in September 2017 and finished in June 2018. Tests were conducted on BASt and IDIADA proving grounds. The test campaign included in its first stage the assessment of four reference production vehicles over selected PROSPECT test cases. 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 second stage, the three prototypes AEB/AES functions developed within PROSPECT project were evaluated in proving grounds. A selection of test scenarios derived from PROSPECT use cases was assigned to each of the prototype cars considering the capabilities of their sensor setup and singularities of developed functions.

In the final stage of the project, both results were collected and compared. The results from consumer testing are summarized in the deliverable D7.1 [8] and show great improvements on the car safety when PROSPECT-like AEB and AES systems are fitted on cars. The consensus after the test campaign is that market vehicles were only addressing at that time only a small portion of use cases found in PROSPECT. Among many facts, developed prototype functions had a remarkable superior performance in all the turning vehicle scenarios, a more rapid actuation in crossing pedestrian scenarios being able of braking or steering according to scene typology.

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 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 [8] and show great improvements on the car safety when PROSPECT-like AEB and AES systems are fitted on cars.

Test results and standardization activities

In July 2017 a pre-testing event was organized at BASt testing tracks in Germany. The idea was to give all demo-car developers the opportunity to get an impression of the new dummy design. Furthermore, they could verify whether the methods for "hiding" the dummy from vehicle sensors at the beginning of the various test scenarios performed as expected.

In final protocol, evaluation of the improvements and benefits of additional steering for Euro NCAP AEB systems is elaborated. In parallel to testing activities, the standardization activities were taking place. Of the biggest interest of PROSPECT partners are the two standardization bodies with corresponding working groups:

- AEB /AES Working Group of Euro NCAP Programme
- Dummy Development and Vehicle-Based Functional Tests ISO Working Groups

Some partners from PROSPECT consortium are active members of those working groups and they transfer project results on a regular basis in the form of reports and in person meetings. The standardization activities are foreseen even beyond of the project duration. Successful implementation of PROSPECT results by standardization bodies will definitely boost competitiveness among car manufacturers and improve safety, reliability and performance of cars fitted with new generation AEB/AES systems by 2025. Moreover, different consumer ratings will provide the best consumer advice to those users that want to buy safe vehicle.

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.

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. Besides, 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 [11]. 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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