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CATS Deliverable 5.1:
CATS verification of test matrix and protocol

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Summary

This report summarizes the work conducted within work package (WP) 5 “Verification of test matrix and protocol” of the Cyclist AEB testing system (CATS) project. It describes the verification process of the draft CATS test matrix resulting from WP1 and WP2, and the feasibility of meeting requirements set by CATS consortium based on requirements in Euro NCAP AEB protocols regarding accuracy, repeatability and reproducibility using the developed test hardware.
For the cases where verification tests or additional information indicated that the protocol needed adaptation, proposed changes were discussed and upon agreement amongst the partners provided to the matrix including supporting argumentation. In WP1 the relevant accident scenarios have been determined, where in WP2 the most relevant accident parameters were extracted from accidentology and an additional observation study. Using these sources of information, a draft CATS test matrix has been developed.

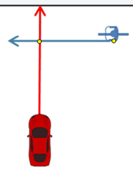
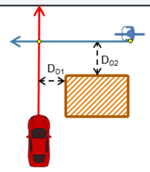
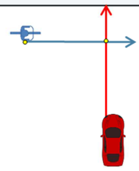
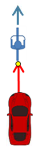
This draft CATS test matrix was used as a basis for the verification process. The process included workshops where all partners of the CATS consortium have been given the possibility to test the scenarios, a full spec test series was performed with a vehicle including a Cyclist-AEB system. Furthermore simulation studies were done and a robustness test series was performed to check the accuracies of the test protocol and the practical usability of the test equipment.

Verification tests and simulations revealed that both the near-side CVNBU crossing scenario with 0% overlap and the far-side CVFB with 50% overlap crossing scenario were approximately equally difficult in terms of feasibility. It was therefore decided to change the collision point in the CVNBU test to 50% instead of 0% and the collision point in the CVFB scenario from 50% to 25%. Both changes still correspond to the parameters found in accidentology. This creates a two-step approach in terms of difficulty where the CVNBU is now less challenging and the CVFB more challenging.

Furthermore it was found in the tests that the lateral accuracy of the target remains a challenge, especially for the longitudinal scenario with a long single belt. As a result, the collision point in the longitudinal scenario is changed from 20% to 25% since it is important that cyclist remains inside the width of the vehicle in terms of trigger an AEB activation. This still corresponds to the parameters found in accidentology.

The resulting final CATS matrix (Version January 2016) is found in Table 1.

Table 1. Final CATS car-to-cyclist AEB test matrix (Version January 2016)

	CVNBU	CVNBO	CVFB	CVLB	
Vehicle speed	20 – 60 km/h	10 – 40 km/h	20 – 60 km/h	30 – 60 km/h	65 - 80 km/h
Cyclist speed	15 km/h	10 km/h	20 km/h	15 km/h	20 km/h
Obstruction	Without	With D1=3.55m, D2=4.80m	Without	Without	Without
Overlap hitpoint	50 %	50 %	25 %	50%	25 %
AEB / FCW	AEB	AEB	AEB	AEB	FCW
# tests [36]	9	7	9	7	4
Layout sketch					
Expected feasibility 2018	YES	YES	NO	YES	
Important notes:	• Main challenge in CVNBU is system robustness (AEB response after collision is unavoidable: cyclist cannot break or steer away to avoid collision).	• Main challenge in CVNBO is the limited time for system response.	• CVFB is not expected to be feasible for production vehicles in 2018, especially due to challenges in Field-of-View requirements, response time and real-world robustness.	• Recommended to verify that the vehicle shows AEB performance with a 25% overlap in the AEB speed range (30 – 60 km/h) to ensure AEB performance at overlaps below 50%.	
	• Field-of-View is a general issue for the 3 crossing scenarios at low vehicle speeds. • System robustness is a general issue for the 3 crossing scenarios at high vehicle speeds.			• Evaluation of FCW considers collision avoidance by steering and not braking.	

Contents

1 Introduction

The overall number of fatalities in traffic accidents in Europe is decreasing significantly. Unfortunately, the number of fatalities among cyclists does not follow this trend [1]. In Figure 1-1 an overview is given of the total number of road fatalities and cyclist fatalities for France, Germany, Italy, the Netherlands, Sweden plus the UK over the period of 2001 to 2012. This graph clearly shows that the trend for cyclists is not decreasing at the same rate as for all road fatalities. It is believed that this is the result of the strongly increasing popularity for cycling in Europe [2] and consequently the increasing number of cyclists on the road.

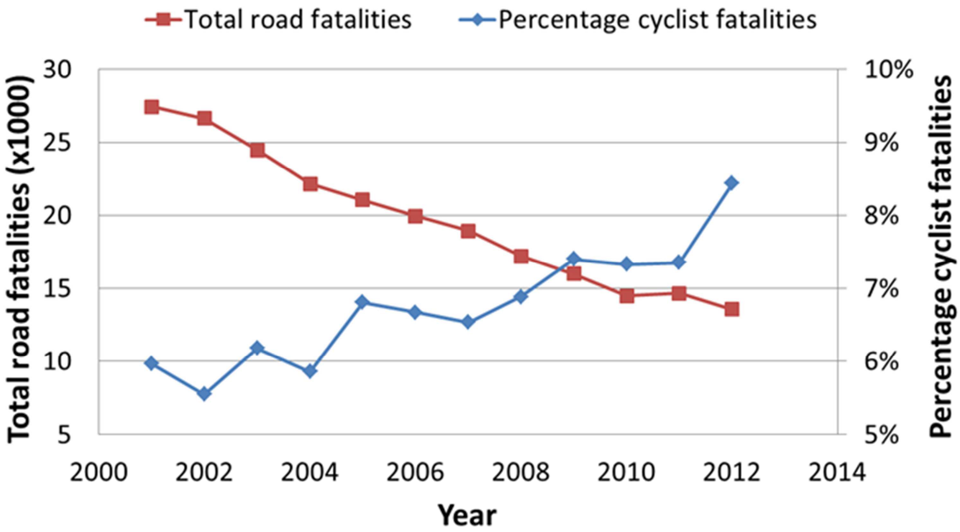


Figure 1-1. Trends of total road fatalities and cyclist fatalities for France, Germany, Italy, the Netherlands, Sweden plus the UK over the period of 2001 to 2012 [1].

A major share of killed cyclists in traffic accidents results from a collision with a motorized vehicle [3]. The automotive industry is making a significant effort in the development and implementation of active and passive safety systems in cars to avoid or mitigate an imminent crash with vulnerable road users. Pedestrians were considered by most in a first step, but systems also applicable for cyclists are following. One of the most promising active safety systems is an Autonomous Emergency Braking-system (AEB). Such systems support the driver e.g. with an audio, visual and/or haptic warning and by automated full or partial braking to avoid or mitigate imminent crashes. Since 2014, AEB systems that aim at avoiding and mitigating car-to-car rear end collisions are part of the Euro NCAP star rating. In 2016, Euro NCAP will introduce AEB for pedestrians as part of their test and assessment procedure. Euro NCAP additionally intends to include Cyclist-AEB systems in the safety assessment from 2018 [4] onwards.

TNO demonstrated a Proof-of-Concept Cyclist-AEB testing system, based on a draft protocol commissioned by the Netherlands Ministry of Infrastructure and the Environment, during the 2013 International Cycling Safety Conference (ICSC - November 2013) in Helmond [5]. In anticipation of the introduction of Cyclist-AEB systems and the corresponding consumer tests, a consortium (CATS: Cyclist-AEB Testing System) has been formed to prepare a test setup and test protocol that covers the most relevant accident scenarios for Cyclist-AEB systems and to develop the test tools necessary for such tests.

In work package WP1, the most dominant accident scenarios were identified using accident data from France, Germany, Italy, The Netherlands, Sweden and the United Kingdom [6]. The focus is hereby set on accidents with killed and seriously injured casualties rather than on the overall accident population. In WP2 [7] the most relevant accident parameters were described. Furthermore in WP2 a first test matrix was presented based on the accident scenarios, accident parameters and a first simulation study performed by BASt [8].

This report summarizes the work conducted in WP5 “verification test matrix and protocol” of the CATS project. The test matrix will be tested in terms of feasibility using simulations and verification workshops of all partners and a current high end vehicle. Furthermore the proposed test protocol will be tested in terms of robustness and accuracy. The resulting ***Final test matrix of the CATS project*** is provided in Chapter 4 of this report.

2 Method

2.1 Introduction

To deduce a test matrix from the accident scenarios and accident parameters, an approach according to the scheme below is used:

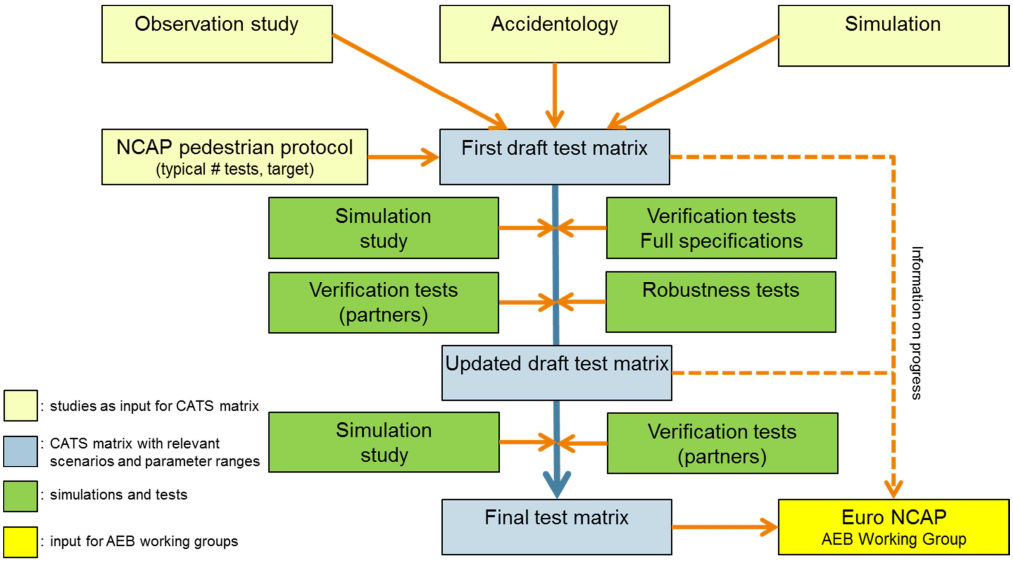


Figure 2-1: Process used in the CATS project to construct and verify the proposed test matrix.

Based on the most dominant accident scenarios identified in WP1 [6] combined with the most relevant parameters with appropriate ranges found in WP2 [7], test scenarios are proposed with input from observation studies [9] to quantify additionally selected parameters and simulations as a first indication for feasibility of each test scenario for different settings of the relevant parameters. The philosophy, conditions and construction of the test scenarios follows as much as possible the current version of the Pedestrian-AEB tests specified in Euro NCAP AEB VRU Test Protocol v1.0.1 [10]. Also the recommendations of the AsPeCSS deliverable for Cyclist-AEB test scenarios [11] are used to provide additional information.

This first draft of the CATS test matrix (version June 2015, as shown in Table 2) has been used as a basis for verification of the feasibility according to specifications with similar accuracy requirements as specified in Euro NCAP AEB VRU Test Protocol v1.0.1 [10]. This requires testing with drive robot and gas/brake robot installed on a test track (AstaZero, Sweden) and was executed with a Volvo XC90 (model 2015) that was equipped with a Cyclist-AEB system. In parallel a test series with a TNO lab car has been conducted to check to accuracies and robustness of the test protocol. Furthermore a verification workshop, where all CATS participants were given the possibility to perform tests according to the updated draft test matrix, has been organized. All test series were performed with an approved version of the bicycle target that has been developed in parallel with the involvement of all CATS participants. Simulation studies have been performed as an additional source of information regarding feasibility. In discussions with the CATS participants, including all sources of information as described above, an updated version of the CATS test matrix was agreed upon.

This updated test matrix has again been tested by all partners in a verification workshop. Furthermore this updated test matrix is checked and compared for feasibility using additional simulations. This resulted in a final CATS test matrix of the Cyclist-AEB test protocol.

All mentioned activities will be described separately in subsequent chapters of this report. The naming convention, based on the timing, of these separate activities can be found in Figure 2-2.

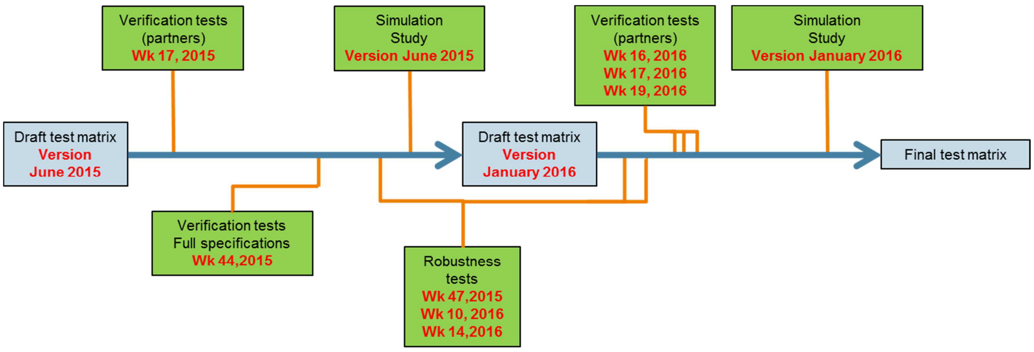
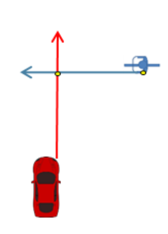
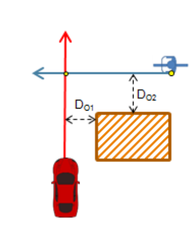
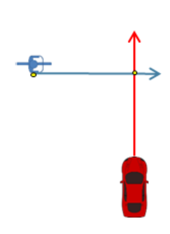
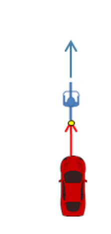
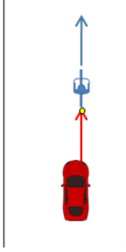


Figure 2-2: Timing schedule and naming convention for the activities shown in Figure 2-1

Table 2. Draft CATS car-to-cyclist AEB test matrix (version June 2015)

	CVNBU	CVNBO	CVFB	CVLB*	
Vehicle speed	20 – 60 km/h	10 – 40 km/h	20 – 60 km/h	30 – 60 km/h	65 - 80 km/h
Cyclist speed	15 km/h	10 km/h	20 km/h	15 km/h	20 km/h
Obstruction	Without	With D1=3.55m, D2=4.80m	Without	Without	Without
Overlap hitpoint	0 %	50 %	50 %	50%	20%
AEB / FCW	AEB	AEB	AEB	AEB	FCW
# tests [36]	9	7	9	7	4
Layout sketch					

*To be eligible for evaluation in AEB VRU cyclist Longitudinal, the AEB system must reduce speed in CVLB – [30 -60] km/h with 20% overlap

The nomenclature of the scenarios has been brought in line with the Euro NCAP standards with a unique identifier for each scenario:

- Car-to-VRU Nearside Bicyclist Unobstructed (**CVNBU**)
  a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the nearside and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.
- Car-to-VRU Nearside Bicyclist Obstructed (**CVNBO**)
  a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the nearside behind an obstruction and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.

- Car-to-VRU Farside Bicyclist (**CVFB**)
  a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the far-side and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.

- Car-to-VRU Longitudinal Bicyclist (**CVLB**)
  a collision in which a vehicle travels forwards towards a bicyclist cycling in the same direction in front of the vehicle.

2.2 **Verification test series – All partners**

Two test series are organized for all CATS participants to perform tests according to the latest test matrix and protocol available at that time as an input into the discussion regarding the test scenarios. The first workshop is performed with the original test matrix and the second with the updated test matrix as can be seen in Figure 2-1. The setup of both verification workshops are discussed below.

2.2.1 Verification workshop - Wk. 17, 2015

The first verification workshop took place at TrafficPort test track in Venlo, the Netherlands during 4 days in March 2015. 2 stations at which tests can be performed were setup. Due to the large number of test vehicles (~16) present during the workshop a reduced number of scenarios have been evaluated. However, the test planning was such that every partner could perform the most relevant tests from each scenario. The proposed test matrix and schedule for the workshop is found in Table 3 and Table 4 For the CVNBO scenario, it is suggested to start with a 150% overlap in order to be sure no impact occurs during the first tests, in which also all test drivers need to get used to the new protocol. When confidence and experience allowed, the collision point was set to its intended 50%. Still, during the first workshop, the partners were urged not to run into the dummy, as only a limited number of prototype dummies were available at the time. The target will be fixed to the platform

Table 3. Global test matrix for the first verification workshop based on the test matrix in Table 2.

Scenario	VUT speed [km/h]	# of tests	Comments
CVNBU	20, 40 ,60	3	
CVNBO	20, 40	2	150% ->50% collision point for safety
CVFB	20, 40 ,60	3	
CVLB	30, 45, 60	3	

Table 4. Global schedule for the first verification workshop

Day/time	Station 1	Station 2
Day 1 13:00 – 16:00	CVLB	CVNBU
Day 2 09:00 – 12:00	CVFB	CVNBO
Day 2 13:00 – 16:00	CVFB	CVNBO
Day 3 09:00 – 12:00	CVLB	CVNBU
Day 3 13:00 – 16:00	CVLB	CVNBU
Day 4 09:00 – 12:00	CVFB	CVNBO
Day 4 13:00 – 16:00	CVFB	CVNBO

A queueing approach is used, meaning that partners with their test vehicles line up at the start of each station and perform the test one at a time.

The platform used is the original "sliding" platform, henceforth know as Platform I (Figure 2-3), originating from the pedestrian AEB setup. Both the crossing and longitudinal scenario are created with a double belt setup. The triggering of the target is performed with light barriers since the GPS method is not possible with so many test vehicles queuing at each station. The target is the bicyclist target version v4. All described equipment has been developed and provided by 4activeSystems GmbH.

2.2.2 Verification workshop – Wk. 16, 17 & 19, 2016

During the 2nd workshop, the final version of the CATS bicycle target (version v5) is used. The workshop has been organized in such a way, that the CATS participants are able for each test scenario to collect as much information as possible up to the point of impact. Therefore impacting the target has been allowed during the 2nd workshop,

To facilitate this, this verification workshop has been split in 3 smaller workshops:

- Week 16, 2016: test track in Fohnsdorf, Austria, close to 4activeSystems GmbH
- Week 17, 2016: test track in Fohnsdorf, Austria
- Week 19, 2016: TrafficPort test track in Venlo, the Netherlands.

The goal was to provide each partner ample time for testing at a single station. The order of the tests in the matrix was adapted to the wishes of the participants present. However, it was made sure that a minimum of tests was performed covering the complete matrix in order to have useful input into the feasibility discussion. Furthermore repeats were performed to evaluate repeatability of the tests. The test matrix is found in the following table:

Table 5. Test matrix for the second verification workshop based on the test matrix in Table 10

Scenario	Vehicle speeds [km/h]	# of tests
CVNBU	20,30,40,50,60	5
CVNBO	10,20,30,40	4
CVFB	20,30,40,50,60	5
CVLB	30,40,50,60	4
CVLB	65,80	2

Again, a queueing approach has been used, meaning that partners with their test vehicles line up at the start of each station and perform the test one at a time.

The platform used for all scenarios is the updated rolling platform (version April 2016), henceforth known as Platform II (Figure 2-3), due to its ability to steer and maintain a highly improved lateral accuracy. The crossing scenario is created with a double belt setup, while the longitudinal scenario is created with a single belt. Just as in the first workshop, the light barriers are used as a trigger for the target. The target is the version 5 bicyclist target. All described equipment has been developed by 4activeSystems GmbH.

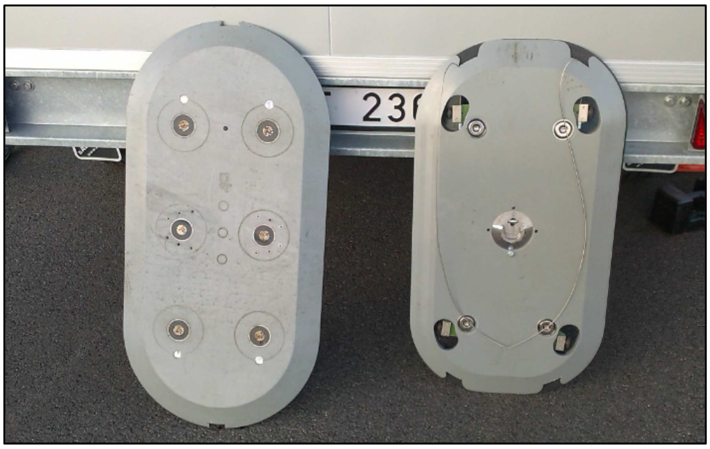


Figure 2-3: target platforms used: the original “sliding” platform (Platform I) used in the crossing scenarios (left) and the “updated” rolling platform (Platform II) for better lateral accuracy and stability for the longitudinal scenarios (right). Platform II has 2 versions: Version October 2015 before the robustness test series and Version April 2016 after the robustness tests.

2.3 **Verification test series – Full specifications**

In this test series the feasibility of the draft test matrix as depicted in Table 2 and test protocol has been checked. The tests are carried out with a Volvo X90 (model 2015) equipped with a Cyclist-AEB system using a fusion algorithm of a radar and camera sensor. The car is installed with a driver and gas/brake robot to test with similar accuracy requirements as specified in Euro NCAP AEB VRU Test Protocol v1.0.1 [10]. The tests have been carried out at the AstaZero test facility in Sweden in October 2015 (wk44, 2015). The weather conditions were dry, sunny with light clouds (low sun towards the test vehicle in the afternoon), 5-10 degrees Celsius and low wind conditions (< 5 m/s).

The target used was the 4activeSystems bicyclist target version v5.

The propulsion system is from 4activeSystems GmbH. In the crossing scenarios the double belt configuration is used with a 75m belt. In the longitudinal scenarios the single belt configuration is used and in these tests the system is limited to 60 km/h for the vehicle speed and 15 km/h for the target speed.

The target platforms are from 4activeSystems GmbH where in the crossing scenarios Platform I is used and in the longitudinal scenarios Platform II (Version October 2015) for improved lateral stability and accuracy (Figure 2-3).

The test matrix for this test series is based on the draft CATS test matrix (version June 2015) and the performance prediction of VCC (Figure 2-4) in order to gain insight in the feasibility of the tests, especially in the region of uncertain performance. Furthermore, the test matrix has been extended with some extra tests to gain insight in the effect of different variables in the test scenarios. The planned tests can be found in Figure 2-4. For each test the speed reduction, moment of AEB activation and moment of FCW have been recorded.

		CVNBO			CVNBU				CVFB	CVLB
		Target speed [km/h] & hitpoint [%}								
		5 - 50%	10 - 50%	15 - 50%	5 - 50%	10 - 50%	15 - 50%	15 - 0%	20 - 50%	15 - 50%
Vehicle speed [km/h]	5									
	10	3			3					
	15	3			3					
	20	1	1		1	1				
	25		3			3				
	30	1	3	3	1	3				1
	35		1	3		1	3	3		
	40		1	1			3	3		1
	45						1	1	3	
	50		1	1			1	1	3	1
	55								1	
	60						1	1	1	1

Figure 2-4: Performance indication based on sensor properties as a function of target and vehicle speed and impact point. No performance (red), possible performance (yellow) and performance (green). The numbers in the table indicate the number of tests planned for that scenario in this test series. The patterned areas are representing the tests in the draft CATS test matrix, version June 2015

Figure 2-5: Example of the test setup: XC90 in near side crossing test (CVNBU)

2.4 Robustness test series

To check the robustness of the entire test method for all the tests in the CATS matrix, a robustness test series has been performed in week 47, 2015. In this test series the practical execution of the described test scenarios is investigated. To assess the repeatability and accuracies, the Euro NCAP AEB VRU Test Protocol v1.0.1 [7] is followed where possible. The used parameters and their limits are given in Table 6, only the specifications for the lateral deviation of the target has been adapted based on known limitations with respect to the lateral stability of the platform. A realistic +/- 0.15m is used instead of +/- 0.05m.
All parameters should be checked from the start of the test, which will be taken as TTC 4s. Furthermore the practical usability of the test target has been assessed.

Table 6. Parameters assessed on accuracy

parameter	accuracy
Speed of VUT	Test speed + 0.5 km/h
Lateral deviation of VUT	0 ± 0.05 m
Yaw velocity	0 ± 1.0 °/s
Speed of target	Test speed ± 0.2 km/h
Lateral deviation of target	*0 ± 0.15 m*
Estimated hit/impact point	-

The test matrix for the robustness tests is found in Table 7. As can be seen not all vehicle speeds are tested, only the minimum, maximum and median velocity. However each test is repeated 3 times with and without dummy on the platform to gather as much information from the tests as possible. Since the system is not able to deal with vehicle speeds higher than 60 km/h yet, the CVLB FCW tests with VUT speeds higher than 60 km/h could not be performed at the time of the robustness tests.

Table 7. Test matrix for the robustness test series

CVNBU	CVNBO	CVFB	CVLB
20 km/h	20 km/h	20 km/h	30 km/h
40 km/h	40 km/h	40 km/h	45 km/h
60 km/h	-	60 km/h	60 km/h

The propulsion system setup including target and platform is identical to the configuration used in the verification test series with the Volvo XC90 (Wk. 44, 2015) with full specifications as described in Section 2.3 and shown in Figure 2-3.

As a test vehicle a rental Toyota Prius has been used including an OxTS GPS-based reference system. The vehicle is controlled by its own internal speed controller while in actual assessment tests a gas/brake robot should be used. Furthermore an ABD steering robot has been installed for path control. All data has been logged with 100Hz on an IMC BUSDAQ system. A video VBOX system has been installed to log videos of the tests. To capture the lateral accuracy of the test target, a HD camera has been placed in line with the travel path of the target. Video analysis has been used to compute the actual deviation at expected impact point (Figure 2-7).

Figure 2-6: Test vehicle for the robustness test series: Toyota Prius

Figure 2-7: Example of computation of lateral accuracy at impact point using video analysis in the longitudinal scenario

Even though no automatic Cyclist-AEB system was installed on the test vehicle, it is desired to have a braking action to come as close to an actual test as possible. Therefore the vehicle is programmed to brake at a fixed TTC, which is 1,05s for the crossing scenarios and 0,70s for the longitudinal scenario. Combined with the braking profile of the test vehicle (0.5G in 0.4s) the expected results can be computed as shown in Table 8.

Table 8. Expected results for the robustness test series using 1,05s and 0,70s braking TTC for the crossing and longitudinal scenarios respectively, combined with the braking profile of the test vehicle (0.5G in 0.4s).

Crossing

Speed [km/h]	Estimated impact speed [km/h]	CVNBO estimated collision point [%]	CVNBU estimated collision point [%]	CVFB estimated collision point [%]
20	0			
40	18	103	80	157*
60	41		38	101

Longitudinal

Speed [km/h]	Estimated impact speed [km/h]
20	0
40	18
60	34

* Impact avoided

All tests are performed at the TrafficPort test track in Venlo, The Netherlands.

After the first test series, 2 additional robustness test series have been performed in order to check the lateral accuracy of the target. In the first workshop (week 47, 2015) it was found that the lateral accuracy of the target was a challenge to achieve. 4activeSystems GmbH performed optimization iterations in order to improve the lateral accuracy. In the first additional series (week 10, 2016), the test vehicle was fully instrumented again as described previously and in the second additional test series (week 14, 2016) it was unequipped since only the lateral accuracy of the target was under investigation here. In these two additional series Platform II (Version October 2015 – Version April 2016) was also used for the crossing scenarios to improve lateral accuracy. The weather was somewhat wet in the first additional test series and dry in the second. The wind was medium to very high in both of these test series.

2.5 Simulation studies

In order to further check the feasibility to show AEB performance in the different tests from the CATS matrix, a simulation study has been performed. This study uses an AEB simulation tool developed by TNO [12]. This Matlab/Simulink based tool can be used to evaluate the performance of an AEB system using a parametrized approach divided in 5 blocks as can be seen in Figure 2-8:

- Surrounding: characterization and initialization of the scenario and the environment. Typical parameters are:
  - Initial vehicle and target distance, speed and acceleration
  - Vehicle and target intersection angle
  - Impact point
  - Vehicle and target geometry
  - View blocking obstruction presence and location
- Sensor: description of the available sensors. Typical parameters are:
  - Sensor type (incl. delays and framerate), location, viewing angle and range
  - Sensor fusion algorithm
  - Target detection and location algorithm
- Driver assistance: description of the AEB algorithm. Typical parameters are:
  - AEB logic (incl. collision detection and AEB activation method)
- Car dynamics: description of the response of the car. Typical parameters are:
  - Brake profile
  - Actuator delay
- Driver behaviour: response of the driver to AEB output (the functionality of this block is not used in this study). Typical parameters are:
  - Driver response to FCW or autonomous brake action
  - Driver brake delay

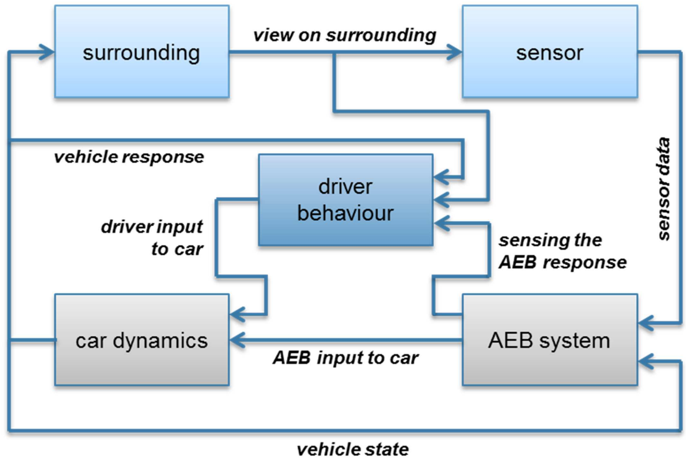


Figure 2-8: Basic scheme of the AEB simulation tool.

The AEB simulation tool is used to compute the speed reduction as a function of initial VUT speed to provide an indication of the feasibility of each of the tests in the test matrix. The following parameters/settings are used in the simulation study in this report:

- CATS test matrices: the results of all draft and final test matrices will be presented
- Sensor:
  - 2x24 and 2x45 degree viewing angle representing “low” and “high” state of the art systems
  - 80m range
  - Front mounted (middle of car)
  - 100% of target in view, 50% to keep detection
  - 0.2s detection delay
- AEB:
  - Brake at TTC = 1.0s
  - Include a cyclist point of no return (PONR), i.e. only activate AEB when a cyclist cannot by itself avoid a collision due to braking with 4 and 7 m/s^2
- Car:
  - Deceleration of 1G with 0.4s to reach 99% of maximum (1^{st} order time constant) (Figure 2-9)
  - Actuator delay of 0.2s
  - 1.9m width with rounded bumper(
  - Figure 2-10)
- Target:
  - CATS target dummy (divided in 3 boxes, Figure 2-11)

target_L = 1.9m
target_W = 0.5m
target_Lf = 1.04m
target_wheelW = 0.1m
target_Lsub = 0.7m
target_Lfsub = 0.3m

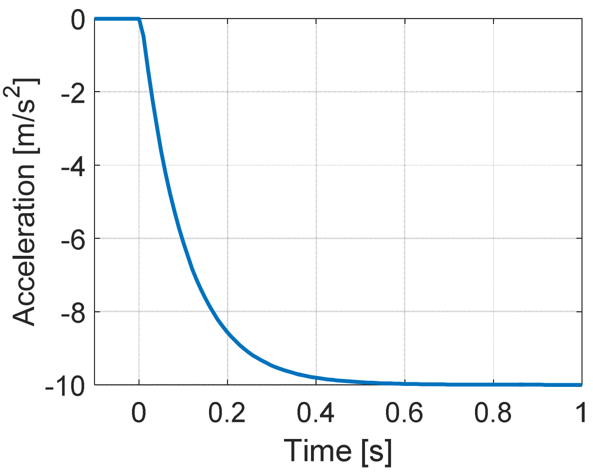


Figure 2-9: Brake profile used for an AEB activation

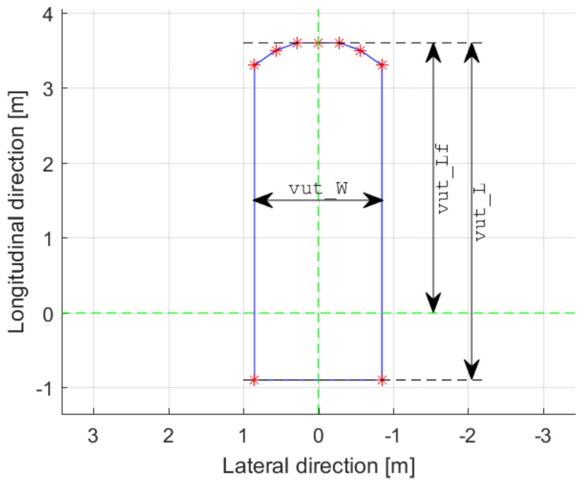


Figure 2-10: VUT geometry used with rounded front end. -0.1m back at 2/6 and 5/6 and 0.3m back at 0 and 1 of vehicle width.

target_L = 1.9m
target_W = 0.5m
target_Lf = 1.04m
target_wheelW = 0.1m
target_Lsub = 0.7m
target_Lfsub = 0.3m

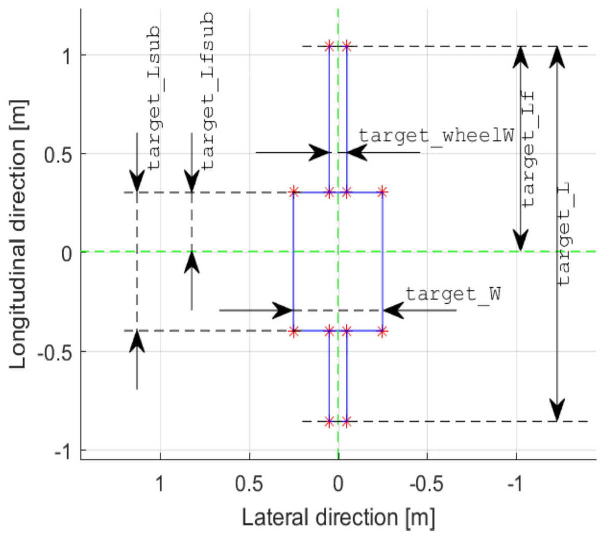


Figure 2-11: Cyclist geometry used.

3 Results

3.1 Verification test series – All partners – wk. 17 2015

Unfortunately, the first 2 test days of the first verification test series (Wk17, 2015) both of the systems malfunctioned. This caused that no tests could be performed. The systems were up and running at the start of the third day. Fortunately the tests went much faster than planned and an extra test slot was introduced in the evening for the third and fourth day. Most partners were able to perform the tests that were scheduled for the week. The actual performed test matrix and schedule is given in Table 9:

Table 9. Actual performed test schedule first verification workshop. Test slot indicates the test day in numbers 1 to 4 and morning, afternoon or evening in letters a to c

Scenario	VUT speed [km/h]	Comment	Test slot
CVNBU	20,30,40,60		1a,3a,3b,4a,4b,4c
CVNBO	20,40	150% collision point	3a,3b
CVNBO	20,30,40	50% collision point	3c,4a,4b,4c
CVFB	20,40,60	Sometimes from nearside	4a,4b,4c
CVLB	30,40,50,60		3a,3b,4a,4b

In terms of realism and feasibility of the test scenarios, feedback from the partners was received. Since no impact was possible the feasibility could only be assessed in terms of sensor feedback.

For the longitudinal scenario it was mentioned that classification was mostly possible, however the double belt setup during this workshop for the longitudinal tests provided some difficulties. Both the propulsion system and return plate are in the travel path of the vehicle, which is not realistic and can affect the detection of the bicyclist. The double belt setup also makes it impossible to test the lower overlap, since the VUT then needs to driver over the return plate and maybe even the belt itself. It is therefore advised to go for a setup in which both items are not visible anymore. Furthermore the length of the belt was perceived as short and therefor the cyclist started moving late. The lateral deviations of the target were rated as high and to such an extent that it was expected to affect the system performance, especially at low overlap.

For the crossing scenarios it was found that detection was mostly possible in CVFB and CVNBU, however it was classified by most CATS participants as being difficult. For the CVNBO scenario the opinion of the partners was divided in terms of possible detection. The setup performed well, however achieving an accurate collision point is challenging when manual vehicle control used in combination with the light barriers to trigger the target due to limited possible control when VUT velocity and path does not remain very constant.

3.2 Verification test series – Full specifications – Wk. 44 2015

In Figure 3-1 the actual number of performed tests is given in relation to the planned tests in Figure 2-4 for the full specifications verification test series (October 2015). The tests are categorized as successful or unsuccessful. Criteria for this difference result from the correct vehicle speed, target speed, collision point, lateral accuracy, etc. It can be seen that not all initially planned tests are performed due to difficulties in setting up the complete test system in the limited time available. However the conducted tests are sufficient to provide an indication of feasibility.

OK/NOK # of tests	CVNBO			CVNBU				CVFB	CVLB
	Target speed [km/h] & hitpoint [%}								
Vehicle speed [km/h]	5 - 50%	10 - 50%	15 - 50%	5 - 50%	10 - 50%	15 - 50%	15 - 0%	20 - 50%	15 - 50%
5									
10				1/2					
15				0/1					
20		0/3		2/0					
25		1/0			2/0				
30		2/0		1/0	1/0				0/2
35					2/0				
40		1/0			2/0	2/0		1/0	0/1
45						2/0	1/0	1/0	
50						1/0	2/0	1/0	0/1
55									
60								1/0	

Figure 3-1: Actual number of tests performed. OK/Not OK. Colours are representing the performance indication based on sensor properties as a function of target and vehicle speed and impact point. No performance (red), possible performance (yellow) and performance (green). The patterned areas represent the current tests in the draft CATS test matrix

Figure 3-2, Figure 3-3 and Figure 3-4 show the performance of the car in terms of speed reduction, moment of AEB activation and moment of FCW, respectively. It can be seen that in the crossing scenarios the car was able to mitigate or avoid the collision in most tests with target speeds of 10 km/h or lower. When the target speed was higher (15 or 20 km/h) there was no performance in terms of speed reduction and AEB activation. However, an FCW was in most tests still provided to the driver at a time before the crash, sufficient for the driver to respond.

In a discussion with VCC, it was indicated that the performance in the crossing scenarios was lower than expected. It was discussed that this is expected to be due to the need for the system to have a robust detection of the cyclist and bicycle with high confidence both for the camera and the radar. The need for this high confidence for an AEB intervention is to avoid false positives. The radar detection had a sufficiently high confidence for AEB intervention, however the camera system did not. Even though the camera system detected the target as a cyclist, it was not early enough with sufficiently high confidence for AEB interventions at a lower TTC. One of the reasons is that the system uses characteristics from the whole 360 degree pedalling sequence of the cyclist. However, the cyclist target developed within CATS does not provide this 360 degree pedalling behaviour, as it is seen from observation studies that a large percentage of cyclists crossing a road stop pedalling.

Additional augmented reality simulations performed by VCC showed that a fixed straight leg position with the leg at the side of the car down and the other leg upward (vertically oriented crankshaft) , gives a good representation of a cyclist. The target used during the test had a horizontally oriented crankshaft, where a vertically oriented crankshaft is preferred, Based on these observations, and an analysis of the observation studies in the Netherlands, in which it was shown that most cyclist have one foot up – one foot down, this posture of the target is therefore updated, as the most realistic representation of a cyclist approaching a crossing.

Speed reduction										
		CVNBO			CVNBU				CVFB	CVLB
		Target speed [km/h] & hitpoint [%}								
		5 - 50%	10 - 50%	15 - 50%	5 - 50%	10 - 50%	15 - 50%	15 - 0%	20 - 50%	15 - 50%
Vehicle speed [km/h]	5									
	10				10					
	15				15					
	20		3/10/20		20					
	25		3			3				
	30		4/11		30	30				>15
	35					0				
	40		12			26/1	0		0	>25
	45						1	0	0	
	50						0	0	0	>35
	55									
	60								0	

Figure 3-2: Speed reduction in km/h for each performed test. Colours represent the performance indication based on sensor properties as a function of target and vehicle speed and impact point. No performance (red), possible performance (yellow) and performance (green). The patterned areas represent the current tests in the draft CATS test matrix

TTC AEB										
		CVNBO			CVNBU				CVFB	CVLB
		Target speed [km/h] & hitpoint [%}								
		5 - 50%	10 - 50%	15 - 50%	5 - 50%	10 - 50%	15 - 50%	15 - 0%	20 - 50%	15 - 50%
Vehicle speed [km/h]	5									
	10				0,66					
	15				0,93					
	20		NA/0,4/0,6		0,96					
	25		0,37			0,35				
	30		0,37/0,51		1,03	1,05				1,5
	35					0,4				
	40		0,3			0,74/0,2	NA		NA	1,05
	45						0,2	NA	NA	
	50						0,1	NA	NA	1,6
	55									
	60								NA	

Figure 3-3: TTC at the moment of AEB activation for each performed test. Colours represent the performance indication based on sensor properties as a function of target and vehicle speed and impact point. No performance (red), possible performance (yellow) and performance (green). The patterned areas represent the current tests in the draft CATS test matrix

TTC FCW		CVNBO			CVNBU				CVFB	CVLB
		Target speed [km/h] & hitpoint [%}								
		5 - 50%	10 - 50%	15 - 50%	5 - 50%	10 - 50%	15 - 50%	15 - 0%	20 - 50%	15 - 50%
Vehicle speed [km/h]	5									
	10				0,6					
	15				1,6					
	20		0,1/0,4/0,8		1,75					
	25		0,96			1,5				
	30		0,6/0,8		2	1,1				1,88
	35					1,3				
	40		0,65			0,66/0,93	NA		0,9	1,96
	45						1,04	NA	0,76	
	50						0,64	0,5	1,65	2,14
	55									
	60								1,14	

Figure 3-4: TTC at the moment of FCW for each performed test. Colours represent the performance indication based on sensor properties as a function of target and vehicle speed and impact point. No performance (red), possible performance (yellow) and performance (green). The patterned areas represent the current tests in the draft CATS test matrix

3.3 Robustness test series – wk. 47 2015

For the first test series (week 47, 2015) the CVNBU and CVNBO crossing testing, the weather and surface was dry, however a high wind (~11m/s) almost perpendicular to the target travel path was present. For the CVFB crossing tests the weather and surface was also dry and the wind was medium strong (~6m/s). The longitudinal tests were performed with again dry weather and surface. The wind was parallel along the travel path of the target and was medium strong (~6 m/s).

Since the wind was blowing in the back of the dummy in the longitudinal scenario, testing with the dummy was possible. However in the crossing scenario the wind pushed the dummy over, making it impossible to conduct a successful test. All results shown for the first test series in the crossing scenario are therefore without the dummy target on the platform. For the two additional test series the dummy could always be used even though there were medium to high winds present.

Below the longitudinal and crossing scenarios are discussed separately in terms of repeatability, accuracy and robustness.

3.3.1 Longitudinal

Figure 3-5 shows the VUT velocity as a function of the VUT distance to the impact point. It can be seen that the repeatability is high, showing always no differences between tests. It can also be seen that the velocity is lower than the set limit of test speed + 0.5 km/h. This is due to the miss-synchronization of the internal speed controller of the test vehicle and the OxTS measurement system. The purple line marks the official start of the test at TTC 4s. At this point the speed is constant and stable. Even though the speed is too low, it is clear that the accuracy would not have been an issue if the two systems were well synchronized.

Figure 3-6 shows the target speed as a function of the target distance to impact point. It can be seen that the target speed is within the limits at the time the tests starts (purple line) for all 3 tests, indicating a high repeatability and accuracy. This enables further analysis of impact point.

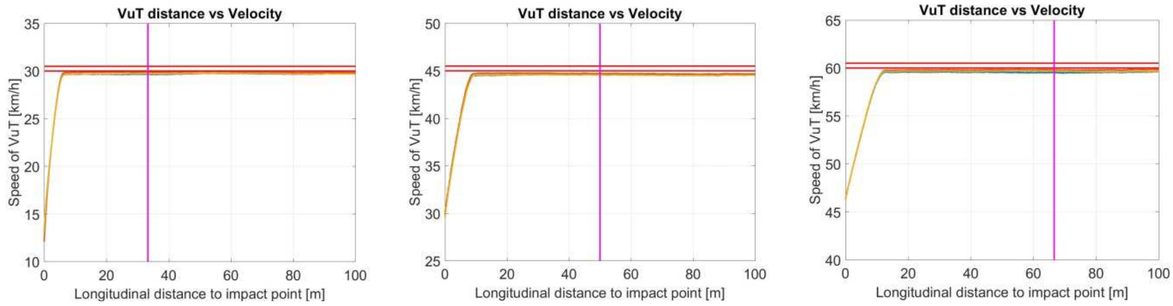


Figure 3-5: VUT speed as a function of VUT distance to impact point for CVLB. Left to right is 30, 45 and 60 km/h. Red lines indicate the needed accuracy and purple line is TTC is 4s indicating the moment the accuracies should be fulfilled

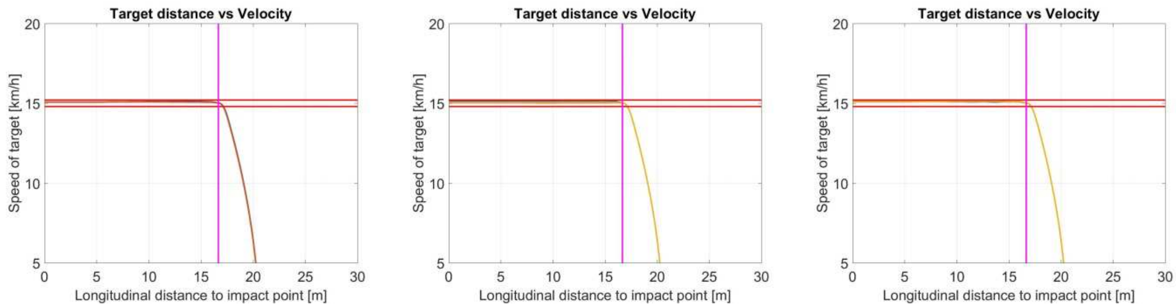


Figure 3-6: target speed as a function of target distance to impact point for CVLB. Left to right is 30, 45 and 60 km/h. Red lines indicate the needed accuracy and purple line is TTC is 4s indicating the moment the accuracies should be fulfilled

The estimated impact point can be found by showing the VUT distance to impact point as a function of target distance to impact point and extrapolating the part of constant velocity (Figure 3-7). It shows that the estimated actual impact point is close to the expected impact point of 0m for all tests. This indicates a robust test method.

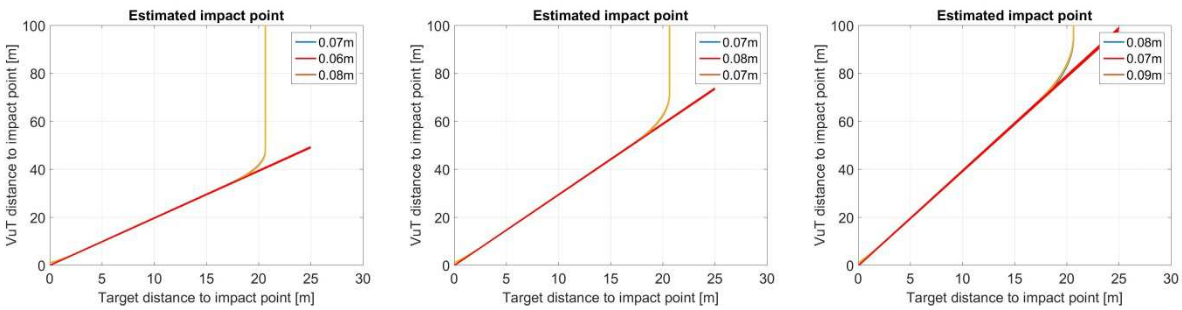


Figure 3-7: VUT distance to impact point as a function of target distance to impact point for CVLB Left to right is 30 ,45 and 60 km/h.

The yaw rate and the lateral accuracy of the test vehicle were within the set specification as depicted in Table 6 due to the use of the steering robot. The plots can be found in appendix A. The lateral accuracy of the target showed some more challenges. Figure 3-8 shows the lateral deviation at estimated impact point computed using video analysis. The platform is manually adjustable in terms of steering to correct the deviation and this was performed several times. It can be seen in that the tests without dummy are more stable, which is in part due to the high wind, however the wheels of the target contacting the ground are also of influence. It also shows that when tests were performed with impact (10-12 and 16-18) the lateral deviation in the subsequent test becomes higher until an adjustment is made.

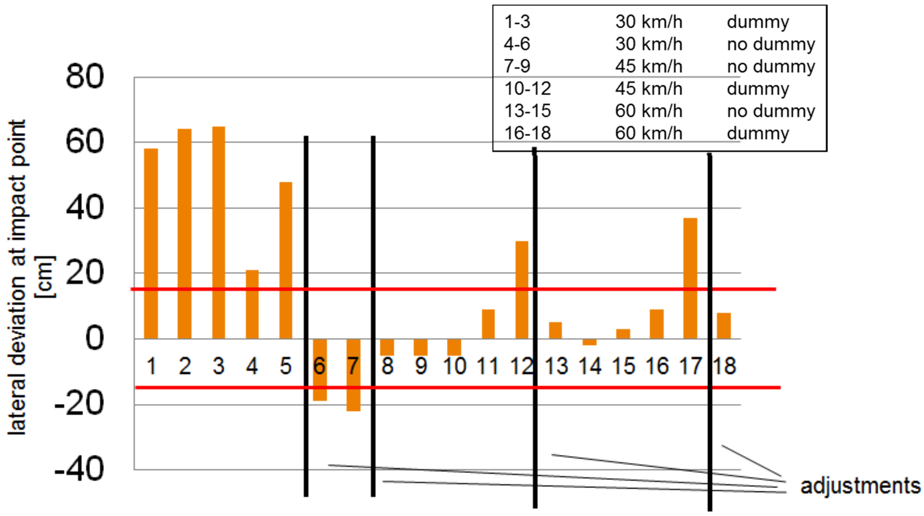


Figure 3-8: Lateral deviation at estimated impact point in the longitudinal scenario

During the impact tests with 45 and 60 km/h the dummy had problems with releasing from the platform. The damage to the target in the 45 km/h tests was limited and testing could continue immediately. The damage to the target in the 60 km/h tests was only to the rear wheel and repairs/reassembly was fast and testing was able to continue within minutes.

Figure 3-9: Dummy target right after the moment of impact with a 60km/h tests. Dummy did not release from platform and damage is visible to rear wheel. However, testing could continue within minutes.

3.3.2 Crossing

Figure 3-10 shows the VUT speed as a function of VUT distance to impact point for all crossing scenarios and speeds tested. Same as for the longitudinal tests, the repeatability is high, showing almost no difference between repeated tests. Also here the miss-synchronization between vehicle speed controller and OxTS measurement system has the effect that the speed it just too low again. In the 20 and 40 km/h tests this seems to be fine since it is stable and constant from the start of the test (purple line at TTC 4s), however it can be seen that at 60 km/h the vehicle is not able to acquire a constant and stable speed at the beginning of the test. This is due to the limited length of the test track used in combination with the acceleration possibilities of the test vehicle. The crossing tests were performed on a different part of the test track than the longitudinal tests. This was done because it was wider to accommodate the crossing scenarios, but unfortunately also shorter. If a longer test track is used the speed requirement is expected, and shown in the longitudinal tests, not to be a problem.

Figure 3-11 shows the target speed as a function of target distance to impact point. Again the tests show a high repeatability with almost no differences between tests. Also the target speed remains within the set limits for this parameter with also being stable and constant from the start of the tests. The exception here is the CVNBO test scenario where the target starts later. This is designed since the target starts behind an obstruction and does not need to start at TTC 4s. In CVFB it can be seen that the velocity of the target starts to go down just before the impact point. This is because of the length of the belt, which was just not long enough for these settings. A safety setting in the systems makes the dummy come to a stop before the end of the travel path of the dummy. In these tests this is done with a deceleration of 2.5 m/s^2. If this value is increased to at least 4 m/s^2 this issue will be solved.

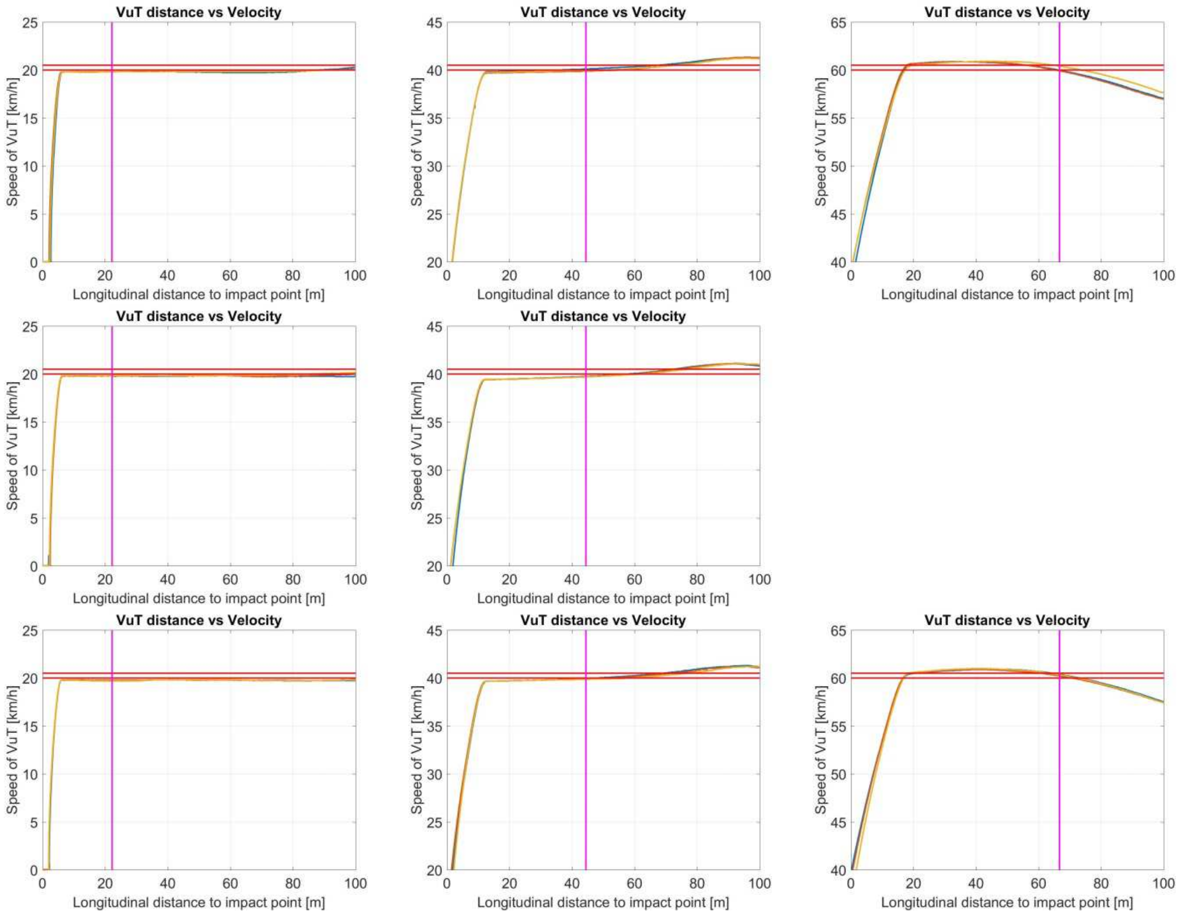


Figure 3-10: VUT speed as a function of VUT distance to impact point. Top to bottom is CVNBU, CVNBO and CVFB. Left to right is 20, 40 and 60 km/h. Red lines indicate the needed accuracy and purple line is TTC is 4s indicating the moment the accuracies should be fulfilled

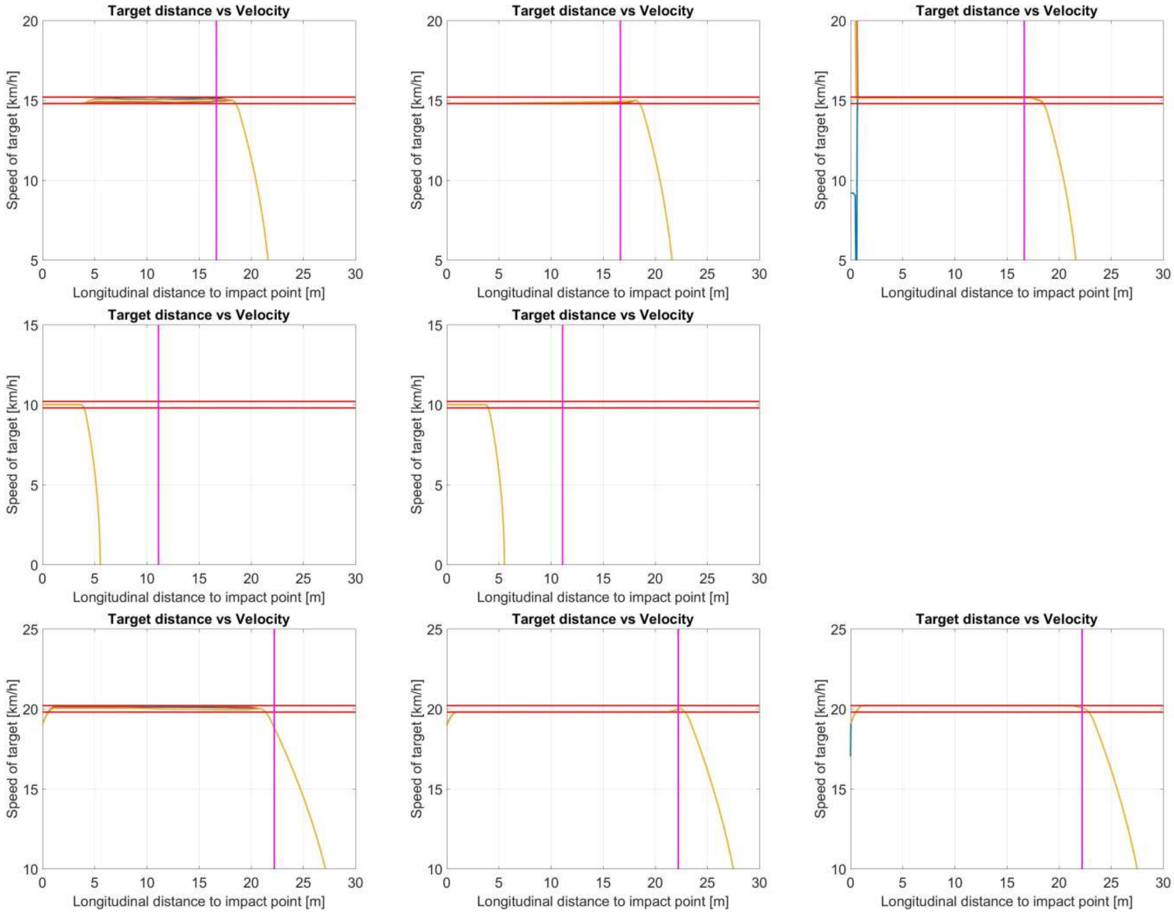


Figure 3-11: target speed as a function of target distance to impact point. Top to bottom is CVNBU, CVNBO and CVFB. Left to right is 20, 40 and 60 km/h. Red lines indicate the needed accuracy and purple line is TTC is 4s indicating the moment the accuracies should be fulfilled

Figure 3-12 shows the VUT distance to impact point as a function of target distance to impact point. If the constant velocity parts are extrapolated the expected collision point can be computed. It can be seen that for the 20 and 40 km/h this expected collision point compares well with the desired collision point. However for the 60 km/h it is too low. This is because the system does not allow the dummy to go faster than the accuracies described in Table 6 as can be seen in Figure 3-11. Since the vehicle speed is too high in the 60 km/h tests, the target will be too late (actually the VUT is too early) at the collision point resulting in too low collision points.

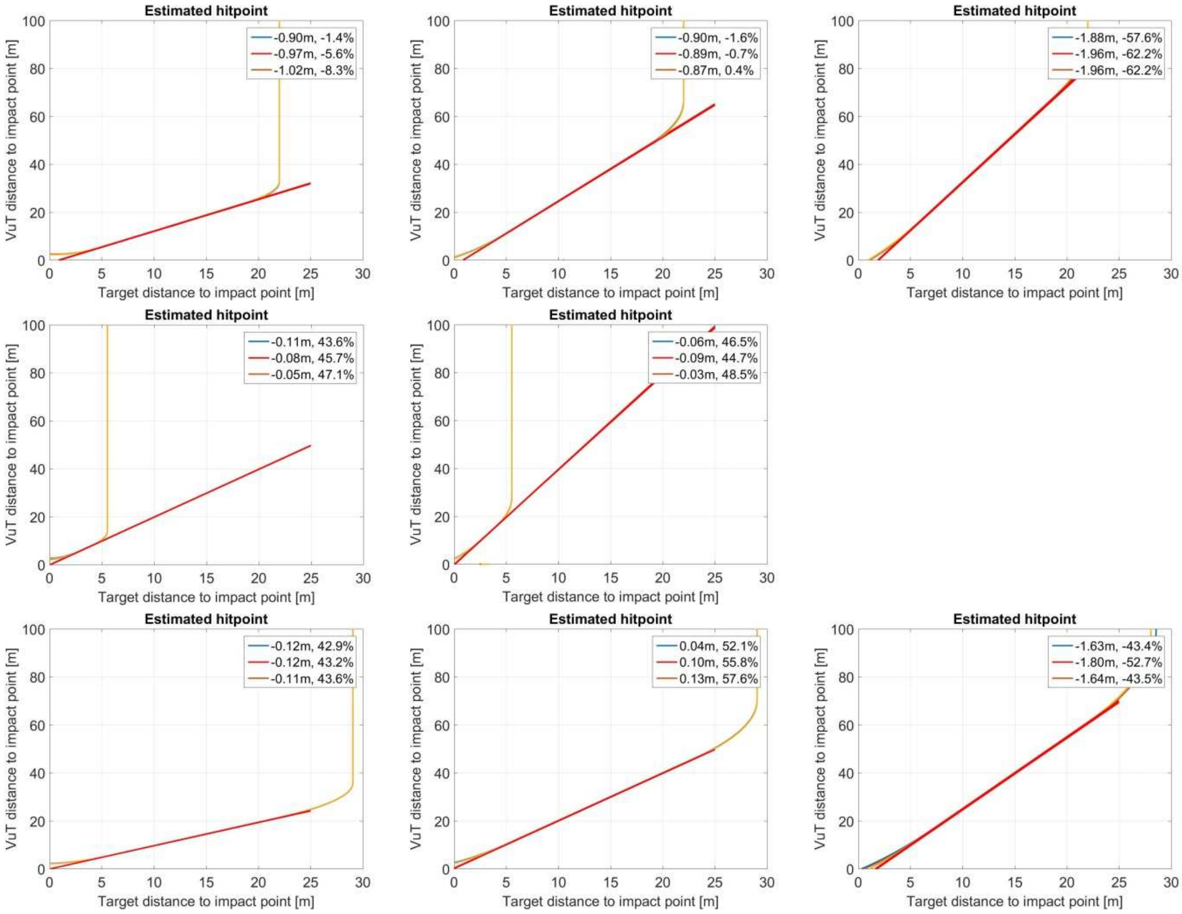


Figure 3-12: VUT distance to impact point as a function of target distance to impact point. Top to bottom is CVNBU, CVNBO and CVFB. Left to right is 20, 40 and 60 km/h.

The yaw rate and the lateral accuracy of the test vehicle were within the specification as depicted in Table 6 due to the use of the steering robot. The plots can be found in appendix A. The lateral accuracy for the target in the crossing scenarios could not be evaluated since no tests with the dummy target were performed. However the lateral accuracy without dummy target was checked and was for all tests lower than 5cm at estimated impact point even after several impacts. Just as for the longitudinal scenarios it shows that the lateral accuracy with dummy on the platform is more difficult than without.

No dummy impact tests were performed in this test series in the crossing scenario. Therefore it is not possible to assess the robustness of the target in these tests, however in-house extensive testing by 4activeSystems GmbH showed a high robustness.

3.4 Robustness test series – wk. 10 & 14 2016

3.4.1 Longitudinal

After the first test series (week 47, 2015) 4activeSystems GmbH optimized the updated platform in terms of its lateral accuracy and this was tested in an additional test series (week 10, 2016). The results of this test series can be found in Figure 3-13. It can be seen that the first 9 tests are, with 1 exception, all within the set accuracy limit. However after the first impact with the 60 km/h test the lateral deviation from the impact point was high and remained as such for all subsequent tests.

Later it was found that these large lateral deviations were due to the impact described above. The platform was damage in such a way that the bottom was loose and was in contact with the ground causing steering. 4activeSystems GmbH changed the bottom cover of the platform and the way it is attached. Furthermore larger and harder wheels were installed to further improve the lateral accuracy. This again was tested in an additional test series (week 14, 2016) for which the results can be found in Figure 3-14. It can be seen that the lateral deviation is reduced substantially for the 15 km/h of the target, especially when keeping in mind that the wind was high to very high during this additional test series. It does, however, reveal that the 20km/h of the target still seems to be a challenge in this setup, which might be an issue when testing the low overlap test for the forward collision warning.

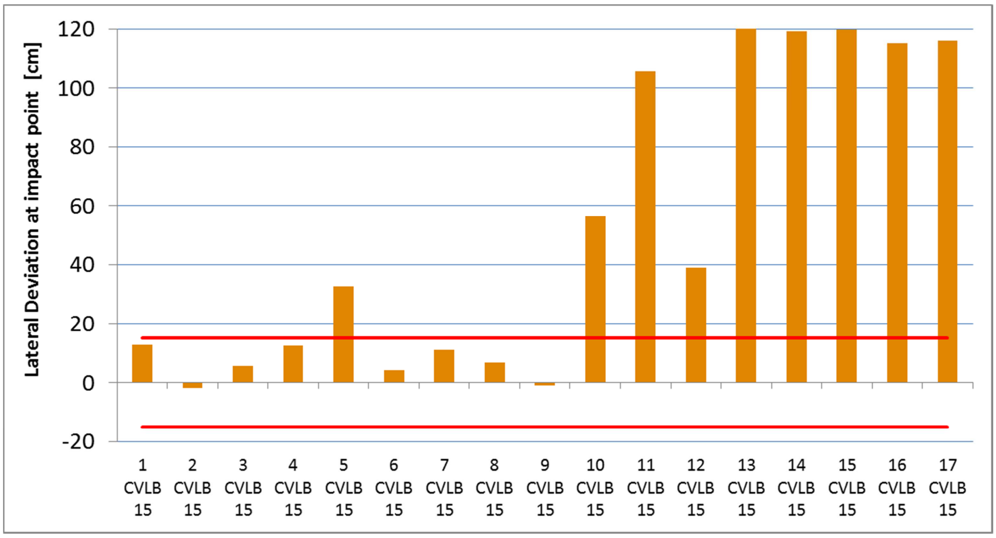


Figure 3-13: lateral deviation at estimated impact point in the longitudinal scenario in the first additional test series (week 10, 2016)

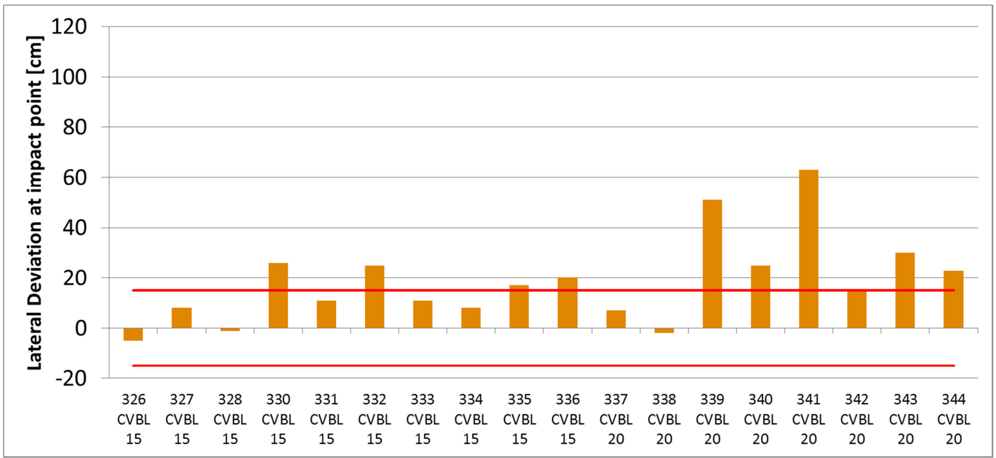


Figure 3-14: lateral deviation at estimated impact point in the longitudinal scenario in the second additional test series (week 14, 2016)

Whereas the dummy did not release from the platform in the original test series, it did in both of the additional test series. The robustness remained high in the longitudinal scenario. With minor repairs and fast reassembly testing could always continue fast.

3.4.2 Crossing

Due to the large impact on the platform in the longitudinal test in the first additional test series (week 10, 2016), the platform was damaged and unable to keep a sufficient lateral accuracy as described in paragraph 3.4.1. This also had the effect that the lateral deviation in the subsequent crossing tests was high as can be seen in Figure 3-15.

In the second additional test series (week 14, 2016) the lateral accuracy was within specifications for most of the tests (Figure 3-16) even though the wind was very high. Just as for the longitudinal scenario, the 20km/h target speed as specified in the CVFB scenario was still a challenge.

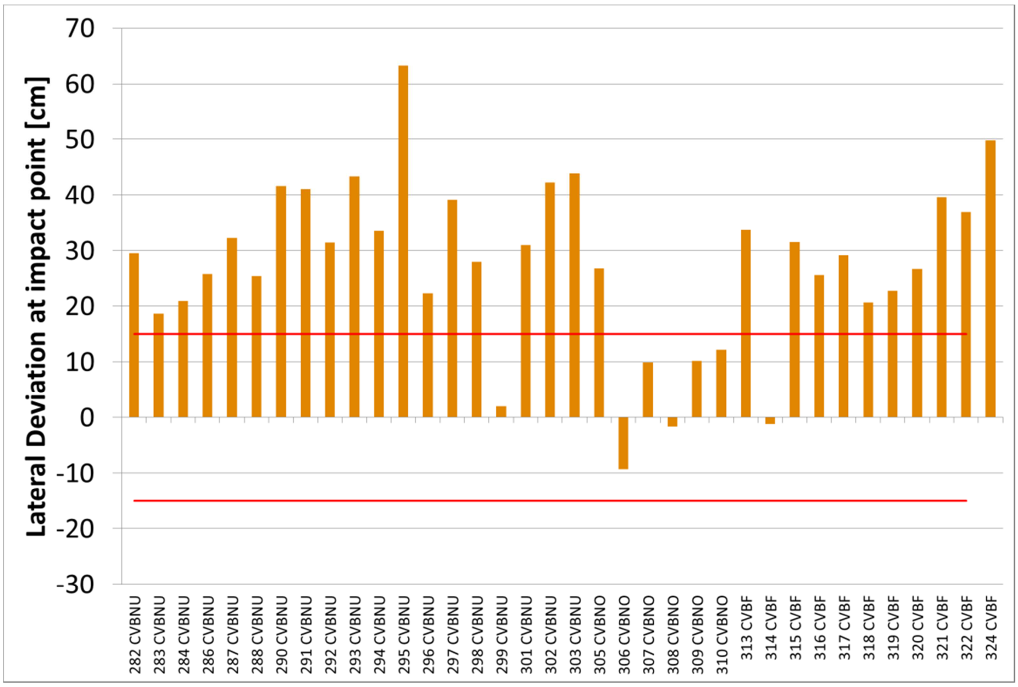


Figure 3-15: lateral deviation at estimated impact point in the crossing scenario in the first additional test series (week 10, 2016)

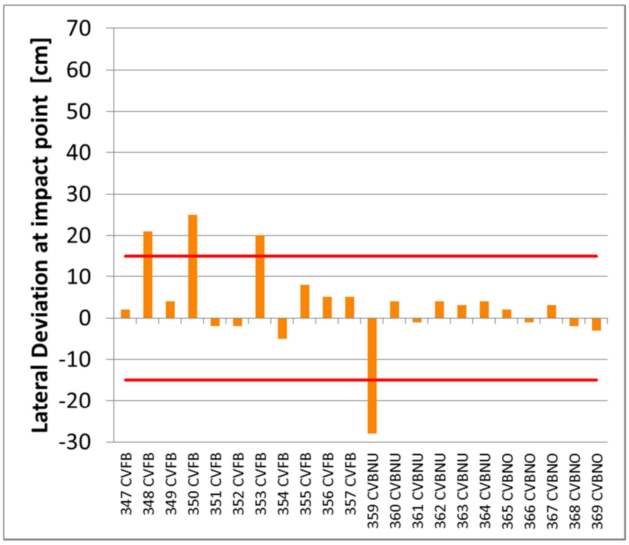


Figure 3-16: lateral deviation at estimated impact point in the crossing scenario in the second additional test series (week 14, 2016)

In both additional test series the dummy target showed a high robustness in the crossing scenario when impacted. The dummy always released from the platform and damages were mostly minor. When something did eventually failed, the part was easily replaced and testing could continue fast.

3.5 Simulation study – Version June 2015

Figure 3-17 shows the simulation results for the Draft CATS test matrix (Version June, 2015) as presented in Table 2. It shows the velocity reduction as a function of initial velocity for all crossing scenarios with narrow and wide viewing angle cyclist AEB systems, translating into 2x 24 and 2x45 degree viewing angle respectively. Furthermore 3 lines per figure can be seen, representing the results for standard AEB braking at 1.0s TTC and including medium and maximum cyclist dynamics (4.5 m/s^2 and 7.0 m/s^2 braking).

It can be seen that CVNBU (target: 15km/h – 0%) shows AEB activation from 45 km/h and up with the narrow viewing angle system and for all velocities in the wide viewing angle system. When there is an AEB activation the car can stop up to 45 km/h before the collision point and avoid the collision up to 50 km/h when not taking into account the possible cyclist dynamics. When cyclist dynamics are added, the car delays its braking activation to ~0.72s and ~0.56s TTC for the medium and maximum possible braking of the cyclist, respectively. This results in a lower velocity reduction. For the medium cyclist dynamics it can still stop before the collision point up to 25 km/h when the AEB is activated, however for the maximum cyclist dynamics a collision is inevitable.

For the CVNBO (target: 10km/h – 50%) it can be seen that the car can stop before the collision point when there is an AEB activation independent on the cyclist dynamics. This is because even for the maximum cyclist possible braking the TTC for AEB activation is still ~0.93s. The “high” state of the art provides better performance due to larger viewing angle increasing performance down to 15 km/h compared to the 30km/h for the “low” state of the art system. The view blocking obstruction seems to have little effect even for the higher speeds. At 40 km/h the detection is at ~1.3s while braking is triggered at 1.0s without cyclist dynamics and as mentioned above at ~0.93s for maximum cyclist dynamics. Only when the detection delay is increased from 0.2s to 0.6 it will have an effect on the moment of AEB activation.

CVFB (target: 20km/h – 50%) shows performance from 50km/h and up for the narrow viewing angle system and from 25km/h for the wide viewing angle system. It will stop before the collision point up to 45km/h and will avoid the collision for the speeds above when AEB is activated at TTC 1.0s, which is the case when no to medium cyclist dynamics are taken into account. When including maximum possible braking the AEB activation lowers to 0.77s TTC and a collision is inevitable from 40km/h and up.

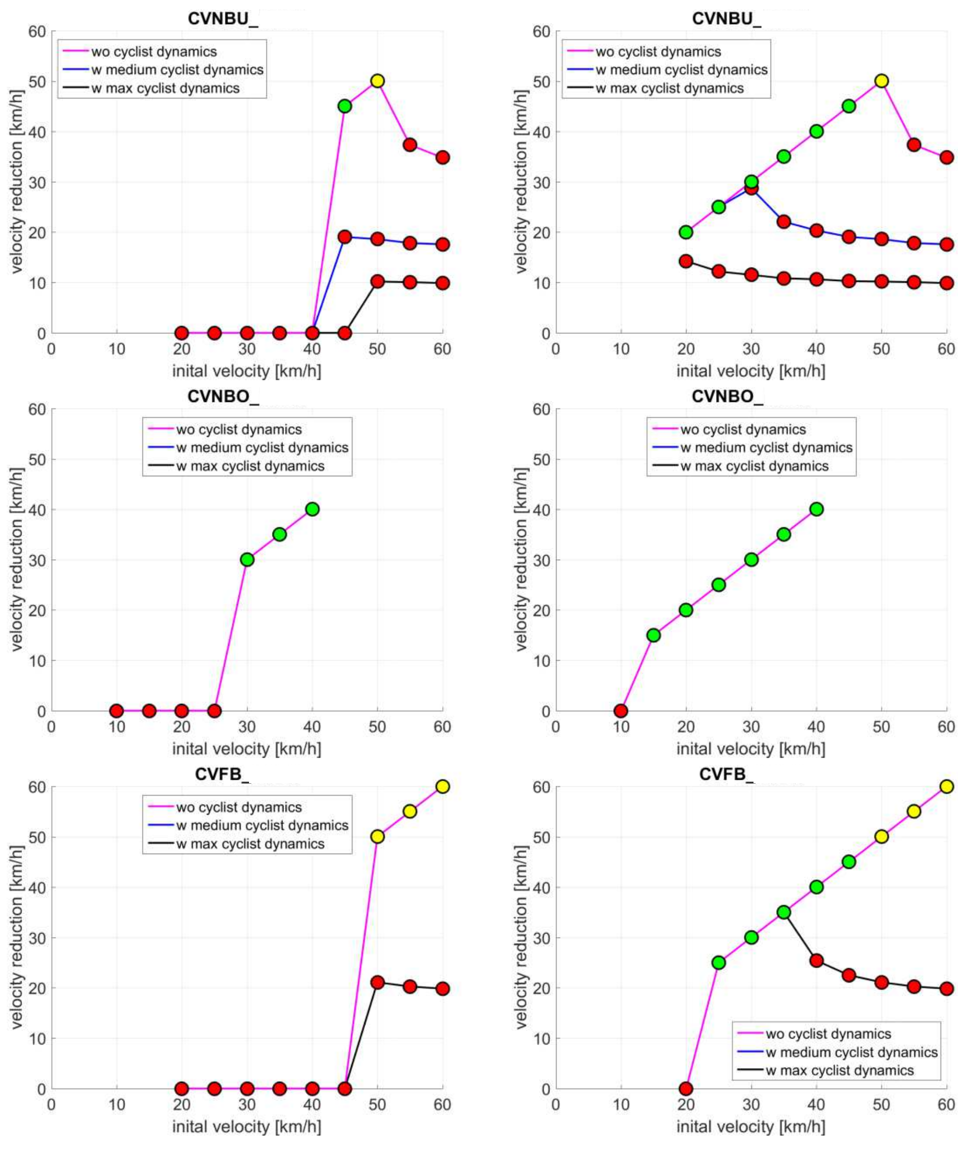


Figure 3-17: Simulation results for the Draft CATS Matrix (Version June 2015) as presented in Table 2. Velocity reduction as a function of initial velocity. Top to bottom is CVNBU, CVNBO and CVFB. Left is the 24 degree viewing angle and right the 45 degree viewing angle. A green dot indicates an avoidance due to full stop, a yellow dot an avoidance due to the target leaving the VUT area and a red dot an impact. The pink line is braking at TTC 1.0s, blue and black line including PONR for 4.5m/s^2 and 7.0 m/s^2 of possible cyclist braking

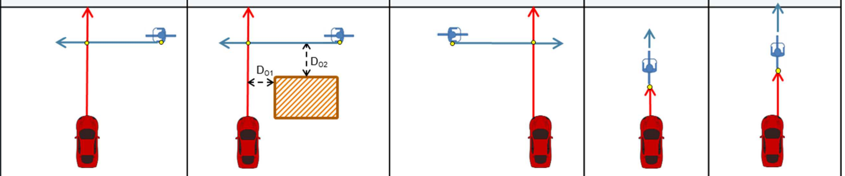
3.6 Updated test matrix

Taking into account all the tests and simulations performed a discussion followed with in the CATS consortium regarding modifications of the existing test matrix. Based on current feasibility it was proposed to change the collision point between the CVFB and CVNBU scenarios. This causes the CVNBU test to become more- and the CVFB less challenging regarding detection and determining AEB activation. In order for the CVFB scenario not to become too challenging the collision point will be changed to 25% instead of 0%. Even though the coverage will be less, the trend of lower overlaps still corresponds with accidentology [6]. In the introduction of the cyclist AEB assessment more focus will then lay on the CVNBU scenario and later evolve towards the more difficult CVFB scenario. This ensures a two-step approach in difficulty, whereas in the original test matrix the difficulty was similar between CVNBU and CVFB. This also enables better discrimination between performances of different systems.

Furthermore it is proposed to change the collision point in the FCW longitudinal scenario to 25% instead of 20% for the higher speeds. This is in part due to the challenges found in the lateral accuracy of the target. Due to the flexible behaviour of a cyclist it is important to have a high lateral accuracy with low overlaps for a robust triggering of the AEB system. This 25% still corresponds to accidentology.

The updated draft test matrix (Version January 2016), which now also included an expected feasibility in 2018 (Also based on information received from industry on future sensor and control systems.) and some important notes, can be found in Table 10.

Table 10. Updated draft CATS car-to-cyclist AEB test matrix (version January 2015)

	CVNBU	CVNBO	CVFB	CVLB	
Vehicle speed	20 – 60 km/h	10 – 40 km/h	20 – 60 km/h	30 – 60 km/h	65 - 80 km/h
Cyclist speed	15 km/h	10 km/h	20 km/h	15 km/h	20 km/h
Obstruction	Without	With D1=3.55m, D2=4.80m	Without	Without	Without
Overlap hitpoint	50 %	50 %	25 %	50%	25 %
AEB / FCW	AEB	AEB	AEB	AEB	FCW
# tests [36]	9	7	9	7	4
Layout sketch					
Expected feasibility 2018	YES	YES	NO	YES	
Important notes:	• Main challenge in CVNBU is system robustness (AEB response after collision is unavoidable: cyclist cannot break or steer away to avoid collision).	• Main challenge in CVNBO is the limited time for system response.	• CVFB is not expected to be feasible for production vehicles in 2018, especially due to challenges in Field-of-View requirements, response time and real-world robustness.	• Recommended to verify that the vehicle shows AEB performance with a 25% overlap in the AEB speed range (30 – 60 km/h) to ensure AEB performance at overlaps below 50%.	
	• Field-of-View is a general issue for the 3 crossing scenarios at low vehicle speeds. • System robustness is a general issue for the 3 crossing scenarios at high vehicle speeds.			• Evaluation of FCW considers collision avoidance by steering and not braking.	

3.7 Verification test series – All partners –Wk. 16, 17 & 19 2016

During the 3 workshops all planned tests, their repeats, and more, could be performed, except for the 85 km/h CVLB test due to the use of the light barriers.

This is because the light barriers could not be placed that far away in order to trigger the target at the correct time.

In terms of realism and feasibility of the test scenarios, feedback from the participants was received.

For the longitudinal scenario several comments were received regarding the lateral accuracy of the target. Even though acceptable robustness tests were performed regarding the lateral accuracy (paragraph 3.4.1), it was still found to be too large based on the visual inspection of the test drivers. If no to little wind was present and no impacts occurred the lateral deviations remained within the specification set. However the lateral accuracy was not achieved in a robust way if there is wind. Furthermore, when the dummy was impacted, the lateral deviation became larger each test until an adjustment was made. With more severe impacts, when parts need to be replaced, it was also observed that several tests were needed to find the correct adjustment for a sufficient lateral accuracy. It is suggested to investigate and optimize the lateral accuracy even further.

What was also commented multiple times was that the dummy starts moving to close to the car, especially at lower VUT speeds. Even though this still corresponds with 4s TTC, the distance between the VUT and target felt too close in the lower VUT speed range. This could be solved by introducing a minimal distance between the VUT and target at the moment of the start of the test. However this does create a longer travel distance of the target, which is not beneficial for the lateral accuracy.

Another comment received was that the collision point in the crossing scenarios seemed not to be correct where the target arrived either too early or too late at the collision point. This is most likely due to the use of the light barriers. The target is triggered using a single light barrier and when the speed of the VUT changes after that, it is not compensated anymore until it reaches the last light barrier. Since only a 0.2 km/h target velocity error is allowed, the target is not able to adjust enough anymore, resulting in an offset of the collision point. This is not the case when using a GPS system, which is used in the official tests (unfortunately not in this test series due to the large amount of participants).

Several comments were also received about the view blocking obstruction in the CVNBO scenario. The obstruction was regarded as sufficient, however not up to a level for official testing. There is a need for a better specification of the properties in terms of geometry and radar properties.

The attachment of the belt to the platform was regarded as a weak point and was suggested to be improved.

The robustness of the target was commented to be good in the crossing scenarios, where the dummy was almost not damaged when impacted and put together quickly. In the longitudinal scenario testing could also continue quickly after an impact, however it needed spare parts in most impacts. This is in itself not an issue, however it could raise the costs of testing.

Just as is described in the draft test matrix (version January 2016), most participants thought that all scenarios are found (partly) feasible except for CVFB, which is thought to be too challenging for introduction in 2018.

3.8 Simulation study – Version January 2016

Figure 3-18 shows the simulation results for the updated Draft CATS test matrix (Version January, 2016) as presented in Table 10. It shows the velocity reduction as a function of initial velocity for all crossing scenarios with narrow and wide viewing angle cyclist AEB systems, translating into 2x 24 and 2x45 degree viewing angle respectively. Furthermore 3 lines per figure can be seen, representing the results for standard AEB braking at 1.0s TTC and including medium and maximum cyclist dynamics (4.5 m/s^2 and 7.0 m/s^2 braking). In this paragraph the results will be compared with the original test matrix of which the analysis can be found in paragraph 3.5.

It can be seen that CVNBU (target: 15km/h – 50%) shows AEB activation from 40 km/h and up for the narrow viewing angle system compared to 45 km/h in the original test matrix where this scenario still had a 0% overlap. For the "wide viewing angle system still all velocities showed an AEB activation. When there is an AEB activation the car can still stop up to 45 km/h before the collision point and avoid the collision up to 55 km/h instead of 50 km/h when not taking into account the possible cyclist dynamics. When cyclist dynamics are added, the car delays its braking activation to ~0.95s and ~0.79s TTC for the medium and maximum possible braking of the cyclist, respectively. This is less delay than in the original test matrix where the car waited to ~0.72s and ~0.56s TTC. This waiting still results in a lower velocity reduction. For the medium cyclist dynamics it can still stop before the collision point up to 40 km/h instead of 25 km/h when the AEB is activated and now even still avoid the collision at 50 km/h. Whereas no stopping before collision point was possible in the original test matrix with maximum cyclist dynamics, now it can up to 35 km/h.

For the CVNBO (target: 10km/h – 50%) nothing changed in the analysis in paragraph 3.5 is still valid.

CVFB (target: 20km/h – 25%) still shows performance from 50km/h and up for the narrow viewing angle system and from 25km/h for the wide viewing angle system. Also it will still stop before the collision point up to 45km/h and will avoid the collision for 50 and 55 km/h when AEB is activated at TTC 1.0s. At 60 km/h the collision is not avoided any more due to the lower overlap which makes it take more time for the cyclist to leave the VUT area. In the original test matrix the medium cyclist dynamics had no effect and braking still was activated at 1.0sTTS, but in the updated test matrix it does and the AEB is activated at ~0.9s TTC. This causes an inevitable collision from 50 km/h and up. When including maximum possible braking the AEB activation lowers from ~0.77s TTC in the original test matrix to ~0.68s and an collision is inevitable from 30km/h and up instead of 40 km/h.

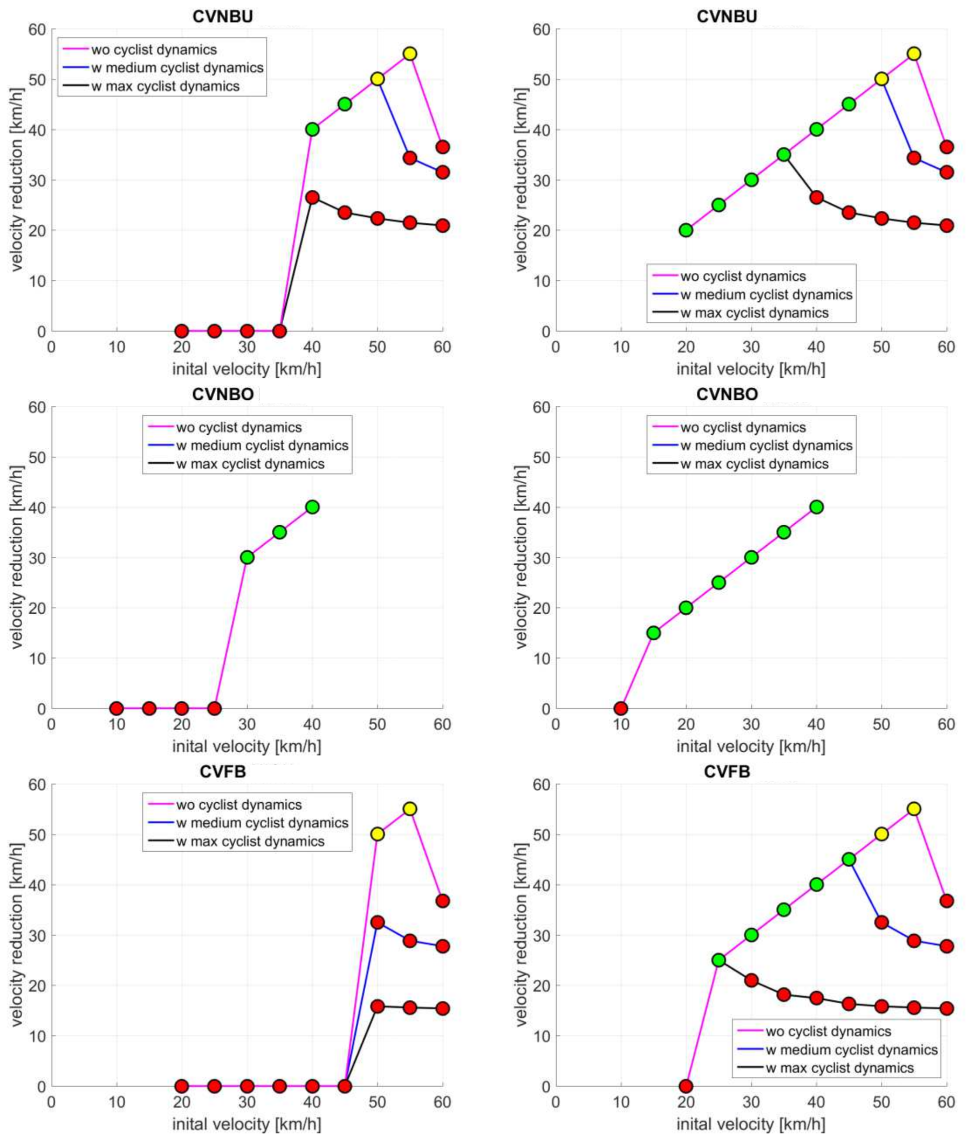


Figure 3-18: Simulation results for the updated Draft CATS Matrix (Version January 2016) as presented in paragraph 3.6. Velocity reduction as a function of initial velocity. Top to bottom is CVNBU, CVNBO and CVFB. Left is the 24 degree viewing angle and right the 45 degree viewing angle. A green dot indicates an avoidance due to full stop, a yellow dot an avoidance due to the target leaving the VUT area and a red dot an impact. The pink line is braking at TTC 1.0s, blue and black line including PONR for $4.5 m/s^2$ and $7.0 m/s^2$ of possible cyclist braking

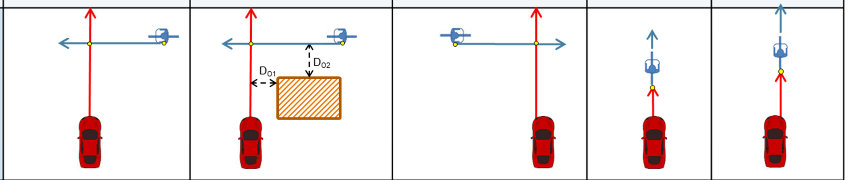
4 Conclusion

From WP1 and WP2 a draft CATS test matrix (version June 2015) is constructed. A full specification test series, a verification workshop with all CATS partners, a robustness test series and a simulation study have been performed using this test matrix as a basis. The first three activities focussed mostly on the feasibility of the test matrix. It was found that the near side (CVNBU) and far side (CVFB) test scenarios were, in terms of their feasibility, similar. In order to ensure a two-step approach in difficulty to enable a better discrimination between performances of different systems, it was suggested to change the collision point from both test scenarios. The CVNBU scenario would change to 50% compared and the CVFB scenario to 25% compared to the original 0% and 50%, respectively. This causes the CVNBU test to become more- and the CVFB less challenging regarding detection and determining AEB activation. Even though the coverage will be less, the trend of lower overlaps still corresponds with accidentology [6].In the introduction of the cyclist AEB assessment more focus will then lay on the CVNBU scenario and later evolve towards the more difficult CVFB scenario.

The robustness test series showed that the practical execution with respect to the set criteria was possible, although the lateral accuracy of the target remained a challenge. It was therefore proposed to change the collision point in the FCW longitudinal scenario to 25% instead of 20% for the higher speeds. This 25% still corresponds to accidentology [6] .

This updated CATS test matrix (version January 2016), which now also included expected feasibility in 2018, was again checked with a verification workshop with all CATS partners and a simulation study. During the discussion following these activities, it was found that no changes were needed to the updated Draft test matrix (Version January 2016) and that this test matrix would become the final CATS matrix. For completeness this can be found again in Table below.

Table 11. Final CATS car-to-cyclist AEB test matrix (Version January 2016)

	CVNBU	CVNBO	CVFB	CVLB	
Vehicle speed	20 – 60 km/h	10 – 40 km/h	20 – 60 km/h	30 – 60 km/h	65 - 80 km/h
Cyclist speed	15 km/h	10 km/h	20 km/h	15 km/h	20 km/h
Obstruction	Without	With D1=3.55m, D2=4.80m	Without	Without	Without
Overlap hitpoint	50 %	50 %	25 %	50%	25 %
AEB / FCW	AEB	AEB	AEB	AEB	FCW
# tests [36]	9	7	9	7	4
Layout sketch					
Expected feasibility 2018	YES	YES	NO	YES	
Important notes:	• Main challenge in CVNBU is system robustness (AEB response after collision is unavoidable: cyclist cannot break or steer away to avoid collision).	• Main challenge in CVNBO is the limited time for system response.	• CVFB is not expected to be feasible for production vehicles in 2018, especially due to challenges in Field-of-View requirements, response time and real-world robustness.	• Recommended to verify that the vehicle shows AEB performance with a 25% overlap in the AEB speed range (30 – 60 km/h) to ensure AEB performance at overlaps below 50%.	
	• Field-of-View is a general issue for the 3 crossing scenarios at low vehicle speeds. • System robustness is a general issue for the 3 crossing scenarios at high vehicle speeds.			• Evaluation of FCW considers collision avoidance by steering and not braking.	

5 Signature

Helmond, September 2nd 2016

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6 References

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[10] Euro NCAP AEB VRU Test Protocol v1.0.1, June 2015

[11] Rodarius, C., Kwakkernaat, M., Edwards, M, *Benefit estimate based on previous studies for pre-crash bicyclist systems and recommendations for necessary changes to pedestrian test and assessment protocol*, AsPeCSS deliverable D1.5, SST.2011.RTD-1 GA No. 285106, June 2014

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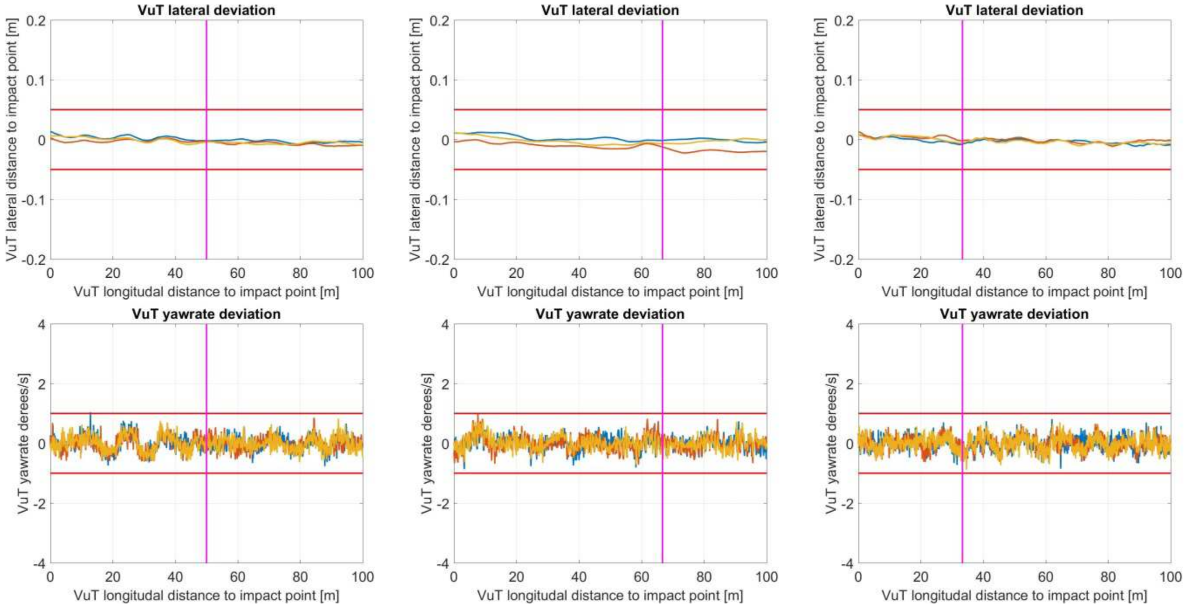
7 Acknowledgements

The CATS consortium gratefully acknowledges the contributions from:

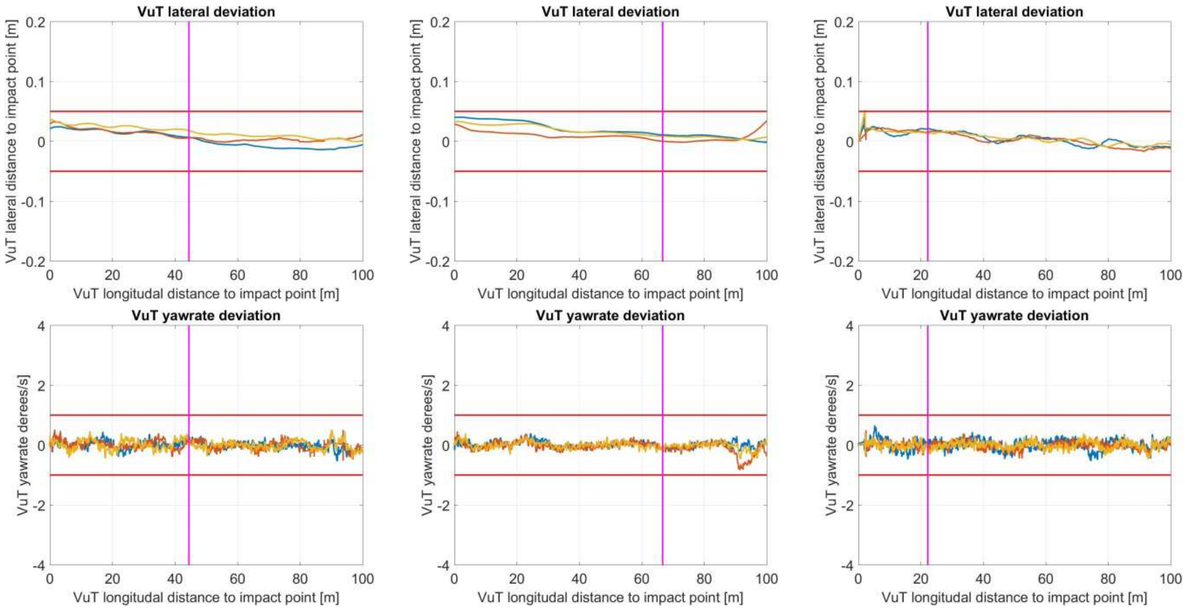
A Robustness test series

In this appendix the lateral deviation and yaw rate with their corresponding limits are shown for each scenario as measured in the robustness test series in week 47 2015. The red lines indicate these limits and the purple line the defined start of the test at 4s TTC.

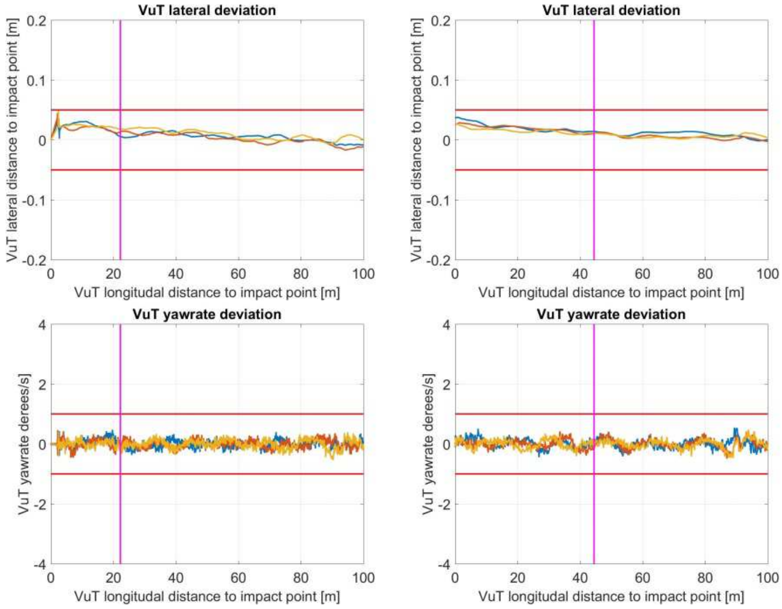
CVLB



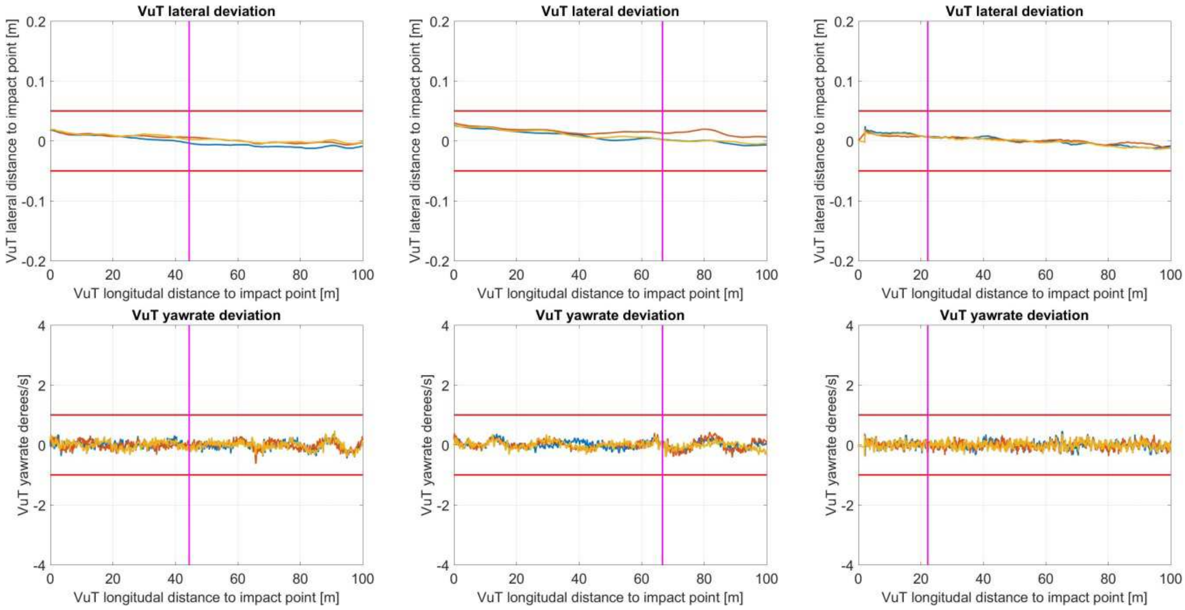
CVNBU



CVNBO


VuT lateral deviation
VuT lateral distance to impact point [m]
VuT longitudal distance to impact point [m]
VuT yawrate deviation
VuT yawrate derees/s]

CVFB


VuT lateral deviation
VuT lateral distance to impact point [m]
VuT longitudal distance to impact point [m]
VuT yawrate deviation
VuT yawrate derees/s]