

# ADVANCING ACTIVE SAFETY TOWARDS THE PROTECTION OF VULNERABLE ROAD USERS: THE PROSPECT PROJECT

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## ABSTRACT

Accidents involving Vulnerable Road Users (VRU) are still a very significant issue for road safety. According to the World Health Organisation, pedestrian and cyclist deaths account for more than 25% of all road traffic deaths worldwide [1]. Autonomous Emergency Braking Systems have the potential to improve safety for these VRU groups.

The PROSPECT project (Proactive Safety for Pedestrians and Cyclists) aims to significantly improve the effectiveness of active VRU safety systems compared to those currently on the market by expanding the scope of scenarios addressed by the systems and improving the overall system performance.

The project pursues an integrated approach:

Newest available accident data combined with naturalistic observations and HMI guidelines represent key inputs for the system specifications, which form the basis for the system development.

For system development, two main aspects are considered: advanced sensor processing with situation analysis, and intervention strategies including braking and steering. All these concepts are implemented in several vehicle prototypes. Special emphasis is put on balancing system performance in critical scenarios and avoiding undesired system activations.

For system validation, testing in realistic scenarios will be done. Results will allow the performance assessment of the developed concepts and a cost-benefit analysis.

The findings within the PROSPECT project will contribute to the generation of state-of-the-art knowledge, technical innovations, assessment methodologies and tools for advancing Advanced Driver Assistance Systems towards the protection of VRUs.

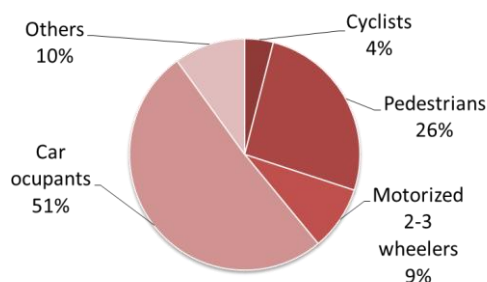
The introduction of a new generation safety system in the market will enhance VRU road safety in 2020-2025, contributing to the 'Vision Zero' objective of no fatalities or serious injuries in road traffic set out in the Transport White Paper [2]. Furthermore, the test methodologies and tools developed within the project shall be considered for the New Car Assessment Programme (Euro NCAP) [3] future roadmaps, supporting the European Commission goal of halving the road toll in the 2011-2020 timeframe.

## KEYWORDS:

Active safety, Advanced Driver Assistance Systems (ADAS), Vulnerable Road Users (VRU)

## INTRODUCTION

In 2015, more than one quarter of the Europe's road traffic deaths were suffered by pedestrians (26%) and cyclists (4%), according to the World Health Organization (WHO) [1]. These percentages show the magnitude of the problem and the need to take action in order to reduce these figures (see Figure 1).



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

Current Autonomous Emergency Braking (AEB) systems in the market have the capability to avoid or mitigate certain accidents with VRU. Nevertheless there is still high potential for improvement in this field.

PROSPECT (Proactive Safety for Pedestrians and Cyclists) is a collaborative research project funded by the European Commission under Grant Agreement n° 634149.

The overall objective of the project is to provide a better understanding of VRU-related accidents and to develop, demonstrate and test an innovative, (pro) active safety system for protecting VRUs. The new system is aimed at being more effective than those currently on the market; this will be achieved by addressing more accident scenarios and improving the overall system performance.

PROSPECT focusses on active safety solutions, where vehicle-based sensors survey the vehicle surroundings. Advanced algorithms enable safety related decision-making and the system developed will take action in case of a critical situation with a VRU.

PROSPECT started in May 2015 and ends in October 2018. The present paper aims to provide an overview of the methodology followed within the project as well as the main findings.

## METHODOLOGY

The project follows an integrated methodology: in-depth accident analysis and naturalistic observations in multiple European countries were performed to gain improved understanding of VRU-related accidents. This knowledge is the key to tailor effective sensor processing, Human Machine Interface (HMI), driver warning and vehicle control strategies to be integrated in simulators and vehicle demonstrators. These demonstrators will in turn be used in functional and user acceptance tests.

Tests on the demonstrators will be performed in realistic traffic conditions and with novel dummy specimen, where the insights from the earlier in-depth accident analysis and naturalistic observation studies are again utilized. Test procedures will be proposed to Euro NCAP and the test results will be used for benefit estimation.

### Accident analysis

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 included 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 were performed including information from recent years.

Several crash databases were analysed and compared: the 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).

## Naturalistic Observations

Complementary to accident studies, naturalistic observations were carried out to provide information that cannot be inferred from accident databases, since these usually do not contain detailed information about the time before the conflict happened.

The first step was to acquire data about indicators of VRU's behaviours that sign their intent in the near future. Naturalistic observations were also used to study correctly managed situations by the road users that could have led to false alarms should the decision be taken by an active safety system.

As seen in Figure 2 and Figure 3, 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) in order to observe interactions with surrounding VRUs.



**Figure 2: View from infrastructure-mounted cameras**



**Figure 3: Video data from in-vehicle camera**

A set of parameters was codified for the traffic conflicts identified in the acquisition. They describe general environmental conditions of the

conflict, infrastructure characteristics (such as layout, amount of lanes, speed limit, etc.), characteristics of the VRU, characteristics of the conflict (visibility, right of way, yielding, conflict management, etc.), VRU intent (i.e. gesture and head/torso orientation), kinematics and trajectories of vehicle and VRU.

## Focus groups

Focus groups were conducted in the United Kingdom and The Netherlands in order to investigate additional characteristics of VRU through traffic, in particular for cyclists. Participants were asked to imagine that they were cycling or driving and the objective was to identify factors that potentially indicated a cyclist's/driver's behaviour.

## User acceptance studies

Acceptance by the user is a key factor to be studied in order to ensure the success of the system. As unjustified system interventions are of special importance, a simulator study was conducted in order to explore the relationship between false alarms and driver acceptance.

This activity was performed in a Pedestrian Alert System (PAS). Subjects were requested to drive during a short time period, encountering different situations of conflict with pedestrians as well as warning actions taken by the system. The objective was to investigate appropriate warning times.

## System specification

The most relevant accident scenarios obtained in a previous phase were clustered in "Use Cases" or "target scenarios" addressed by the project.

Use cases include detailed information about the road layout, right-of-way, as well as manoeuvre intention of the driver. Use Cases are the key for the system specification, which is the basis for the development of the new active safety system within the PROSPECT project.

Additionally, Naturalistic observations and Focus groups were used to contribute to the specification of the use cases, and to calibrate the most representative cases that will be used for the test development.

## HMI and actuation technologies

HMI guidelines were also generated in the context of an automated VRU detection system. Based on the literature, a set of heuristics to guide the choice

of feedback mode for the different actions of an automated system was defined in order to provide HMI recommendations as part of the system specification.

### **System development and demonstrators**

For system development, two main aspects are considered:

- ✓ Advanced sensor processing with situation analysis.
- ✓ Intervention strategies including braking and steering.

All the developed concepts will be implemented in several vehicle prototypes.

Special emphasis will be put on balancing system performance in critical scenarios and avoiding undesired system activations.

### **Testing activities**

A collection of ‘test scenarios’, representative for all accident scenarios, was required to be defined and specified within the project. These cases must take into account relevant parameters and values in order to test and validate the new systems.

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).
- Testing in driving simulator: 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. Thus, 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 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, if interventions of active systems are rare, they may lead to unpredictable reactions from non-aware drivers.

## **RESULTS**

Main results on accident analysis, use cases, user requirements and HMI guidelines, first developments and testing activities are presented in this section.

### **Accident analysis**

An in-depth accident analysis involving VRUs was already performed in Europe, focused mainly in pedestrians and cyclists. The most relevant accident scenarios have been clustered in use cases or target scenarios addressed by the project.

The focus of the project was on crashes with two participants. All relevant VRU traffic scenarios were considered, with a special focus on urban environments, where the large majority of VRU accidents occur.

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 showed that the crashes between passenger cars and pedestrians or cyclists are from highest relevance for Europe.

Figure 4 shows a summary of the most relevant accident scenarios related to car-to-cyclist crashes that 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		

**Figure 4: Most relevant car-to-cyclist scenarios**

Additionally, 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 could be gained about the situations faced by the drivers especially why they

sometimes failed to manage these crash situations [4].

Regarding car-to-pedestrian accidents, the Accident Scenarios introduced in the European project AsPeCSS [5], [6] were considered as basis. The information obtained from the analysed 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” was considered. The most relevant car-to-pedestrian accident scenarios can be seen in Figure 5.

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 carriage way on a straight road away from vehicle / towards vehicle; No Obstruction
PROSPECT_UC_PD_8	No Pictogram	6%	Driving Backwards
Others		14%	Others

**Figure 5: 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 D2.1. “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.

### Naturalistic Observations

Analyses performed for each conflict identified during the naturalistic observations provide descriptions of a battery of VRUs’ characteristics,

which helped to identify the clues that can predict VRUs’ behaviour in the near future, such as head and torso orientation.

Besides, kinematic information is able to give clues about VRU path prediction.

Additional studies were performed in order to determine the influence of scene context on certain cyclist behaviour parameters based on already available data sets.

The information about Naturalistic Observations and additional studies is available in Deliverable D2.1. [7].

### Focus groups

The subjects (cyclists and drivers) in the focus groups identified behavioural cues which were considered relevant in indicating or influencing cyclists.

Additionally, environmental characteristics which may also affect a cyclist’s future path, such as road characteristics which the subjects felt may affect a cyclist’s/driver’s behaviour were identified.

This information has an influence on the user requirements of the system to be developed. In-detail information can be found in [8].

### User acceptance studies

A novel model of user acceptance was developed based on the understanding gained from the literature review and the first simulator study to investigate driver acceptance, initially looking at Pedestrian Alert Systems.

The study was carried out on subjects driving for a short time period and resulted in an average warning time range which seemed to be more appropriate for driver acceptance. Nevertheless, further work should also consider other factors that are likely to influence the reliability and capability of PAS and contribute to false alarms.

Besides, it is necessary to consider the longitudinal effects of familiarisation with a technology, which is likely to influence acceptance over days/weeks/months of exposure.

In detail information can be found in one of the project’s deliverables (D2.2. “User needs and functional requirements”, see [9]).

A methodology for user acceptance is currently in development within the project, focusing on the balance between performance and unjustified activations of the system.

### System specification and use cases

The initial derivation of use cases was made from GIDAS data, which was weighted and clustered. The first derivation of Use Cases was later cross-checked and confirmed by a case-by-case analysis. A new method was developed within the project which, unlike previous approaches, compiles the analysed use cases, case-by-case, taking into account the driver's point of view [4].

As a result of this methodology, in total 37 car-to-cyclist use cases were defined. For every use case the following data is available: number of fatally injured persons; number of seriously injured persons; number of slightly injured persons, pictograms, accident coverage that corresponds to the derived use cases. In-detail information is available on Deliverable D3.1 of the project [9].

Relevant parameters that are useful for designing an (pro) active VRU System based on the experience in developing AEB VRU Systems were defined for each Use Case: age, time of day, obstruction, initial speed of the vehicle, collision speed of the vehicle, initial speed of the cyclist, collision speed of the cyclist, age of the cyclist, percentage of daytime, and percentage of obstruction. Some of these parameters are shown in Figure 6, Figure 7 and Figure 8:



Figure 6: Accident pictograms (on the right, PROSPECT pictogram)

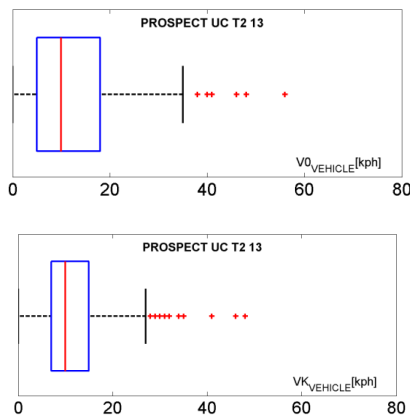


Figure 7: Use Case - velocity profiles

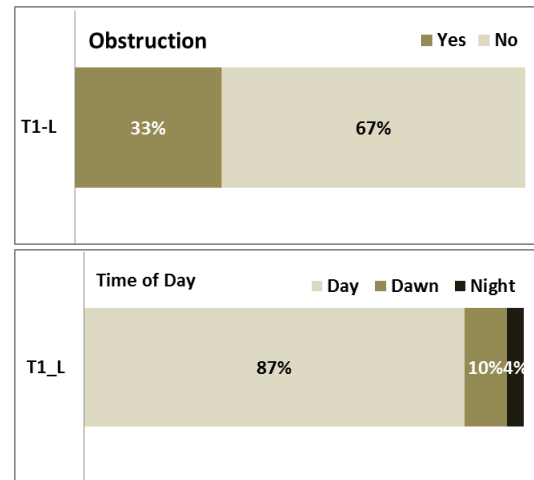


Figure 8: Use Case information about obstruction and time of day

Most car-to-pedestrian scenarios were already available from the ASPECCS project, hence focus was put on the pedestrians turning scenarios, defining the next parameters: injury level, age distribution of the pedestrian, junction layout, velocities of the collision partners, impact location on vehicle, position of the collision partners in the junction area at time of impact, vehicle dynamic status at time of impact.

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.

### HMI, actuation and control strategies

An HMI guideline was generated focusing on the choice and combination of modes/feedback types for active safety system actions at various 'levels of automation' (LOA). This information is available on D2.2. "User needs and functional requirements", see [9].

The HMI specification includes modes to present information and warnings to the driver and its timing. All of the different possible feedback types possible within a vehicle were considered, starting with a classification into modes: visual, auditory and haptic.

Detailed information of the HMI design to support AEB systems (extended to Autonomous Vehicle Systems) performed within PROSPECT is described on [10].

Furthermore, the specification of the vehicle control components to be developed within the project includes not just warning or information actions, but also highly dynamic braking and automated steering actions.

### **System development and demonstrators**

The development work of the sensor processing components is already in progress, and preliminary prototypes will be available for testing in 2017. 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 / sensitivity microwave radar sensors (i.e. MIMO – Multiple Input Multiple Output), and micro-Doppler effect for radar-based VRU classification.

Based on VRU detected and captured information over time, the first models of determination of critical situations and collision risk estimation were obtained.

Situation analysis, driver / VRU information / warning and vehicle control strategies are also under development. In certain situations, the system will be expected to send a warning signal to the driver. However, in emergency situations that cannot be handled by the driver, the system will take immediate control over the vehicle. Conceptual plans have been designed regarding vehicle control strategies for braking, steering or combined braking / steering interventions that will be later implemented into the demonstrator vehicles.

Multiple 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. [12].

### **Testing activities**

From the accident scenarios, the most representative test cases were defined in the project, resulting in a preliminary test protocol, available in Deliverable D7.4 of the project [13].

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

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

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

## **CONCLUSION**

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 will facilitate novel anticipatory driver warning and vehicle control strategies, which will significantly increase system effectiveness without increasing the false alarm / activation rate.

Knowledge and technologies to be developed in the project will be relevant for different vehicle categories (passenger cars, vans, trucks and buses), with main focus on passenger cars.

The project will result in a more complete set of vehicle control measures that can be taken to avoid/mitigate VRU accidents (combined steering and braking) and the means to communicate system operation in an intuitive and effective way to the driver. The project will also define novel test equipment and test methodologies and procedures which will be proposed to the Euro NCAP 2020 test programmes.

The impact of the system developed is expected to increase in about 36% with respect to the state-of-the-art systems, representing a significant reduction in terms of VRU accidents. This percentage is tentatively calculated taking into account accident coverage and system effectiveness.

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.

The findings within the project presented in this paper will contribute to the next generation of state-of-the-art knowledge 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 increasingly automated vehicles towards fully autonomous vehicles.

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