

NEXT-GENERATION Active Safety and Testing: The Horizon 2020 Project PROSPECT

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ABSTRACT

PROSPECT (Proactive Safety for Pedestrians and Cyclists) is a collaborative research project involving most of the relevant partners from the automotive industry (including important active safety vehicle manufacturers and tier-1 suppliers) as well as academia and independent test labs, funded by the European Commission in the Horizon 2020 research program.

PROSPECT's primary goal is the development of novel active safety functions, to be finally demonstrated to the public in three prototype vehicles. A sound benefit assessment of the prototype vehicle's functionality requires a broad testing methodology which goes beyond what has currently been used.

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.

For this task, data from a real driving study with subjects in a suburb of Munich, Germany was used. Further data from Barcelona will be available soon.

The data suggests that intersection crossing can be broken down into five phases, two phases with straight deceleration / acceleration, one phase with constant radius and speed turning, and two phases where the bend is imitated or ended. In these latter phases, drivers mostly combine lateral and longitudinal accelerations and drive what is called a clothoid, a curve with curvature proportional to distance travelled, in order to change lateral acceleration smoothly rather than abrupt. The data suggests that the main parameter of the clothoid, the ratio distance travelled to curvature, is mostly constant during the intersections.

This parameter together with decelerations and speeds allows the generation of synthetic robot program files for a reproduction of natural driving styles using robots, allowing a much greater reproducibility than what is possible with human test drivers. First tests show that in principle it is possible to use the driving robots for vehicle control in that manner; a challenge currently is the control performance of the robot system in terms of speed control, but it is anticipated that this problem will be solved soon.

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, standard mobile and light obstruction elements for quick reproduction of obstructions of view, and a concept for tests in realistic surroundings.

First tests using the PROSPECT test methodology will be conducted over the summer 2017, and final tests of the prototype vehicles developed within PROSPECT will be conducted in early 2018.

INTRODUCTION

PROSPECT (Proactive Safety for Pedestrians and Cyclists) is a collaborative research project involving most of the relevant partners from the automotive industry (including important active safety vehicle manufacturers and tier-1 suppliers) as well as academia and independent test labs, funded by the European Commission in the Horizon 2020 research program.

PROSPECT's starting point is a better understanding of relevant Vulnerable Road User (VRU) accident scenarios (combining multiple European accident studies with urban naturalistic observations). Improved VRU sensing and situational analysis (enlarged sensor coverage; earlier and more robust detection; sophisticated path prediction and intent recognition) will allow the developed functions and systems to act early and safe more vulnerable road users. Advanced HMI and especially vehicle control strategies (combined vehicle steering and braking for collision avoidance) will extend the benefit even further to those accident configurations where the reaction time is still short. The functions will be shown in three vehicle demonstrators.

In order to appropriately assess the performance of PROSPECT functions, extensive testing is needed.

The vehicle tests will make use of novel realistic VRU dummy specimen, mounted on fully self-drivable platforms. Tests with those tools will be carried out on test tracks, but PROSPECT will also partially leave the clean test track to show the function's benefit with tests in realistic surroundings.

Focus of this paper is the path from specification of use cases to an appropriate test methodology. Since the PROSPECT functions are designed to work not only during straight driving (like most of today's active safety functions), but also in intersection situations, specifically realistic (human-like) driving behavior in the demonstrator vehicles is important. This should preferably be derived from naturalistic driving studies to mimic a human driving style as close as possible, even if driving robots are used.

The paper will on the one hand describe the basic objectives of the EU funded project PROSPECT in terms of deriving test cases, being close to real world traffic surroundings, for VRU active safety systems. On the other hand special emphasis is laid on the correct determination of realistic turning maneuvers of the vehicle under test at intersection situations, specifically for bicycle scenarios.

A general overview over the PROSPECT project can be found in paper 17-0193. More information on the derivation of use cases from accident data can be found in ESV paper 17-0396 and in the appropriate PROSPECT deliverables ([1], [2]).

DEMONSTRATOR VEHICLES AND FUNCTIONS

There are three vehicles in development [3]:

Demonstrator car I is able to quickly detect and classify vulnerable road users 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 (approximately 150 ms from start of braking to fully cycling ABS).

Demonstrator car II is equipped with a high-resolution, high field-of-view stereo camera system (total angle coverage of 75°) and an additional short range RADAR sensor. In the near range (longitudinal distance up to ~ 30 m) a more detailed analysis of the VRUs will be executed. Accurate background/foreground segmentation helps to extract intention-related attributes like head and body pose. Based on this more 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.

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 rearward approaching, quick 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) .

All vehicles are able to automatically steer and / or brake to avoid accidents.

GENERAL TEST METHODOLOGY

For details on PROSPECT's test methodology see [4].

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) and possible 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.

It could in principle be possible that the collision partner (bicycle or pedestrian) reacts towards the active safety intervention in the VUT, but such a complex reaction with the required assumptions goes beyond the scope of the project.

Additional objects such as static or moving vehicles obscuring the pedestrian or bicycle dummy initially might be added to the test scene, depending on the use case to be tested.

Performance criteria in active safety tests are:

- Speed reduction, in case the active safety function reduces the speed of the VUT.
- Warning timing, given in the variable Time-To-Collision (TTC), for those systems and functions that depend on driver intervention to avoid the accident.
- A combination of speed reduction or accident avoidance with warning timing, for combined systems.

In current active safety tests, the VUT speed (up to the time of automatic brake intervention) during a maneuver and also the speed of the opponent are held constant. Since PROSPECT goes beyond that in test cases where the VUT turns, this is not sufficient. In nearly all turning scenarios, it is anticipated that the VUT will slow down while negotiating the turn and might accelerate again afterwards. At least the movement of the bicycle or pedestrian will be constant since there are no test cases where the opponent turns.

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. The opponent (bicycle or pedestrian) on the other hand is controlled completely with a time-synchronized propulsion system.

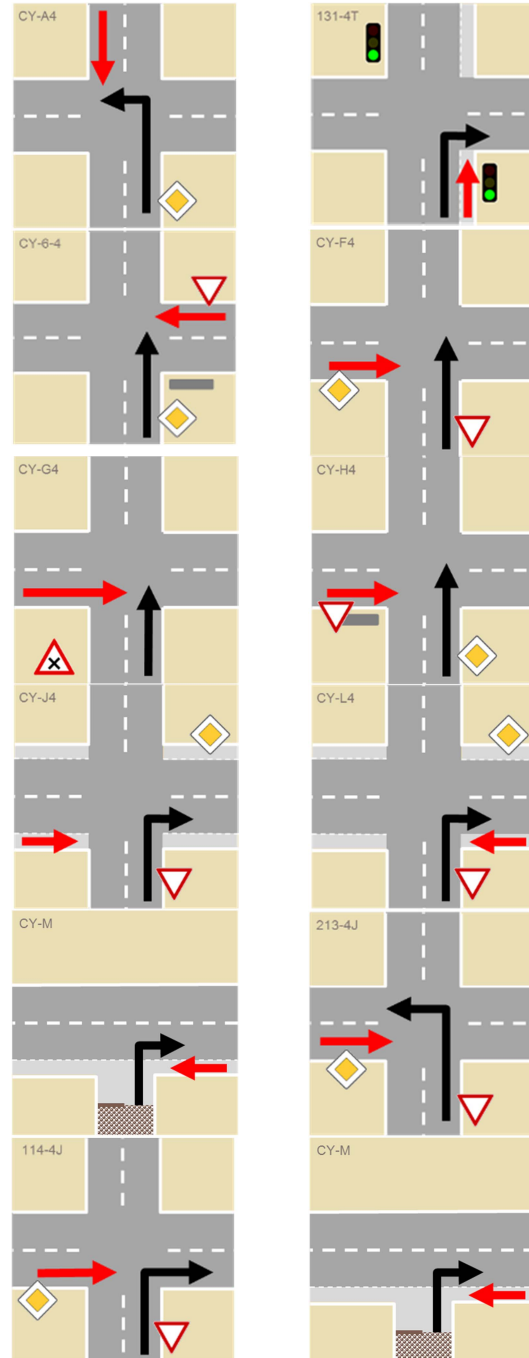


Figure 1: Overview over bicycle intersection test cases

Use cases as detailed description of representative accident situations

PROSPECT functions are defined to avoid or mitigate bicycle and pedestrian accidents. The use cases for these functions therefore are representative descriptions of accident scenarios: Use case definitions contain a geometric description of a scene (including road geometry, but also lane, obstructions,

traffic signs), generic behavior and speeds of the accident participants, and also traffic rules, if possible. An overview over the use case is presented in Figure 1.

All use cases were derived from detailed accident data by classification of individual accident characteristics (see paper 17-0396 for more details): They are a condensed form of important characteristics observed in a larger set of accidents. While a total number of 64 use cases had been defined in the project (for bicycles and pedestrians), a total of 16 bicycle use cases makes up the 20 most relevant use cases out of the 64 (by fatalities as well as by seriously injured persons): 12 on intersections and 4 in straight driving scenarios.

Test cases

Test cases are more detailed than the defined use cases - they are a description of how to reproduce a specific use case on the test track.

The various test cases are summarized in Table 1, 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: non-priority). 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.

Test tools

The vehicle should be instrumented with driving robots and an accurate position measurement tool to maintain a good reproducibility, see Figure 2 and Figure 3 for examples. The use of driving robots is standard in active safety tests.

The vehicle's instrumentation should be able to measure the following quantities with the typically required accuracies:

- VUT and VRU speed to 0.1 km/h
- VUT and VRU lateral and longitudinal position to 0.03 m
- VUT and VRU yaw rate to 0.1 °/s or yaw acceleration to 0.1 °/s²
- VUT and VRU longitudinal acceleration to 0.1 m/s²
- VUT Steering wheel velocity to 1.0 °/s
- Sampling rate of 0.01 s

Table 1: Excerpt of Test cases, Intersection Bicycle Test Cases

ID	VUT Track	VUT Speed profile (km/h)	VRU Track	VRU Speed (km/h)	Signs / Clutter	Other
CBIP 01	Large road	Turning Left (30-60)	Large road (opposite VRU)	20	Priority signs on large road	-
CBIP 02	Large road	Constant (30-50)	Small road (from right)	10	Priority on large road, yield on small road	Small road obscured
CBIP 03	Large road	Constant (40-60)	Small road (from left)	15	Priority on large road, yield on small road	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	-

Driving robots would then allow the following reproducibilities:

- Speed of VUT: desired speed + 1.0 (and - 0) km/h
- Speed of VRU: desired speed ± 0.2 km/h
- Lateral and longitudinal distance of VUT and VRU to desired position 0 ± 0.05 m
- Synchronization of VUT and VRU within 0.02 s (preferably use UTC time for both).



Figure 2: Control equipment

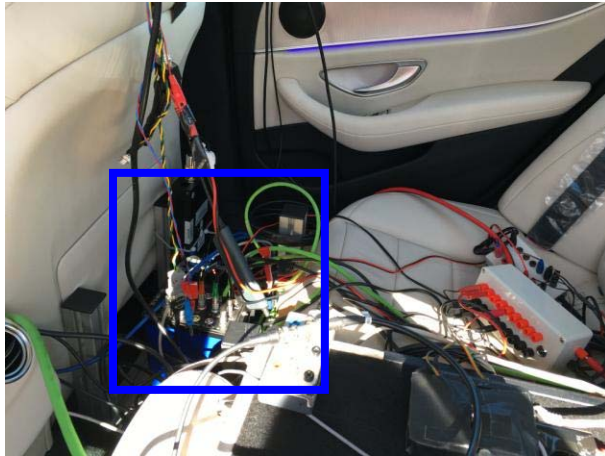


Figure 3: Measurement equipment

Obstruction of View

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.

Besides a visual obstruction for the VRU, the obstruction should also represent a concrete wall or edge of a building for radar sensors; especially it should not look like a parked vehicle, since most obstructions of sight in the accident data were actually solid structures. The obstruction should be easy to move for efficient testing of different test scenarios. The solution for this is a modular wall made of panels with wood, aluminum and supporting structure with small rollers underneath. Depending on the test scenario, several of these panels would be combined together.

The concept is shown in Figure 4.

The panels will be made of a sandwich structure with a solid wooden plate to carry the structure followed by a curtain of rotatable aluminum elements (lamellae) in a wooden housing with total dimensions of 200 x 200 x 21 cm (see Figure 4). The complete structure stands on four small spherical rollers to allow an easy manual maneuvering on the test ground and has a foldable pillar to fix it on the ground with weights. The turnable lamellae can be adjusted in the vertical axis to reflect most of the radar signal away from the VUT to the side. Together with the wooden plate (and some absorption foam if necessary) a comparable radar cross section of a real concrete wall or building obscuring a VRU should be realizable. For visual sensors like cameras the outer wooden plate could be covered with an image fitting to the tested scenery.

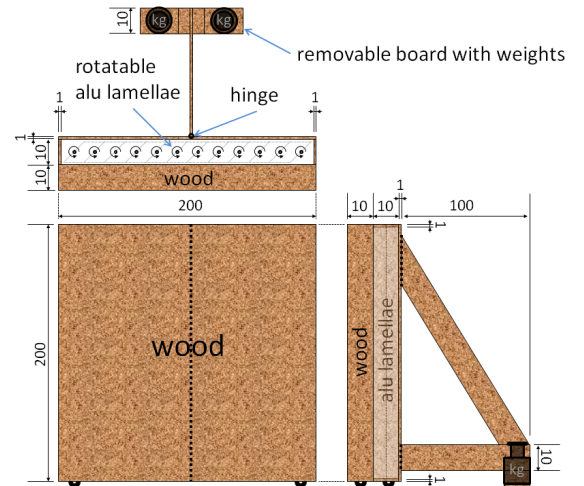


Figure 4: Principle structure of the mobile obstruction panel for the VRU in PROSPECT

The obstruction object will be designed with assistance from and validated by RADAR experts from PROSPECT (e.g. Bosch, Continental ADC) during the development timeframe. Key validation criterion is whether it sufficiently blocks the RADAR sensor's view and whether it does not produce an unrealistically high RADAR reflectivity.

Intersection Geometry on closed Test Track

For the first PROSPECT tests on a closed test track the project has to define a standard intersection geometry for the defined test cases. The proposed intersection (see Figure 5) 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.

On the proving ground it has to be possible to enter the intersection with the VUT at the desired speed from all directions (maximum speed for priority / large road: 60 km/h from both directions, maximum speed for small / non-priority road: 40 km/h). From experience, at least 100 m acceleration length plus ca. 80 m of constant speed straight driving are required for tests at 60 km/h (40 km/h: ca. 50 m acceleration length plus ca. 50 m straight driving).

The initial positions of the VUT and the VRU for the related test scenarios from D3.1 are labeled with A – H. These tracks should be aligned at the center of the respective lane.

As a next step, it will be the task of the test labs to implement and refine this type of intersection on their test tracks. If necessary, final test speeds at some tracks / locations / legs of the intersection may be limited by the available acceleration length and acceleration road geometry.

Concept for Realistic Testing

Active safety systems mostly depend on image processing. The image processing algorithms improve over the years and put the algorithm developers into the position to take various optical and radar cross section cues into account, such as:

- the lane the VUT travelling in, and whether the VRU is already in that lane,
- the priority situation between the traffic participants,
- traffic lights,

- traffic signs,
- the presence of a zebra crossing,
- is the VUT on a sidewalk,

and certainly a high number of others, where a single detail might be of a low importance in itself but could have a major influence in the evaluation of a critical situation. It is impossible to present all possible cues to the vehicle on a clean environment such as a test track. On the other hand, artificial tests on a clean test track are not fully representative for accident scenarios found in reality in the way that angles of intersections, lane width, road inclinations and obstructions do differ. A comparison between test results generated from tests in complex and realistic scenarios with clean test track scenarios will give an indication on how robust PROSPECT functions are and what the performance gain due to the contextual information is in actual use cases.

Since the exact same test tools will be used on a test track and in realistic surroundings, 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

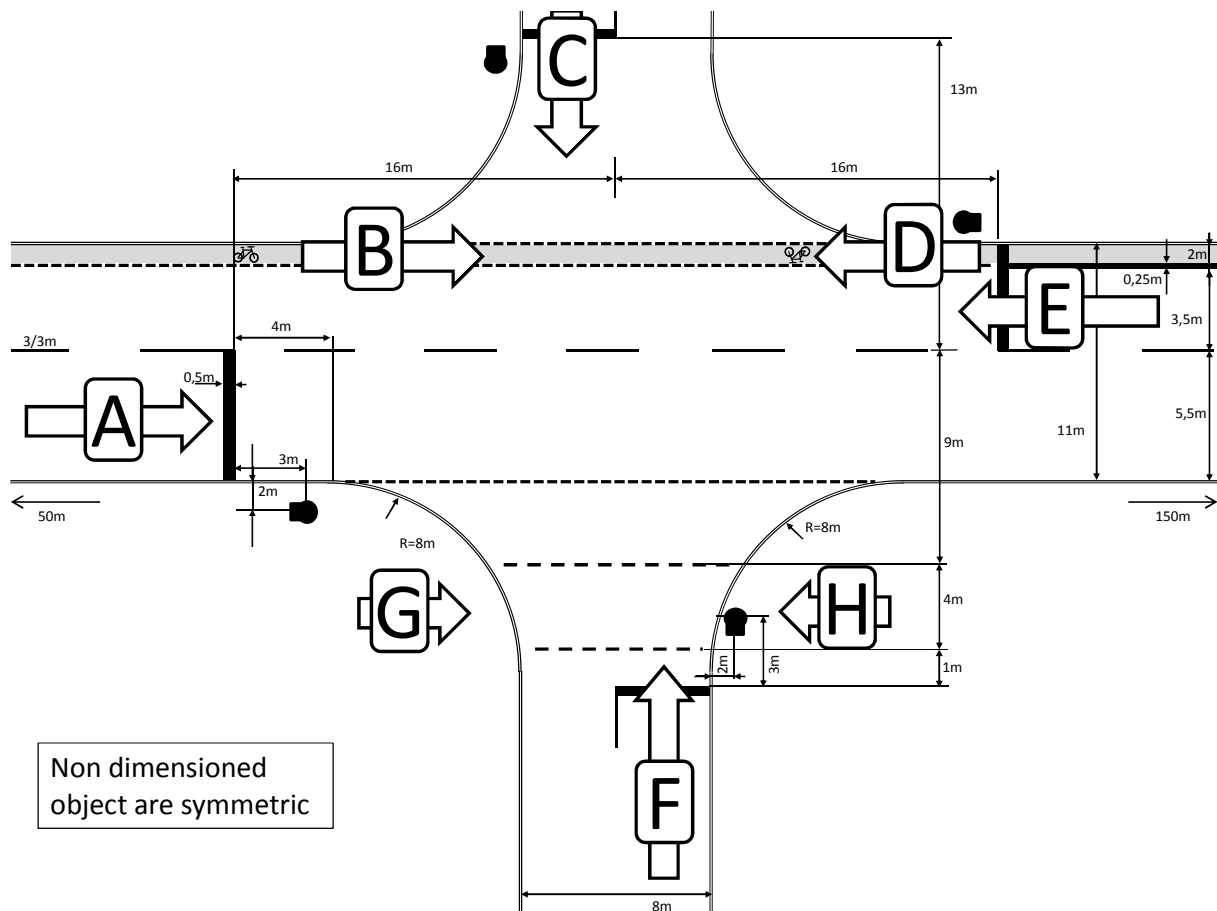


Figure 5: Versatile intersection to be implemented on test track

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.).

PROSPECT's aim is to test on two different real intersections, and then perform as much test cases as possible in that specific location. For instance, one intersection can be a non-sign priority-to-the-right intersection, and the other intersection will have priority signs and a bicycle lane.

Testing in real intersections is possible under the following conditions:

- the intersection is closed to other traffic by own personnel,
- it is possible for residents to access their homes, e.g. by either momentary stopping testing or by declaring a deviation,
- the actual intersections are selected by local authorities from a larger number of candidate intersections,
- the testing will take a limited time,
- no danger is generated for parked vehicles.

BEHAVIOR

Initial speed ranges for VUT as well as for the accident partner (bicycle or pedestrian) are available, based on accident database evaluations. To reduce the complexity, it can be assumed that bicycle or pedestrian do not change speeds during the course of the accidents, and that those traffic participants do travel on a straight line.

Specific behaviors for the VUT are required to depict the conflict situation realistically: e.g. a speed profile for constant speed crossing of an intersection, a speed profile as well as trajectories for turning into or from a non-priority street.

As mentioned above, the collision opponent (bicycle or pedestrian) will have a constant speed and will very likely be linear, but a large set of test cases will include a turning VUT. The exact turning geometry and speed of the VUT should be representative for those patterns found in traffic observations.

Unlike current test procedures for straight-line driving and braking, the PROSPECT intersection scenarios require a driving style with an active driver. It will be necessary for a good assessment to define a trajectory-speed-combination that "feels" natural, but it very reproducible, for instance because it is driven by robots.

The key to this natural driving is to identify how typical subjects drive in the real world through bends for various types of intersections.

There will be two different data sets of subjects driving cars available: one from the suburb of the city of Munich in southern Germany, provided by Audi, and one from the city of Barcelona in Catalonia, provided by IDIADA (not available yet). The data sets contain recordings of vehicle movement data over time, which need to be filtered. Appropriate intersections will be defined and the data for during passing these will be isolated (currently only the Munich data set is available for evaluation).

Finally representative driving styles per intersection (generic vehicle trajectory and vehicle speed profile) will be defined and transferred to driving robots. If these driving styles feel "naturally" (to be judged by human drivers), they can be used in the test scenarios.

Data Set

The study consisted of a sample of 48 participants, of which 14 were female and 34 male. The participants' age ranged from 21 to 60 years, with a mean age of $M=30.0$ years ($SD=11.5$ years). As a requirement to be allowed to attend the study, drivers had to have their driver's license for more than 5 years or in total 200.000 km driving experience since they obtained their license. On average, participants obtained their driving license 12.6 years ago ($SD=10.8$ years).

The route in this data set as well as intersection that are appropriate for the test cases (see Table 2) is shown in Figure 6.

The test vehicle was an Audi A6 with integrated measurement technology. The vehicle was equipped with a head-up display (HUD) showing driving related information, e.g. current driving speed and permitted speed limit. Other functions like Adaptive Cruise Control (ACC) had been deactivated, so that all participants had to control for speed and distance by themselves during the complete study.

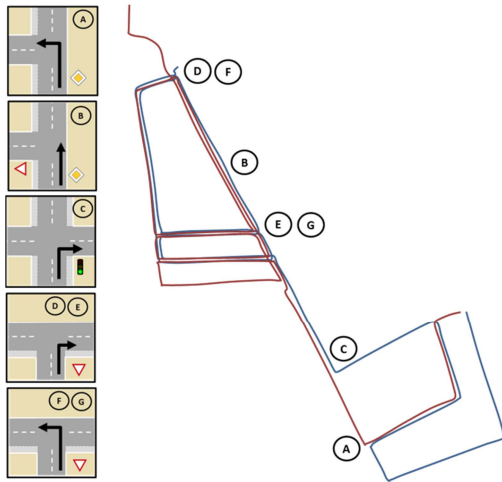


Figure 6: Layout of the route

This dataset contains several intersections that are appropriate for the test cases, see Table .

A total number of 711 measurements is available, an average of 71 crossings for each one of the 10 intersections. The average 10 measurements were recorded with the vehicle coming from and going to different directions. Table 2 shows the test cases where sufficient data for evaluation is available.

Table 2: Intersections for test cases

ID	Intersection	Behavior
CBIP 01	'A', starting north, going east	Turning left from priority, higher speed
CBIP 03	'B', starting north, going south	Crossing an intersection with 40-60 km/h
CBIG	'C', starting north, going south	Turning right at green light, 10-30 km/h
CBIP 04	'D' & 'E', Starting west, going south	Turning right into priority street
CBIP 05	'F' & 'G', Starting west, going north	Turning left into priority street

Criteria for data analysis

Human driving styles in intersections are expected to be the curvature of their turn and the speed profile, both as function of a parameter that characterizes the completion of the turn.

Human drivers assumingly drive in a way that minimizes the change in lateral acceleration, for instance by increasing the curvature of their trajectory smoothly.

A common geometric figure in road planning is the so-called clothoid: a curve with a direct relation

between distance travelled on the curve d and curvature κ (the reciprocal of the curve radius), according to this equation:

$$\kappa = k_{\kappa} \cdot d$$

The curvature is available as the quotient of vehicle speed and vehicle turn rate (yaw rate):

$$\kappa = \frac{\dot{\psi}}{v_x}$$

both of these quantities are directly measured.

The relation between curvature and distance on the curve, as taken from the NDS data, allows the judgment whether human drivers drive in clothoids, and if so, with what generic parameter k_{κ} .

An appropriate parameter for the turn completion therefore is the distance d , starting at the turn initiation.

Another important criterion for driving style characterization is the speed profile while crossing the bend as function of time, distance or yaw angle travelled.

Exemplary Analysis for "Turning Left from Priority"

The data set provided by Audi & Universität der Bundeswehr contains 7 measurements from intersection 'K' with the vehicle coming from the north and turning to the east with no stopping in-between, which seems reasonably relevant in situations that might have led to an accident. In the majority of the test runs, the vehicle had stopped, probably to yield to another vehicle with priority.

A trajectory of the situation is shown in Figure 7. During increase of curvature, the curvature increases mostly linear with the travelled distance, see Figure 8.

The factor k_{κ} is in the region of 0.12 1/m per 5 to 10 m: $k_{\kappa} = 0.024$ to 0.012 1/m².

A full overview over the relevant motion variables of the vehicle (speed, curvature, lateral acceleration, longitudinal acceleration) as function of time is shown in Figure 9.

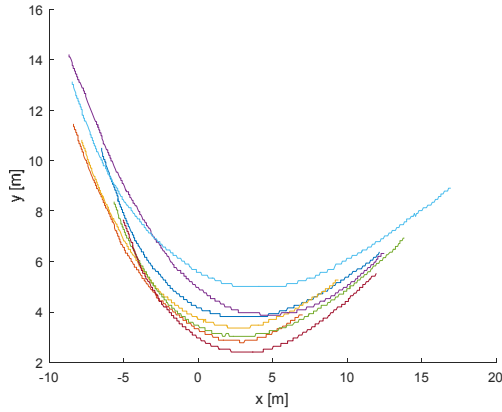


Figure 7: Trajectories for scenario turning left from priority

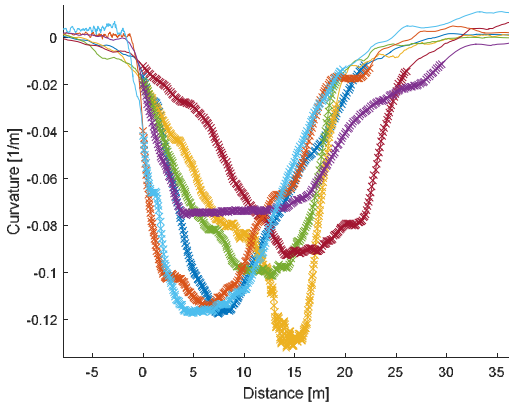


Figure 1: Curvature as function of distance travelled

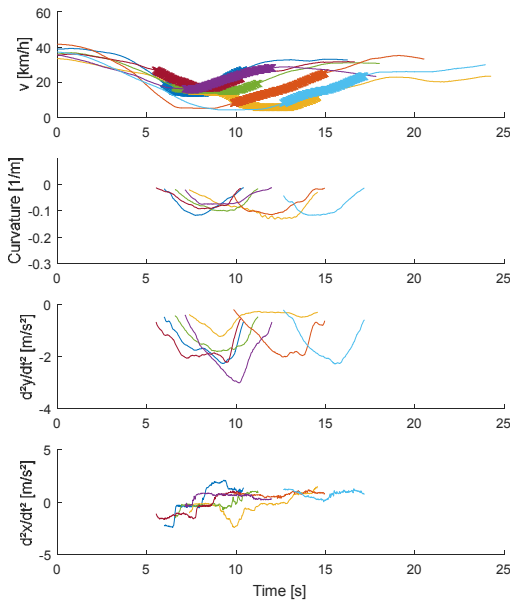


Figure 9: Vehicle movement as function of time

The data suggests clearly that the turn can be broken down into four phases:

- Phase I: speed adjustment while going straight
- Phase II: speed adjustment and increase of curvature (clothoid, entering the bend)
- Phase III: constant radius cornering
- Phase IV: acceleration and decrease of curvature until final speed is reached (clothoid, leaving the bend)
- Phase V: acceleration on straight track to final speed

In phase I, the speed is decreased from a starting speed of approximately 40 km/h down to approximately 25 km/h, where the turn is initiated, while the speed still decreases to the slowest turn speed of 5 to 17 km/h, depending on the measurement. The maximum lateral acceleration in the turn has an absolute value of 2 to 3 m/s², the longitudinal acceleration in during the braking phase is approximately -1 m/s², and when accelerating again to the final speed of approximately 35 km/h, is it 1 m/s² as well.

Representative turning behavior

The analysis of all available data for the other behaviors as well shows that the observed phases can be found in all scenarios. There is one scenario that shows an additional fifth phase: a straight line acceleration to the final speed after completion of the turn, see Table 3.

For testing, it will be crucial that the driving style is comparable to human driving. The parameters from Table 3 can be converted into synthetic driving robot parameter files. If executed, these files would result in the following , see Figures 10 to 13.

Table 3: Behavior in intersections

	Phase I	Phase II	Phase III	Phase IV	Phase V
Turning left from priority road	$v_0=40$ km/h $a_x=1$ m/s ² $v_{end}=25$ km/h	$k_x=0.01$ 1/m ² $\kappa=0.12$ 1/m	$a_y=2.5$ m/s ² $R=8.3$ m $v=17$ km/h	$k_x=-0.01$ 1/m ² $a_x=1$ m/s ² $v_{end}=35$ km/h	-
Passing straight with priority	-	-	$v=35...$ 50 km/h	-	-
Turning right from priority	$v_0=40$ km/h $a_x=1.5$ m/s ² $v_{end}=14$ km/h	$k_x=0.015$ 1/m ² $\kappa=0.17$ 1/m	$a_y=2.5$ m/s ² $R=6$ m $v=14$ km/h	$k_x=-0.01$ 1/m ² $a_x=1$ m/s ² $v_{end}=35$ km/h	-
Turning right into priority	$v_0=40$ km/h $a_x=1.5$ m/s ² $v_{end}=15$ km/h	$k_x=0.025$ 1/m ² $\kappa=0.1$ 1/m	$a_y=2$ m/s ² $R=10$ m $v=16$ km/h	$k_x=-0.025$ 1/m ² $a_x=1$ m/s ² $v_{end}=35$ km/h	-
Turning left into priority	$v_0=40$ km/h $a_x=1.1$ m/s ² $v_{end}=20$ km/h	$k_x=0.04$ 1/m ² $\kappa=0.2$, $v_{min}=1$ km/h	-	$k_x=-0.02$ 1/m ² $a_x=1.4$ m/s ² $v_{end}=20$ km/h with	$v_{end}=50$ km/h $a_x=2$ m/s ² .

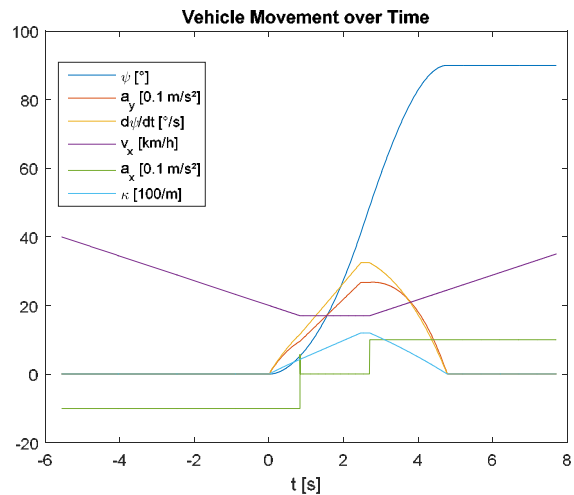


Figure 10: Turning left from priority

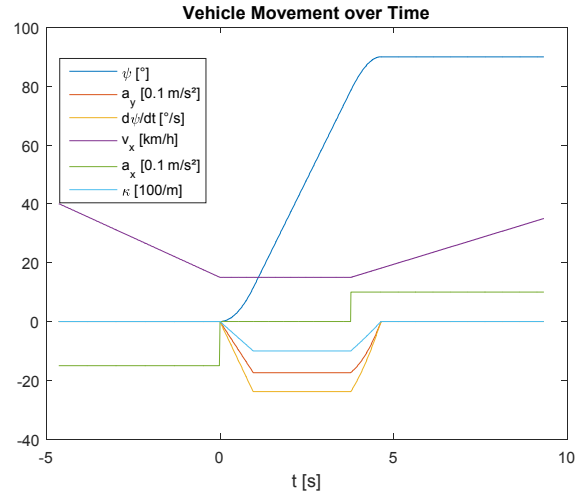


Figure 11: Turning right at green

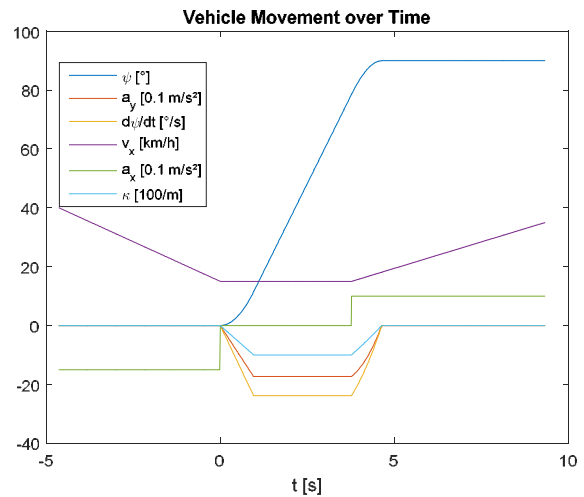


Figure 12: Turning right into priority

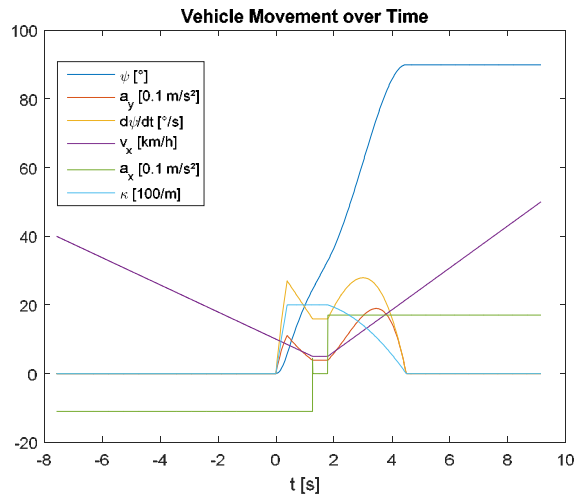


Figure 13: Turning left into priority

Verification using driving robots

First verification runs using robot program files as described above have been conducted with BAST's Mercedes GLC and Anthony Best Dynamics SR15 and CBAR driving robots.

These measurements show that the tool chain allows the creation of robot program files from the parameters derived from NDS data. The measured curvature corresponds quite well with the desired values.

On other hand, the measurements show also that the robot control algorithms have an issue with the speed profile: in all cases, the robot fails to adjust the initial deceleration and especially the speed control during the turn, which generates a large control error. The robot then tries to eliminate the control error in the acceleration phase after the bend, which results in an unexpectedly high acceleration.

All this affects the heavily speed-dependent variables lateral acceleration, yaw angle over time and yaw rate.

A comparison of desired vehicle movement data versus measurement data is depicted in Figures 14 to 17. Desired data is shown with solid lines, measurement data is shown with '+'-signs (every 25 data points).

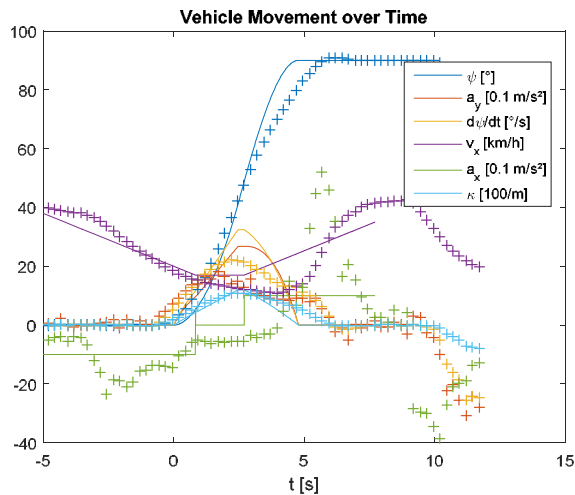


Figure 14: CBIP01 measured data vs. desired data

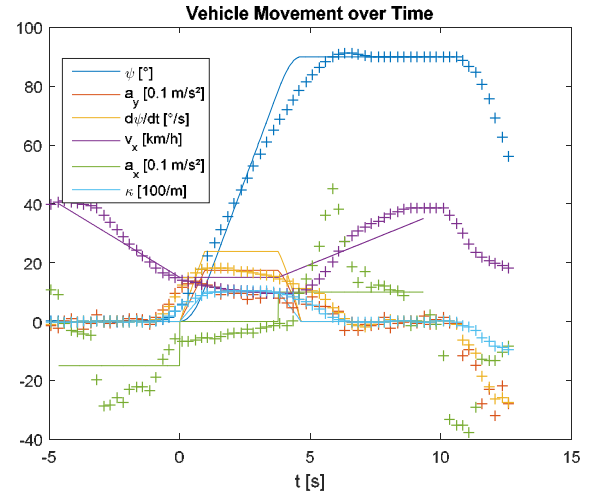


Figure 15: CBIN04 measured data vs. desired data (driven as left turn)

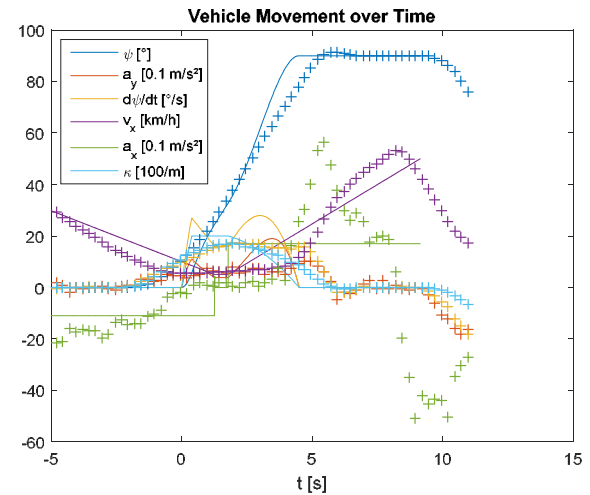


Figure 16: CBIN05 measured data vs. desired data

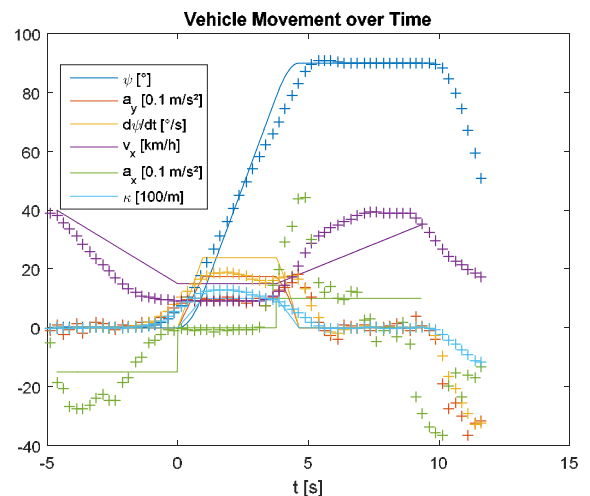


Figure 17: CBIG measured data vs. desired data (driven as left turn)

CONCLUSION

PROSPECT (Proactive Safety for Pedestrians and Cyclists) is a collaborative research project involving most of the relevant partners from the automotive industry (including important active safety vehicle manufacturers and tier-1 suppliers) as well as academia and independent test labs, funded by the European Commission in the Horizon 2020 research program.

PROSPECT's primary goal is the development of novel active safety functions, to be finally demonstrated to the public in three prototype vehicles. A sound benefit assessment of the prototype vehicle's functionality requires a broad testing methodology which goes beyond what has currently been used.

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.

For this task, data from real driving studies with subjects in a suburb of Munich, Germany was used. Further NDS data from Barcelona will be available soon.

The data suggests that intersection crossing can be broken down into five phases, two phases with straight deceleration / acceleration, one phase with constant radius and speed turning, and two phases where the bend is initiated or ended. In these latter phases, drivers mostly combine lateral and longitudinal accelerations and drive what is called a clothoid, a curve with curvature proportional to distance travelled, in order to change lateral acceleration smoothly rather than abrupt. The data suggests that the main parameter of the clothoid, the ratio distance travelled to curvature, is mostly constant during the intersections.

This parameter together with decelerations and speeds allows the generation of synthetic robot program files for reproduction of natural driving styles using robots, allowing a much greater reproducibility than what is available with human test drivers. First tests show that in principle it is possible to use the driving robots for vehicle control in that manner; a challenge currently is the control performance of the robot system in terms of speed control, but it is anticipated that this problem will be solved soon.

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,

standard mobile and light obstruction elements for quick reproduction of obstructions of view, and a concept for tests in realistic surroundings.

First tests using the PROSPECT test methodology will be conducted over the summer, and final tests of the prototype vehicles developed within PROSPECT will be conducted in early 2018.

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