Advancing active safety and testing methodologies towards the protection of Vulnerable Road Users: The project PROSPECT

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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 is to significantly improve the effectiveness of active VRU safety systems compared to those currently on the market by: (i) expanding the scope of scenarios addressed (ii) improving the overall Autonomous Emergency Braking (AEB) system performance (iii) proposing extensive validation methodologies. Concepts for sensors and control systems will be 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. Since PROSPECT functions are developed to prevent accidents in intersections, a key aspect of the test methodology is the reproduction of natural driving styles on the test track with driving robots. User acceptance tests are also crucial in PROSPEC for the success of all active safety systems. The findings contribute not only to the augmentation of state-of-the-art knowledge but as well to technical innovations like assessment methodologies and tools for testing.

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

1. Introduction and motivation

Accidents involving Vulnerable Road Users (VRU) remain a significant issue for road safety, accounting for more than 25% of road fatalities in the European Union **[1]**. These percentages show the magnitude of the problem and the need to take action in order to reduce these figures (see Fig. 1).

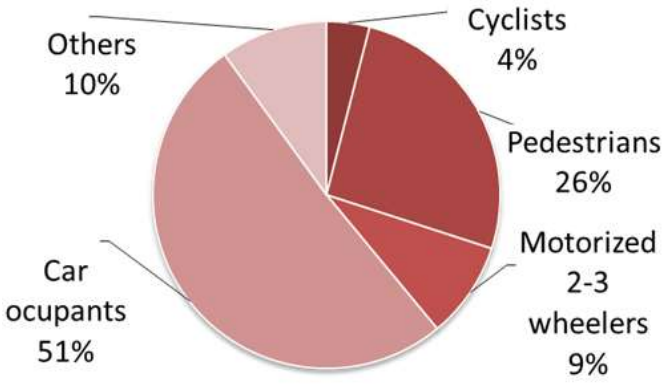


Fig. 1. *Road traffic deaths by type of road user in Europe (Source: WHO, 2015)*

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."

Advanced Driver Assistance Systems (ADAS) are the basis for the development of automated cars. Putting the focus on active safety features, the introduction of Autonomous Emergency Braking (AEB) functions will be a must for vehicles sold in the United States and in the European Union by 2020, since AEB Systems have the potential to increase safety for drivers as well as for VRU.

´**PRO**active **S**afety for **PE**destrians and **C**yclis**T**s´ 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 cyclist 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 represents a key input for the system specifications, integration and demonstration to the public in three project prototype vehicles. These demo-vehicles are extensively tested in realistic scenarios. PROSPECT broad testing methodology goes 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). The concept for realistic testing includes an intersection marking which allows the efficient testing of all test cases, mobile and light obstruction elements and realistic surroundings like traffic signs or lights.

The PROSPECT project technical approach is presented herein below (see Fig. ***2***).

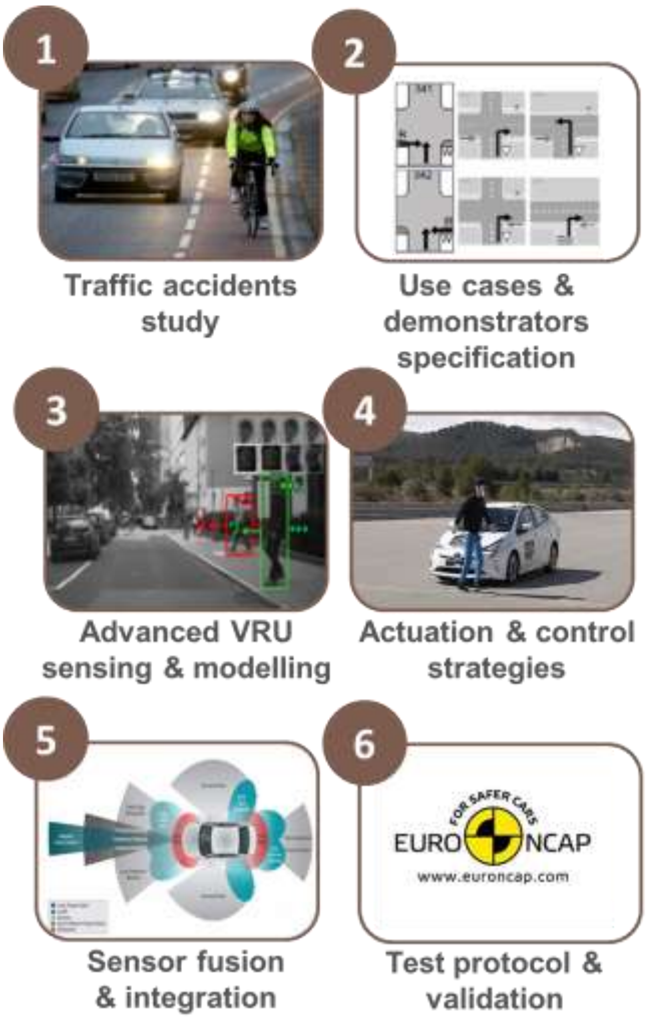


Fig. 2. *The PROSPECT project technical approach*

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 will act actively when necessary. Being an active safety solutions focused on VRU, the system developed in PROSPECT will take action when a critical situation with a VRU occurs. Moreover, each of the demonstrators will have its unique focus:

- I demonstrator is equipped with stereo vision camera and high resolution radars, featuring high dynamic brake system combined with power assisted steering actuator.
- II demonstrator will feature 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 will include advanced warning/HMI and control strategies to evaluate interaction between the driver and the vehicle inside PROSPECT.
- Advanced realistic pedestrian and cyclist dummies including platform propulsion system will improve realistic testing by extending dummies trajectories, organic materials, kinematics and physical behavior.

AEB Systems have the high-potential to improve VRU safety. The findings within the PROSPECT contribute not only to the generation of state-of-the-art knowledge of VRU-vehicle behavior 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 2020-2024 Euro NCAP road-maps **[3]**.

2. Accident analysis: “Accident scenarios” and “Use 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).

The focus of the project is 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.

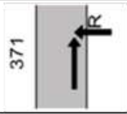
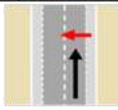
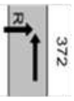
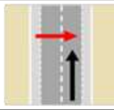
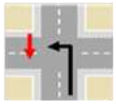
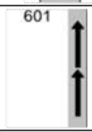
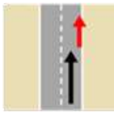
Accident type	UTYP Pictogram	PROSPECT pictogram (basic version)
(I) Car straight on, cyclist from near-side		
(II) Car straight on, cyclist from far-side		
(III) Car turns		
(IV) Car and cyclist in longitudinal traffic		
(V) Others		

Fig. 3. *Most relevant car-to-cyclist scenarios*

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 **[4].**

In the analysis of car-to-pedestrian accidents, the Accident Scenarios introduced in the European project AsPeCSS **[5], [6]** 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*.

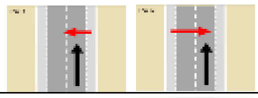
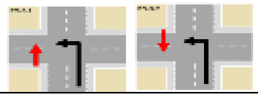
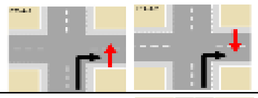
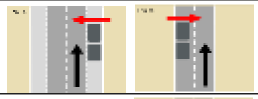
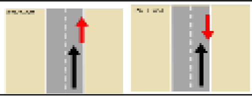
PROSPECT_UC_PD_x (x=1…8)	Pictogram	in %	Description
PROSPECT_UC_PD_1 PROSPECT_UC_PD_2		23% 22%	Crossing a straight road from near-side / off-side; No obstruction
PROSPECT_UC_PD_3a PROSPECT_UC_PD_3b		5,5% 5,5%	Crossing at a junction from the near-side / off-side; vehicle turning across traffic
PROSPECT_UC_PD_4a		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

Fig. 4. *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 "Accident Analysis, Naturalistic Driving Studies and Project Implications" **[7]**. The most relevant accident scenarios have been clustered in "Use Cases" or "target scenarios" addressed by the project.

3. Naturalistic Observations

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. *5*, two types of naturalistic observations were carried out in three 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.

a

b

Fig. 5. *Two types of naturalistic observations were carried out:*
(a) View from infrastructure-mounted cameras, (b) Video data from in-vehicle camera

A set of parameters have been coded for the traffic conflicts identified in the acquisition. They describe (1) the general environmental conditions of the conflict (light, precipitation, road surface, traffic density, etc.), (2) the infrastructure (layout, dedicated lanes, speed limit, etc.), (3) the characteristics of the VRU (type, equipment, etc.), (4) the encounter characteristics (visibility, right of way, yielding, conflict management, estimated impact point, etc.), (5) the intents of the VRU (head/torso orientation, gesture), (6) kinematics and trajectories of both car and VRU.

Analyses performed on each use case provide descriptions of a battery of VRUs' behaviour when involved in a specific conflict that helped to identify the clues that can predict VRUs' behaviour in the near future.

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 focusses on active safety solutions, where the vehicle survey 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 will take action in case of a critical situation with a VRU, increasing the effectiveness of current active safety systems.

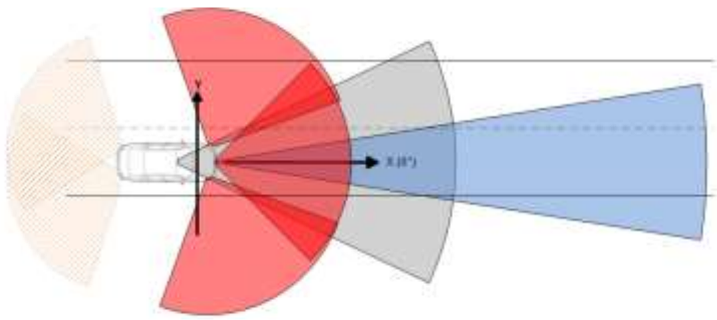
Improved VRU sensing and situational analysis functions (enlarged sensor coverage; earlier and more robust VRU detection and classification; sophisticated path prediction and reliable intent recognition) will be shown in three vehicle demonstrators at the final project event at IDIADA proving ground (Spain) in October 2018. All vehicles will be able to automatically steer and / or brake to avoid accidents. Special emphasis will be 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 appropriate PROSPECT deliverables **[8].**

This section provides an overview of the applied methodology pursued in this project in relation to PROSPECT car demonstrators.

4.1. 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. **6** shows the addressed use cases and utilized sensors of the demonstrator.

a



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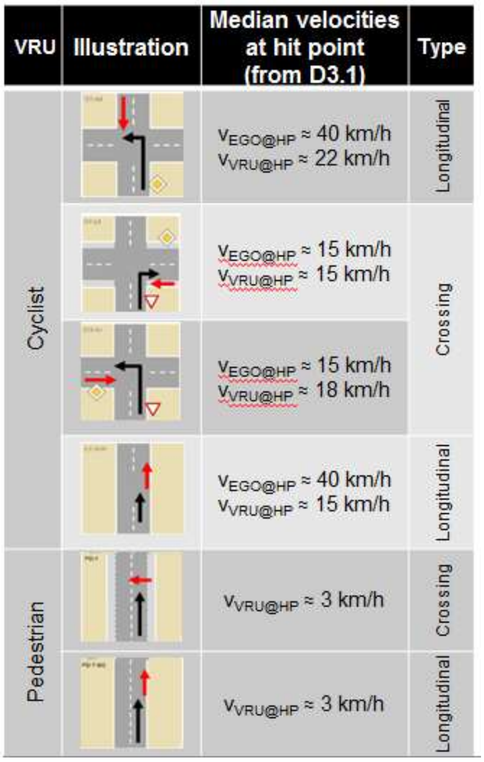


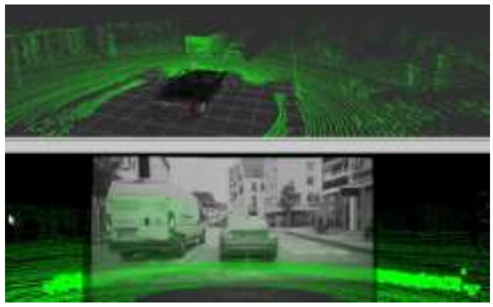
VRU	Illustration	Median velocities at hit point (from D3.1)	Type
Cyclist		$v_{EGO@HP} \approx 40$ km/h $v_{VRU@HP} \approx 22$ km/h	Longitudinal
Cyclist		$v_{EGO@HP} \approx 15$ km/h $v_{VRU@HP} \approx 15$ km/h	Crossing
Cyclist		$v_{EGO@HP} \approx 15$ km/h $v_{VRU@HP} \approx 18$ km/h	Crossing
Cyclist		$v_{EGO@HP} \approx 40$ km/h $v_{VRU@HP} \approx 15$ km/h	Longitudinal
Pedestrian		$v_{VRU@HP} \approx 3$ km/h	Crossing
Pedestrian		$v_{VRU@HP} \approx 3$ km/h	Longitudinal

c

Fig. 6. *Demonstrator car I - vehicle with functional setup and addressed use cases:*
(a) Sensors integration site RADARS, (b) Overview Radar sensor setup (3x Long Range Radar for VRU detection & classification over >180°), (c) Use Case selection (cyclists and pedestrians at day and night).

4.2. 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. *7* 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.



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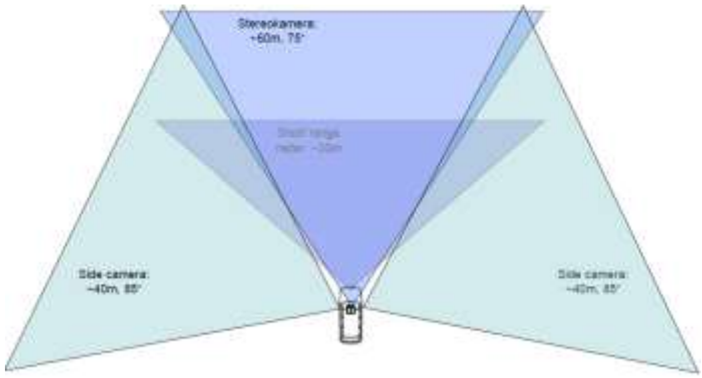

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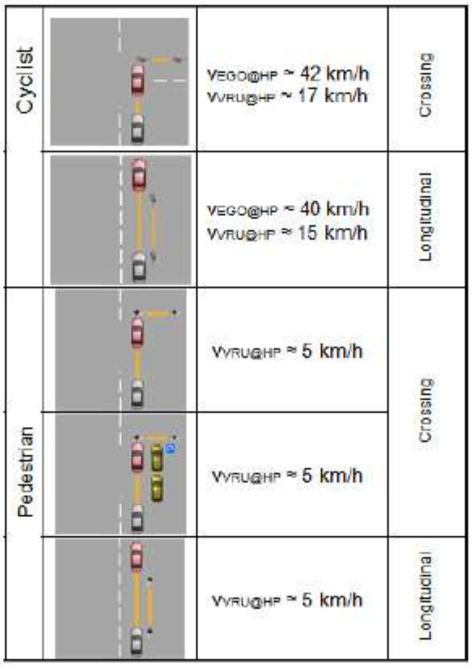


Cyclist		$v_{EGO@HP} \sim 42$ km/h $v_{VRU@HP} \sim 17$ km/h	Crossing
Cyclist		$v_{EGO@HP} \sim 40$ km/h $v_{VRU@HP} \approx 15$ km/h	Longitudinal
Pedestrian		$v_{VRU@HP} \approx 5$ km/h	Crossing
Pedestrian		$v_{VRU@HP} \approx 5$ km/h	Crossing
Pedestrian		$v_{VRU@HP} \sim 5$ km/h	Longitudinal

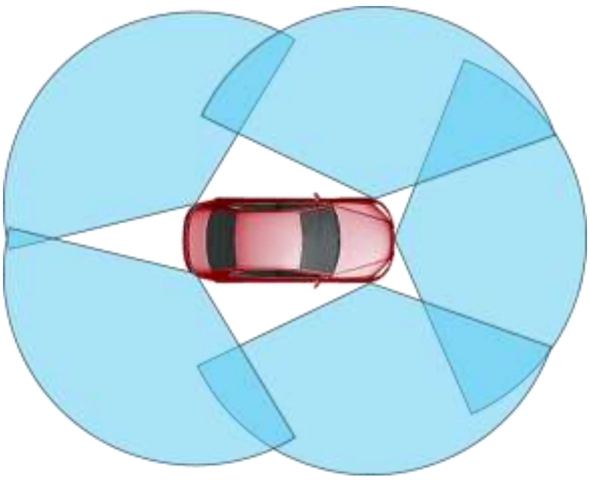
c

Fig. 7. *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 (~60m, 75°) and two side-oriented cameras covering a horizontal FOV of roughly 210°, (c) The addressed use cases (cyclists and pedestrians, crossing and longitudinal where car can have high speed and early detection needed).

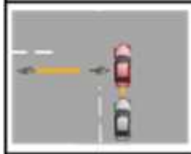
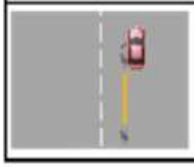
4.3. Demonstrator car III

Demonstrator car III will focus 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 Fig. **8** for more details.

a



b

Illustration	Median velocities at hit point (HP)	Required FOV zone	Type
	$v_{EGO@HP} \approx$ 23 km/h $v_{VRU@HP} \approx$ 15 km/h		car turning
	$v_{EGO@HP} \approx$ 42 km/h $v_{VRU@HP} \approx$ 17 km/h		car crossing
	$v_{EGO@HP} \approx$ 0 km/h $v_{VRU@HP} \approx$ 15 km/h		car standing
	$v_{EGO@HP} \approx$ 0 km/h $v_{VRU@HP} \approx$ 20 km/h		

c

Fig. 8. *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 (car turning right with cyclist approaching from behind, car crossing with cyclist coming from the left side, car standing and cyclist risks to hit the opening door - either left or right).

4.4. Mobile driving simulator

Within the project, a mobile driving demonstrator is 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 **[7]** 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 will be carried out with Audi driving simulator in order to evaluate these hypotheses. One of the planned studies deals with the role of sensory conspicuity of cyclists within the detection of cyclists in specific scenarios by car drivers. The results of these studies will account for a better understanding of possible reasons why car drivers often fail to handle such situations properly. Fig. *9* 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).

Fig. 9. *Audi Mobile driving simulator presentation during PROSPECT technical meeting at BASt, Cologne, 2016.*

5. Next generation testing

A sound benefit assessment of the prototype vehicle's functionality requires 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 preliminary test protocol **[9]**. A key aspect of the test methodology is the provision of exact copies of natural driving styles on the test track with driving robots. For this task, data from real driving studies with subjects in a suburb of Munich, Germany and from Barcelona was used.

5.1. Test methodologies and assessment protocols

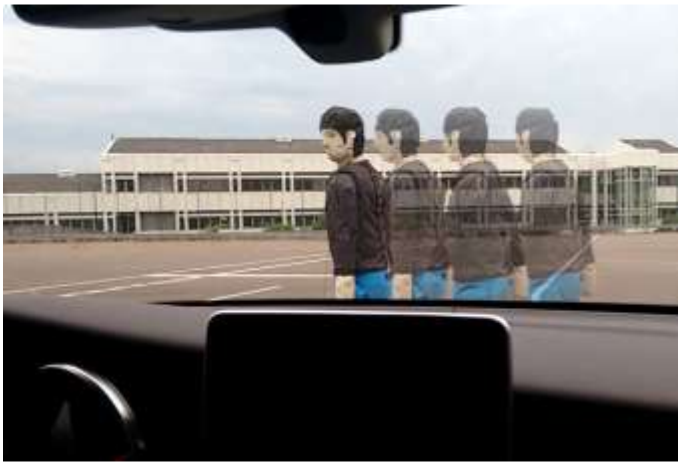
Apart from technology demonstrators that will help to maintain and extend the leadership of European car manufacturers in intelligent vehicles and for autonomous driving, PROSPECT will take a step forward in defining test and assessment methods for Euro NCAP AEB VRU systems. Euro NCAP will directly benefit from the project’s findings and results, especially by being supplied with deliverables including test protocol as a proposal for consumer testing (final deliverable under preparation), the below mentioned dummy 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 2016 to 2020, however more important with respect to PROSPECT will be the roadmap 2020 to 2024 (expected to be published in the fourth quarter of 2017) which announces several requirements for e.g. steering intervention and cross-junction AEB systems that need specifically conditioned VRUs. PROSPECT results will be an early input for the definition of all these requirements.

5.2. Testing tools

PROSPECT focuses on functions that avoid collisions with other traffic participants, so at least one other traffic participant will be part of the test as well. Active safety functions might or might not be able to avoid a collision, so the “other” traffic participant will need to be an impactable dummy, a surrogate either for a bicycle or a pedestrian. Both objects (Vehicle-Under-Test (VUT) impact partner) will initially be 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 are already completed by partner 4activeSystems to obtain higher degrees of freedom (head rotation, torso angle, pedaling, side leaning, etc.) and an improved behavior during the acceleration- and stopping-phase (see Fig. ***10***). The demonstrator vehicles will make use of novel realistic VRU dummy specimen features for a better object classification and prediction of intended VRU movements. The dummies are mounted on fully self-driving platforms to take into account even complex test scenarios with different arbitrary movements.



a

b

Fig. 10. *Examples of advanced dummy features:*
(a) Pedestrian dummy full stop and rotate head towards approaching car, (b) Pedaling cyclist dummy with rotating wheels.

A reproducible movement of the VUT is achieved by using driving robots that are able to follow a path with a lateral tolerance as low as 5 centimeter, see Fig. ***11*** for examples. The use of driving robots is standard in active safety tests. The opponent (bicycle or pedestrian) on the other hand is controlled completely with a time-synchronized propulsion system.

a

b

Fig. 11. *Examples of instrumented car with equipment: (a) Control equipment (b) Measurement equipment.*

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

The principle concept for the obscuration objects and a versatile intersection layout that allows the conduction of all defined intersection test cases are shown in next figures (see Fig. ***12*** and Fig. ***13***).

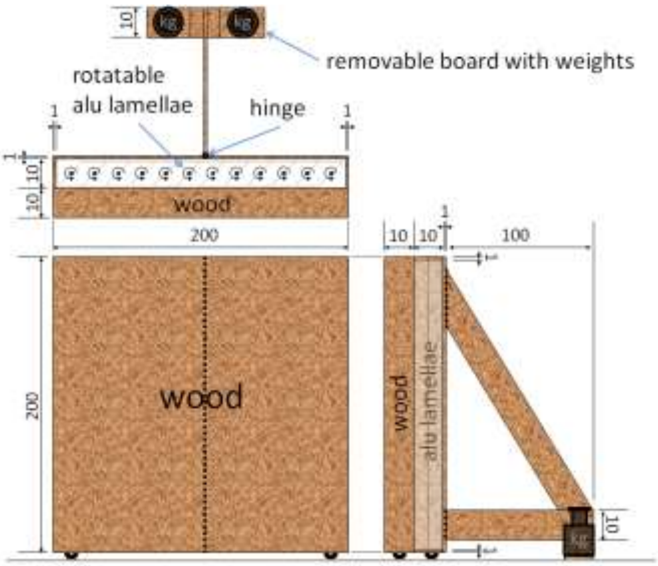


Fig. 12. *Basic structure of the mobile obstruction panel for the VRU in PROSPECT.*

Further elements of the PROSPECT test methodology are 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 concept is shown in Figure 4.

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).

Since there is a bicycle lane only on one side of the priority street, the intersection allows the conduction of test runs with or without additional bicycle lane. An additional spot for crossing bicyclists (without zebra crossing) is added to one of the two non-priority legs. Four referenced positions allow a reproducible placement of either traffic signs or traffic lights. The stopping lines shown on all for legs should be quickly removable; they are only needed if the intersection is configured to have traffic lights.

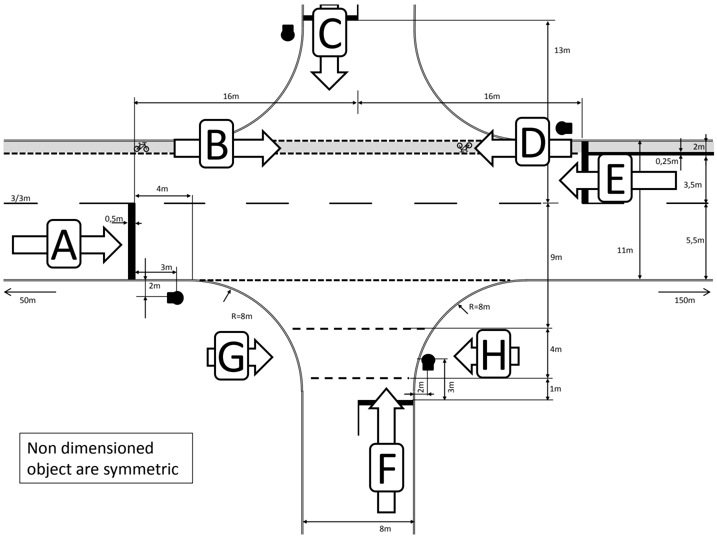


Fig. 13. *PROSPECT intersection with tracks*

Since the exact same test tools will be used on a test track and in realistic surroundings by BASt and IDIADA, all tests will be repeatable (test results measured in the same condition will be comparable) and test results from a test track will be 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.).

5.3. Types of testing activities

PROSPECT considers 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). Preparation of the test tracks will be necessary and is currently in process.

- 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. Nevertheless, driver reaction and response is of vital importance since these measures will ultimately be applied in normal vehicles. Full motion driving simulators will be used for the collection of data regarding the interaction between the driver and the safety function. 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.
- 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. A methodology for user acceptance was developed within the project, focusing on the balance between performance and unjustified activations of the system.

Moreover, the test results will be used for benefit estimation of the PROSPECT systems. An important aspect of the project will be 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.

At this stage the project consortium implements 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 depend strongly on testing activities that will take place in 2018 and will be extrapolated to the EU-28 level. Finally, the expected fleet penetration rates for 2020-2025 will be analysed.

The Table 1 herein below shows an excerpt of the defined test cases with an ID string (nomenclature: CBIP, Car-Bicycle-Intersection-Priority for the Car, CBIG, Car-Bicycle-Intersection-Green Light, CBIN Car-Bicycle-Intersection-Non-Priority). The road type, from which the VUT or the VRU is arriving, is indicated by the variable VUT Track or VRU Track, respectively (large road: priority, small road: nonpriority). The remaining variables specify the behavior class (i.e. turning left), and the speeds for the VTU and VRU (given in km/h). Speed ranges and behaviors have been selected according to what has been found within the use case generation **[10].**

Table 1 *Examples of Test Cases defined within PROSPECT - Intersection Bicycle Test Cases (extract)*

ID	VUT track & speed (km/h)	VUR track & speed (km/h)	Sign /other
CBIP01	Large road, Turning left (30-60)	Large road (opposite VRU), 20	Priority signs on large road
CBIP02	Large road, Constant (30-50)	Small road (from right), 10	Priority on large road, yield on small road, obscured
CBIP03	Large road, Constant (40-60)	Small road (from left), 15	Priority on large road, yield on small road, obscured
CBIG	Large road, Turning right (10-30)	Large road (same VRU), being overtaken, 15	Green traffic lights on large road
CBIN 01	Small road, Slight deceleration (15-30)	Large road (from left), 20	Priority on large road, yield on small road
CBIN 02	Small road, Slight deceleration (20-40)	Large road (from right), 15	No signs or priority from right
CBIN 03	Small road, Slight deceleration (10-30)	Large road (from right), 20	Priority on large road, yield on small road
CBIN 04	Small road, Tight turn right (10-25)	Large road (from left) on bicycle lane, 20	Priority on large road, yield on small road / Bicycle lanes on large road
CBIN 05	Small road, Tight turn right (10-25)	Large road (from right) on bicycle lane, 15	Priority on large road, yield on small road / Bicycle lanes on large road
CBIN 06	Small road, Tight turn left (10-25)	Large road (from left), 20	Priority on large road, yield on small road
CBIN 07	Small road, Tight turn right (10-30)	Large road (from left), 20	Priority on large road, yield on small road

5.4. Test results

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 perform as expected.

What now follows is the next round of baseline tests according to the PROSPECT test methodology that started in September 2017 with four most advanced production vehicles from Audi, BMW, TME and VCC. These tests represent the baseline for the state-of-the-art of AEB systems and will focus on testing dummy-vehicle interactions. The other objectives of testing production vehicles against the first PROSPECT draft test program are to generate not only baseline data but as well to refine the test procedures **[9]**. In the final stage of the project, these results will be compared with the prototype performance. The hypothesis that will be deeply studied is 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 will be conducted in the first half of 2018; in surroundings and conditions as realistic as possible to real urban roads. The preliminary results from consumer testing will be summarized in this publication.

6. Conclusion remarks and next steps

The proliferation and performance of ADAS systems has increased in recent years. PROSPECT's primary goal is 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 corresponding vehicle / simulator, one mobile simulator, dummy specimen) will integrate 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. Information about the demonstrators to be developed in the project is available on Deliverable D3.2. **[8]**. Disruptive AEB systems will be finally demonstrated to the public in three prototype vehicles with the use of realistic dummy specimen during the final PROSPECT event in October 2018 at IDIADA testing tracks, Spain.

A driving simulator fulfilling the required characteristics has already been implemented in order to be able to execute a first subset of the PROSPECT use cases.

In the context of testing tools development, advanced articulated dummies – Pedestrian and Cyclist – are already developed to obtain higher degrees of freedom (head rotation, torso angle, pedaling, side leaning, etc.) and an improved behaviour during the acceleration- and stopping-phase.

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]**. The CATS project (Cyclist-AEB Testing System) has worked on the introduction of Cyclist-AEB systems and the corresponding consumer tests in order to obtain a test setup and test protocol and results have been shared with Euro NCAP for their 2018 protocols **[12], [13]**. With respect to CATS, more complex car-to-cyclist scenarios will be implemented in demonstrators and assessed through testing activities within the PROSPECT project. The test methodologies generated in this project will be proposed to Euro NCAP for standardization. The test methodologies and tools shall be considered for 2020-2024 Euro NCAP test programmes, supporting the European Commission goal of halving the road toll.

The impact of the developed system is expected to increase in about 36% the effectiveness respect to the state-of-the-art VRU AEB systems, representing a significant reduction in terms of VRU accidents. An important aspect of the project will be to estimate the real-world benefit of the developed systems, i.e. the improvement for traffic safety in terms of saved lives or reduction of serious injuries taking into account the overall benefit - not only the system performance measured in detection rate or speed reduction.

The findings within the project that are presented in this paper will contribute especially to the state-of-the-art about accident analysis, advanced sensing, decision-making and control technologies, assessment methodologies and tools for advancing Advanced Driver Assistance Systems towards the safety of VRUs.

Moreover, the project results will also enable the improvement of today’s ADAS features and will be useful to solve some of the challenges for the development and deployment of increasingly automated vehicles towards fully autonomous vehicles.

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