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CATS Deliverable 6.1:
CATS Final project summary report

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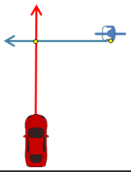
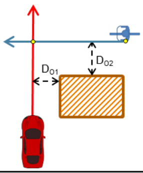
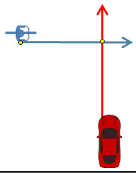
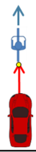
Summary

To support and prepare the introduction of Cyclist-AEB systems and the appropriate consumer tests of such systems, TNO has taken the initiative to set-up a project with passenger car manufacturers and suppliers with the support of research and development partners (such as BASt and 4activeSystems) to develop a testing system and test protocol for Cyclist-AEB systems: CATS, Cyclist-AEB Testing System.

This report describes the setup of the project and the approach that was followed from the start in June 2014 to the conclusion in June 2016. Moreover, the report summarises the most important results out of the project. The project has delivered:

- A verified test protocol for Cyclist-AEB systems in Euro NCAP format, according to the following test matrix (final CATS test matrix, version June 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
Collision point*	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% collision point with a VUT speed of 45 km/h to ensure AEB performance at a collision point 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.	

* collision point, defined as percentage of the width of the vehicle-under-test (see Figure 20-Figure 22)

  The project has provided a solid background for the choices in this matrix, based on detailed accidentology analyses, an observation study, simulations, robustness tests and verification tests. An indication is given regarding the expected feasibility of an appropriate Cyclist-AEB system response for the different test scenarios. The main challenges for AEB systems have been included in the matrix as well.
- A bicyclist and bike target (BT) that represents an average adult human bicyclist on an average European utility bike, including detailed specifications. Also an appropriate propulsion system has been developed for the BT. Target and propulsion system are developed such, that all tests as specified in the test matrix can be performed.
- Detailed project reports with the analyses and results. These project reports are made public after conclusion of the project. Moreover, the results have been presented at several relevant international conferences and congresses.

  Moreover, the results were communicated to relevant stakeholders not only in Europe, but worldwide, specifically in Japan and the US.

Contents

1 Introduction

Where the number of road fatalities for the EU28 is decreasing every year, the number of cyclist fatalities decreases at a slower pace. In Figure 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 [17]. 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 [18] and consequently the increasing number of cyclists on the road, while accident scenarios for occupants and pedestrians are increasingly addressed by passive and active safety systems.

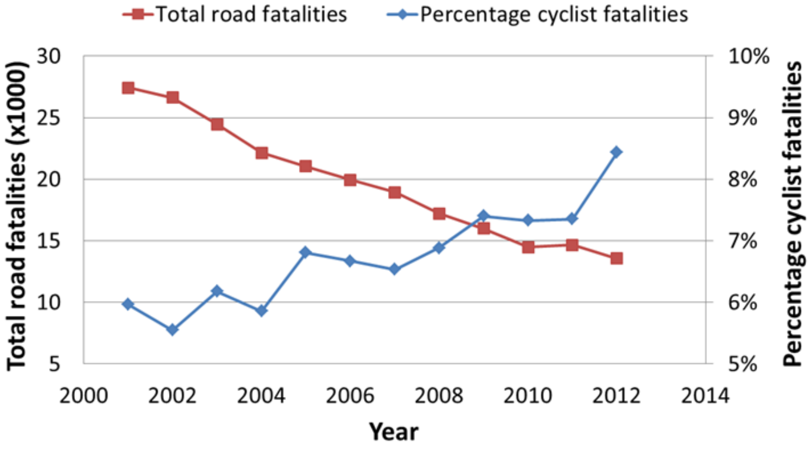


Figure 1 Trends of total road fatalities and cyclist fatalities for France, Germany, Italy, the Netherlands, Sweden plus the UK over the period of 2001 to 2012 [17].

To protect vulnerable road users in collisions with cars, the automotive industry is developing and implementing passive safety systems to mitigate injuries once a collision is unavoidable. More recently, in addition to passive safety systems, active systems are being developed and deployed that aim at collision avoidance and mitigation. With on-board sensors such as camera and radar, a real-time estimate is made of the current traffic situation, and the risk of running into a collision is continuously computed, in order to determine appropriate action. One of the most promising active safety systems, Autonomous Emergency Braking-systems (AEB), supports the driver e.g. with an audio, visual and/or haptic warning and by automated braking to avoid or mitigate imminent crashes. Currently, AEB systems that aim at avoiding and mitigating car-to-car and car-to-pedestrian collisions are part of the Euro NCAP test protocol and star rating. Avoidance or mitigation of cyclist-car accidents is of increasing relevance for the reduction of fatalities and seriously injured amongst road users. This has also been recognized by Euro NCAP, which will include the assessment of Cyclist-AEB systems from 2018 onwards in their safety assessment [16], see Figure 2.
In anticipation of the introduction of Cyclist-AEB systems and the corresponding consumer tests, in the spring of 2014, TNO has taken the initiative to set up a consortium (CATS: Cyclist-AEB Testing System) 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.

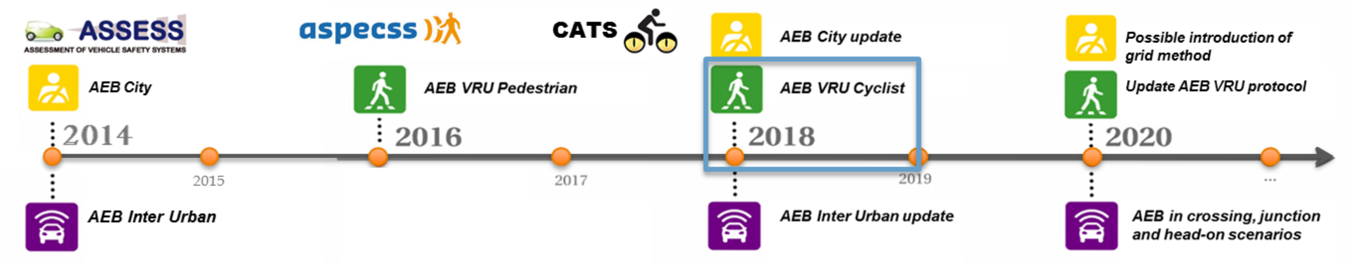


Figure 2: Euro NCAP AEB roadmap 2014 – 2020

The CATS project was unique in the fact that developments were performed in a consortium of 10 car manufacturers and 7 automotive suppliers, with BASt as review partner. The project was supported by the Netherlands Ministry of Infrastructure and the Environment.
The cooperation in the project has stimulated the harmonization and acceptance of the protocol, target and test setup. The progress and intermediate results including the used methodology have been shared on a regular basis during the project with stakeholders in Europe, Japan and the USA. Euro NCAP indicated to consider the results of the CATS project as the main input to draft the test protocol, including scenarios and target for Cyclist-AEB systems in 2018.
The assessment of Cyclist-AEB systems and the corresponding scoring scheme was outside the scope of the CATS project. CATS fully focussed on proposing a feasible test matrix, and developing the test equipment with which the proposed tests can be performed.

The report shows the process for coming to a proposal for the Cyclist-AEB test matrix (in short: CATS test matrix) and the test equipment including a cyclist target needed to perform the tests. Moreover, in Chapter 2, the process for verification, communication and dissemination of the results is described. A summary of the most important results is given in Chapter 3.

2 The CATS project

2.1 Objectives and project setup

The objectives of the CATS project are to:

- Analyse the most relevant cyclist accident scenarios in EU countries,
- Prepare the introduction of a Cyclist-AEB protocol for consumer tests & alignment with AEB working groups of Euro NCAP, ACEA/JAMA/KAMA and CLEPA,
- **Propose a test setup (incl. hardware) and test protocol for Cyclist-AEB systems based on technical and scientific considerations**.

The CATS project has resulted in a Cyclist-AEB protocol for consumers tests, which is proposed to industry and Euro NCAP:

- Report on accident scenarios
- Delivery of one dummy set (hardware delivery) to each project participant
- Report on propulsion system and dummy specifications
- Report on AEB verification tests
- Test protocol description & specification, including a proposal for a test matrix

TNO has managed the CATS project in which 10 car manufacturers and 7 TIER1 suppliers cooperated. 4activeSystems GmbH (4a), an SME based in Austria, has developed and manufactured the target and propulsion system according to the specifications set up in the project. The project consisted of 6 work packages, namely:

- WP1 Accident Analysis
- WP2 Test scenario definition
- WP3 Dummy development
- WP4 Propulsion system development
- WP5 Verification testing
- WP6 Dissemination & Euro NCAP AEB WG involvement

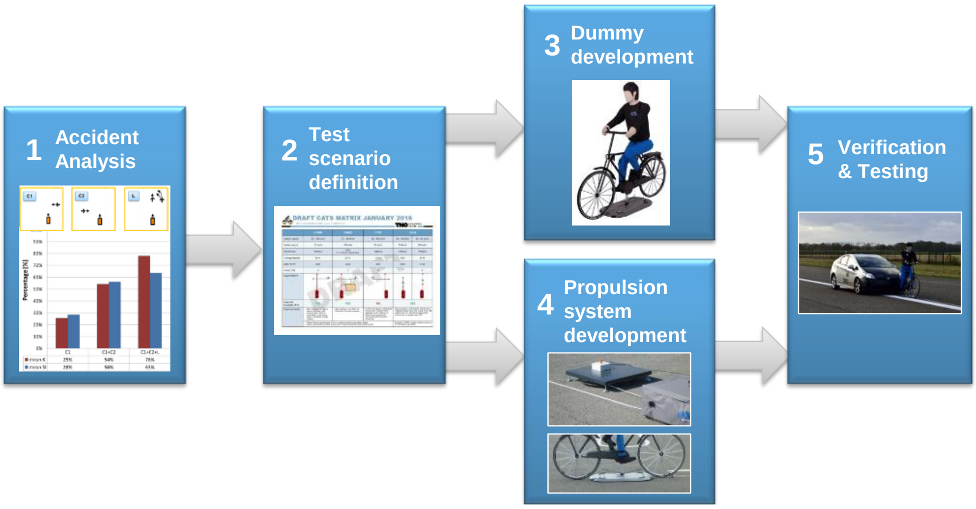


Figure 3: Overview of the work packages in CATS focused at protocol and target development

WP1 Accident analysis

- Objective
  - Analysis of cyclist to passenger car accident scenarios in EU (with a focus on Germany, Netherlands, Sweden, France, Italy and the UK)
  - Focus on killed and severely injured
  - Select the most relevant accident scenarios for test protocol development
- Activities
  - Review of national cyclists data of various countries
  - Definition of the 3 to 4 most relevant accident scenarios and its corresponding statistic information (based on relevance and feasibility)
- Deliverables
  - D1.1: Presentation on final accident scenarios
  - D1.2: Report on final accident scenarios (Public)

WP2 Test scenario definition

- Objective
  - Determination of scenario parameters based on literature, accidentology and real life measurements
  - Definition of the 3 to 4 most relevant test scenarios
- Activities
  - Translation of accident scenarios from WP1 to test scenarios
  - Determination of parameter values based on literature, accidentology and real-life measurements
  - Definition of a test protocol
- Deliverables
  - D2.1: Presentation of draft test protocol
  - D2.2: Report on accident parameters and test scenarios (Public)
  - D2.3: Report on observation study (Public)

WP3 Dummy development

- Objective
  - Development of a representative cyclist and bicycle dummy (using the pedestrian dummy as a basis) taking dummy characteristics for relevant sensor systems, crashworthiness and stability into account
- Activities
  - Development of an adult cyclist and bicycle dummy starting from the adult pedestrian dummy.
  - Check bicycle legislation in Europe (e.g. reflectors) to develop the bicycle target. For the size of the bike target, the average Dutch urban bicycle is used as a basis.
  - Specification of representative (sensor) properties for the cyclist and bicycle dummy (RCS, vision, movements)
  - Sensor workshop with stakeholders (also outside project)
- Deliverables
  - D3.1: Presentation on dummy requirements
  - D3.2: Report on final dummy specifications (Public)
  - D3.3: Final prototype dummy set (1 cyclist dummy & 1 bicycle dummy)
  - D3.4: Dummy specifications document (Public)

WP4 Propulsion system development
- Objective
  - Development of a propulsion system for cyclist AEB test scenarios as defined in WP2
- Activities
  - Specification of a propulsion system suitable for the 4 selected test scenario's; based on existing 4a pedestrian propulsion system
- Deliverables
  - D4.1: Presentation describing propulsion system requirements
  - D4.2: Report describing final propulsion system specification (Public)

Remark: The propulsion system itself and/or parts needed to upgrade the 4a pedestrian propulsion system setup is NOT included as deliverable in CATS.

WP5 Verification
- Objective
  - Verify the draft CATS protocol and test setup
- Activities
  - Verification of draft protocol and test setup by TNO with one state-of-the-art Cyclist-AEB system
  - Verification of draft protocol and test setup by all partners
- Deliverables
  - D5.1: Report on verification of protocol (Public)
  - D5.2: Report on final test protocol (Public)

WP6 Dissemination and involvement of AEB working groups
- Objective
  - Communication of results and taking care of involvement of AEB working groups of Euro NCAP, ACEA/JAMA/KAMA and CLEPA
- Activities
  - Definition of communication & dissemination plan
  - Giving presentations on relevant conferences
- Deliverables
  - Presentations and papers (Public)
  - D6.1: Final project report (Public)
  - D6.2: Presentation with overview of dissemination results

2.2 **Project approach**

A rather traditional approach has been used, starting the project by studying car-to-cyclist accidents in the EU (WP1). Data were mainly obtained from France, Germany, Italy, the Netherlands, Sweden and the United Kingdom. On the basis of these data, the 5 most common scenarios for accidents between passenger cars and cyclists were selected. These scenarios describe the trajectories and manoeuvres of cyclists and cars for several seconds up to the moment of impact. Only data of killed and seriously injured cyclists due to collision with a passenger car were included in this study.
Next step was to construct test scenarios for the most dominant accident scenarios. An in-depth study into the accident parameters was conducted in WP2 to determine the most relevant parameters and the most relevant ranges of these parameters (Table 1).

Table 1: Parameters in car-to-cyclist accident scenarios

Describing the accident scene	Parameters for the accident partners
Precipitation	Cyclist speed
Lighting conditions	Cyclist age, gender, size and posture
Location	Helmet use
Road layout (view blocking obstructions)	Vehicle Speed
Speed limit	Vehicle braking
Season	Collision point (for each of the partners)

Although the very detailed GIDAS-based Pre-Crash Matrix [20] was used in this study in addition to other mostly less-detailed databases, not all parameter ranges could be revealed, especially regarding the influence of the road layout and the presence of view-blocking obstructions in the scene. Moreover, the accident databases do not reveal information regarding cyclist pedalling behaviour and leg position in the approach of an intersection or crossing.
It was decided by the participants in CATS to study the phenomenon of view-blocking obstructions and the influence thereof by conducting observation studies on locations with many passenger car-to-cyclist interactions for which the view of the driver to the approaching cyclist (and vice versa) is limited. Such specific locations were found in the Netherlands. The studies revealed the influence on the cyclist and vehicle speed in an approach of an intersection in the presence of a strong view-blocking obstruction. As a side effect, these studies also revealed important information regarding the typical posture of a cyclist and the cyclist's pedalling behaviour when crossing a street.

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

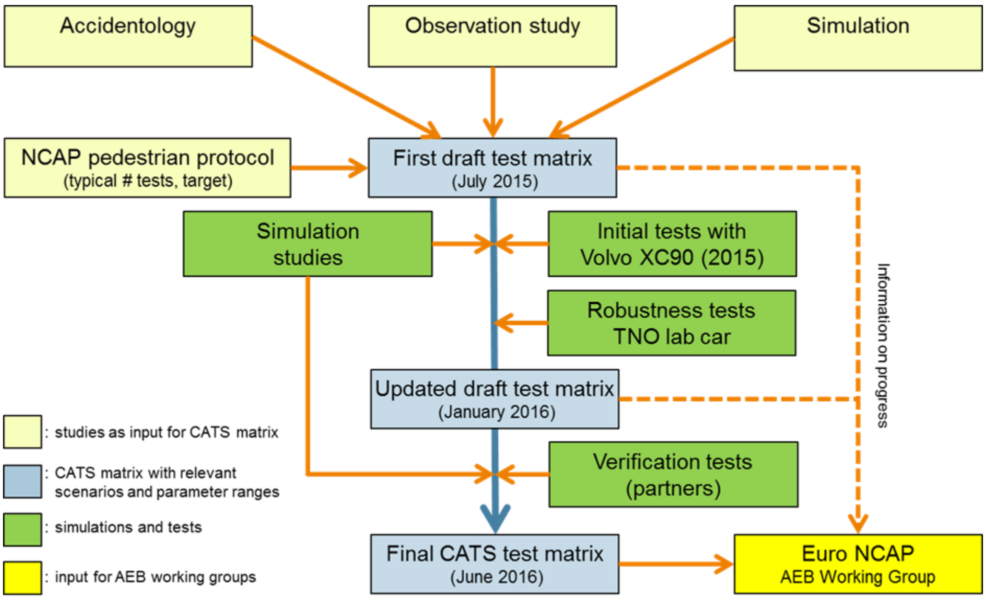


Figure 4: Process used in the CATS project to construct and verify the proposed test matrix.

Based on the most dominant accident scenarios, test scenarios have been proposed with input from accidentology (most relevant parameters with appropriate ranges) and observation studies to quantify additionally selected parameters. A simulation study performed by BASt and TNO provided input on the 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 [21]. Also the recommendations of the AsPeCSS deliverable for Cyclist-AEB test scenarios [22] were used to provide additional information.
The first draft of the CATS test matrix was used as a basis to define verification tests according to the full specifications (Euro NCAP type of test with drive robot and gas/brake robot installed on a certified test track) with a Volvo XC90 (version 2015). The verification tests were performed at the AstaZero test track in Sweden with an agreed version of the bicycle target that has been developed in parallel with all CATS participants [5], [13] in WP3 and WP4.
As is seen from the scheme above, simulations and robustness tests with a TNO lab car have been used to fine-tune the matrix. A final verification was performed by all participants in CATS. In these tests, all partners had the possibility to test the protocol as developed in CATS. In contrast to the initial verification test with the Volvo XC90 and the robustness tests, no steer and gas/brake robots were used in the tests open to all the partners.
Based on the feedback out of these tests provided by the partners, a final CATS test matrix of the cyclist-AEB test protocol as input to the Euro NCAP AEB VRU working group was decided upon.

2.3 Communication and dissemination

Euro NCAP has been updated on the progress during the complete CATS project. Intermediate results out of the project, e.g. results of accidentology, the draft test scenarios, and the dummy requirements were communicated to the AEB mirror groups within ACEA/JAMA/KAMA and CLEPA, and to the Euro NCAP AEB VRU working group according to the following communication scheme depicted in Figure 5. TNO shared information out of the project with the different working groups, after consensus was reached and the CATS partners had given approval for sharing the information. This formal approach was followed to enhance clarity and uniformity of the communication out of the CATS project, considering the large number of industrial partners that are involved in CATS.

In addition to the AEB working groups, also the ACEA TF Safety was informed through FCA in the cases that consolidated information became available out of the CATS project.

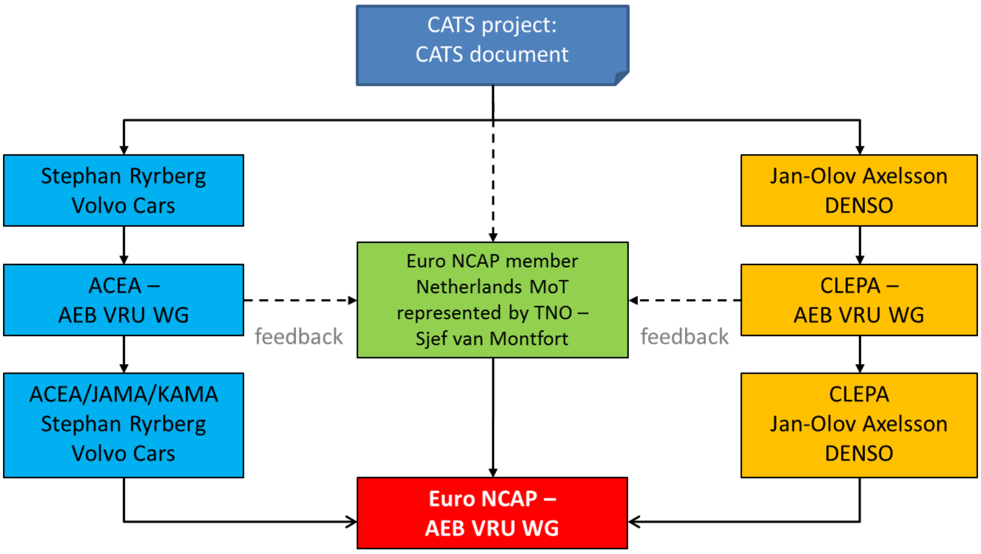


Figure 5: Communication scheme for CATS for the involvement of Euro NCAP, ACEA/JAMA/KAMA and CLEPA.

The communication plan anticipated the presentation of CATS results on relevant international congresses and conferences. The following presentations were given with reference to CATS:

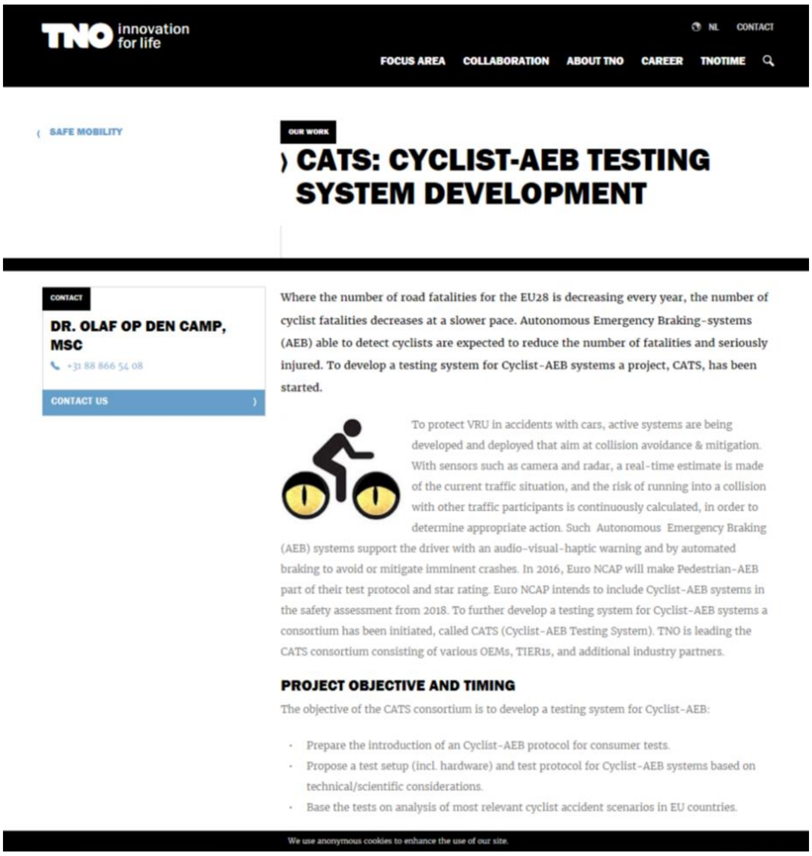
Table 2: Overview of CATS papers accompanied by presentation on conferences and congresses

ICSC 2014, Goteborg Sweden, 18-19 November 2014 Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol, O.M.G.C. Op den Camp, A. Ranjbar, J. Uittenbogaard, E. Rosen, S.H.H.M. Buijssen
Haus der Technik "Fahrerassistenz und Aktive Sicherheit", Essen Germany, 14 April 2015 Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol, Olaf Op den Camp, Arian Ranjbar, Jeroen Uittenbogaard, Erik Rosen, Rikard Fredriksson, Stefanie Buijssen-de Hair
ICSC 2015, Hannover Germany, 15-16 September 2015 Observation study into the influence of a view-blocking obstruction at an intersection on bicycle and passenger car velocity profiles, O. Op den Camp, S. de Hair, E. de Gelder, I. Cara
VDI Wissensforum: Fahrzeugsicherheit, Berlin Germany, 25-26 November 2015 Specification of a cyclist target and test setup for the evaluation of Cyclist-AEB systems, Sjef van Montfort, Olaf Op den Camp, Martin Fritz , Thomas Wimmer
FISITA 2016, Busan Korea, 26-30 September 2016 Cyclist target and test setup for the evaluation of cyclist-autonomous emergency braking (AEB) systems, Olaf Op den Camp, Sjef van Montfort, Jeroen Uittenbogaard, Joke Welten
ICSC 2016, Bologna Italy, 2-4 November 2016 Overview of main accident parameters in car-to-cyclist accidents for use in the AEB-system test protocol, J. Uittenbogaard, O. M.G.C. Op den Camp, S. van Montfort

Table 3: Overview of CATS related presentations (in addition to paper presentations)

Japan Automobile Research Institute (JARI), Ibaraki Japan, 2 March 2015 Presentation of CATS project: accidentology & selection of accident scenarios, Olaf Op den Camp, Sjef van Montfort, Koichi Kawaguchi
National agency for automotive safety and victim's aid (NASVA), National Traffic Safety and Environment Laboratory (NTSEL), Tokyo Japan, 4 March 2015 Presentation of CATS project: accidentology & selection of accident scenarios, Olaf Op den Camp, Sjef van Montfort, Koichi Kawaguchi
Carhs Safety Assist, Aschaffenburg Germany, 20 May 2015 CATS: car – bicyclist accident analysis and bicyclist dummy development, Heiko Schebdat, Sjef van Montfort
SAE 2016 Government - Industry meeting, Washington US, 20-22 January 2016 Evaluating AEB for Prevention of Pedestrian and Cyclist Crashes, Richard Schram, Euro NCAP (material provided by CATS).
ERTRAC-EUCAR Innovation Demonstration Day, Zaventem Belgium, 16 June 2016 Cyclist Autonomous Emergency Braking, Anita Fiorentino (FCA)
VDI Wissensforum: Safety Systems, Düsseldorf Germany, 29-30 June 2016 Advances in cyclist safety, Olaf Op den Camp
SAE 2016 From ADAS to Autonomous Driving, Munich Germany, 29 Nov-1 Dec 2016 Development of a cyclist target and test setup for the evaluation of cyclist-AEB system, Sjef van Montfort

A website was set up for CATS on a TNO server. The website is used to share publicly available information. All agreed deliverables that are marked 'Public', will be made available on this site: **www.TNO.nl/CATS** (expected per 02.09.2016)



2.4 Project participants

The following car manufacturers and automotive suppliers participated in the project:

The project was supported by the *Netherlands Ministry of Infrastructure and the Environment*:

As co-development partner, the Austrian company *4activeSystems GmbH (4a)* was involved. 4a had a main focus on target and propulsion system development, manufacturing and validation:

As review partner, the German *Federal Highway Research Institute* (*BASt*) was involved throughout the project. The BASt also set up a simulation study to check the feasibility of the first CATS draft test matrix:

3 Summary of results

3.1 Accident scenarios D1.2 [1]

A road traffic accident data analysis has been performed covering 6 European countries: France (LAB), Germany (GIDAS), Italy, Netherlands (BRON), Sweden (STRADA) and the UK (STATS19). Accidents involving one bicycle and one M1 vehicle (passenger car) were selected. The bicycle is defined as a legal bicycle, which excludes mopeds, scooters or speed-pedelecs (electric bike with support up to 45 km/h). Results have been presented for the numbers of fatalities (or killed K) and of seriously injured (SI). The following pre-processing of data was performed before the data were used:

- From the five datasets referring to German accidents, the GIDAS-based PCM dataset provides most details on accident parameters, and this is consequently used. Analyses have shown that PCM is highly representative for GIDAS and GIDAS is highly representative for Germany.
- The dataset from the UK (STATS19) has been translated towards right-hand driving traffic conditions at the EU main land.

To provide sufficient data for analysis, cases in the various databases for a larger period of time are considered. The evolution of accident scenarios with time is not studied, and consequently the occurrence of scenarios is assumed constant.
Figure 6 shows the accident scenarios that are distinguished in CATS. As can be seen in this figure, the road layout is not included in the scenario definitions; the scenario is defined by the combination of the orientation of the bicycle with respect to the car and the driving manoeuvre of the car and the bicycle. This is similar to the approach as used in the FP7 AsPeCSS project to propose pedestrian test scenarios [23], which formed the basis for the Euro NCAP AEB pedestrian test protocol. Accident data from 6 European countries have been analysed and the number of fatalities and seriously injured were distinguished regarding the 10 scenarios from Figure 6. Accidents that could not be assigned to any of the 10 scenarios have been allocated to the group Remaining (Re).

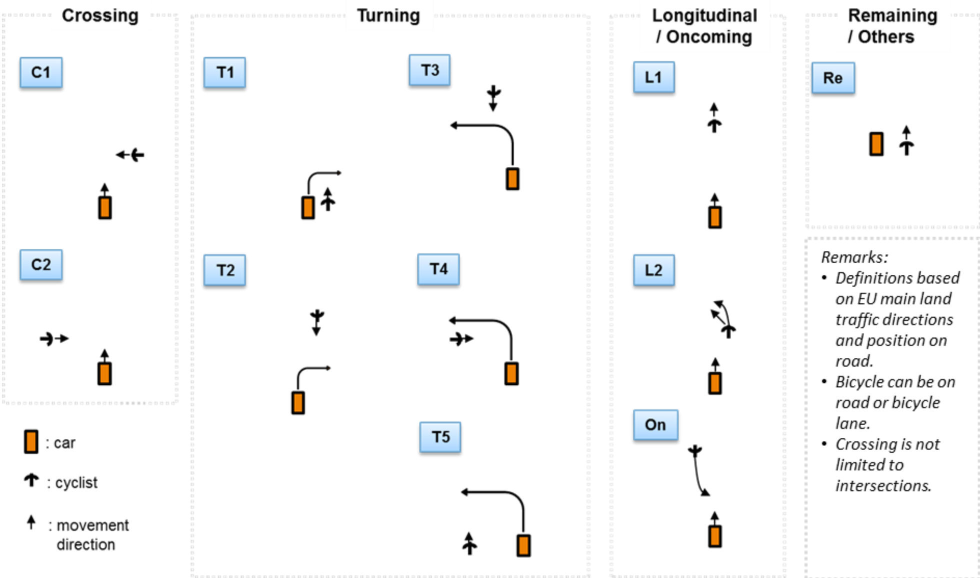


Figure 6: Overview of distinguished car-to-cyclist accident scenarios

Table 4: Description of car-to-cyclist accident scenarios

Scenario	Description
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side
T1	• Car turning right • Cyclist is riding straight in the same direction as the car before turning • Blind spot scenario
T2	• Car turning right • Cyclist is riding straight in the opposite direction of the car before turning
T3	• Car turning to the left, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight
T4	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight, coming from the far side of the car. • Some similarity with C2
T5	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight in the same direction as the car before turning
L L1 L2	• Car and cyclist driving in the same direction • Cyclist is riding straight and hit by the car from the rear • Cyclist is swerving to the left in front of the car and hit by the car from the rear
On	• Car driving straight, driving towards the far road side in a passing manoeuvre • Bicyclist coming in the opposite (on-coming) direction riding straight
Re	• All other scenarios that are not covered by any of the previously described scenarios.

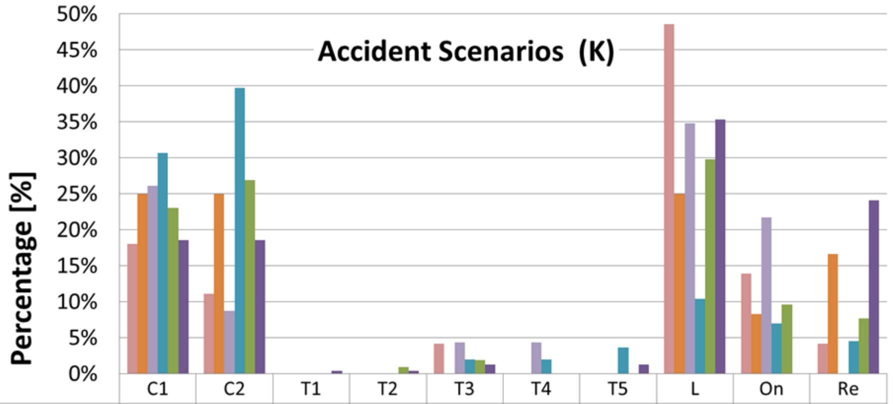
An extensive check has been performed to determine whether the 10 scenarios given in Figure 6 cover all relevant scenarios for car-to-cyclist collisions [31].
The data from the databases do not enable a clear distinction between the scenarios L1 and L2. Consequently, these two scenarios have been combined into one longitudinal scenario L. For the definition of the test protocol in a later stage, the selection of test parameters should reflect the fact that both L1 and L2 are covered by L.

After selection of the scenario classification, the distributions for these scenarios in the different databases have been determined. Since each database uses a different strategy in coding scenarios, this conversion is done per database separately. For selection and prioritization of car-to-cyclist accident scenarios to be included in a test protocol, information was further merged into a single percentage for each scenario. This percentage provides an indication how many fatalities and seriously injured are covered in the 6 considered countries. A weighting method was proposed in which an average percentage is determined over the 6 countries, based on the number of cyclist fatalities per million inhabitants taken from the CARE database [17]. In this way, a single percentage for each scenario resulted, weighting the percentages for the different countries to the number of cyclist fatalities per million inhabitants. In other words, the larger the percentage of cyclist fatalities in a country, the larger the weight of the specific car-to-cyclist scenarios that are found for the related country. The weighting factors are given in the table below:

Table 5: Weighting factors based on the ratio of cyclist fatalities and the total number of road fatalities per one million inhabitants in 2001-2010 [17]

Country	# road fatalities per million inhabitants	# cyclist fatalities per million inhabitants	Weighting [%]
France	62	2,8	11%
Germany	45	6,0	26%
Italy	68	5,4	-
Netherlands	32	9,2	38%
Sweden	28	3,6	15%
UK	30	2,3	10%

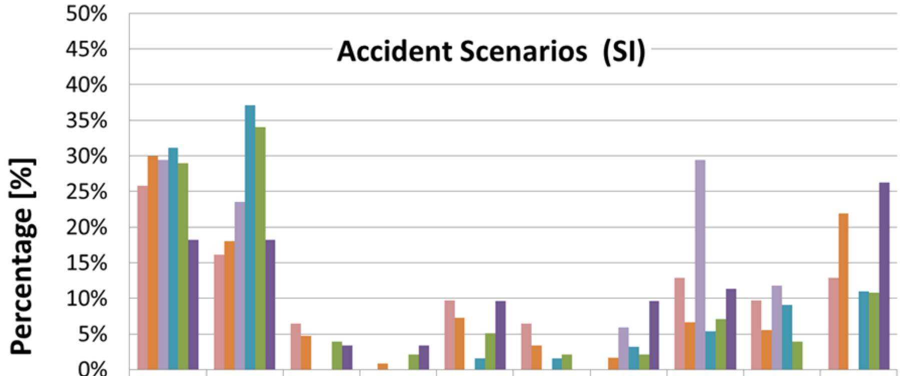
It should be noted that the data from Italy come from an in-depth database with limited cases (23 fatalities and 17 seriously injured) and are not intended to perform statistical analyses with. Therefore, in the remainder of this paper, the small number of Italian cases will not be considered for statistical analysis.
For the 6 considered countries, the percentages of killed and seriously injured are calculated for each of the accident scenarios from Figure 6. This results in the following distributions of fatally injured (K) and seriously injured (SI) over the different accident scenarios:



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	18%	11%	0%	0%	4%	0%	0%	49%	14%	4%
Germany	25%	25%	0%	0%	0%	0%	0%	25%	8%	17%
Italy	26%	9%	0%	0%	4%	4%	0%	35%	22%	0%
Netherlands	31%	40%	0%	0%	2%	2%	4%	10%	7%	5%
Sweden	23%	27%	0%	1%	2%	0%	0%	30%	10%	8%
UK	19%	19%	0%	0%	1%	0%	1%	35%	0%	24%

Figure 7: Distribution of fatally injured over the 9 accident scenarios that are distinguished for 6 EU countries.

Figure 7 clearly shows that, looking to the number of fatalities, the scenarios C1 (crossing cyclist from the near side), C2 (crossing cyclist from the far side) and L (longitudinal scenario where the vehicle collides from the rear of the cyclist) are dominant. Also the On-scenario (in which the front of the car collides with the front of the cyclist) seems relevant, but it covers clearly a smaller number of accidents than C1, C2 and L. From the turning scenarios (T1 to T5), only T3 (cyclist running straight, vehicle turning left) seems to be of relevance, but the fraction for T3 is small compared to C1, C2, or L.



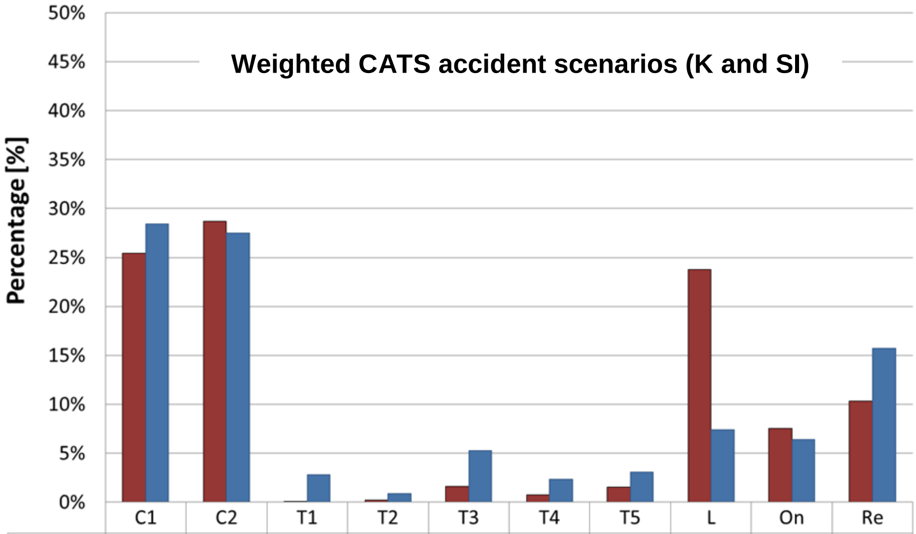
	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	26%	16%	6%	0%	10%	6%	0%	13%	10%	13%
Germany	30%	18%	5%	1%	7%	3%	2%	7%	6%	22%
Italy	29%	24%	0%	0%	0%	0%	6%	29%	12%	0%
Netherlands	31%	37%	0%	0%	2%	2%	3%	5%	9%	11%
Sweden	29%	34%	4%	2%	5%	2%	2%	7%	4%	11%
UK	18%	18%	3%	3%	10%	0%	10%	11%	0%	26%

Figure 8: Distribution of seriously injured over the 9 accident scenarios that are distinguished for 6 EU countries.

The relevance of the top-3 of scenarios for fatalities does not deviate between countries; the top-3 scenarios contain the same scenarios for all 6 countries, except for the fatal scenarios in France and Italy. Some deviations are seen in priorities per country between the top-3 of C1, C2, and L. For France, a considerable higher fraction of fatalities is found for the longitudinal scenario L, compared to the crossing scenarios C1 and C2. It should be noted that the data from France only cover the period of one year, and that a relatively small number of fatalities have been included in this study (72). In contrast, for the Netherlands the L-scenario is rather small compared to C1 and C2. Covering 14 years and over 900 fatalities in total, this is expected to be significant. A possible reason is found in the wide application of separated bike lanes, especially along rural roads in the Netherlands. Herewith the cyclists and motorized vehicles are physically separated, leading to only a relatively small number of fatalities in L-scenarios. In general, due to the high speed difference on rural roads, a collision according to an L scenario will more likely result in fatal injury for the cyclist. This not only leads to a small percentage for L in the Netherlands, but also to relatively higher values for C1 and C2.

The distribution for accidents leading to seriously injured cyclists deviates slightly from that for fatalities. Most clearly seen is the strong decrease in the percentage allocated to the L scenario. Although still present as one of the top-3 dominant scenarios, it cannot easily be distinguished from the On-scenario, except for Italy, where the L scenario for seriously injured is as important as the C1 crossing scenario.

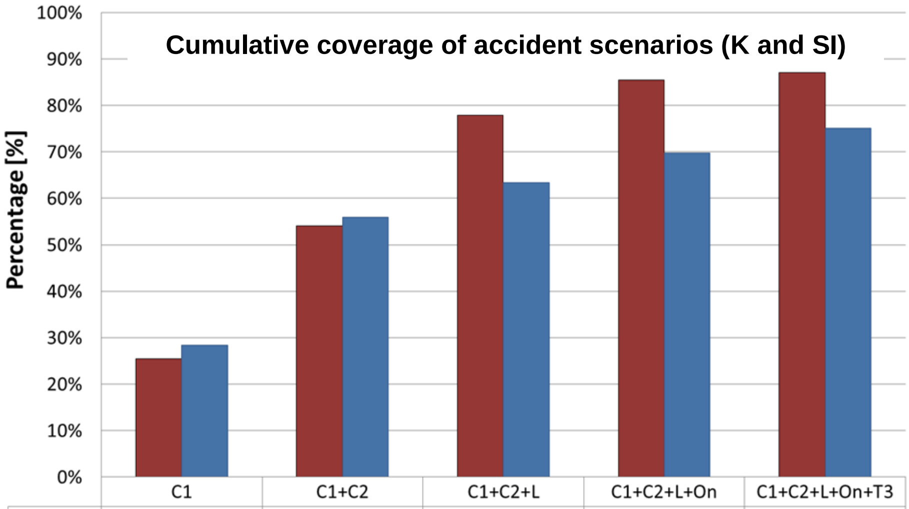
Based on the weighting method that is proposed in the previous section, an average percentage is determined over 5 countries (the original 6 minus Italy), based on the number of cyclist fatalities per million inhabitants taken from the CARE database [17]. The weighted average over the countries except Italy, using the factors from Table 5, is given in the next graph (for both fatalities and seriously injured):



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
mean K	25%	29%	0%	0%	2%	1%	2%	24%	8%	10%
mean SI	28%	28%	3%	1%	5%	2%	3%	7%	6%	16%

Figure 9: Distribution of fatalities and seriously injured over the 9 accident scenarios, weighted average over 5 countries. The red columns refer to fatalities (K), where the blue columns refer to seriously injured (SI).

This figure shows that C1 and C2-scenarios are dominant and equally important, followed by the L-scenario. Less important is the On-scenario. From the scenarios where the car is making a turn (T), the T3-scenario is most common, but this scenario is covering fewer accidents than the C1, C2, and L scenario. Next graph presents the cumulative coverage of the most important scenarios:



	C1	C1+C2	C1+C2+L	C1+C2+L+On	C1+C2+L+On+T3
mean K	25%	54%	78%	85%	87%
mean SI	28%	56%	63%	70%	75%

Figure 10: Cumulative coverage of scenarios in the order of importance.

Putting the scenarios in order of relevance and importance, considering the number of fatalities and seriously injured due to car-to-cyclist collisions in the EU-countries France, Germany, Italy, the Netherlands, Sweden and the UK, the next sequence applies: C1, C2, L, On and T3. The scenarios C1, C2 and L together cover already between 78% and 63% of the fatal and serious car-to-cyclist accidents respectively.

CATS will focus on the top-3 accident scenarios: C1, C2 and L	
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side
L L1 L2	• Car and cyclist driving in the same direction • Cyclist is riding straight and hit by the car from the rear • Cyclist is swerving to the left in front of the car and hit by the car from the rear

3.2 Test parameters and conditions D2.2 [2]

Next step in the test protocol development was the determination of the test parameters such as vehicle speed, bicycle speed, the presence of view blocking obstructions, collision point on the vehicle, type of bicycle and size of cyclist. Moreover, parameters describing the level of light or precipitation need to be selected. The car-to-cyclist accidents from the databases used for scenario selection have been studied to provide ranges for these parameters that give a representative coverage of the real-life conditions. In addition to that an observation study has been conducted to select parameters for which limited information is available in the accident databases.

Weather and lighting conditions
The percentage of cyclist-to-car accidents for different types of precipitation is given in Figure 11. It shows that the majority, more than 80% of these accidents occur when there is no precipitation (dry). There is no significant difference in precipitation between accidents with seriously injured or fatalities. Furthermore, no difference was found in precipitation for the separate accident scenarios.

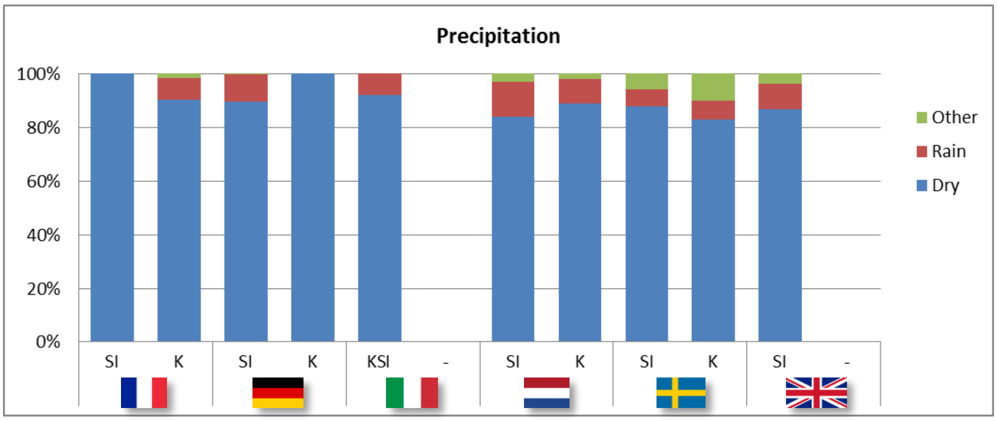


Figure 11: Overview of car-to-cyclist accidents by precipitation. Separated per country and divided over seriously injured (SI) and fatalities (K).

Figure 12 shows the cyclist-to-car accidents distinguished by different lighting conditions. For all data sources, it shows that the fatal accidents occur more often in low lighting conditions than the accidents with seriously injured. However, the majority of the accidents occur during daylight: 75%-90% for the seriously injured accidents and 65%-75% for the fatal accidents respectively. It is noted that even though accidents occur in low lighting conditions at dusk/dawn or at night, there is still the possibility for the presence of artificial street lighting.

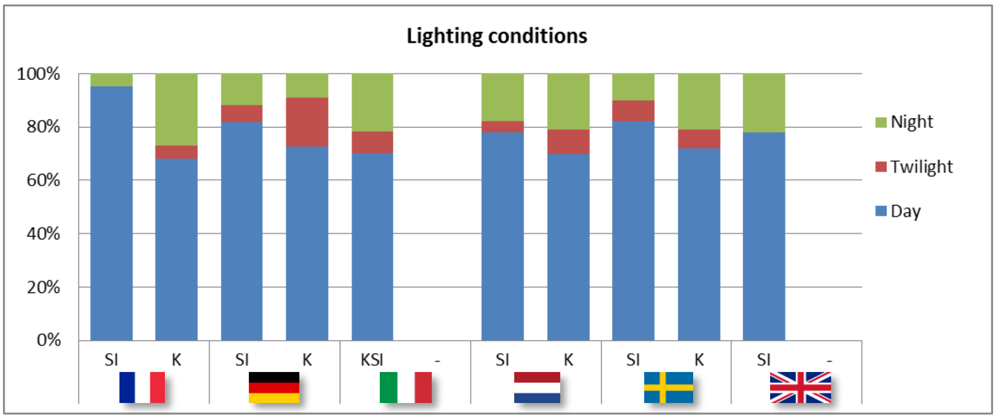


Figure 12: Overview of car-to-cyclist accidents by lighting condition. Separated per country and divided over seriously injured (SI) and fatalities (K).

Based on this overview of typical weather and lighting conditions for car-to-cyclist accidents, it has been proposed to consider only daylight conditions and dry weather conditions for the CATS test protocol.

Accident location: urban/rural

The accident location provides input to the expected speed of the accident partners. A separate study providing more details on the speed distributions for cyclists and vehicles is discussed in a later paragraph. Figure 13 shows the distribution of cyclist-to-car accidents over rural and urban locations in Sweden, distinguished for the different accident scenarios. A similar distribution is found for Germany and France. It appears that fatal accidents occur more often in rural areas. Moreover, crossing scenarios occur more often in urban areas for both accidents with seriously injured (~60%-95%) and fatal accidents (~50%-65%). For longitudinal scenarios, fatal accidents clearly occur more often in rural areas.

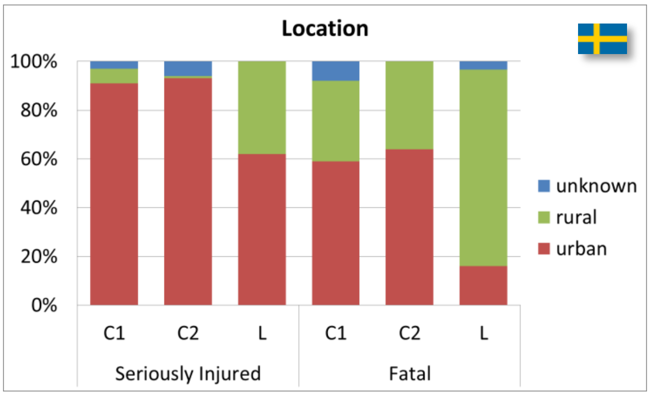


Figure 13: Overview of car-to-cyclist accidents by location, divided over seriously injured (SI) and fatalities (K).

As a result, crossing scenarios will mainly be considered for urban conditions, while for the longitudinal scenario, urban and rural conditions will be considered.

View blocking obstruction

View-blocking obstructions can seriously hinder and delay the detection of an approaching bicycle from the perspective of the car. Similarly, such an obstruction might limit the view from the bicyclist at the approaching vehicles. Late detection and identification of a bicycle because of a view-blocking obstruction, limits the probability for a driver or an automated braking system to avoid or mitigate the collision with a bicycle that appears from behind an obstruction. The size and the location of the obstruction determine the time at which the cyclist becomes visible, given the speed of both car and bicycle.

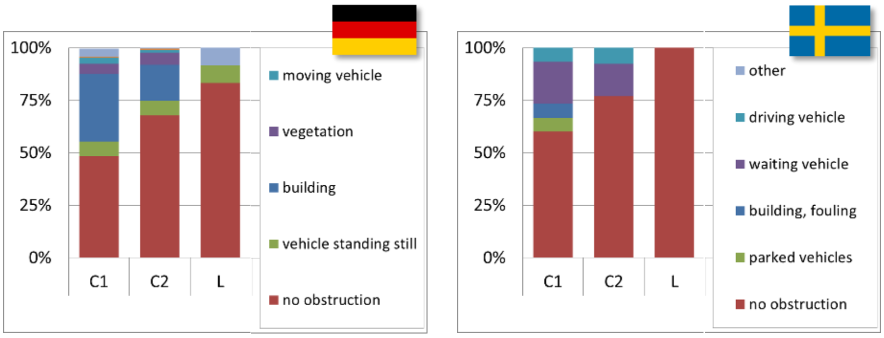


Figure 14: Type of obstruction in seriously injured accidents distributed over the different dominant scenarios.

Looking at the separate dominant accident scenarios for both Germany and Sweden (Figure 14), it is seen that view-blocking obstructions are more common in the crossing scenarios than in the longitudinal scenario. Even between the crossing scenarios a difference is visible, where C1 (crossing bicycle from near-side, i.e. bicycle approaching from the right side in European mainland driving directions) occurs more often with a view-blocking obstruction than C2 (crossing bicycle from far-side). This might be explained by the fact that, since C1 is defined as a crossing scenario from the near side of the vehicle, it is more likely for the view on the bicycle to be blocked by an obstruction in the near side crossing scenario. In the C1 scenario a substantial part of the accidents (~40% to 50%) occur with a view-blocking obstruction, where the largest part is due to a permanent full obstruction such as a building or a high hedge (fouling, vegetation).

For this reason, it has been proposed to provide one test scenario for cyclist-AEB tests with a well-defined full view-blocking obstruction for the near side (C1).

In contrast to pedestrian scenarios, where a pedestrian might wait at the road edge before deciding to start crossing the street, cyclists move much more continuously towards the crossing and based on the traffic situation, priority rules and personal preferences either stop or continue to cross the intersection of roads. Information on such typical crossing behaviour or behaviour in the approach of an intersection is important for AEB-system development.
Based on the GIDAS-based PCM data [20], a cumulative distribution has been determined for the time-to-collision (TTC) at which the vehicle has been able to see the cyclist in case of accidents in crossing scenarios with a permanent view-blocking obstruction (Figure 15). This distribution covers all passenger car-to-cyclist crossing accidents with a permanent view blocking obstruction and MAIS1+ injuries (n=38, C1=31, C2=7). The figure shows that about 20% of these accidents occur when the vehicle is able to see the cyclist for 1 second or less before the crash. For 2 seconds or less it covers about 80% of the cyclist accidents. The median (50^{th}

percentile of the curve) of the cyclist accidents with a permanent view-blocking obstruction has a TTC of approximately 1.5 seconds at which the vehicle is able to see the cyclist.

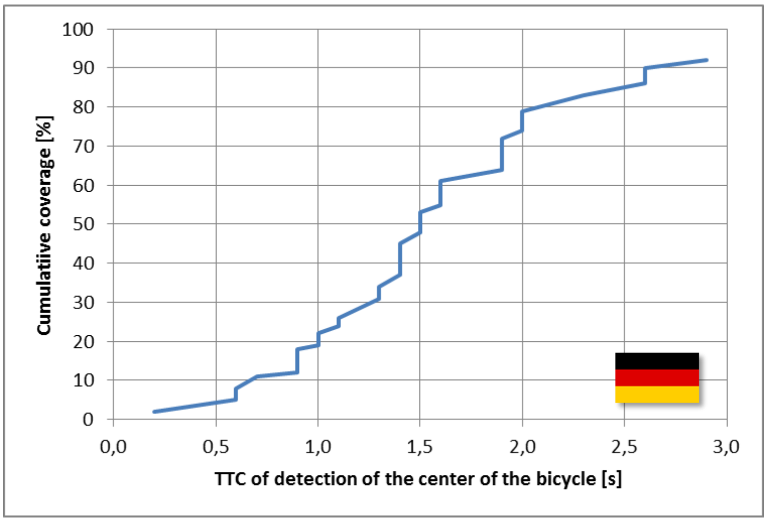


Figure 15: Cumulative distribution plot for the TTC of detection in case of accidents in which a permanent view-blocking obstruction was present.

The number of accidents, for which detailed information on the effect of view-blocking obstructions is available, is limited. Even when the presence of a view-blocking obstruction has been included in the accident record as a possible factor in the accident, detailed information on type, size and location of the obstruction is often missing.

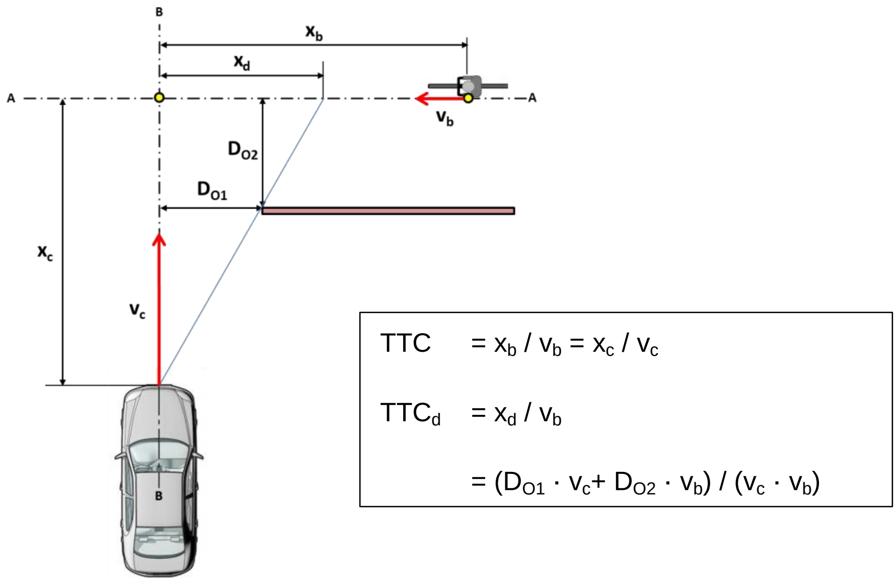


Figure 16: Typical measures to quantify the position and severity of a view-blocking obstruction. The underscore b refers to the bicycle and c to the car.

To determine the location and size of a relevant and realistic view-blocking obstruction, keeping in mind a typical TTC for cyclist detection from Figure 15, dimensions are used that are based on characteristic measures for infrastructural elements. In the table below, Dutch guidelines for the width of urban road layout designs are found [35]:

Table 6: Dutch guidelines for the width of urban road layout designs

Road layout	*Guidelines*
Sidewalk	1.2m – 1.8m
Double bicycle track	2.0m – 4.0m
Two way road	5.4m – 7.0m
One way road	~ 3.5m

For a severe view-blocking obstruction, where the car drives in the middle of its lane on a two-lane road with a pedestrian sidewalk, the value of D_{O1} (Figure 16) could be as low as 3.55 m. For a double cyclist lane bordered by a pedestrian sidewalk crossing this road, the value of D_{O2} would be around 4.80 m.

For the placement of the obstruction in the obstructed C1 scenario, it has been proposed to use D_{O1} = 3.55 m and D_{O2} = 4.80 m.

In order to come up with a relevant and realistic set of parameters regarding the speed distribution of both car and bicycle, and the size and location of typical view-blocking obstructions for bicycle crossing scenarios, an observation study has been performed by TNO [3]. The two sites for the observation study have a rather severe view-blocking obstruction, to determine the influence of such an obstruction on the velocity profile of both bicycles and cars, with values for D_{O1} and D_{O2} close to 3.55 and 4.80m respectively. Previous observation studies have shown that cyclists anticipate very well in traffic [36]. They continue pedalling and hardly decrease speed when riding on a priority bicycle lane crossing a road with a clear unobstructed view on the approaching vehicles.
Based on the observation study that was performed on two crossings in the Eindhoven-area, the following conclusions have been drawn:

- Bicycles appear to reduce their speed in the approach of an intersection, in case the view at the intersection is severely hindered by a permanent full view-blocking obstruction. Approximately 6 km/h of speed reduction was measured in one case, and in the other case the speed reduction was estimated at 4 to 5 km/h. The speed reduction always coincides with the fact that bicyclists stop pedalling. For all cyclists observed during this study, more than 80% stopped pedalling in approaching the intersection with view-blocking obstruction. The usual early anticipation by bicyclists on cross-traffic [36] does not seem possible in case the view on this cross-traffic is severely hindered.
- Also cars generally reduce speed in approaching the intersection. Where for cyclists, a severe view-blocking obstruction prevents early anticipation on cross-traffic, a severe obstruction for car drivers might cause them to overlook the traffic from the right that might appear from behind the obstruction. This could explain the fact that the measured speed reduction for cars in the obstructed case was less (in average) than the speed reduction for the unobstructed case.
- A speed reduction of the bicycle from 20 to 15 km/h results in an increase of the TTC to detection of approximately 0.25 seconds. A further speed reduction from 15 to 10 km/h, would lead to an additional increase in TTC_d of approximately 0.50 seconds.

Vehicle speed

Similar to most Euro NCAP test protocols for ADAS systems, in the Cyclist-AEB performance tests, the speed of the test vehicle is varied in a relevant speed range. To determine the relevant range for the 3 accident scenarios, both the speed limit at accident locations has been studied, as the data on vehicle speed that has been collected in the accident databases. In the speed limit for the separate dominant scenarios for Sweden is shown. In the figure, accidents with seriously injured and fatal accidents are distinguished.

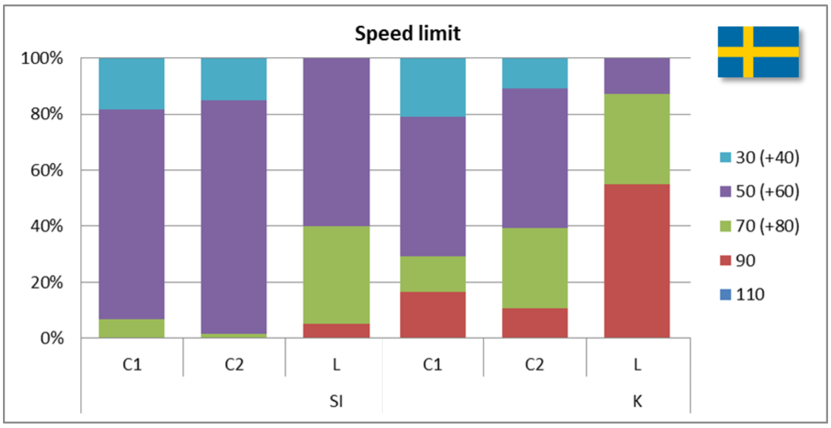


Figure 17: Overview of car-to-cyclist accidents by speed limit in Sweden, distinguished to accident scenario for accidents with seriously injured and fatal accidents.

The figure shows that higher speed limits are found for fatal accidents, and that the longitudinal L scenario happens more often at higher speed limits than the C1 or C2 scenario. This is in agreement with the earlier observation that C1 and C2 more often happen in urban areas compared to the L-scenario. Although only a figure for Sweden is shown, this is a general trend for the other investigated countries as well. Figure 18 shows the cumulative distributions of the vehicle speed for the separate dominant accident scenarios, for the seriously injured and fatal accidents combined, based on the German data sources. It can be seen that in the longitudinal scenario the highest vehicle speeds are found compared to the 2 crossing scenarios.

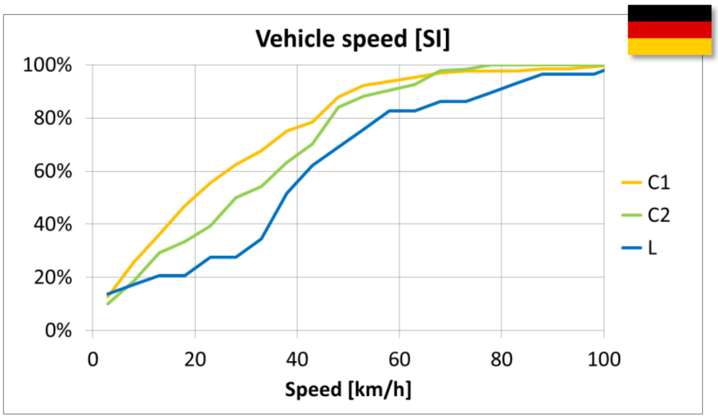


Figure 18: Cumulative vehicle speed distribution distinguished for the 3 accident scenarios in CATS, as found for accidents with seriously injured in Germany.

The 50th and 90th percentile of the initial vehicle speeds of the separate accident scenarios can be found in Table 7:

Table 7: Vehicle speed distribution for the CATS accident scenarios

Scenario	*50th percentile [km/h]*	*90th percentile [km/h]*
C1	~20	~50-55
C2	~20-25	~50-55
L	~40-45	~70-80

Bicycle speed
In accidents it is rather difficult to determine the bicycle speed upon collision with the vehicle. Nevertheless, the bicycle speed distributions in the studied databases show a large resemblance.

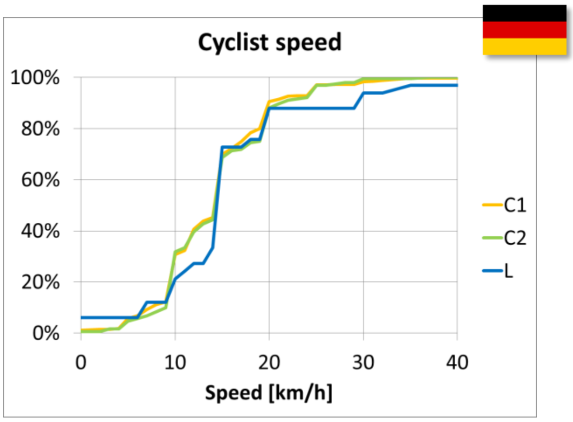


Figure 19: Cumulative bicycle speed distribution distinguished for the 3 accident scenarios in CATS, as found for fatal accidents and accidents with seriously injured in Germany.

The 50th and 90th percentile cyclist speed of both the seriously injured and fatal accidents is 12-15 km/h and 20-25 km/h respectively. This is in agreement with bicycle speeds from naturalistic bicycle studies [24].
Studying the correlation between vehicle and bicycle speed, it is found that only for the longitudinal L-scenario the bicycle speed seems to increase with increasing vehicle speed. This can be explained by the large number of rural accidents in the longitudinal scenario where it can be expected that both the vehicle and cyclist speed are higher. However this conclusion is based upon a small sample.

Based on the findings regarding the bicycle speed and vehicle speed in the different scenarios, the following speed ranges have been proposed:

#	*Vehicle speed [km/h]*	*Bicycle speed [km/h]*
C1 unobstructed	*20 – 60*	*15*
C1 obstructed	*10 – 40*	*10*
C2 unobstructed	*20 – 60*	*20**
L urban	*30 – 60*	*15*
L rural	*65 – 80*	*20*

* To include a higher relevant bicycle speed in at least one crossing scenario.

A distinction is made between an urban and a rural longitudinal scenario, as both scenarios appear to be relevant. The expected behaviour for the AEB system in the two L-scenarios however is different: where in urban scenarios an AEB action might ultimately be expected, an AEB action in a longitudinal scenario at higher speeds in rural areas might lead to dangerous situations. Consequently, for the rural L-scenario, only a timely FCW (forward collision warning) is expected.

Collision point

The following definition for the collision point is used for C1, C2 and L, where the width of the vehicle is considered equal to the length of the cyclist. For crossing scenarios, the reference point of the target is located at the centre of the bottom bracket (crank shaft) and for the longitudinal scenario at the most rearward point on the rear wheel:

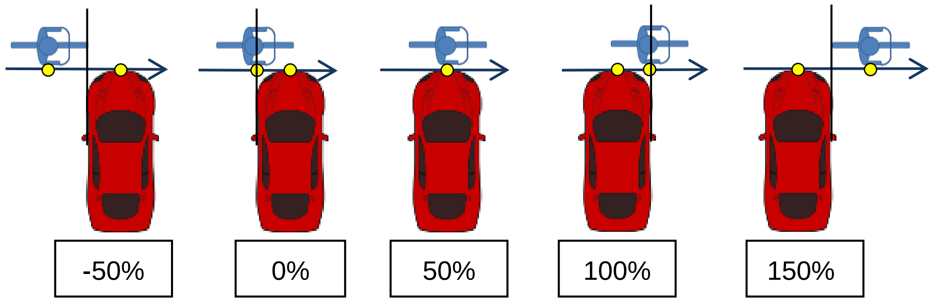


Figure 20: Collision point definition in the C2 scenario

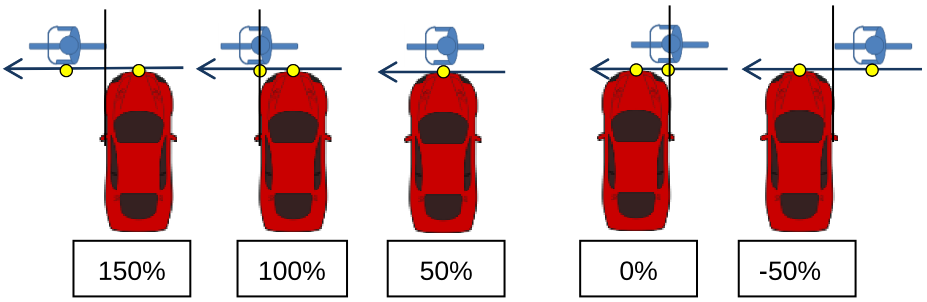


Figure 21: Collision point definition in the C1 scenario

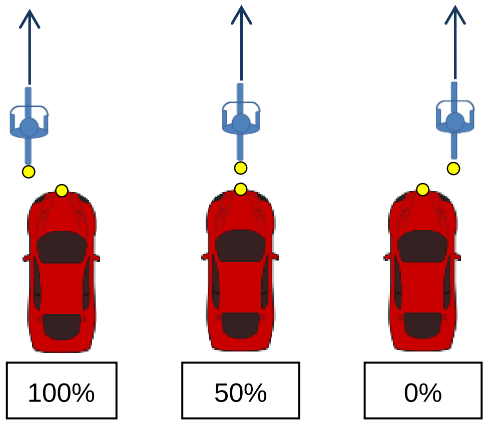


Figure 22: Collision point definition in the L scenario

In Figure 23, the collision point on the car front is given for the crossing and longitudinal accident scenarios. The impact location on the cyclist is not included and only based on the width of the vehicle.

For the crossing scenarios it is seen that the cyclist is mostly impacted at the centre of the car front. Moreover, a collision point on the car at the near side front in the C1 scenario and the far side front in the C2 scenario is most likely.

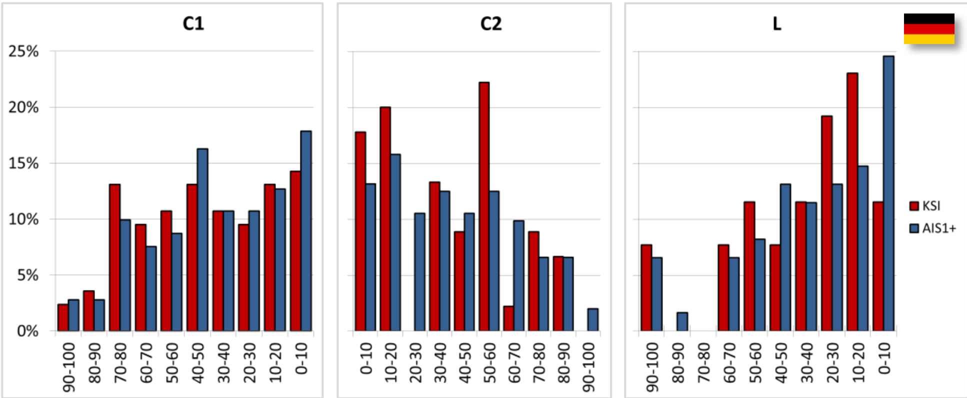


Figure 23: Overview of cyclist accidents in target population by collision point for the crossing and longitudinal accident scenarios for both the low severity injuries (MAIS1+) and the seriously injured and fatalities (KSI)

For the longitudinal scenario it shows that the bicycle is more likely to be impacted by the near side of the vehicle front. This is the side of the road where the bicycle is expected to ride. When the bicycle makes an unexpected swerve or when the vehicle passes while driving too close to the near side of the road the bicycle will most likely be impacted with the near front side of the car.

The following collision points have been proposed for the different scenarios in agreement with the distributions in the accident databases:	
#	*Collision point*
C1 unobstructed	*50%*
C1 obstructed	*50%*
C2 unobstructed	*25% (far side)*
L urban	*50%*
L rural	*25% (near side)*

3.3 Bicycle and cyclist target, D3.2 [4] and D3.4 [5]

A check in the accident databases is performed regarding the age of the cyclists that are involved in cyclist-to-car accidents. The figure clearly shows that the vast majority of cyclists involved in accidents are adults. It is for this reason that the bicyclist and bike target (BT) that has been developed in the CATS project represents an average adult human bicyclist on an average European utility bike. Requirements for target relate to the BT including a platform, which is needed to keep the bike and bicyclist upright during testing.

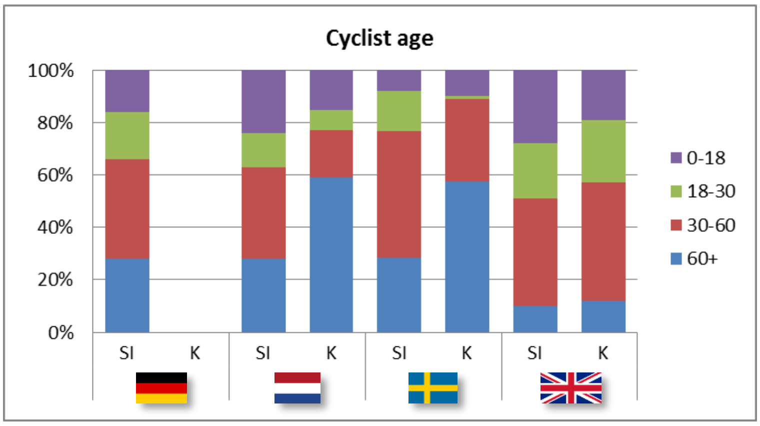


Figure 24: Overview of cyclist accidents by cyclist age.

The BT is designed to work with the following types of automotive sensors technologies: RADAR, Video, Laser and Near-IR-based system similar to the Euro NCAP AEB VRU protocol [21]. An overview has been made on the legal requirements cyclists and bicycles in the EU28. The BT has been developed such, that it represents a legal cyclist – bike combination on European roads. Moreover, the cyclist target specifications should resemble the ACEA pedestrian target specification [33], except for its posture on the bike.

Figure 25: Bike target dimensions

Table 8: Bike target dimensions with tolerances

Segment	X	Z	Unit	Tolerance	Unit
0 Centre of bottom bracket of bike	0	280	mm	± 10	mm
1 Centre axis front wheel	670	340	mm	± 10	mm
2 Centre axis rear wheel	-540	340	mm	± 10	mm
3 Front top frame	430	855	mm	± 10	mm
4 Rear top frame	-215	860	mm	± 10	mm
5 Handle bars	310	1180	mm	± 10	mm
6 Saddle	-235	935	mm	± 10	mm

7 Lower edge left foot[†]	105	495	mm	± 20	mm
8 Lower edge right foot	80	200	mm	± 20	mm
9 Knee point, left [‡]	150	860	mm	± 20	mm
10 Knee point, right	85	700	mm	± 20	mm
Total height	1865		mm	± 20	mm
Total length	1890		mm	± 20	mm
A Torso angle	10 (optional 30)		°	± 2	°

- Wearing reflective clothing or a helmet are both not mandatory under all conditions for bicyclists in any of the EU28 countries. For that reason neither reflective clothing nor a helmet will be part of the BT specification.
- Front, rear, pedal and wheel reflectors are mandatory in many of the EU28 countries and are therefore included in the specifications of the BT. The specification for the reflectors are not uniform over the EU28 countries, but the most common ones have been selected for the BT specifications. The front, rear and all four pedal reflectors (left – right and front - rear) should be marked BS6102/2 (or equivalent) and coloured respectively white (front), red (rear) and amber (pedals). The front and rear reflector should be located on the bike target between 350mm and 900mm from the ground level, with the white front reflector positioned between most forward point of bike target and point 4 in Figure 25 facing forward. The red rear reflector is positioned between most rearward point of the bike target and point 8 in Figure 25 facing rearward. The amber coloured pedal reflectors should be on the front and rear side of both left and right pedal. The wheel reflectors are white reflective strips on both sides of the rims or tyres.
- As mudguards, gear cases and luggage racks are fitted on most bikes in the EU, therefore they are included in the BT specifications.
- Both the fact that the CATS test protocol [2] only includes daytime tests and the fact that front and rear light are not mandatory in most EU countries during daylight, front and rear lights are not included in the bike target requirements.

For a realistic representation with respect to the micro-Doppler effect the bike target (BT) is fitted with rotating wheels. Both wheels should be in permanent contact with the ground to make sure that the wheel rotational speed is in agreement with the actual bike speed. The space between the spokes should be transparent and not give reflections for radar or visual systems independent of the viewing angle.

Within the CATS project the inclusion of rotating pedals and moving legs has been considered, however forward motion on a bicycle does not necessarily require moving neither pedals nor legs:

The observation study on bicyclist behaviour showed that the majority of the bicyclists (over 80%) stop pedalling when approaching a crossing [4]. Therefor nor rotating pedals nor moving legs are included in the specifications of bike and bicyclist target.

[†] Lowest point of shoe – centre line tibia

[‡] Knee point: rotation point of knee

The posture of bicyclist target represents a natural driving position, facing forward, both hands on the steering wheel. The observation study performed showed that the majority of bicyclist have one foot down and the other foot up when approaching a crossing [3], [12]. The same dummy posture is used for all driving directions, with right foot down and left foot up. The posture definition includes: torso angle, hip angles, knee angles, shoulder angles and elbow angles.
For test practicality the bicyclist and bike target (BT) has limited weight (max. 11kg) and lacks any hard impact points to prevent damage of the test vehicle (VUT). It should be possible to repair damage to both VUT and BT related to impact speeds (up to 60km/h for crossing scenarios and 45km/h for longitudinal scenarios) with limited time and costs. Any repair to the BT should not affect the properties related to representation of real bicyclist & bike, nor the stability.

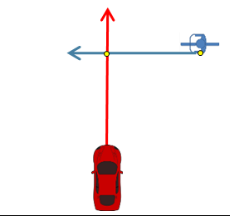
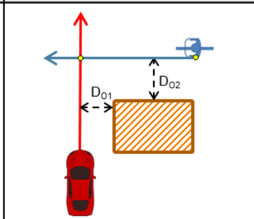
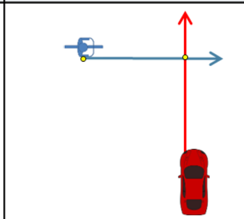
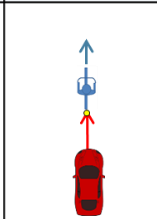
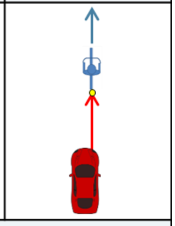
Figure 26: Bicyclist and bike target

The propulsion system for the BT is developed such that it is possible to perform tests with vehicle speeds from 10km/h up to 80km/h and bicyclist and bike target (BT) speeds from 10km/h up to 22km/h. The speed of the BT should remain constant for at least 25m in crossing and longitudinal scenarios with a tolerance of ±0.2km/h, similar to Euro NCAP AEB VRU protocol [21].
An exact and reproducible positioning of the BT has to be guaranteed. The deviation of the position in the direction of BT movement from the test path should be 0 ± 0.05 m. The deviation of the position perpendicular to the direction of BT movement from test path should be 0 ± 0.10m for crossing and 0 ± 0.15m for longitudinal scenarios.

3.4 Final CATS test matrix D5.2 [8]

In the CATS matrix (Final version dated June 23rd, 2016) is shown for the car-to-cyclist AEB test scenarios, based on the considerations as discussed in this chapter. It includes the C1 accident scenario as a crossing test scenario reference, but also with view blocking obstruction. The C2 accident scenario is suggested to be used to vary cyclist speed and the collision point on the vehicle. The L accident scenario is divided in an urban and rural (inter-urban) part. The preparation and tolerances of the test scenario, test track, bicycle/cyclist dummy and vehicle are proposed to follow the Euro NCAP AEB VRU Test Protocol v1.0.1 [21].

Table 9: Final CATS test matrix, version June 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
Collision point*	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% collision point with a VUT speed of 45 km/h to ensure AEB performance at a collision point 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.	

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 at 50% of the vehicles width 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 at 50% of the vehicles width 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 at 25% of the vehicle's width from the farside 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. In the CVLB scenario an urban AEB (30 – 60 km/h) and a rural (inter-urban) FCW phase (65 – 80 km/h) is distinguished.

Verification of the CATS test matrix

The proposed CATS crossing scenarios have been evaluated regarding feasibility by means of virtual simulations and physical tests. Details of the simulation tool are given in D5.1 [7]. As a performance measure, the resulting speed reduction by the AEB system has been considered for the different test speeds of the VUT. Maximum performance in a test is achieved in case the accident is avoided, for which either the achieved speed reduction is equal to the initial test speed, or the speed reduction of the VUT is such that the cyclist can safely pass in front of the VUT. The simulations have been performed for 2 sensor systems: a current state-of-the-art system with a sensor field-of-view (FoV) of 2x24° and a system with beyond 2018 specifications with a FoV of 2x45°. This leads to the following results:

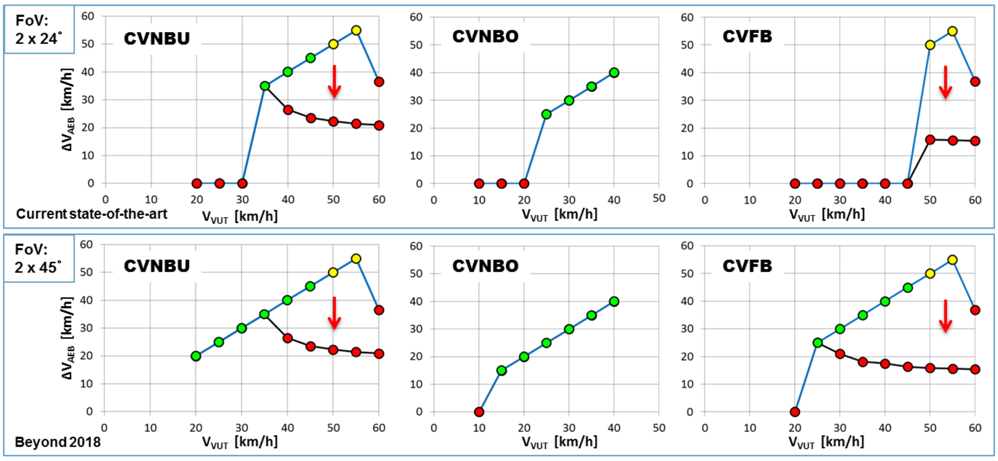


Figure 27: Simulation results for the CATS crossing scenarios for 2 different sensor FoVs.
: full collision avoidance, VUT comes to a full stop
: full collision avoidance by reduction of speed, cyclist passes safely in front of VUT
: collision, no speed reduction or speed reduction insufficient

The blue line indicates a system that directly responds upon detection and identification of an imminent collision with a cyclist. This is however unrealistic system behaviour. A real AEB-system usually waits with the initiation of an AEB-braking action, until the system has made sure that the cyclist is no longer capable to avoid a collision. Such a response is required to avoid false positive system responses and improve the customer acceptance of the system. The longer the system needs to wait with an AEB action at higher vehicle speeds, the more difficult it is to come to a full stop in the short time that remains until collision (results on the black line). It is for this reason that for the crossing scenarios, the higher range test vehicle speeds are challenging because of the general issue of system robustness.
The simulation results also show that at low vehicle speeds, i.e. speeds of the vehicle that are in the same order of magnitude as the cyclist speed, the crossing bicyclist might be outside the field-of-view (FoV) of the current state-of-the-art sensors, and no appropriate AEB action can be taken. In case the vehicle has a speed of 20 km/h and the approaching cyclist also has a speed of 20 km/h, then a sensor FoV of at least 2x45° is required. Since such sensor systems are beyond 2016 state-of-the-art, such a scenario is not expected to be feasible in 2018, when the Cyclist-AEB protocol will be implemented by Euro NCAP.

It is proposed to Euro NCAP to start tests at the expected best performing VUT speed and then go down from this speed, and go up from this speed until an insufficient speed reduction is measured.

Discussion of the CATS test matrix with Euro NCAP

As part of the CATS dissemination activities, the CATS test matrix has been shared (as DRAFT) at different stages with the AEB VRU working groups of ACEA/JAMA/KAMA, CLEPA and Euro NCAP. Based on this input, Euro NCAP presented a DRAFT proposal during Euro NCAP AEB VRU WG in June 2016, which is very much in agreement with the proposal of CATS. Euro NCAP proposes the following adaptations to and introduction of the final CATS matrix:

- The CVNBO (obstructed test) will be postponed to 2020. Euro NCAP considers this scenario as too challenging for 2018 systems.
- The CVFB will also be postponed to 2020, in agreement with the notes out of the CATS project. It is very likely that there will be a symmetry check in which a CVNBU test will be repeated for the farside with equal cyclist speed and a 50% impact point on the vehicle.
- The speed range for the longitudinal FCW will be extended from 50 to 80 km/h, to have a larger overlap with the AEB speed range, so warning systems only will have a larger range of assessment.

4 Signature

Helmond, September 2nd 2016

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6 Acknowledgements

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A Papers published within the CATS project

1. O.M.G.C. Op den Camp, A. Ranjbar, J. Uittenbogaard, E. Rosen, S.H.H.M. Buijssen, Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol, Proceedings ICSC 2014, Göteborg [10]
2. Olaf Op den Camp, Arian Ranjbar, Jeroen Uittenbogaard, Erik Rosen, Rikard Fredriksson, Stefanie Buijssen-de Hair; Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol; Fahrer-Assistenz und aktive Sicherheit, Haus der Technik, Essen, 16-17 April 2015 [11]
3. O.M.G.C Op den Camp, S.H.H.M. de Hair, E. de Gelder, I. Cara; Observation study into the influence of a view-blocking obstruction at an intersection on bicycle and passenger car velocity profiles, Proceedings ICSC 2015, Hannover [12]
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Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol

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ABSTRACT
The overall number of fatalities in road traffic accidents in Europe is decreasing. Unfortunately, the number of fatalities among cyclists does not follow this trend with the same rate [5]. In the Netherlands, a major share of killed cyclists in traffic accidents was the result of a collision with a motorised vehicle [2]. The automotive industry is making a significant effort in the development and implementation of safety systems in cars to avoid or mitigate an imminent crash with vulnerable road users, and more specifically with cyclists. The current state-of-the-art of active safety systems, Autonomous Emergency Braking (AEB), is being widely introduced. A car equipped with AEB makes use of onboard sensors such as camera and radar, to track and trace traffic participants that possibly interfere with the trajectory of the car. This information is used to warn the driver in case of a possibly critical situation and/or to brake in case the driver does not respond and the risk of collision does not decrease. Currently, AEB systems that are designed to avoid car-to-car collisions are part of the Euro NCAP star rating. In 2016, Euro NCAP will include AEB systems for pedestrians in the star rating. It is the intention of Euro NCAP to include AEB systems for cyclists in the star rating beginning of 2018 [3]. To support and prepare the introduction of Cyclist-AEB systems and the resulting consumer tests of such systems, TNO has taken the initiative to set-up a consortium of car manufacturers and suppliers with the support of Euro NCAP laboratories (such as BASt) to develop a testing system and test protocol for Cyclist-AEB systems. This paper reports the first steps towards this protocol in which an in-depth road accident study is performed to determine what accident scenarios are most relevant for car-to-cyclist collisions. Data of killed and seriously injured cyclists due to collision with a passenger car were included in this study. An overview is given for the following European countries: Germany, the Netherlands, Sweden, France, Italy, and the United Kingdom. Analysis shows that scenarios in which the bicyclist crosses the trajectory of a car in an approximately perpendicular direction is most relevant in all studied countries. Longitudinal scenarios in which car and cyclist are driving in the same direction and the cyclist is hit at the rear end by the car also cover a significant portion of serious accidents.

Keywords: car, cyclist, AEB, safety-systems, scenarios, accidents.

1 INTRODUCTION

Where the number of road fatalities for the EU28 is decreasing every year, the number of cyclist fatalities decreases at a slower pace. In Figure 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 [4]. 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 [5] and consequently the increasing number of cyclists on the road.

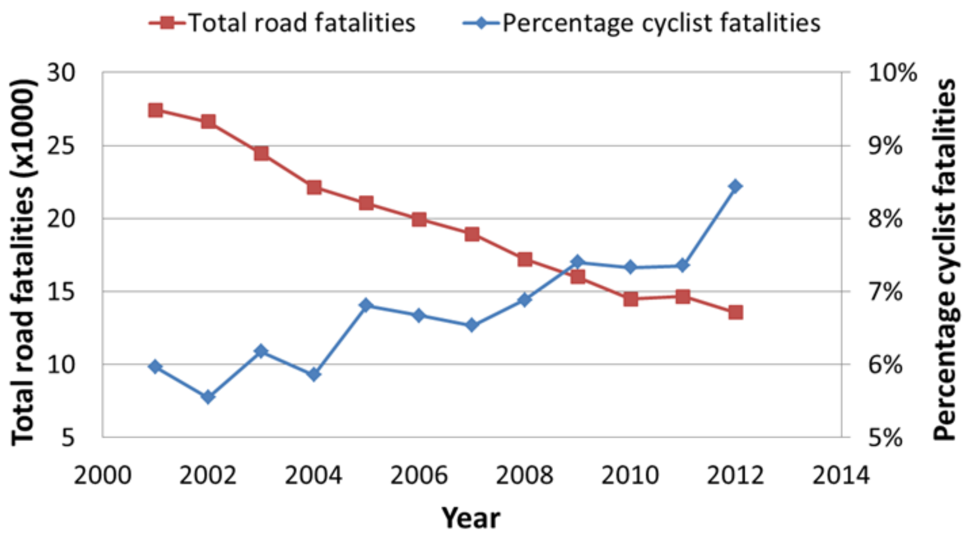


Figure 1. Trends of total road fatalities and cyclist fatalities for France, Germany, Italy, the Netherlands, Sweden plus the UK over the period of 2001 to 2012 [4].

To protect vulnerable road users in collisions with cars, the automotive industry is developing and implementing passive safety systems to mitigate injuries once a collision is unavoidable. More recently, in addition to passive safety systems, active systems are being developed and deployed that aim at collision avoidance and mitigation. With on-board sensors such as camera and radar, a real-time estimate is made of the current traffic situation, and the risk of running into a collision with other traffic participants is continuously calculated, in order to determine appropriate action. One of the most promising active safety systems, Autonomous Emergency Braking-systems (AEB) support the driver e.g. with an audio, visual and/or haptic warning and by automated braking to avoid or mitigate imminent crashes. Currently, AEB systems that aim at avoiding and mitigating car-to-car collisions are part of the Euro NCAP star rating. In 2016, Euro NCAP will make AEB for pedestrians part of their test protocol and star rating. Euro NCAP intends to include Cyclist-AEB systems in the safety assessment from 2018 [3].

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 test. Data on accidents between cyclists and passenger cars have been collected from sources to cover as many different EU countries as possible. In addition to the CARE database [4], accident data have been collected specifically for Belgium, France, Germany, Hungary, Italy, the Netherlands, Spain, Sweden and the United Kingdom. Some data sources did not provide sufficient information on the accident configuration, and for this reason, data from Belgium, Spain and Hungary have not been included in this study. This paper presents data for France, Germany, Italy, the Netherlands, Sweden and the United Kingdom.

As data originate from different sources, data had to be merged into one common scenario template before analysing the importance of different accident scenarios. The used methods are discussed in the next section. After the data has been collected into the common template, the results of the analyses will be shown per country, differences between countries will be discussed and an overall conclusion on the relevance of different scenarios will be drawn.

2 METHOD

A road traffic accident data analysis has been performed covering 6 European countries:

France: Data are considered from LAB (Laboratoire d'Accidentologie et de Biomécanique et d'études du comportement humain PSA Peugeot Citroën – RENAULT) that use a database created for the French project called VOIESUR [6]. The objective of this database is to have an intermediary level of detail between national data and in-depth data. The codification has been done from French police reports. About 8.500 accident cases were coded by a specialist during 1,5 years. The databases distinguishes between fatalities, severely injured (hospitalized for at least 24h) and slightly injured (received medical care but not admitted to hospital for more than 24h).

Germany: Three data sources for Germany have been studied:

GIDAS, the German In-Depth Accident Study, is a cooperation between BASt and the Automotive Research Association (FAT). Approximately 2,000 accidents involving personal injury are recorded in the area of Dresden and Hanover annually. From GIDAS, data were used for fatalities (check-box: killed within 30 days after the accident) and seriously injured coded as AIS2+ , excl. fatalities (according to the abbreviated injury scale [7]).

GIDAS-based PCM [8]: By simulating the pre-crash scenario, additional and standardized data to describe the pre-crash-sequence of an accident are generated and documented in an additional database called GIDAS-based Pre-Crash-Matrix (PCM) in very high detail. The PCM contains the major relevant data to reproduce the pre-crash-sequence of traffic accidents from the GIDAS database until 5 seconds before the first collision.

German national accident data comprising a five years period from 2008 to 2012 from the official German national accident statistics enriched by data from BASt.

Italy: Fiat Group Automobiles enforces accident data collection from 2011. The in-depth accident database is an FIAT internal database [9] with the following information: accident circumstances, vehicle and injury severity (killed, injured, not injured; each injury is coded according to AIS [7]). For the CATS activities, a distinction is made between fatalities (killed) and injured (MAIS ≥ 2, excl. fatalities). Data are collected in cooperation with several Italian Universities and the police.

Netherlands: BRON Netherlands national road crash register; police registered numbers of casualties, drivers and crashes [10]. Serious road injuries are reported to be casualties who have been seriously injured in a traffic crash in the Netherlands. This means that they have been admitted to a (Dutch) hospital with injury of a minimum AIS value of 2 for which they received treatment. The seriously injured numbers are exclusive of the number of fatalities (defined as killed due to the accident, within 30 days after the accident happened).

Sweden: Data are used from the Swedish Transport Administration fatal database STA and the Swedish Traffic Accident Data Acquisition STRADA [11]. STRADA is a national information system collecting data of injuries and accidents in the entire road transport system. STRADA is based on information from the police as well as the hospitals. The hospital records consist of ICD diagnoses and AIS coded injuries. Car-to-cyclists cases resulting AIS2+ were selected from STRADA.

United Kingdom: The STATS19 Road Accident dataset is used for the UK [12]. The police definition of serious injury covers casualties admitted to hospital, as well as those with specific types of injury (for example fractures or severe cuts). Severity of injury is known to be prone to misclassification in STATS19 due to the difficulties of such assessment by non-experts at the scene of the accident. Comparisons with death registration statistics show that very few, if any road accident fatalities are not reported to the police.

Accidents involving one bicycle and one M1 vehicle (passenger car) were selected. The bicycle is defined as a legal bicycle, which excludes mopeds, scooters or speed-pedelecs. Results will be presented for the numbers of fatalities (or killed K) and of seriously injured (SI).

Table 1. Overview of analyzed road traffic accident data sources

#	Country	Source	Killed (K)		Seriously Injured (SI)		Period
			definition	*n*	*definition*	*n*	
1	France	LAB	Fatal	72	severely injured	620	2011
2	Germany	GIDAS based PCM	Fatal	11	AIS2+	360	1999-2012
3	Germany	GIDAS*	Fatal	12	AIS2+	514	2006-2013
4	Germany	National accident statistics	Fatal	345	AIS2+	11964	2008-2012
5	Italy	FIAT internal database	Fatal	23	AIS2+	17	2003-2014
6	Netherlands	BRON	Fatal	902	seriously injured	10854	2000-2013
7	Sweden	STA/STRADA	Fatal	104	AIS2+	435	2005-2014 K 2010-2014 SI
8	UK	STATS19	Fatal	116	seriously injured	2699	2008-2010

The following pre-processing of data was performed before the data were used:

- Five datasets referring to German accidents were received for analysis from different sources: 3 based on GIDAS, one dataset using the GIDAS-based Pre-Crash-Matrix (PCM), and one dataset referring to national accident statistics. In a sensitivity study [13], these 5 datasets were compared. As the study revealed that the same trends in distribution over the scenarios are found, only one dataset has been selected for inclusion in the current study. The GIDAS-based PCM dataset provides most details on accident parameters, and is consequently used. Analyses have shown that PCM is highly representative for GIDAS and GIDAS is highly representative for Germany.
- The dataset from the UK (STATS19) has been translated towards right-hand driving conditions at the EU main land.

To provide sufficient data for analysis, cases in the various databases for a larger period of time are considered. The evolution of accident scenarios with time is not studied, and consequently the occurrence of scenarios is assumed constant.
Figure 2 shows the accident scenarios that are distinguished in CATS. As can be seen in this figure, the road layout is not included in the scenario definitions; the scenario is defined by the combination of the orientation of the bicycle with respect to the car and the driving manoeuvre of the car and the bicycle. This is similar to the approach as used in the FP7 AsPeCSS project to propose pedestrian test scenarios [12], which formed the basis for the Euro NCAP pedestrian test protocol. Accident data

* Three independent studies using the GIDAS database were received; only the one in which AIS2+ does not include fatalities is shown in the table for clarity.

from 6 European countries have been analysed and the number of fatalities and seriously injured were distinguished regarding the 10 scenarios from Figure 2. Accidents that could not be assigned to any of the 10 scenarios have been allocated to the group Remaining (Re).

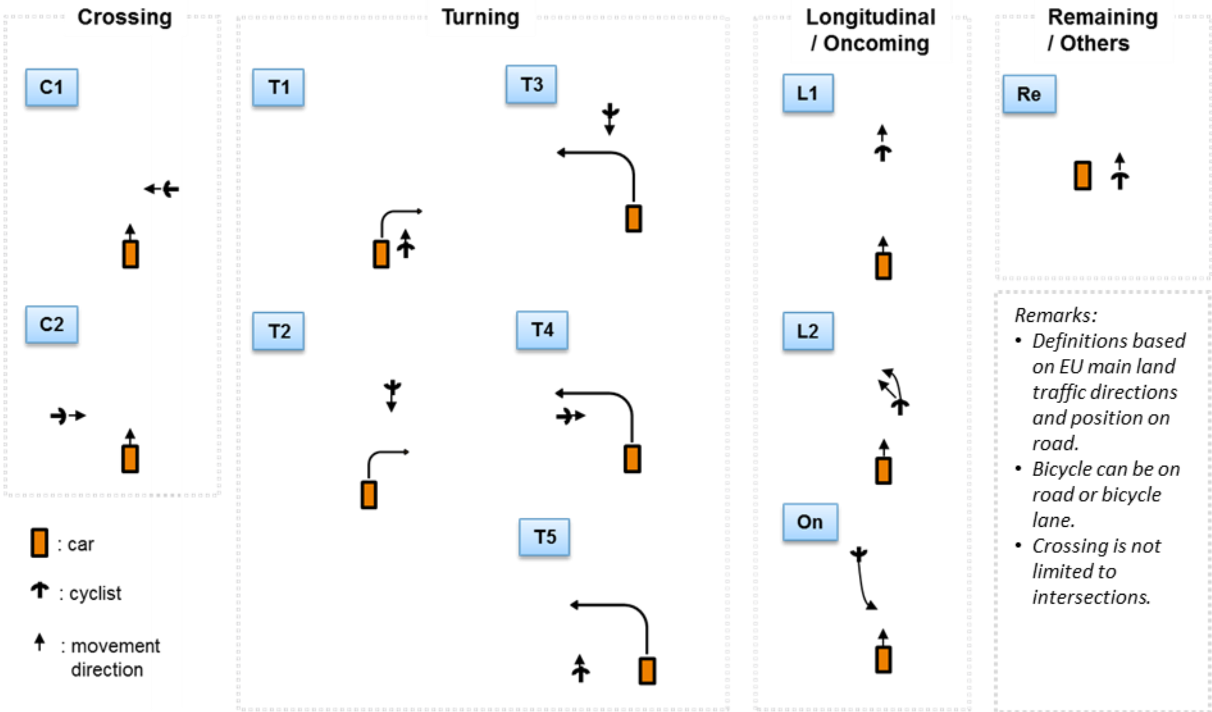


Figure 2 Overview of distinguished car-to-cyclist accident scenarios

Table 2. Description of car-to-cyclist accident scenarios

Scenario	Description
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side
T1	• Car turning right • Cyclist is riding straight in the same direction as the heading of the car before turning • Blind spot scenario
T2	• Car turning right • Cyclist is riding straight in the opposite direction as the heading of the car before turning
T3	• Car turning to the left, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight
T4	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight, coming from the far side of the car. • Some similarity with C2
T5	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight in the same direction as the heading of the car before turning
L L1 L2	• Car and cyclist driving in the same direction • Cyclist is riding straight and hit by the car from the rear • Cyclist is swerving to the left in front of the car and hit by the car from the rear
On	• Car driving straight, possibly driving towards the far road side in a passing manoeuvre • Bicyclist coming in the opposite (on-coming) direction riding straight
Re	• All other scenarios that are not covered by any of the previously described scenarios.

An extensive check has been performed to determine whether the 10 scenarios given in Figure 2 cover all relevant scenarios for car-to-cyclist collisions. This was done by comparing the scenarios of Figure 2 to an approach followed by Autoliv [14] in which a matrix is used with 12 scenarios that do cover 100% of all possible collision variations:

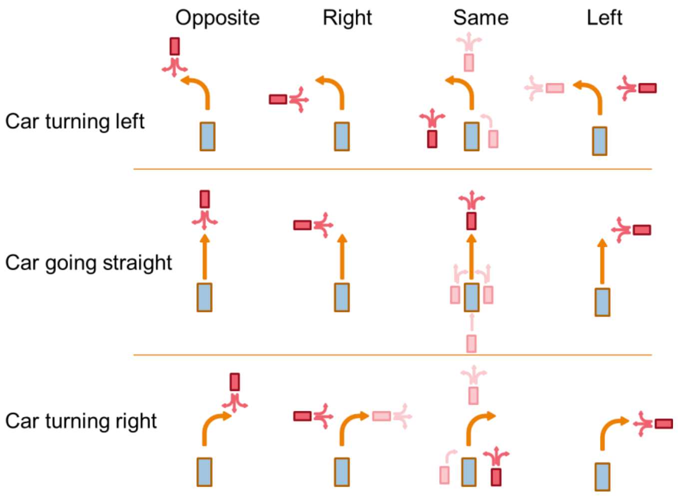


Figure 3. Matrix approach to cover 100% of the collision scenarios

In Figure 4 all CATS scenarios are merged with the matrix approach. Since the scenarios in GIDAS-based PCM are well described, data from this database are used to check how well the CATS scenarios cover the relevant scenarios. The percentages that are given in each of the matrix cells indicate the percentage of GIDAS-based PCM AIS2+ cases that cover the scenarios in that cell. The match is shown for AIS2+ to have a sufficient number of representative cases to be divided over the scenarios. Cells that solely include 'pink' car turning scenarios cover only a small portion of the GIDAS-based PCM scenarios (less than 3%), except for T14 (which covers a percentage of 11%). This is due to the strict definition of a turning car in GIDAS-based PCM, where a car with a small steering angle is already defined as turning, which is not the case in other databases. Actually, there is a large similarity between the T14 and the C1 scenario.

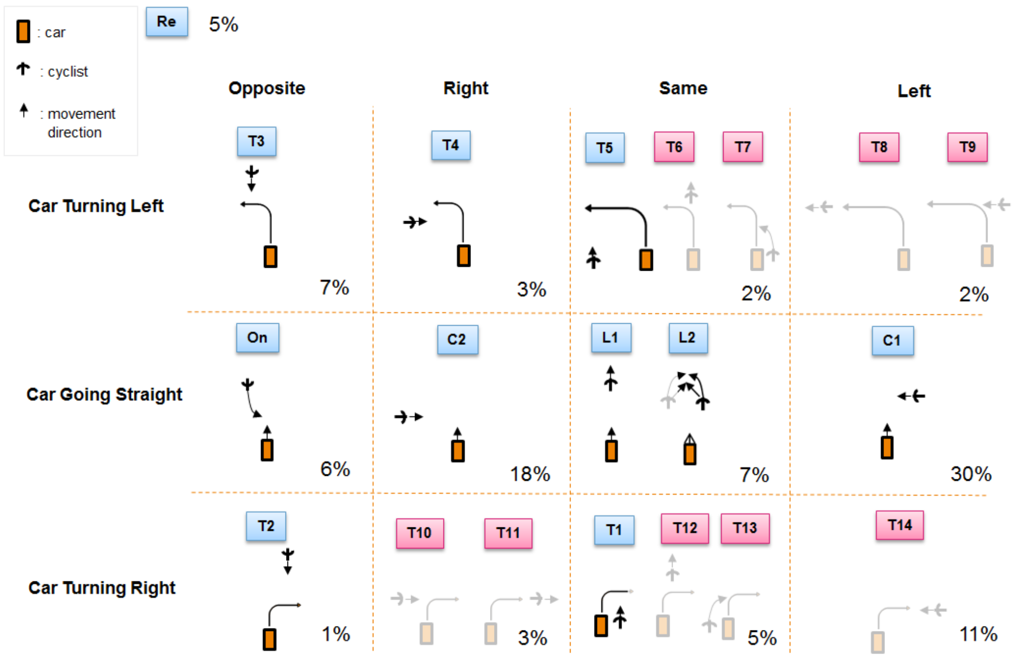


Figure 4. Merging the GIDAS based PCM scenarios to the CATS scenarios in the matrix approach

The mixed cells {T5, T6, T7} and { T1, T12, T13} only cover a relatively small percentage (≤5%), and in those cells, the scenarios T1 and T5 (that are part of the CATS scenarios) are more likely to occur than the other scenarios. The remaining group Re covers for example the scenarios in which the cyclists is colliding with a slow or parked vehicle. This group is distinguished from the L scenarios.

Making the conversion from the scenarios in Figure 2 to the matrix approach in Figure 3, confirms that all relevant scenarios are captured by the scenarios from the CATS approach in Figure 2, except for scenario T14, which shows large similarities with C1. Consequently, the scenario classification from Figure 2 will be used from now on.
The data from the databases do not show a clear distinction between the scenarios L1 and L2. In Figure 5, the heading and position of the bicycle with respect to the car is given for many different longitudinal scenarios from the detailed GIDAS-based PCM database at 2 seconds before collision. Even in these detailed data, no clear distinction can be made between the L1 and L2 scenario.

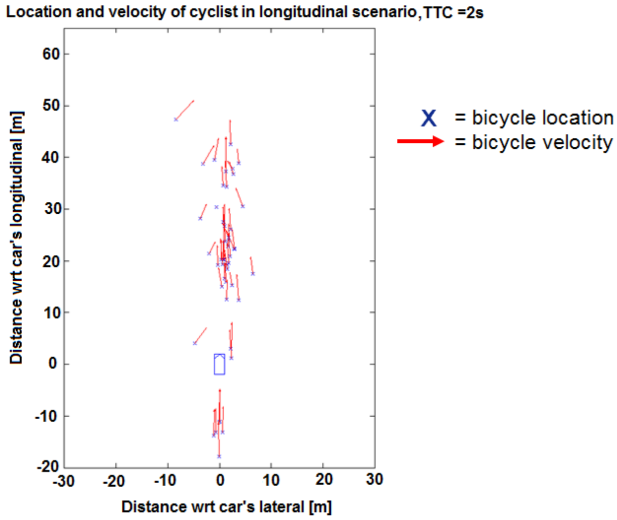


Figure 5. Location and heading of bicycle with respect to the car for several cases 2 seconds before collision.

Consequently, these two scenarios are combined into one longitudinal scenario L. For the definition of the test protocol in a later stage, the selection of test parameters should reflect the fact that both L1 and L2 are covered by L.

Now that the scenario classification is selected, the distributions for these scenarios in the different databases need to be determined. Since each database uses a different strategy in coding scenarios, this conversion is done per database separately. By means of an example, Appendix A shows how the conversion is performed for the databases from the 6 countries.

For selection and prioritization of car-to-cyclist accident scenarios to be included in a test protocol, information needs to be further merged into a single percentage for each scenario. This percentage should provide an indication how many fatalities and seriously injured are covered in the 6 considered countries. A weighting method is proposed in which an average percentage is determined over the 6 countries, based on the number of cyclist fatalities per million inhabitants taken from the CARE database [4]. In this way, a single percentage for each scenario results, weighting the percentages for the different countries to the number of cyclists fatalities per million inhabitants. In other words, the larger the percentage of cyclist fatalities in a country, the larger the weight of the specific car-to-cyclist scenarios that are found for the related country. The weighting factors are given in the table below:

Table 3. Weighting factors based on the ratio of cyclist fatalities and the total number of road fatalities per one million inhabitants in 2001-2010 [4]

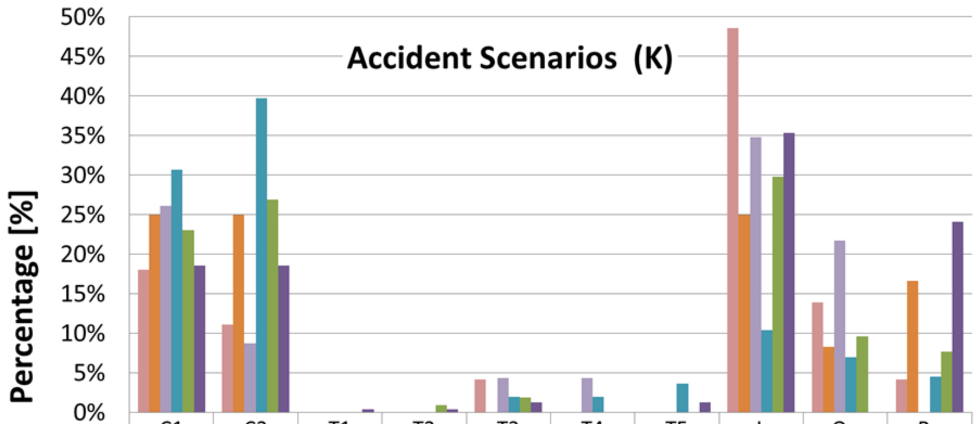
Country	# road fatalities per million inhabitants	# cyclist fatalities per million inhabitants	Weighting [%]
France	62	2,8	11%
Germany	45	6,0	26%
Italy	68	5,4	-
Netherlands	32	9,2	38%
Sweden	28	3,6	15%
UK	30	2,3	10%

The FIAT internal database is not considered in this weighting, since the cases in the database are assumed not to be representative for Italy, and therefore this database cannot be used for statistical analyses.

Further research is needed to develop an appropriate approach for weighting the results for essentially different databases.

3 RESULTS AND DISCUSSION

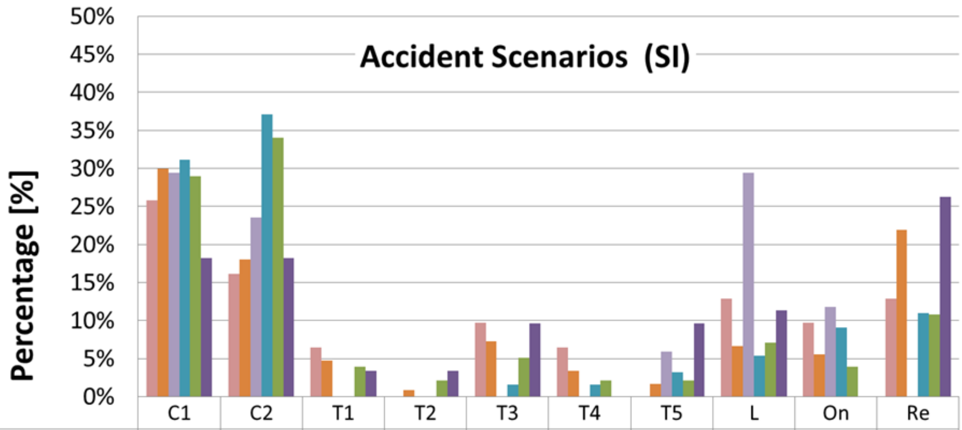
For the 6 considered countries, the percentages of killed and seriously injured are calculated for each of the accident scenarios from Figure 2. This results in the following distributions of fatally injured (K) and seriously injured (SI) over the different accident scenarios:



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	18%	11%	0%	0%	4%	0%	0%	49%	14%	4%
Germany	25%	25%	0%	0%	0%	0%	0%	25%	8%	17%
Italy	26%	9%	0%	0%	4%	4%	0%	35%	22%	0%
Netherlands	31%	40%	0%	0%	2%	2%	4%	10%	7%	5%
Sweden	23%	27%	0%	1%	2%	0%	0%	30%	10%	8%
UK	19%	19%	0%	0%	1%	0%	1%	35%	0%	24%

Figure 6. Distribution of fatally injured over the 9 accident scenarios that are distinguished for 6 EU countries.

Figure 6 clearly shows that, looking to the number of fatalities, the scenarios C1 (crossing cyclist from the near side), C2 (crossing cyclist from the far side) and L (longitudinal scenario where the vehicle collides from the rear of the cyclist) are dominant. Also the On-scenario (in which the front of the car collides with the front of the cyclist) seems relevant, but it covers clearly a smaller number of accidents than C1, C2 and L. From the turning scenarios (T1 to T5), only T3 (cyclist running straight, vehicle turning left) seems to be of relevance, but the fraction for T3 is small compared to C1, C2, or L.



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	26%	16%	6%	0%	10%	6%	0%	13%	10%	13%
Germany	30%	18%	5%	1%	7%	3%	2%	7%	6%	22%
Italy	29%	24%	0%	0%	0%	0%	6%	29%	12%	0%
Netherlands	31%	37%	0%	0%	2%	2%	3%	5%	9%	11%
Sweden	29%	34%	4%	2%	5%	2%	2%	7%	4%	11%
UK	18%	18%	3%	3%	10%	0%	10%	11%	0%	26%

Figure 7. Distribution of seriously injured over the 9 accident scenarios that are distinguished for 6 EU countries.

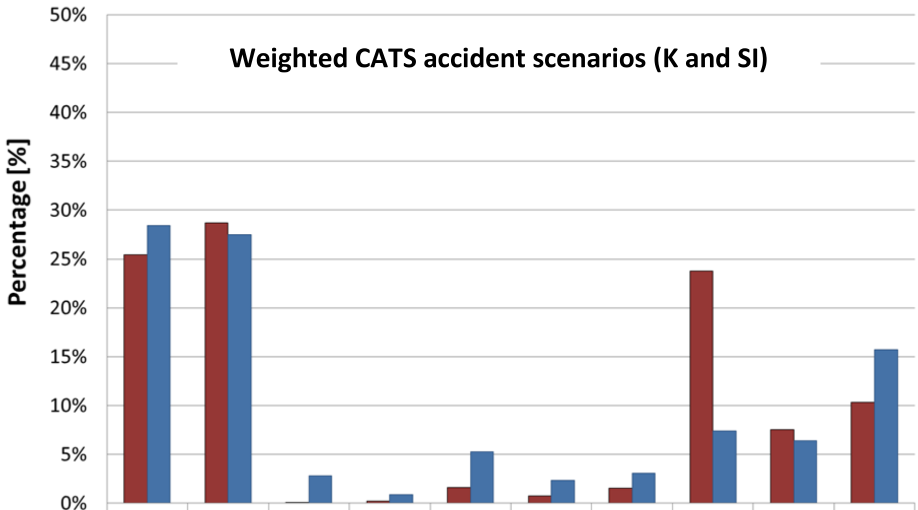
The relevance of the top-3 of scenarios for fatalities does not deviate between countries; the top-3 scenarios contain the same scenarios for all 6 countries (Appendix: Figure 10), except for the fatal scenarios in France and Italy. Some deviations are seen in priorities per country between the top-3 of C1, C2, and L. For France, a considerable higher fraction of fatalities is found for the longitudinal scenario L, compared to the crossing scenarios C1 and C2. It should be noted that the data from France only cover the period of one year, and that a relatively small number of fatalities have been included in this study. In contrast, for the Netherlands the L-scenario is rather small compared to C1 and C2. Covering 14 years and over 900 fatalities in total, this is expected to be significant. A possible reason is found in the wide application of separated bike lanes, especially along rural roads in the Netherlands. Herewith the cyclists and motorized vehicles are physically separated, leading to only a relatively small number of fatalities in L-scenarios. In general, due to the high speed difference on rural roads, a collision according to an L scenario will more easily result in fatal injury for the cyclist. This not only leads to a small percentage for L in the Netherlands, but also to relatively higher values for C1 and C2.

Another striking result is the fact that in the Netherlands the C2 scenario (bike crossing from far side) shows a higher percentage than the C1 scenario (bike from near-side). A possible explanation results from the fact that the parameters describing the accident scenario in the Dutch BRON database [10] are limited. An approach is followed in which scenarios as described in BRON are translated to the scenarios from Figure 2. For many crossing scenarios in BRON, no distinction is made between near side or far side scenarios (see Appendix A). Consequently, 50% of those crossing scenarios are allocated to C1 and the other 50% to C2. Other scenarios are clearly indicated as far side, making the fraction of C2 scenarios larger than the C1 scenarios.

The distribution for accidents leading to seriously injured cyclists deviates slightly from that for fatalities. Most clearly seen is the strong decrease in the percentage allocated to the L scenario. Although still present as one of the top-3 dominant scenarios, it cannot easily be distinguished from the On-scenario, except for Italy, where the L scenario for seriously injured is as important as the C1 crossing scenario (Appendix B Figure 11).

It should be noted that the data from Italy come from an in-depth database and are not intended to perform statistical analyses with. Therefore, in the remainder of this paper, the small number of Italian cases will not be considered for further analysis and comparison with other countries.

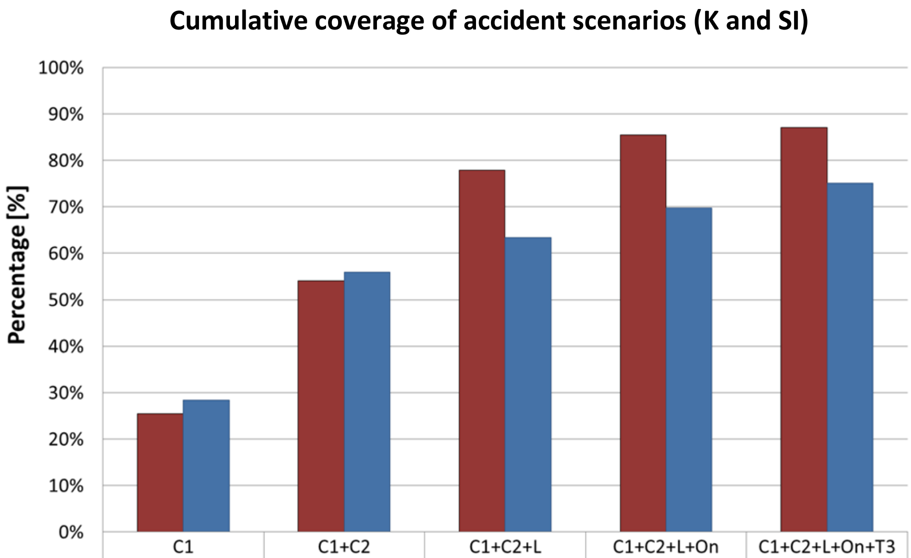
Based on the weighting method that is proposed in the previous section, an average percentage is determined over 5 countries (the original 6 minus Italy), based on the number of cyclist fatalities per million inhabitants taken from the CARE database [4]. The weighted average over the countries except Italy, using the factors from Table 3, is given in the next graph (for both fatalities and seriously injured):



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
mean K	25%	29%	0%	0%	2%	1%	2%	24%	8%	10%
mean SI	28%	28%	3%	1%	5%	2%	3%	7%	6%	16%

Figure 8. Distribution of fatalities and seriously injured over the 9 accident scenarios, weighted average over 5 countries. The red columns refer to fatalities (K), where the blue columns refer to seriously injured (SI).

This figure shows that C1 and C2-scenarios are dominant and equally important, followed by the L-scenario. Less important is the On-scenario. From the scenarios where the car is making a turn (T), the T3-scenario is most common, but this scenario is covering less accidents than the C1, C2, and L scenario. Next graph presents the cumulative coverage of the most important scenarios:



	C1	C1+C2	C1+C2+L	C1+C2+L+On	C1+C2+L+On+T3
mean K	25%	54%	78%	85%	87%
mean SI	28%	56%	63%	70%	75%

Figure 9. Cumulative coverage of scenarios in the order of importance.

4 CONCLUSION

Putting the scenarios in order of relevance and importance, considering the number of fatalities and seriously injured due to car-to-cyclist collisions in the EU-countries France, Germany, Italy, the Netherlands, Sweden and the UK, the next sequence applies: C1, C2, L, On and T3. The scenarios C1, C2 and L together cover already between 78% and 63% of the fatal and serious car-to-cyclist accidents respectively.

Table 4. Description of scenarios in order of importance to cyclist casualties due to collision with a passenger car.

Scenario	Description	% covered for K	% covered for SI
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side	25	28
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side	29	28
L L1 L2	• Car and cyclist driving in the same direction • Cyclist is riding straight and hit by the car from the rear • Cyclist is swerving to the left in front of the car and hit by the car from the rear	24	7
On	• Car driving straight, possibly driving towards the far road side in a passing manoeuvre • Bicyclist coming in the opposite (on-coming) direction riding straight	8	6
T3	• Car turning to the left, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight	2	5

Next step in the test protocol development is the determination of the test parameters such as vehicle speed, bicycle speed, the presence of view blocking obstructions, collision point on the vehicle, type of bicycle and size of cyclist. Moreover, parameters describing the level of light or precipitation need to be selected. The car-to-cyclist accidents from the databases used for scenario selection will be studied to provide ranges for these parameters that give a representative coverage of the real-life conditions. In addition to that, observation studies may be used in case not all parameters can be selected based on the currently available data in the databases. These studies might for instance be used for the presence and size of view blocking obstructions.

ACKNOWLEDGEMENT

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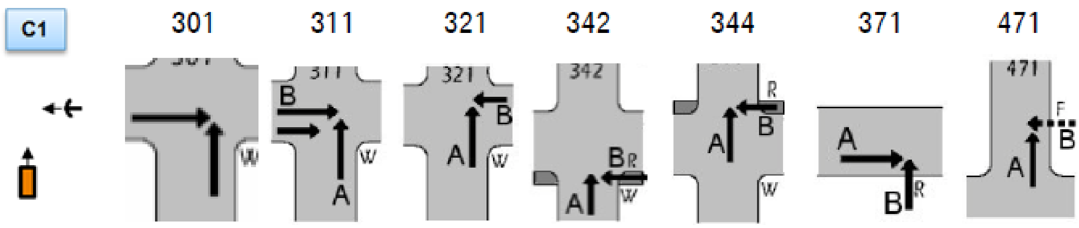
APPENDIX A: CONVERSION OF DATABASES TO CATS SCENARIOS

In each of the databases, the accident scenarios describing the movement of car and bicycle just before the collision, is coded and described in a different way. Consequently, the conversion of scenarios from the database to the scenarios from Figure 2, has been performed separately. The conversion for each of the countries is explained by an example:

France: LAB France provided the data according to the scenarios from Figure 2. Although a distinction was made in e.g. C1 for a regular intersection and C1 for a roundabout, in the total results such distinction is no longer made.

Germany: In the GIDAS database, the scenarios are coded with a 3-digit code. In a conversion table the different scenarios are related to the scenarios from Figure 2. As an example, the figure below shows which GIDAS scenarios are all considered a bicycle crossing from the near side C1:



Italy: Each of the 40 cases in the FIAT internal database were studied separately. From a description of the movement of bicycle and car, one of the CATS scenarios was selected. Thereafter, for each of the CATS scenarios, the number of cases (fatal or seriously injured) were added to the results shown in Figure 6 and Figure 7.

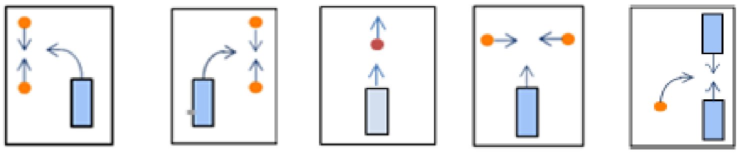
The Netherlands: In the BRON database, each case is related to a manoeuvre. A list of many different manoeuvres is used in BRON. By selecting car-to-cyclist fatalities (and similar for seriously injured), the number of cases per manoeuvre is given, and the resulting list is sorted upon the percentage of cases covered by the manoeuvre. Only those manoeuvres are considered that at least cover 2% of the cases. In the table below, an example is given for fatalities for some of the most relevant manoeuvres:

Manoeuvre	# fatalities	CATS scenarios	Distribution proposed
Side impact on crossing	327	C1 / C2	50% C1, 50% C2
Other side impact	190	C1 / C2	50% C1, 50% C2
Right side impact with crossing vehicle	85	C2	100% C2
Rear end collision without turning	75	L1 / L2	50% L1, 50% L2
Frontal without lane change	63	On	100% On

After the manoeuvres have been attributed to the CATS scenarios, all cases (for fatalities and seriously injured separately) are added for the CATS scenarios, to come to the results given in Figure 6 and Figure 7.

Sweden: Autoliv provided the data according to the scenarios from Figure 2 [11]. Each accident case was opened up from the two databases STA and STRADA and accident descriptions were studied in detail case-by-case to conclude the most likely accident scenario in each case.

UK: Data from the UK were distinguished in 5 accident scenarios according to [15]:



1 2 3 4 5

In a second step, CATS scenarios were allocated to each of these 5 scenarios according to the next scheme:

UK accident scenario	CATS scenarios	Distribution proposed
1	T1 / T2	50% T1, 50% T2
2	T3 / T5	50% T3, 50% T5
3	L1 / L2	50% L1, 50% L2
4	C1 / C2	50% C1, 50% C2
5	C1 / C2	50% C1, 50% C2

All CATS scenarios that could not be allocated to one of the UK scenarios was put in the group “other”. This group consists of T4, On, and Re. No further distinction was made for the latter group, which results in the fact that no estimate is given for the percentage covered by the On-scenario.

APPENDIX B: OVERVIEW OF SCENARIO RELEVANCE PER COUNTRY

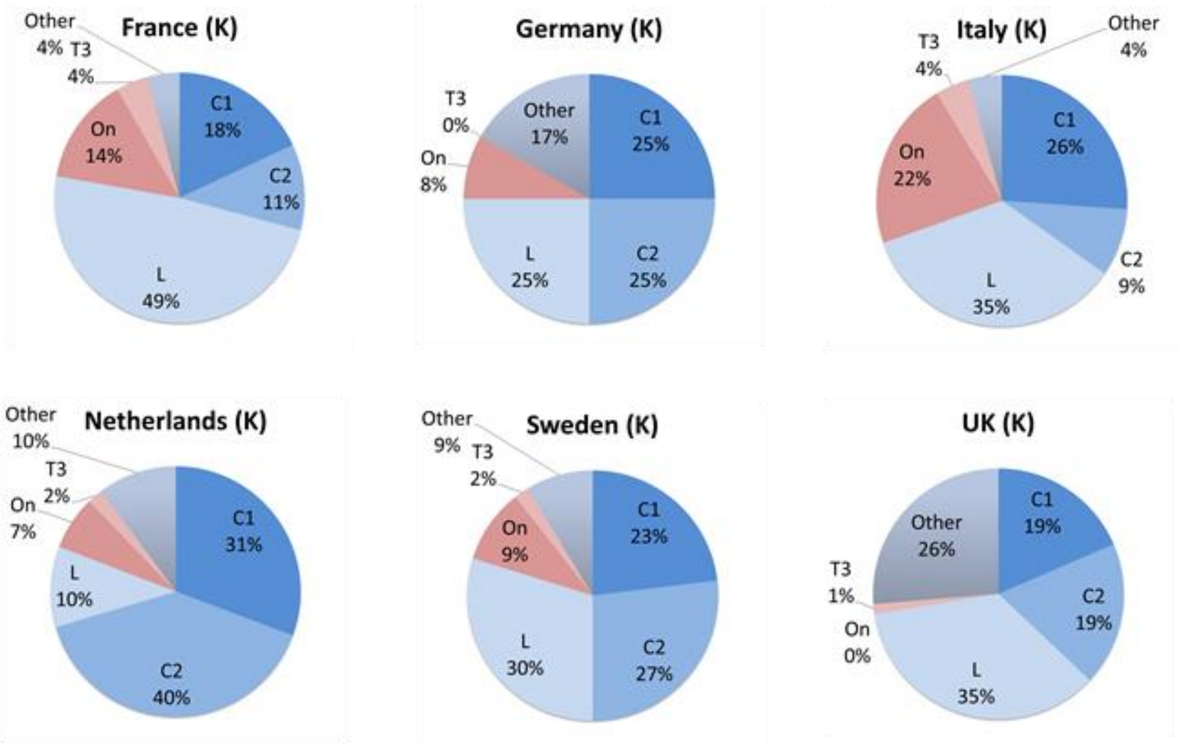


Figure 10. The distribution of scenarios per country for the fatal cyclist accidents. In blue the scenarios C1, C2 and L, in red the scenarios On and T3, and in grey all remaining scenarios (other).

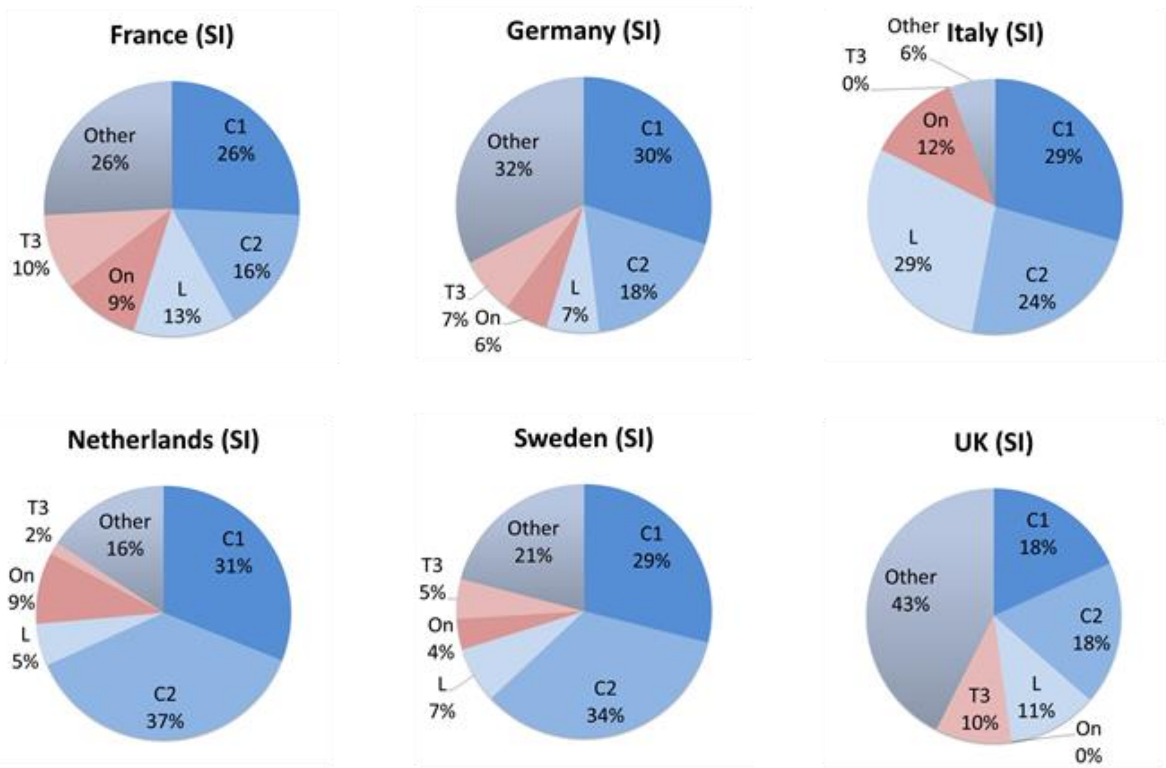


Figure 11. The distribution of scenarios per country for cyclist accidents resulting in serious injuries. In blue the scenarios C1, C2 and L, in red the scenarios On and T3, and in grey all remaining scenarios (other).

14 Overview of main accident scenarios in car-to-cyclist accidents for use in AEB-system test protocol

Olaf Op den Camp, Arian Ranjbar, Jeroen Uittenbogaard, Erik Rosen, Rikard Fredriksson, Stefanie Buijssen-de Hair

Abstract

The overall number of fatalities in road traffic accidents in Europe is decreasing. Unfortunately, the number of fatalities among cyclists does not follow this trend with the same rate [5]. In the Netherlands, a major share of killed cyclists in traffic accidents is the result of a collision with a motorised vehicle [2]. The automotive industry is making a significant effort in the development and implementation of safety systems in cars to avoid or mitigate an imminent crash with vulnerable road users, and more specifically with cyclists. The current state-of-the-art of active safety systems, Autonomous Emergency Braking (AEB), is being widely introduced. A car equipped with AEB makes use of on-board sensors such as camera and radar, to track and trace traffic participants that possibly interfere with the trajectory of the car. This information is used to warn the driver in case of a possibly critical situation and/or to brake in case the driver does not respond and the risk of collision does not decrease. Currently, AEB systems that are designed to avoid car-to-car collisions are part of the Euro NCAP star rating. In 2016, Euro NCAP will include AEB systems for pedestrians in the star rating. It is the intention of Euro NCAP to include AEB systems for cyclists in the star rating beginning of 2018 [3].

To support and prepare the introduction of Cyclist-AEB systems and the resulting consumer tests of such systems, TNO has taken the initiative to set-up a consortium of car manufacturers and suppliers with the support of Euro NCAP laboratories (such as BASt) to develop a testing system and test protocol for Cyclist-AEB systems. This paper reports the first steps towards this protocol in which an in-depth road accident study is performed to determine what accident scenarios are most relevant for car-to-cyclist collisions. Data of killed and seriously injured cyclists due to collision with a passenger car were included in this study. An overview is given for the following European countries: Germany, the Netherlands, Sweden, France, Italy, and the United Kingdom. Analysis shows that scenarios in which the bicyclist crosses the trajectory of a car in an approximately perpendicular direction is most relevant in all studied countries. Longitudinal scenarios in which car and cyclist are driving in the same direction and the cyclist is hit at the rear end by the car also cover a significant portion of serious accidents.

1. Introduction

Where the number of road fatalities for the EU28 is decreasing every year, the number of cyclist fatalities decreases at a slower pace. In Figure 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 [4]. 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 [5] and consequently the increasing number of cyclists on the road.

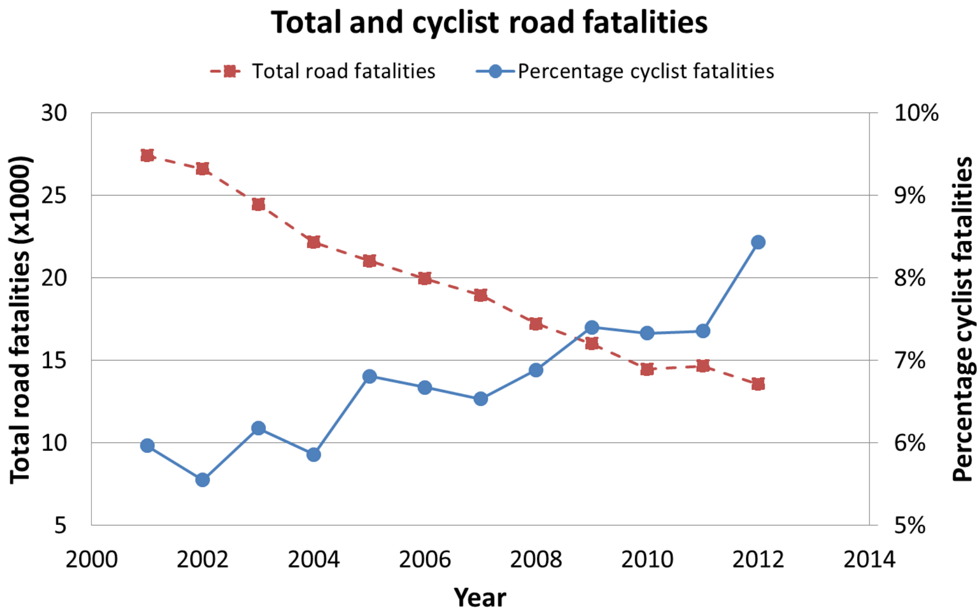


Figure 1: Trends of total road fatalities and cyclist fatalities for France, Germany, Italy, the Netherlands, Sweden plus the UK over the period 2001 to 2012 [4].

To protect vulnerable road users in collisions with cars, the automotive industry is developing and implementing passive safety systems to mitigate injuries once a collision is unavoidable. More recently, in addition to passive safety systems, active systems are being developed and deployed that aim at collision avoidance and mitigation. With on-board sensors such as camera and radar, a real-time estimate is made of the current traffic situation, and the risk of running into a collision with other traffic participants is continuously calculated, in order to determine appropriate action. One of the most promising active safety systems, Autonomous Emergency Braking-systems (AEB) support the driver e.g. with an audio, visual and/or haptic warning and by automated braking to avoid or mitigate imminent crashes. Currently, AEB systems that aim at avoiding and mitigating car-to-car collisions are part of the Euro NCAP star rating. In 2016, Euro NCAP will make AEB for pedestrians part of their test protocol and star rating. Euro NCAP intends to include Cyclist-AEB systems in the safety assessment from 2018 [3].

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 test. Data on accidents between cyclists and passenger cars have been collected from sources to cover as many different EU countries as possible. In addition to the CARE database [4], accident data have been collected specifically for Belgium, France, Germany, Hungary, Italy, the Netherlands, Spain, Sweden and the United Kingdom. Some data sources did not provide sufficient information on the accident configuration, and for this reason, data from Belgium, Spain and Hungary have not been included in this study. This paper presents data for France, Germany, Italy, the Netherlands, Sweden and the United Kingdom.

As data originate from different sources, data had to be merged into one common scenario template before analysing the importance of different accident scenarios. The used methods are discussed in the next section. After the data has been collected into the common template, the results of the analyses will be shown per country, differences between countries will be discussed and an overall conclusion on the relevance of different scenarios will be drawn.

2. Method

A road traffic accident data analysis was performed covering 6 European countries:

France: Data are considered from LAB (Laboratoire d'Accidentologie et de Biomécanique et d'études du comportement humain PSA Peugeot Citroën – RENAULT) that use a database created for the French project called VOIESUR [6]. The objective of this database is to have an intermediary level of detail between national data and in-depth data. The codification has been done from French police reports. About 8.500 accident cases were coded by a specialist during 1,5 years. The database distinguishes between fatalities, severely injured (hospitalized for at least 24h) and slightly injured (received medical care but not admitted to hospital for more than 24h).

Germany: Three data sources for Germany have been studied:

GIDAS, the German In-Depth Accident Study, is a cooperation between BASt and the Automotive Research Association (FAT). Approximately 2,000 accidents involving personal injury are recorded in the area of Dresden and Hanover annually. From GIDAS, data were used for fatalities (check-box: killed within 30 days after the accident) and seriously injured coded as AIS2+ , excl. fatalities (according to the abbreviated injury scale [7]).

GIDAS-based PCM [8]: By simulating the pre-crash scenario, additional and standardized data to describe the pre-crash-sequence of an accident are generated and documented in an additional database called GIDAS-based Pre-Crash-Matrix (PCM) in very high detail. The PCM contains the major relevant data to reproduce the pre-crash-sequence of traffic accidents from the GIDAS database until 5 seconds before the first collision.

German national accident data comprising a five years period from 2008 to 2012 from the official German national accident statistics enriched by data from BASt.

Italy: Fiat Group Automobiles enforces accident data collection from 2011. The in-depth accident database is a FIAT internal database [9] with the following information: accident circumstances, vehicle and injury severity (killed, injured, not injured; each injury is coded according to AIS [7]). For the CATS activities, a distinction is made between fatalities (killed) and injured (MAIS ≥ 2, excl. fatalities). Data are collected in cooperation with several Italian Universities and the police.

Netherlands: BRON Netherlands national road crash register; police registered numbers of casualties, drivers and crashes [10]. Serious road injuries are reported to be casualties who have been seriously injured in a traffic crash in the Netherlands. This means that they have been admitted to a (Dutch) hospital with injury of a minimum AIS value of 2 for which they received treatment. The seriously injured numbers are exclusive of the number of fatalities (defined as killed due to the accident, within 30 days after the accident happened).

Sweden: Data are used from the Swedish Transport Administration fatal database STA and the Swedish Traffic Accident Data Acquisition STRADA [11]. STRADA is a national information system collecting data of injuries and accidents in the entire road transport system. STRADA is based on information from the police as well as the hospitals. The hospital records consist of ICD[1] diagnoses and AIS coded injuries. Car-to-cyclists cases resulting in AIS2+ were selected from STRADA.

United Kingdom: The STATS19 Road Accident dataset is used for the UK [12]. The police definition of serious injury covers casualties admitted to hospital, as well as those with specific types of injury (for example fractures or severe cuts). Severity of injury is known to be prone to misclassification in STATS19 due to the difficulties of such assessment by non-experts at the scene of the accident. Comparisons with death registration statistics show that very few, if any road accident fatalities are not reported to the police.

Accidents involving one bicycle and one M1 vehicle (passenger car) were selected. The bicycle is defined as a legal bicycle, which excludes mopeds, scooters or speed-pedelecs. Results will be presented for the numbers of fatalities (or killed K) and of seriously injured (SI).

Table 1: Overview of analyzed road traffic accident data sources

#	Country	Source	Killed (K)		Seriously Injured (SI)		Period
			definition	*n*	*definition*	*n*	
1	France	LAB	Fatal	72	severely injured	620	2011
2	Germany	GIDAS based PCM	Fatal	11	AIS2+	360	1999-2012
3	Germany	GIDAS[2]	Fatal	12	AIS2+	514	2006-2013
4	Germany	National accident statistics	Fatal	345	AIS2+	11964	2008-2012
5	Italy	FIAT internal database	Fatal	23	AIS2+	17	2003-2014
6	Netherlands	BRON	Fatal	902	seriously injured	10854	2000-2013
7	Sweden	STA/STRADA	Fatal	104	AIS2+	435	2005-2014 K 2010-2014 SI
8	UK	STATS19	Fatal	116	seriously injured	2699	2008-2010

The following pre-processing of data was performed before the data were used:

- Five datasets referring to German accidents were received for analysis from different sources: 3 based on GIDAS, one dataset using the GIDAS-based Pre-

[1] The International Statistical Classification of Diseases and Related Health Problems, usually called International Classification of Diseases (ICD), is the standard diagnostic tool for epidemiology, health management and clinical purposes, which is maintained by the World Health Organization.

[2] Three independent studies using the GIDAS database were received; only the one in which AIS2+ does not include fatalities is shown in the table for clarity.

Crash-Matrix (PCM), and one dataset referring to national accident statistics. In a sensitivity study [13], these 5 datasets were compared. As the study revealed that the same trends in distribution over the scenarios are found, only one dataset has been selected for inclusion in the current study. The GIDAS-based PCM dataset provides most details on accident parameters, and is consequently used. Analyses have shown that PCM is highly representative for GIDAS and GIDAS is highly representative for Germany.

- The dataset from the UK (STATS19) has been translated towards right-hand driving conditions at the EU main land.

To provide sufficient data for analysis, cases in the various databases for a larger period of time are considered. The evolution of accident scenarios with time is not studied, and consequently the occurrence of scenarios is assumed constant.
 shows the accident scenarios that are distinguished in CATS. As can be seen in this figure, the road layout is not included in the scenario definitions; the scenario is defined by the combination of the orientation of the bicycle with respect to the car and the driving manoeuvre of the car and the bicycle. This is similar to the approach as used in the FP7 AsPeCSS project to propose pedestrian test scenarios [12], which formed the basis for the Euro NCAP pedestrian test protocol. Accident data from 6 European countries have been analysed and the number of fatalities and seriously injured were distinguished regarding the 10 scenarios from Figure 2. Accidents that could not be assigned to any of the 10 scenarios have been allocated to the group Remaining (Re).

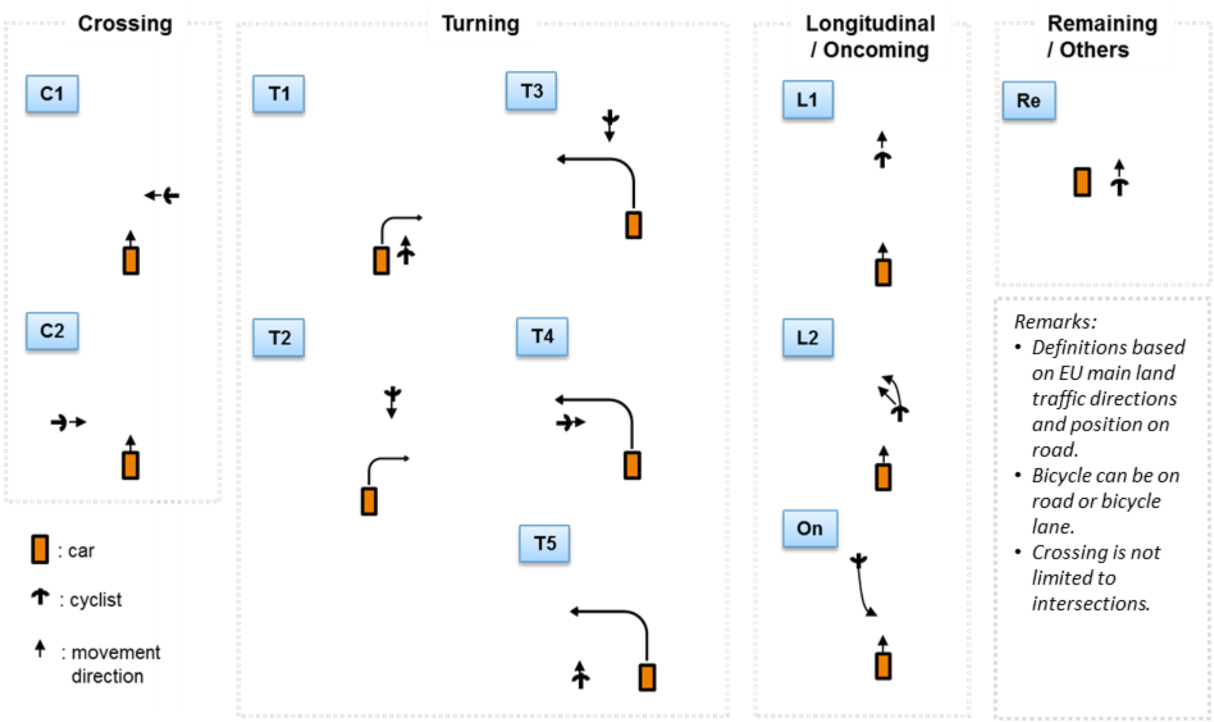


Figure 2: Overview of distinguished car-to-cyclist accident scenarios

Table 2: Description of car-to-cyclist accident scenarios

Scen.	Description
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side
T1	• Car turning right • Cyclist is riding straight in the same direction as the heading of the car before turning • Blind spot scenario
T2	• Car turning right • Cyclist is riding straight in the opposite direction as the heading of the car before turning
T3	• Car turning to the left, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight
T4	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight, coming from the far side of the car. • Some similarity with C2
T5	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight in the same direction as the heading of the car before turning
L L1 L2	• Car and cyclist driving in the same direction • Cyclist is riding straight and hit by the car from the rear • Cyclist is swerving to the left in front of the car and hit by the car from the rear
On	• Car driving straight, possibly driving towards the far road side in a passing manoeuvre • Bicyclist coming in the opposite (on-coming) direction riding straight
Re	• All other scenarios that are not covered by any of the previously described scenarios.

An extensive check has been performed to determine whether the 10 scenarios given in Figure 2 cover all relevant scenarios for car-to-cyclist collisions. This was done by comparing the scenarios of Figure 2 to an approach followed by Autoliv [14] in which a matrix is used with 12 basic scenario varieties that do cover 100% of all possible collision variations:

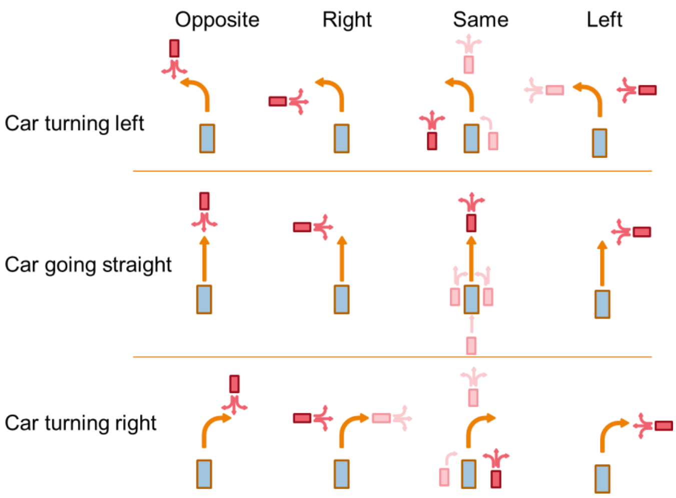


Figure 3: Matrix approach to cover 100% of the collision scenarios

In Figure 4, all CATS scenarios are merged with the matrix approach. Since the scenarios in GIDAS-based PCM are well described, data from this database are used to check how well the CATS scenarios cover the relevant scenarios. The percentages

that are given in each of the matrix cells indicate the percentage of GIDAS-based PCM AIS2+ cases that cover the scenarios in that cell. The match is shown for AIS2+ to have a sufficiently high number of representative cases to be divided over the scenarios.
Cells that solely include 'light grey' car turning scenarios cover only a small portion of the GIDAS-based PCM scenarios (less than 3%), except for T14 (which covers a percentage of 11%). This is due to the strict definition of a turning car in GIDAS-based PCM, where a car with a small steering angle is already defined as turning, which is not the case in other databases. Actually, there is a large similarity between the T14 and the C1 scenario.

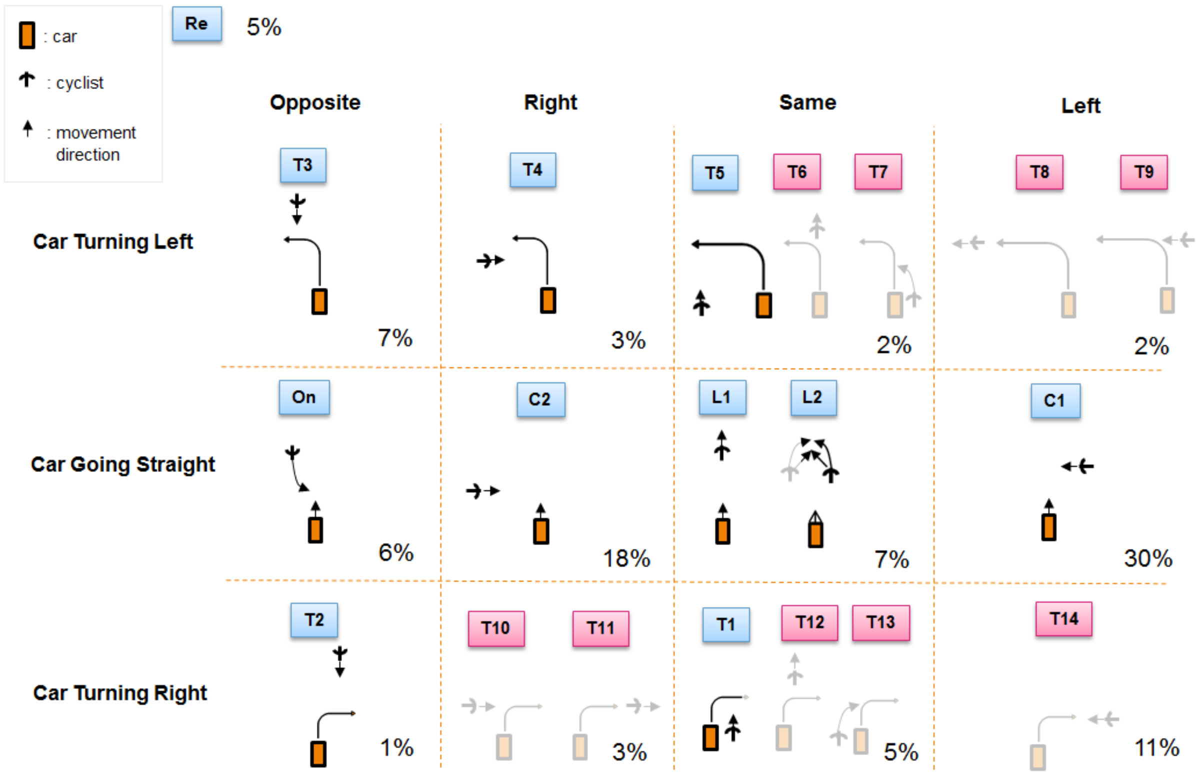


Figure 4: Merging the GIDAS based PCM scenarios to the CATS scenarios in the matrix approach

The mixed cells {T5, T6, T7} and {T1, T12, T13} only cover a relatively small percentage (≤5%), and in those cells, the scenarios T1 and T5 (that are part of the CATS scenarios) are more likely to occur than the other scenarios. The remaining group Re covers for example the scenarios in which the cyclist is colliding with a slow or parked vehicle. This group is distinguished from the L scenarios.

Making the conversion from the scenarios in Figure 2 to the matrix approach in Figure 3, confirms that all relevant scenarios are captured by the scenarios from the CATS approach in Figure 2, except for scenario T14, which shows large similarities with C1. Consequently, the scenario classification from Figure 2 will be used from now on.

The data from the databases do not show a clear distinction between the scenarios L1 and L2. In Figure 5, the heading and position of the bicycle with respect to the car is given for many different longitudinal scenarios from the detailed GIDAS-based PCM database at 2 seconds before collision. Even in these detailed data, no clear distinction can be made between the L1 and L2 scenario.

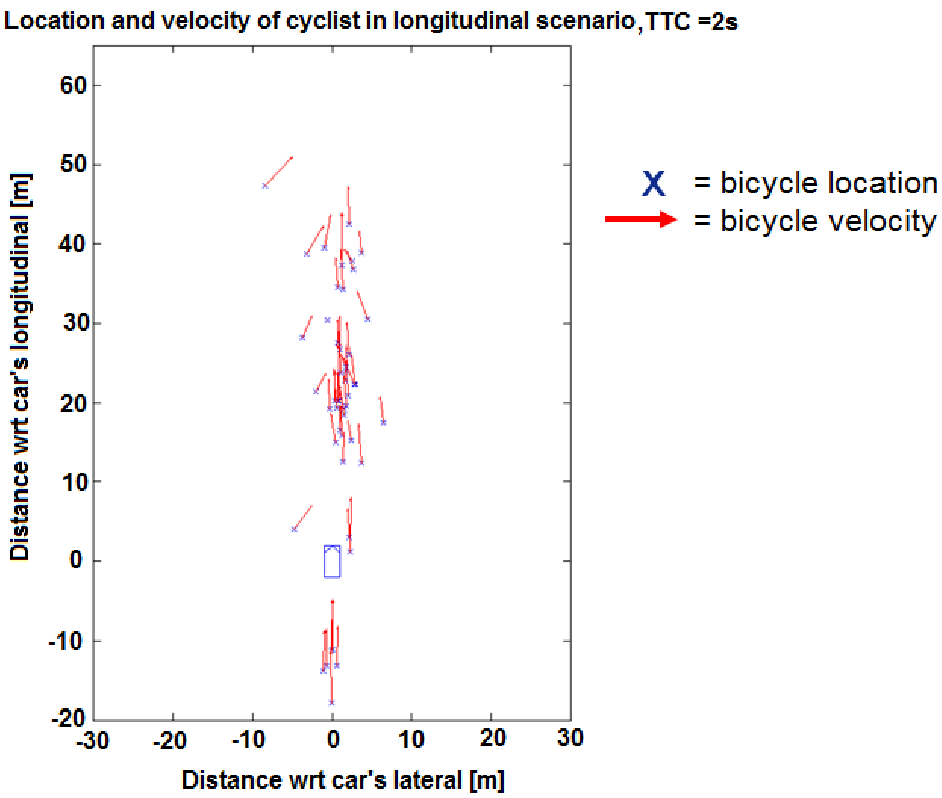


Figure 5: Location and heading of bicycle with respect to the car for several cases 2 seconds before collision

Consequently, these two scenarios are combined into one longitudinal scenario L. For the definition of the test protocol in a later stage, the selection of test parameters should reflect the fact that both L1 and L2 are covered by L.

Now that the scenario classification method is selected, the distributions for these scenarios in the different databases need to be determined. Since each database uses a different strategy in coding scenarios, this conversion is done per database separately. By means of an example, Appendix A shows how the conversion is performed for the databases from the 6 countries.

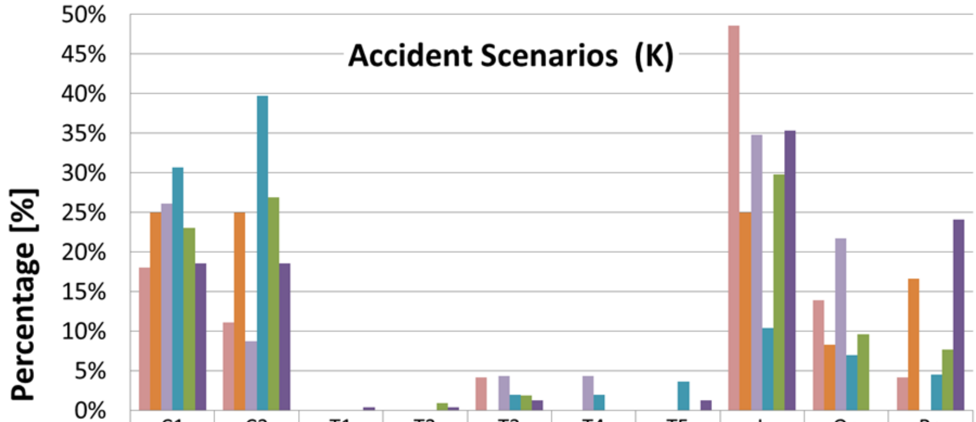
For selection and prioritization of car-to-cyclist accident scenarios to be included in a test protocol, information needs to be further merged into a single percentage for each scenario. This percentage should provide an indication how many fatalities and seriously injured are covered in the 6 considered countries. A weighting method is proposed in which an average percentage is determined over the 6 countries, based on the number of cyclist fatalities per million inhabitants taken from the CARE database [4]. In this way, a single percentage for each scenario results, weighting the percentages for the different countries to the number of cyclists fatalities per million inhabitants. In other words, the larger the percentage of cyclist fatalities in a country, the larger the weight of the specific car-to-cyclist scenarios that are found for the related country. The weighting factors are given in the table below:

Table 3: Weighting factors based on the ratio of cyclist fatalities and the total number of road fatalities per one million inhabitants in 2001-2010 [4]

Country	**# road fatalities per million inhabitants**	**# cyclist fatalities per million inhabitants**	**Weighting [%]**
France	62	2,8	11%
Germany	45	6,0	26%
Italy	68	5,4	-
Netherlands	32	9,2	38%
Sweden	28	3,6	15%
UK	30	2,3	10%

The FIAT internal database is not considered in this weighting, since the cases in the database are assumed not to be representative for Italy, and therefore this database cannot be used for statistical analyses.
Further research is needed to develop an appropriate approach for weighting the results for essentially different databases.

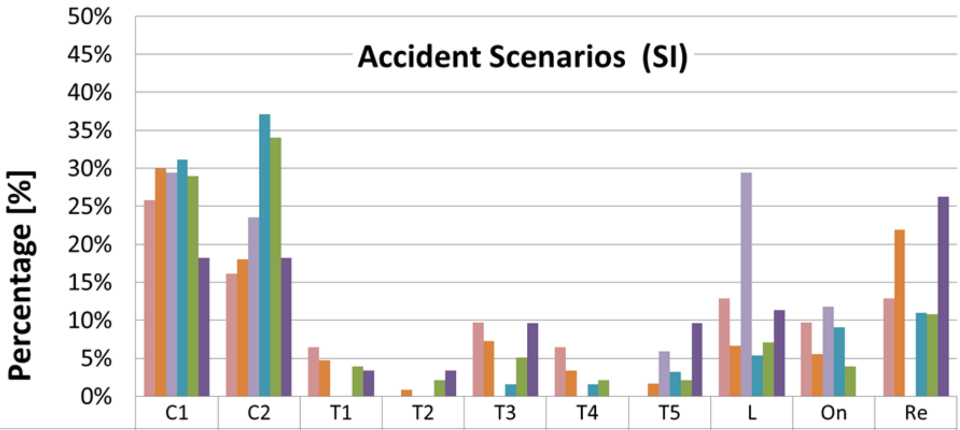
3. Results and discussion



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	18%	11%	0%	0%	4%	0%	0%	49%	14%	4%
Germany	25%	25%	0%	0%	0%	0%	0%	25%	8%	17%
Italy	26%	9%	0%	0%	4%	4%	0%	35%	22%	0%
Netherlands	31%	40%	0%	0%	2%	2%	4%	10%	7%	5%
Sweden	23%	27%	0%	1%	2%	0%	0%	30%	10%	8%
UK	19%	19%	0%	0%	1%	0%	1%	35%	0%	24%

Figure 6: Distribution of fatally injured over the 9 accident scenarios that are distinguished for 6 EU countries

For the 6 considered countries, the percentages of killed and seriously injured are calculated for each of the accident scenarios from Figure 2. This results in the above distributions of fatally injured (K) and seriously injured (SI) over the different accident scenarios. This figure clearly shows that, looking to the number of fatalities, the scenarios C1 (crossing cyclist from the near side), C2 (crossing cyclist from the far side) and L (longitudinal scenario where the vehicle collides from the rear of the cyclist) are dominant. Also the On-scenario (in which the front of the car collides with the front of the cyclist) seems relevant, but it covers clearly a smaller number of accidents than C1, C2 and L. From the turning scenarios (T1 to T5), only T3 (cyclist running straight, vehicle turning left) seems to be of relevance, but the fraction for T3 is small compared to C1, C2, or L.

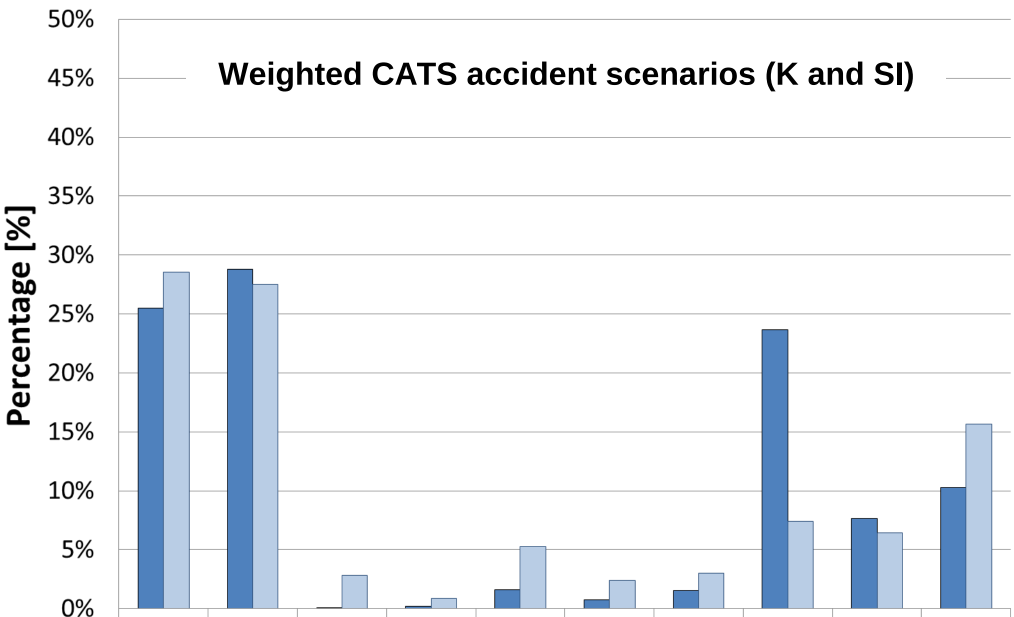


	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	26%	16%	6%	0%	10%	6%	0%	13%	10%	13%
Germany	30%	18%	5%	1%	7%	3%	2%	7%	6%	22%
Italy	29%	24%	0%	0%	0%	0%	6%	29%	12%	0%
Netherlands	31%	37%	0%	0%	2%	2%	3%	5%	9%	11%
Sweden	29%	34%	4%	2%	5%	2%	2%	7%	4%	11%
UK	18%	18%	3%	3%	10%	0%	10%	11%	0%	26%

Figure 7: Distribution of seriously injured over the 9 accident scenarios that are distinguished for 6 EU countries

The relevance of the top-3 of scenarios for fatalities does not deviate between countries; the top-3 scenarios contain the same scenarios for all 6 countries (Appendix: Figure 10), except for the fatal scenarios in France and Italy. Some deviations are seen in priorities per country between the top-3 of C1, C2, and L. For France, a considerable higher fraction of fatalities is found for the longitudinal scenario L, compared to the crossing scenarios C1 and C2. It should be noted that the data from France only cover the period of one year, and that a relatively small number of fatalities have been included in this study. In contrast, for the Netherlands the L-scenario is rather small compared to C1 and C2. Covering 14 years and over 900 fatalities in total, this is expected to be significant. A possible reason is found in the wide application of separated bike lanes, especially along rural roads in the Netherlands. Herewith the cyclists and motorized vehicles are physically separated, leading to only a relatively small number of fatalities in L-scenarios. In general, due to the high speed difference on rural roads, a collision according to an L scenario will more easily result in fatal injury for the cyclist. This not only leads to a small percentage for L in the Netherlands, but also to relatively higher values for C1 and C2.

Another striking result is the fact that in the Netherlands the C2 scenario (bike crossing from far side) shows a higher percentage than the C1 scenario (bike from near-side). A possible explanation results from the fact that the parameters describing the accident scenario in the Dutch BRON database [10] are limited. An approach is followed in which scenarios as described in BRON are translated to the scenarios from Figure 2. For many crossing scenarios in BRON, no distinction is made between near side or far side scenarios (see Appendix A). Consequently, 50% of those crossing scenarios are allocated to C1 and the other 50% to C2. Other scenarios are clearly indicated as far side, making the fraction of C2 scenarios larger than the C1 scenarios.
The distribution for accidents leading to seriously injured cyclists deviates slightly from that for fatalities. Most clearly seen is the strong decrease in the percentage allocated to the L scenario. Although still present as one of the top-3 dominant scenarios, it cannot easily be distinguished from the On-scenario, except for Italy, where the L scenario for seriously injured is as important as the C1 crossing scenario (Appendix B Figure 11).
It should be noted that the data from Italy come from an in-depth database and are not intended to perform statistical analyses with. Therefore, in the remainder of this paper, the small number of Italian cases will not be considered for further analysis and comparison with other countries.
Based on the weighting method that is proposed in the previous section, an average percentage is determined over 5 countries (the original 6 minus Italy), based on the number of cyclist fatalities per million inhabitants taken from the CARE database [4]. The weighted average over the countries except Italy, using the factors from Table 3, is given in the next graph (for both fatalities and seriously injured):



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
mean K	25%	29%	0%	0%	2%	1%	2%	24%	8%	10%
mean SI	29%	28%	3%	1%	5%	2%	3%	7%	6%	16%

Figure 8: Distribution of fatalities and seriously injured over the 9 accident scenarios, weighted average over 5 countries, red for fatalities (K), blue for seriously injured (SI)

This figure shows that C1 and C2-scenarios are dominant and equally important, followed by the L-scenario. Less important is the On-scenario. From the scenarios where the car is making a turn (T), the T3-scenario is most common, but this scenario is covering less accidents than the C1, C2, and L scenario. Next graph presents the cumulative coverage of the most important scenarios:

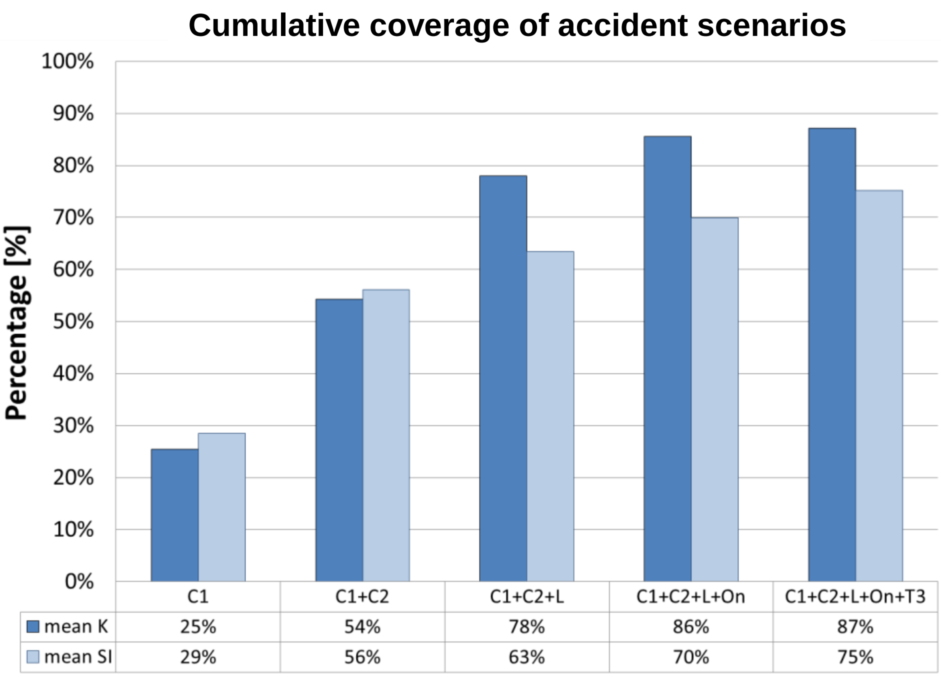


Figure 9: Cumulative coverage of scenarios in the order of importance

4. Conclusion

Putting the scenarios in order of relevance and importance, considering the number of fatalities and seriously injured due to car-to-cyclist collisions in the EU-countries France, Germany, Italy, the Netherlands, Sweden and the UK, the next sequence applies: C1, C2, L, On and T3.

Table 4: Description of scenarios in order of importance to cyclist casualties due to collision with a passenger car

Scen.	Description	% covered for K	% covered for SI
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side	25	28
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side	29	28
L L1 L2	• Car and cyclist driving in the same direction • Cyclist is riding straight and hit by the car from the rear • Cyclist is swerving to the left in front of the car and hit by the car from the rear	24	7

On	• Car driving straight, possibly driving towards the far road side in a passing manoeuvre • Bicyclist coming in the opposite (on-coming) direction riding straight	8	6
T3	• Car turning to the left, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight	2	5

The scenarios C1, C2 and L together cover 78% and 63% of the fatal and serious car-to-cyclist accidents respectively.

Next step in the test protocol development is the determination of the test parameters such as vehicle speed, bicycle speed, the presence of view blocking obstructions, collision point on the vehicle, type of bicycle and size of cyclist. Moreover, parameters describing the level of light or precipitation need to be selected. The car-to-cyclist accidents from the databases used for scenario selection will be studied to provide ranges for these parameters that give a representative coverage of the real-life conditions. In addition to that, observation studies may be used in case not all parameters can be selected based on the currently available data in the databases. These studies will for instance be used for the presence and size of view blocking obstructions.

Acknowledgement

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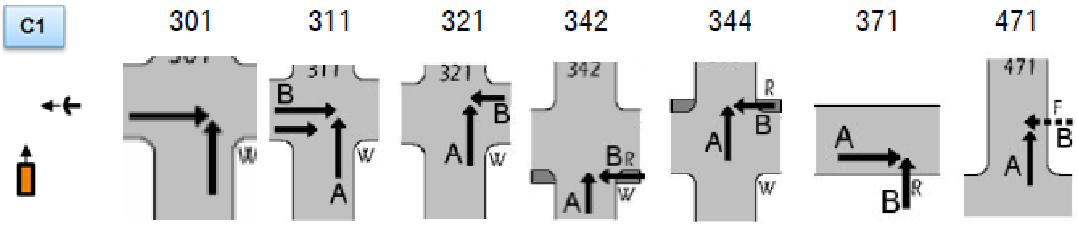
Appendix A: Conversion of databases to CATS scenarios

In each of the databases, the accident scenarios describing the movement of car and bicycle just before the collision, is coded and described in a different way. Consequently, the conversion of scenarios from the database to the scenarios from Figure 2, has been performed separately. The conversion for each of the countries is explained by an example:

France: LAB France provided the data according to the scenarios from Figure 2. Although a distinction was made in e.g. C1 for a regular intersection and C1 for a roundabout, in the total results such distinction is no longer made.

Germany: In the GIDAS database, the scenarios are coded with a 3-digit code. In a conversion table the different scenarios are related to the scenarios from Figure 2. As an example, the figure below shows which GIDAS scenarios are all considered a bicycle crossing from the near side C1:



Italy: Each of the 40 cases in the FIAT internal database were studied separately. From a description of the movement of bicycle and car, one of the CATS scenarios was selected. Thereafter, for each of the CATS scenarios, the number of cases (fatal or seriously injured) were added to the results shown in Figure 6 and Figure 7.

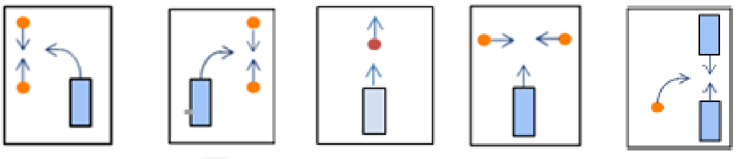
The Netherlands: In the BRON database, each case is related to a manoeuvre. A list of many different manoeuvres is used in BRON. By selecting car-to-cyclist fatalities (and similar for seriously injured), the number of cases per manoeuvre is given, and the resulting list is sorted upon the percentage of cases covered by the manoeuvre. Only those manoeuvres are considered that at least cover 2% of the cases. In the table below, an example is given for fatalities for some of the most relevant manoeuvres:

Manoeuvre	# fatalities	CATS scenarios	Distribution proposed
Side impact on crossing	327	C1 / C2	50% C1, 50% C2
Other side impact	190	C1 / C2	50% C1, 50% C2
Right side impact with crossing vehicle	85	C2	100% C2
Rear end collision without turning	75	L1 / L2	50% L1, 50% L2
Frontal without lane change	63	On	100% On

After the manoeuvres have been attributed to the CATS scenarios, all cases (for fatalities and seriously injured separately) are added for the CATS scenarios, to come to the results given in Figure 6 and Figure 7.

Sweden: Autoliv provided the data according to the scenarios from Figure 2 [11]. Each accident case was opened up from the two databases STA and STRADA and accident descriptions were studied in detail case-by-case to conclude the most likely accident scenario in each case.

UK: Data from the UK were distinguished in 5 accident scenarios according to [15]:



1 2 3 4 5

In a second step, CATS scenarios were allocated to each of these 5 scenarios according to the next scheme:

UK accident scenario	CATS scenarios	Distribution proposed
1	T1 / T2	50% T1, 50% T2
2	T3 / T5	50% T3, 50% T5
3	L1 / L2	50% L1, 50% L2
4	C1 / C2	50% C1, 50% C2
5	C1 / C2	50% C1, 50% C2

All CATS scenarios that could not be allocated to one of the UK scenarios was put in the group “other”. This group consists of T4, On, and Re. No further distinction was made for the latter group, which results in the fact that no estimate is given for the percentage covered by the On-scenario.

Appendix B: Overview of scenario relevance per country

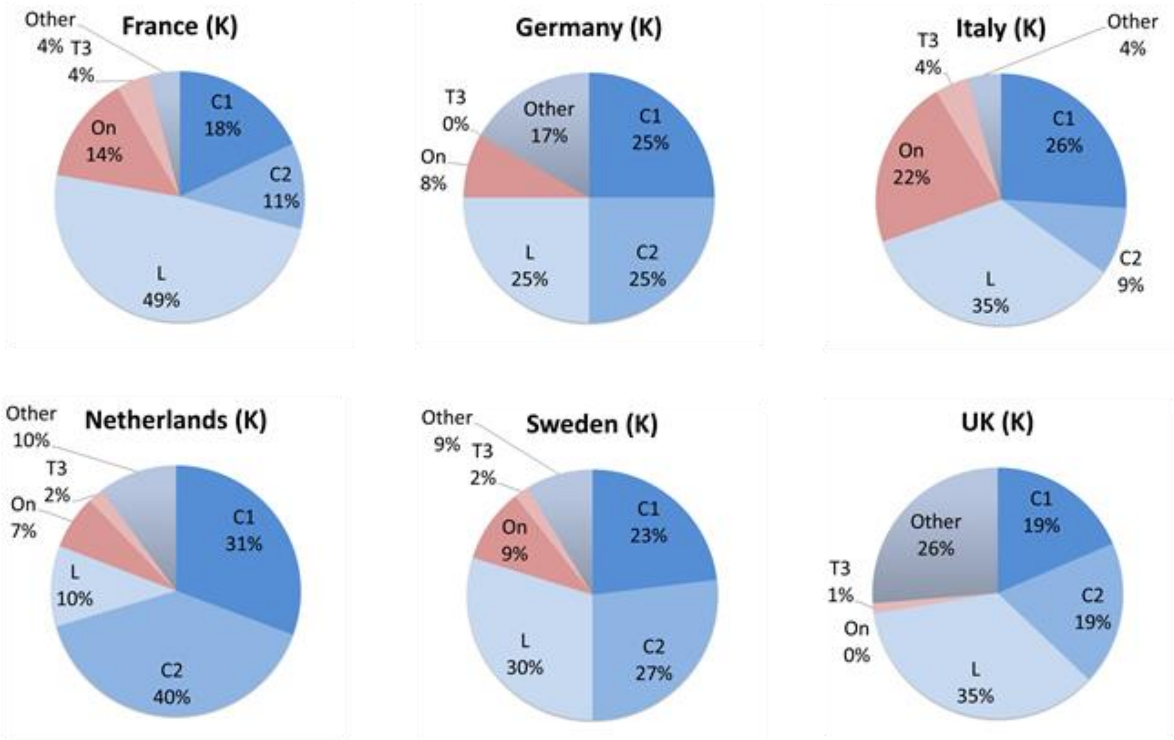


Figure 10: The distribution of scenarios per country for the fatal cyclist accidents

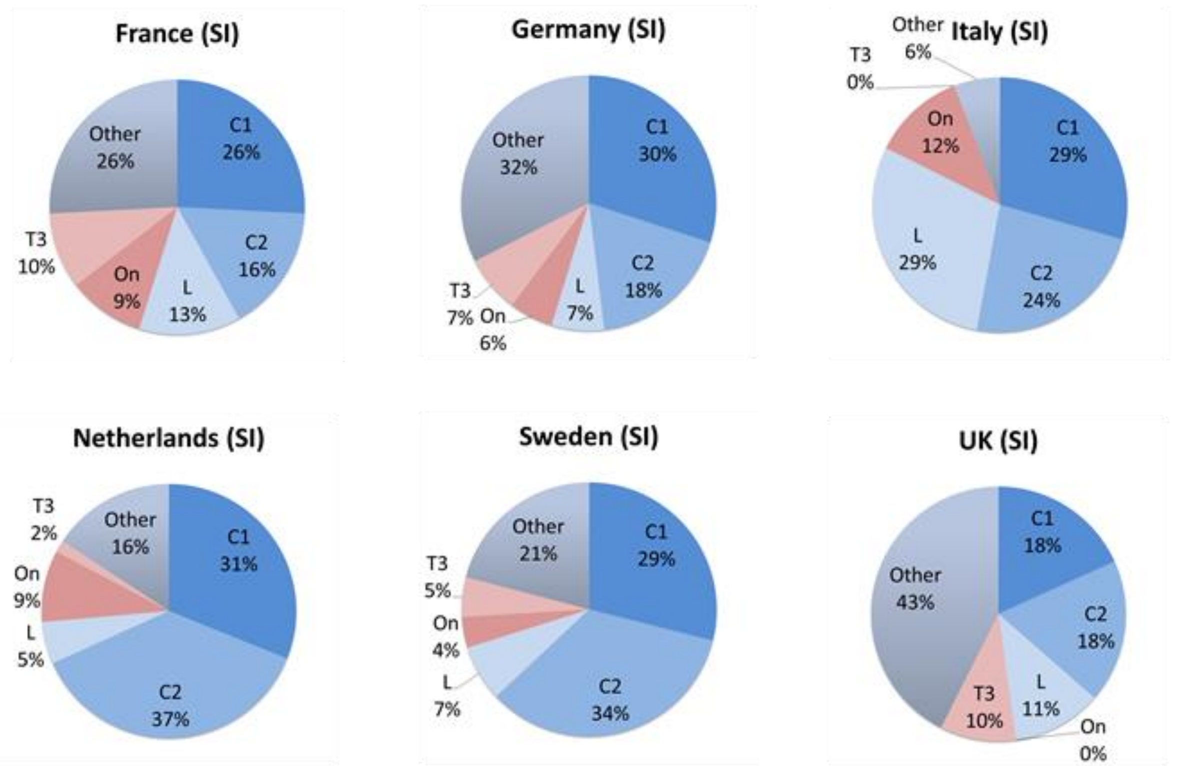


Figure 11: The distribution of scenarios per country for cyclist accidents resulting in serious injuries

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Observation study into the influence of a view-blocking obstruction at an intersection on bicycle and passenger car velocity profiles

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ABSTRACT

From 2018, AEB systems dedicated to avoid or mitigate car-to-cyclist collisions will be considered in the safety assessment by Euro NCAP. To test such systems, appropriate equipment is being developed in the project CATS "Cyclist-AEB Testing System". Accidentology was used to determine the most common car-to-cyclist accident scenarios in the EU [1]. The testing setup and test equipment has been developed to deal with the most relevant scenarios: a cyclist crossing the path of the car from the right, a cyclist crossing the path of the car from the left, and a longitudinal scenario in which the car and cyclist are driving in the same direction, and the car drives into the cyclist from the rear.

Apart from the test equipment, the testing protocol, and more specifically the ranges of the test parameters in the tests need to be determined from e.g. accidentology. From these studies, it appears that a significant part of collisions in crossing scenarios occurs in the presence of a view-blocking obstruction (e.g. cars and trucks parked at the road side, buildings or bushes and hedges). Such obstructions prevent an open view on intersections and crossing cyclists can only be detected relatively late by a car driver. In a similar way, the crossing cyclist has a limited view on the approaching car, and will not see the car until shortly before car and bicycle trajectory meet. Accident databases that have been used, even detailed databases such as GIDAS [4][6], contain only limited data on the specific bicycle and passenger car velocity during the approach of an intersection with a view-blocking obstruction.

To study the influence of the presence of a view-blocking obstruction on the behaviour of both bicyclists and car drivers in their approach of an intersection, an observation study has been set up. This paper describes the setup of such an observation study and the results of the study at 2 intersections with severe view-blocking obstruction in urban areas in the Netherlands. The first results show that all bicyclists reduce their speed, while some cars do not reduce speed at all near severe view blocking obstructions.

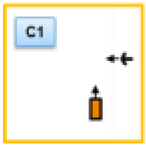
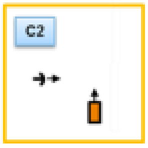
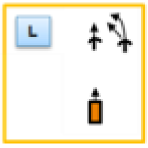
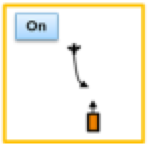
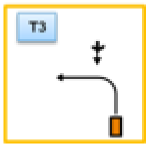
Keywords: Autonomous Emergency Braking, Cyclist, View-blocking obstruction, Velocity.

1. INTRODUCTION

The overall number of fatalities in road traffic accidents in Europe is decreasing. Unfortunately, the number of fatalities among cyclists does not follow this trend with the same rate [2]. A major share of killed cyclists in traffic accidents is the result of a collision with a motorized vehicle [3]. The automotive industry is making a significant effort in the development and implementation of safety systems in passenger cars to avoid or mitigate an imminent crash with vulnerable road users, and more specifically with cyclists. The current state-of-the-art of active safety systems, Autonomous Emergency Braking (AEB), is being widely introduced. A passenger car equipped with AEB makes use of on-board sensors such as cameras and radars to track and trace traffic participants that possibly interfere with the trajectory of the car. This information is used to warn the driver in case of a possibly critical situation and/or to brake in case the driver does not respond and the risk of collision does not decrease. To support and prepare

the introduction of Cyclist-AEB systems and the appropriate consumer tests of such systems, TNO has taken the initiative to set-up a consortium of passenger car manufacturers and suppliers with the support of Euro NCAP laboratories (such as BASt) to develop a testing system and test protocol for Cyclist-AEB systems.
Within CATS in-depth road accident studies have been performed to determine what accident scenarios are most relevant for car-to-cyclist collisions [1]. From accident analyses using databases from Germany, the Netherlands, Sweden, France, Italy, and the United Kingdom the percentage of seriously injured and fatalities covered by the most common scenarios has been determined.

Table 1: Percentage of fatalities and seriously injured covered by the 5 most common accident scenarios (the orange box represents a passenger car and the other symbol a bicycle, the arrows indicate the direction of movement)

Scenario description and coverage in 6 studied countries (F, D, I, NL, S, UK):					
Seriously injured	28%	28%	7%	6%	5%
Fatalities	25%	29%	24%	8%	2%

Scenarios in which the bicyclist crosses the trajectory of a car in an approximately perpendicular direction is most relevant in all studied countries, covering well over 50% of the seriously injured and fatal car-to-cyclist accidents (C1+C2) in Table 1. An independent study by Kühn et al. from the UDV German Insurers Accident Research, came to the same conclusion studying the UDB database in Germany that is based on the contents of insurers' claim files [5].
Figure 1 shows possible testing scenarios to cover the C1 and C2 accident scenarios from Table 1. The test parameters to be selected for the tests are the passenger car speed, the bicycle speed, the direction of the bicycle crossing the car path, the contact point between bicycle and car in case of collision, and the possible presence, size and location of view-blocking obstructions.

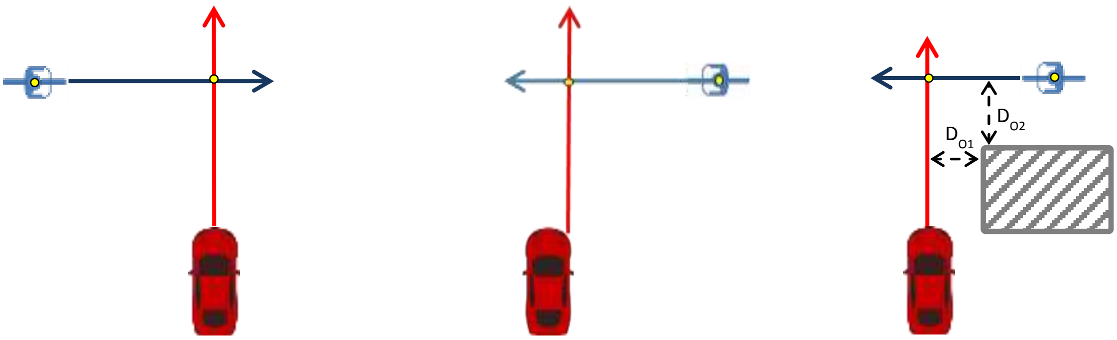


Figure 1: Different car-to-cyclist crossing scenarios. The right graph shows the presence of a view-blocking obstruction.

View-blocking obstructions can seriously hinder and delay the detection of an approaching bicycle from the perspective of the car. Similarly, such an obstruction might limit the view from the bicyclist at the approaching vehicles. Late detection and identification of a bicycle because of a view-blocking obstruction, limits the probability for a driver or an automated braking system to avoid or mitigate the collision with a bicycle that appears from behind an obstruction. The size and the location of the obstruction determine the time at which the cyclist becomes visible, given the speed of both car and bicycle.

Looking at the separate dominant accident scenarios for both Germany and Sweden (Figure 2), it can be seen that view-blocking obstructions are more common in the crossing scenarios than in the other accident scenarios. Even between the crossing scenarios a difference is visible, where C1 (crossing bicycle from near-side, i.e. bicycle approaching from the right side in European mainland driving directions) occurs more often with a view-blocking obstruction than C2 (crossing bicycle from far-side). This might be explained by the fact that, since C1 is defined as a crossing scenario from the near side of the vehicle, it is more likely for the view on the bicycle to be blocked by an obstruction in the near side crossing scenario. In the C1 scenario a substantial part of the accidents (~40% to 50%) occur with a view-blocking obstruction, where the largest part is due to a permanent full obstruction such as a building or a high hedge (fouling, vegetation). For this reason, it is proposed to provide one test scenario for cyclist-AEB tests with a well-defined full view-blocking obstruction for the near side (C1).

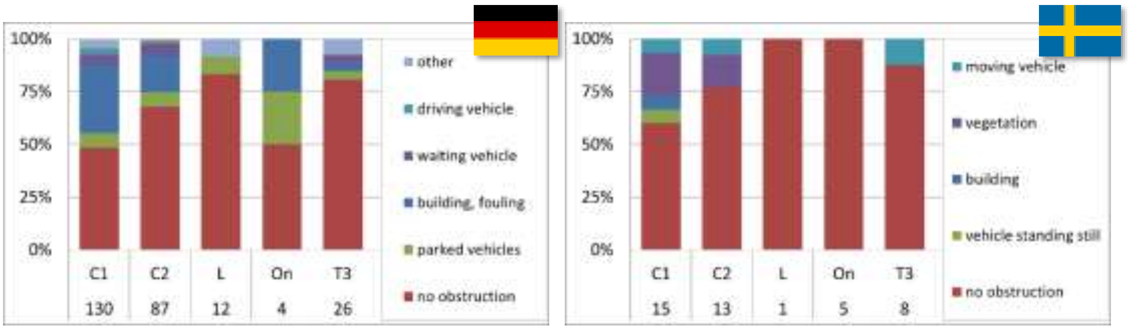


Figure 2: Type of obstruction in seriously injured accidents distributed over the different dominant scenarios. The left figure refers to data from Germany (GIDAS-PCM [6]), the right figure to data from Sweden [10].

In contrast to pedestrian scenarios, where a pedestrian might wait at the road edge before deciding to start crossing the street, cyclists move continuously towards the crossing and based on the traffic situation, priority rules and personal preferences either stop or continue to cross the intersection of roads. Information on such typical crossing behaviour or behaviour in the approach of an intersection is important for AEB-system development.
Based on the GIDAS-based PCM data [6], a cumulative distribution has been determined for the time-to-collision (TTC) at which the vehicle has been able to see the cyclist in case of accidents in crossing scenarios with a permanent view-blocking obstruction (Figure 3). This distribution covers all passenger car-to-cyclist crossing accidents with a permanent view blocking obstruction and MAIS1+ injuries (n=38, C1=31, C2=7). Figure 3 shows that about 20% of these accidents occur when the vehicle is able to see the cyclist for 1 second or less before the crash. For 2 seconds or less it covers about 80% of the cyclist accidents. The median (50th percentile of the curve) of the cyclist accidents with a permanent view-blocking obstruction has a TTC of approximately 1.5 seconds at which the vehicle is able to see the cyclist.

The number of accidents, for which such detailed information is available, is limited. The curve of Figure 3 is based on 38 accidents. Even when the presence of a view-blocking obstruction has been included in the accident record as a possible factor in the accident, detailed information on type, size and location of the obstruction is often missing. In order to come up with a relevant and realistic set of parameters regarding the speed distribution of both car and bicycle, and the size and location of typical view-blocking obstructions for bicycle crossing scenarios, an observation study has been proposed by TNO.

The objective of such an observation study is to determine the influence of the presence of a view-blocking obstruction on the behaviour of cars and bicycles when approaching a crossing. Previous observation studies have shown that cyclists anticipate very well in traffic [8]. They continue pedaling and hardly decrease speed when riding on a priority bicycle lane crossing a road with a clear unobstructed view on the approaching vehicles. The hypothesis is that both bicyclists and car drivers reduce speed in case the view on the crossing is limited because of an obstruction (e.g. building, fouling, parked car). The more the view is limited, the larger the effect on speed reduction is expected to be.

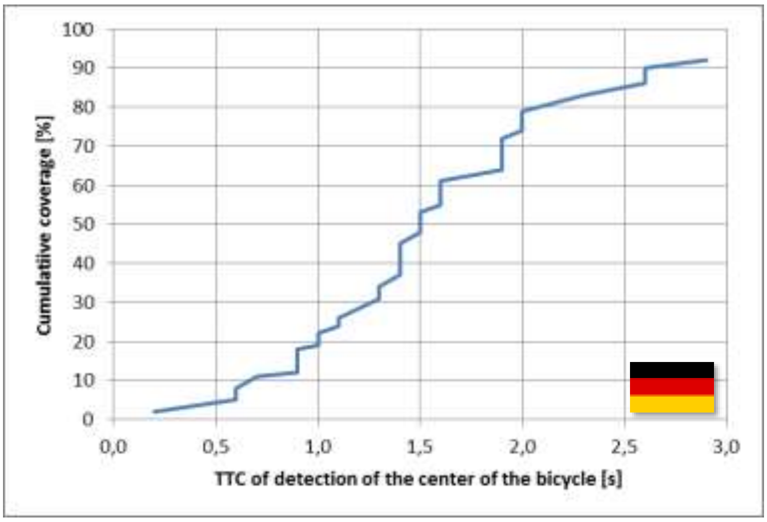


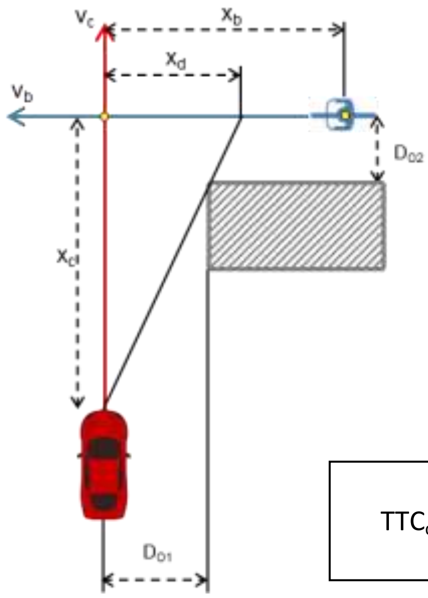
Figure 3: Cumulative distribution plot for the TTC of detection in case of accidents in which a permanent view-blocking obstruction was present.

To check this hypothesis, 2 bicycle crossings with a reasonably severe permanent view-blocking obstruction have been selected in the Eindhoven area. With an automotive radar, the velocity as function of the distance to the crossing has been measured for a considerable number of passenger cars and bicycles. Interactions between bicycles and passenger cars are excluded from the results, as it is our intention to study the influence of an obstruction, not the braking of a cyclist once it detects an approaching car.
In the next section, the measurement method is explained. The criteria for selection of an intersection, the measurement equipment and the test protocol are discussed. In Section 3, the crossing in Son en Breugel (village close to Eindhoven) is described and the results of the measurements at this specific site are discussed. In Section 4, the on-site measurements on a crossing near the center of Eindhoven are discussed. The paper will be concluded with a section regarding conclusions and recommendations.

2. METHOD

2.1. Parameters to be measured

To determine the influence of the presence of a view-blocking obstruction on the speed profile during the approach of both bicycles and passenger cars at a crossing scenario, the speed over the last several seconds needs to be measured for both bicycles and passenger cars. For each individual bicycle and passenger car, we are interested in the speed profile during the approach.
An important parameter that determines the severity of view-blocking by an obstruction is given by the time-to-collision-for-detection (TTC_d). For a car and a bicycle at crossing trajectories, the TTC indicates the time until the car or the bicycle meets the crossing point of the two paths in case no changes occur in the speed of the car and the bicycle. The TTC_d shows at what moment in time, counted from the moment of impact, the car (front center) is able to see the bicycle (center), or in other words, when the bicycle appears from behind the view-blocking obstruction.



$$TTC = \frac{x_b}{v_b} = \frac{x_c}{v_c}$$

$$TTC_d = \frac{x_d}{v_b} = \frac{D_{O1} \cdot v_c + D_{O2} \cdot v_b}{v_c \cdot v_b}$$

Figure 4: Definition of TTC in a car-to-cyclist crossing scenario in which x denotes distance and v velocity. The underscore b refers to the bicycle and c to the car.

For specification of the cyclist detection and identification algorithms that are part of Cyclist-AEB systems, the behaviour of the cyclist during the approach is important as well. Such behaviour concerns whether or not cyclists stop pedaling when approaching the intersection or when they start looking (e.g. turning head) to check for other approaching traffic.

2.2. Measurement equipment

To perform a continuous speed measurement on traffic participants, an automotive radar that is able to detect bicycles and cars is used. The short-range-radar with a field-of-view of +/- 20° and a range of 50 m is integrated in a road-side-unit which in addition to the radar consists of a platform to run filtering and target tracking algorithms, a data recorder, a wireless communication unit based on ITS-G5, and a battery [11]. Filtering is done based on lifetime of the detected objects (the time the object is in the detection range), the minimum velocity of the object, and by selecting a region of interest in which the important objects are expected.

Since we are interested to study the influence of a view-blocking obstruction on the behaviour of approach for both bicyclists and car drivers, the measurements for bicycles and cars are performed independently. When $TTC > TTC_d$, the driver is not able to see the bicycle and vice versa. In case $TTC < TTC_d$, then both driver and bicyclist possibly adapt their behaviour based on the presence of the counterpart in traffic. For this reason, this study mainly focuses on the behaviour of the bicyclist and driver for $TTC > TTC_d$. To classify the view-blocking obstruction, the TTC_d for different speeds of the bicyclist and the car will be given.

In order not to influence the measurements in any way, the automotive radar and the platform connected to the radar are hidden into a garbage bin. Such a garbage bin often stands at the side of the road in urban areas, so it will not be noticed by the approaching traffic participants, and consequently no influence from the presence of such equipment on the behaviour of traffic participants is expected.
The garbage bin with the radar is located at the road edge as much as possible in line with the direction of the approaching car. The radar is positioned opposite to the driving direction of the traffic that is being measured, at the opposite side of the crossing to have a reliable measurement of the speed up to the ‘collision point’, the point at which the car path and the bicycle

path intersect. Moreover, the radar unit has been placed as much as possible in line with the driving direction of the bicycles or the cars, in order to achieve the highest possible accuracy.
Figure 5 shows how the radar is integrated into the garbage bin, and how the measurement direction is aligned:

Figure 5: The garbage bin with the radar, measurement and logging equipment.

To check the accuracy of the radar, verification runs have been performed with a test car crossing an intersection from both sides using cruise control at 20, 30 and 40 km/h (Figure 6). Although the radar measures a constant lower speed (blue solid line) than the set speed of the cruise control (green solid line), it is assumed that the radar measurement is reliable, as usually the cruise control set speed is slightly higher than the actual speed. The measured variation in speed is less than +/- 1 km/h, which is the result of both real speed variations and measurement inaccuracy. This is an indication that the measurement accuracy of the radar is at least +/- 1 km/h.

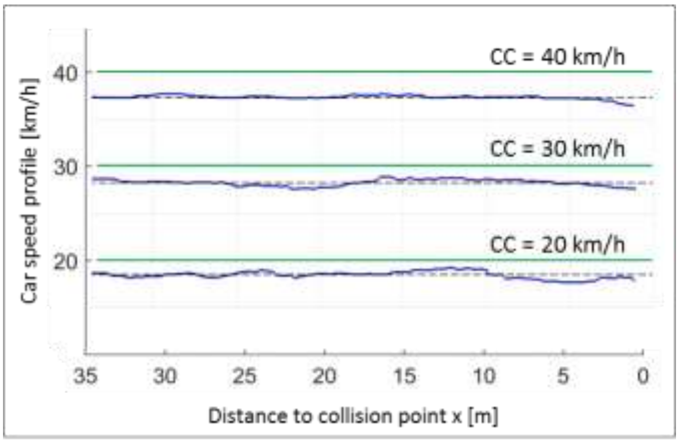


Figure 6: Measured speed with radar for car on cruise control

Action cameras are mounted on traffic sign poles near the intersection to record the events at the intersection during the complete measurement session. In case of unexpected results in the measurements, the recorded video can be used to determine the cause for such event during the offline analyses of the measurement sessions. From the video footage, selections of cars and bicycles can be made in case radar measurements are disturbed.
For each bicyclists, camera images are used to determine whether or not the bicyclist stops pedaling and whether or not the bicyclist comes to a full stop before crossing.
Since we need to determine the response of the car driver to a view-blocking obstruction that limits the view on crossing traffic, the speed profile of individual cars approaching the crossing are being measured. The cars that have a path that interacts with other traffic on the same

road, such as a car that needs to pass a bicycle driving in the same direction, need to be discarded from the results. The recorded videos are used for this purpose as well.

2.3. Selection of measurement sites

The following criteria were applied to select appropriate intersections for measuring bicycle and car speed profiles in the presence of a clear view-blocking obstruction at a crossing:

- Urban area with a preferred speed limit of 50 km/h (also 30 km/h possible).
- Cars face a severe obstruction that prevents a direct view on the cyclists from the near side (right-hand graph in Figure 1).
- The obstruction is permanent, either hedge or building giving a severe blocking of the view.
- Cyclists have priority, however:
  - no traffic control lights,
  - no stop signs (for neither the cyclist, nor the car),
  - no or only low speed bumps should be present at the selected intersection.
- Significant traffic flow of passenger cars and bicycles, however with limited number of interactions between traffic participants for the measurement equipment to be able to distinguish individual passenger cars and bicycles.
- No specific requirements apply regarding road layout, such as the presence or absence of a separate cycle path.

To determine the location and size of a relevant and realistic view-blocking obstruction, keeping in mind a typical TTC for cyclist detection from Figure 3, dimensions are used that are based on characteristic measures for infrastructural elements. In the table below, Dutch guidelines for the width of urban road layout designs are found [7]:

Table 2. Dutch guidelines for the width of urban road layout designs

Road layout	*Guidelines*
Sidewalk	1.2m – 1.8m
Double bicycle track	2.0m – 4.0m
Two way road	5.4m – 7.0m
One way road	~ 3.5m

For a rather severe view-blocking obstruction, where the car drives in the middle of its lane on a two-lane road with a pedestrian sidewalk, the value of D_{O1} (Figure 4) could be as low as 3.55 m. For a double cyclist lane bordered by a pedestrian sidewalk crossing this road, the value of D_{O2} would be around 4.80 m.
The sites for the observation study should have a rather severe view-blocking obstruction, to determine the influence of such an obstruction on the velocity profile of both bicycles and cars. Hence we aim for obstruction with values for D_{O1} and D_{O2} close to 3.55 and 4.80 m respectively.
Starting from the criteria described above, two sites have been selected in the Eindhoven area in the Netherlands:

- A busy bicycle crossing has been selected in the village of *Son en Breugel*, where the permanent obstruction is found in a high hedge. The lane that is used exclusively by bicyclists and pedestrians, connects a living area with the busy village center, in which also a school is located. It is a non-prioritized intersection, where bicyclists have the right-of-way over cars from the left, but have to yield right-of-way for any traffic (cars, bicycles) from the right.
- The other site is a non-priority 4-armed crossing in the center of *Eindhoven*. In this case, the view is permanently obstructed by a building. Also in this case, traffic from the right has the right-of-way.

At both sites, the legal speed limit is 30 km/h. Practically, most vehicles drive (slightly) faster than that. Also in both cases, a very shallow speed bump is found. The road markings clearly indicate a crossing of traffic, but the geometry of the speed bump does not challenge the speed of an approaching car.

3. RESULTS SON EN BREUGEL

3.1. Description of the measurement site (obstruction by a hedge)

The first obstruction that has been studied is located in the village of *Son en Breugel*, about 10 km north of *Eindhoven*. The obstruction blocks the view from the cars driving on the *Boslaan*, a main road through the village center, towards the *Esdoornlaan* bicyclists lane on the right. This part of the *Esdoornlaan* is a dead-end street, that is frequently used by cyclists to go to the village center, where schools, shops and other public buildings are found. The view-blocking obstruction consists of a high permanent (green) hedge, that borders the premises of the house at the corner of the *Boslaan* - *Esdoornlaan* intersection. The speed limit is 30 km/h. In the figure below a view on the site is given, both from the obstructed and unobstructed side. In this figure, the red arrow indicates the driving direction of the car and the orange arrow the driving direction of the bicycle (the blue arrow represents traffic from the side opposite to the bicycle path, unobstructed view).

Figure 7: Bicycle-crossing at Boslaan in Son en Breugel (left obstructed, right un-obstructed).

GoPro cameras have been used to record the complete time of testing. In case a vehicle and a bicycle approached the crossing driving in the same direction or when cars turn onto the *Boslaan* from the side street, the radar could often not distinguish between the different objects, which resulted in a measurement that needed to be discarded. The video recordings were used to make the appropriate selection.

The dimensions of the crossing were measured using a measurement wheel. This includes the dimensions of the view-blocking obstruction, or more specifically the distance of the obstruction to both the car path (D_{O1} = 4.5 m) and the bicycle path (D_{O2} = 5.0 m). Using these dimensions, the TTC_d is determined for the obstructed crossing as function of both the vehicle (Vc) and bicycle speed (Vb) and shown in Figure 8.
This particular crossing provides the possibility to measure the speed profile of cars approaching from the opposite direction as well. The idea is to compare the speed profiles for the cars in the unobstructed case from those of the cars approaching the obstructed case.

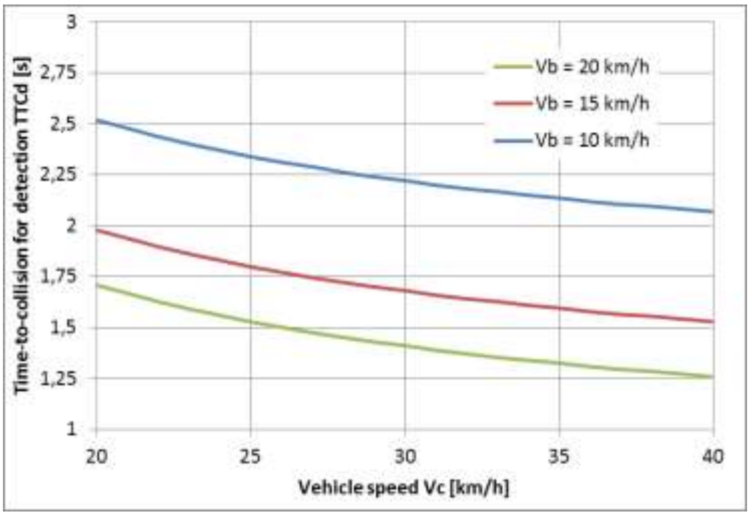


Figure 8: Time-to-collision for detection at the obstructed crossing in Son en Breugel, as function of both bicycle speed Vb and vehicle speed Vc.

3.2. Results bicycles

At the crossing in *Son en Breugel*, only the speed profile is measured for the cyclists approaching the *Boslaan* from the side where the obstruction is located. These cyclists have priority over the cars that approach the crossing from the left side. The view of the cyclists towards the cars coming from the right side is far less obstructed: TTC_d is roughly 0.75 sec. larger for cars from the right than for cars from the left side (at an average bicycle speed of 15 km/h). During a typical weekday morning, the speed profile has been measured for 44 bicycles that approached the *Boslaan* from the side of the view-blocking obstruction. Using the video recordings and the speed profile measurements from the radar, the behaviour of the cyclists has been determined. A distinction was made between the trajectory of the cyclist (going straight, turning right, turning left) and the traffic conditions due to crossing cars during the cyclist's approach. This leads to the results as given in Table 3.

Table 3: Results for bicycle measurements (Son en Breugel)

Bicycle manouevre		*Stopped pedaling*		*Continued pedaling*
		Continued riding	*Full stop*	*Continued riding*
Straight	**total**	**20**	**9**	**2**
	no cars present	9		
	car from left	8	2	2
	car from right	3	7	
Turning left	**total**	**4**	**6**	**2**
	no cars present	3	1	2
	car from left		2	
	car from right		3	
	cars from both sides	1		
Turning right	**total**	**1**	**0**	**0**
	cars from both sides	1		
Total # bicycles		25	15	4

In Figure 9, the speed profiles of the cyclists as measured by the radar are plotted versus the distance to the 'collision point' (the point where the bicycle path crosses the vehicle path).
While most bicycles stopped pedaling but continued riding, a decrease in the speed is seen for all bicycles. The 50^{th}-percentile profile starts at a speed of almost 14 km/h (rather similar to

the average bicycle speed found in accident studies [9]) and a decrease in speed with almost 6 km/h has been measured in approach of the crossing with the view-blocking obstruction. No bicycle during the measuring period maintains a speed higher than 10 km/h. It also seems at this intersection, that stronger braking is applied for faster driving bicycles.

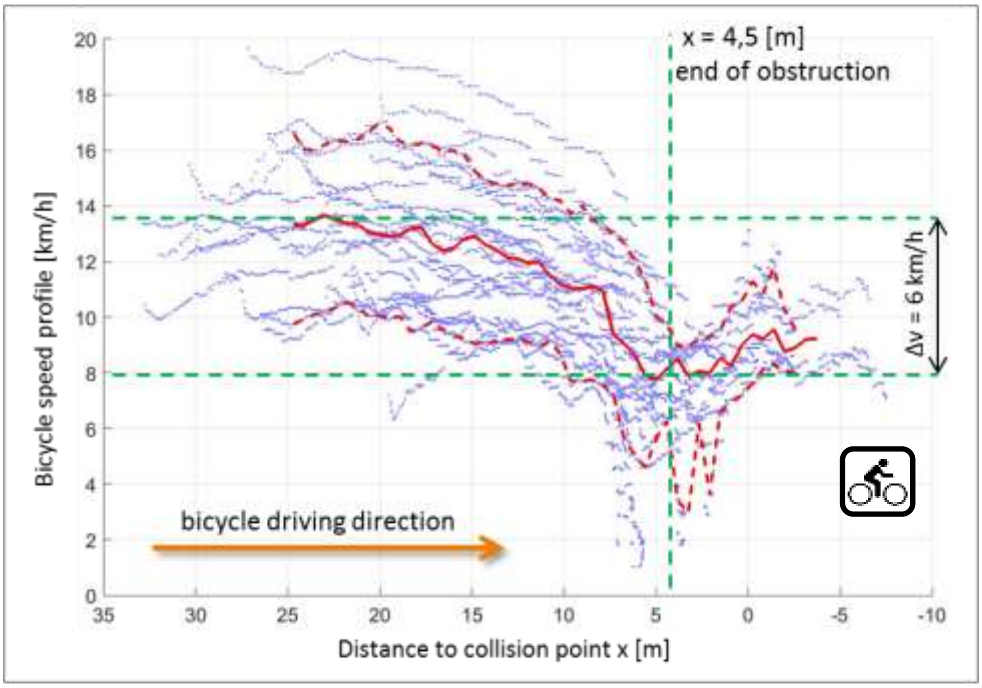


Figure 9: Measured bicycle velocity profiles near a severe view-blocking obstruction. In blue the different profiles for 27 cyclists that the radar could distinguish during the full approach of the crossing. The solid red curve indicates the 50th-percentile profile, the red dashed lines indicate the 10th and 90th-percentile curve.

The study clearly shows a decrease of speed by bicyclists in approaching an intersection with crossing car traffic, in case the view on the approaching cars is blocked by a permanent obstruction, even if the bicyclists themselves have priority.

3.3. Results passenger cars

In a similar way, speed profiles have been determined for the passenger cars approaching this intersection. Also these measurements have been performed during a typical weekday morning. The speed profiles for 340 cars approaching the intersection from the direction with an obstructed view (Figure 7) have been determined. Subsequently, the profiles for 321 cars approaching the same crossing from the opposite side (with unobstructed view) have been measured. The results for the car speed profiles are shown in Figure 10.

The 50th-percentile curves (the solid red lines in both figures) show that the median approach speed from both sides is almost equal at 37 km/h. Where in the obstructed case, the speed is only reduced to 27 km/h (10 km/h speed reduction), in the unobstructed case, the speed reduction is approximately 15 km/h.

The larger median speed reduction for the situation where no view-blocking obstruction is present, is explained by the fact that cars approaching the non-obstructed side street, have to give yield to all traffic, not only cyclists but other cars as well. Since the traffic from the right is easily seen by the drivers, most cars reduce speed and in many cases even stop completely.

From the measurements, it appears that in both situations, the cars reduce speed in the approach of the crossing. In the obstructed case, some cars seem to overlook the fact that a cyclist might appear from behind the view-blocking obstruction and do not reduce speed (or only very slightly).

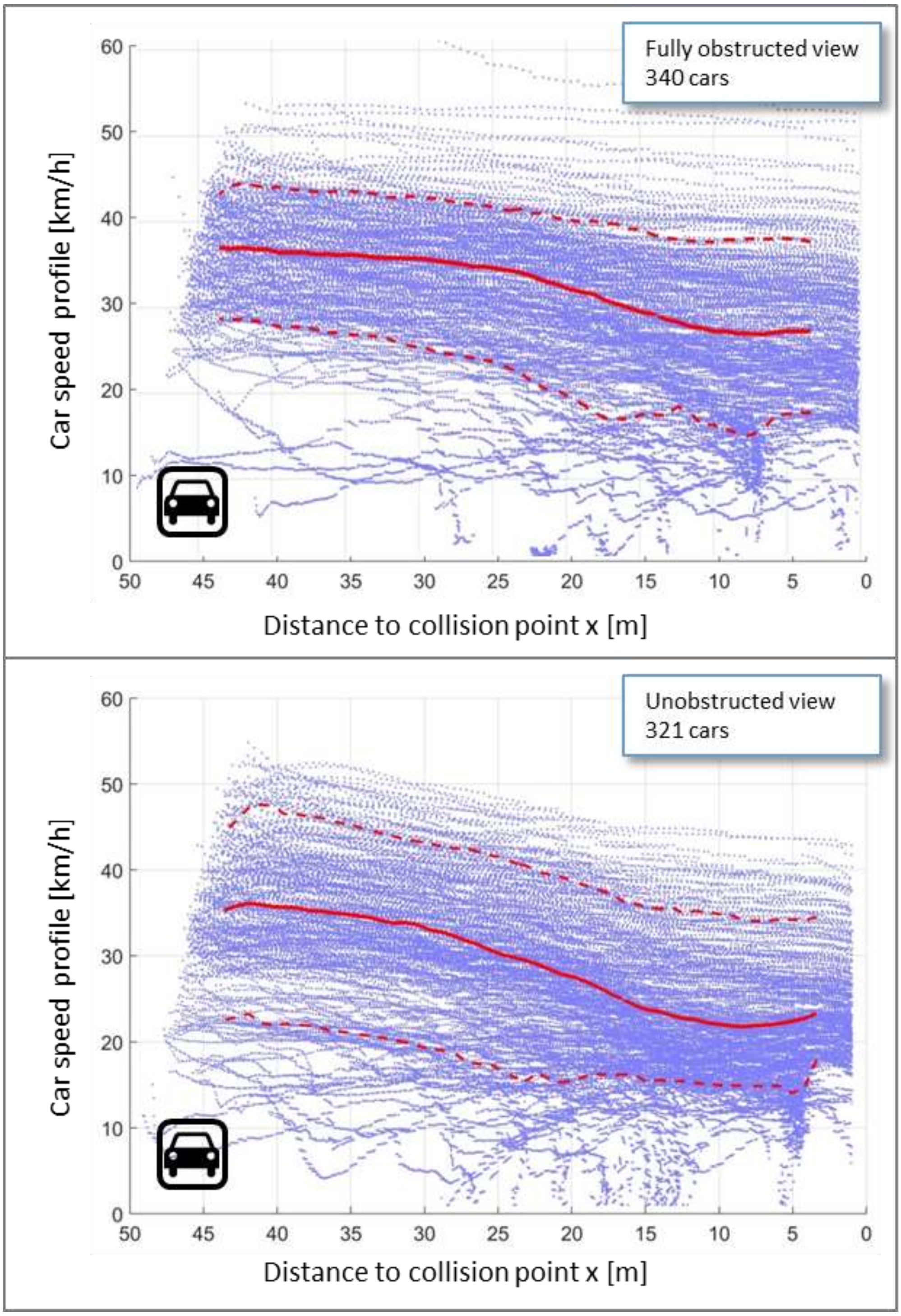


Figure 10: **Radar measured speed profiles (blue curves) for cars crossing the intersection from the direction with view-blocking obstruction and the opposite direction without view-blocking obstruction. The solid red curve indicates the 50th-percentile profile, the red dashed lines indicate the 10th and 90th-percentile curve.**

Figure 11: Traffic sign warning car drivers for cyclists from the near side (priority)

The village council of *Son en Breugel* placed a traffic sign (Figure 11) to specifically warn drivers for cyclists coming from the right at the intersection with the severe view blocking obstruction. At the time of the measurements, this traffic sign was <u>not</u> present. It had been removed for several months.

4. RESULTS EINDHOVEN

4.1. Description of the measurement site (obstruction by a building)

The second intersection with view-blocking obstruction has been studied in the center of *Eindhoven*, corner *Hastelweg – Sint Trudostraat*. In this case, the permanent obstruction is a house, separated only from the road by a pedestrian sidewalk. It is a 4-armed crossing in a 30 km/h living area, with a significant amount of traffic. The obstruction is challenging as parked cars in the side street force bicycles (and other traffic) to drive close to the middle of this street. With dimensions D_{O1} = 4.3 m and D_{O2} = 4.9 m, this obstruction is slightly more severe (lower TTC_d) than that in *Son en Breugel*.

Figure 12: Intersection at *Sint Trudostaat – Hastelweg* Eindhoven with a house as view-blocking obstruction

The orange arrow indicates the bicycle traffic coming from the right that has been studied, where the red arrow represents the car traffic that needs to give priority to all traffic (vehicles and bicycles) from the right. Although the road markings make this intersection look like a roundabout, it is not used as a roundabout. The cyclists nor the passenger cars follow the cir-

cular pattern of the markings when making a turn. The very shallow speedbump that is integrated in the intersection does not challenge the speed of any traffic participant.
Due to the character of this intersection, in all directions a mixture of bicycles, cars and other traffic participants is found. During the measurement period of 4 hours in peak traffic in the morning (starting at 7:00), more than 500 cars and more than 200 bicycles were counted. In case of multiple objects being simultaneously present in the field-of-view of the radar, it appears difficult to distinguish the separate traffic partners over the full range of travel. For this reason, in this paper only the behaviour of the bicyclists in approaching the intersection with the blocked view will be reported. Analysis of all measured speed profiles will be performed in a later stage.

4.2. Results

Similar to the analyses in Son en Breugel, a distinction has been made for the behaviour of the bicyclists coming out of the side street. The intended direction of the bicyclist was recorded, as well as the shown behaviour: stop pedaling or continue pedaling, coming to a full stop or continue riding.
From 175 out of more than 200 cyclists, the pedaling- and stop/go-behaviour has been recorded. For the cyclists going straight, more than 85% stopped pedaling. Even with no cross-traffic, the vast majority of cyclists stops pedaling during the approach of the intersection. Only when turning right and no interaction with other traffic is expected, the number of cyclists that continue pedaling is twice the number of cyclists that stop pedaling. In all other cases, more cyclists stop pedaling than continue pedaling.
Preliminary investigation of the speed profiles for cyclists show also for Eindhoven a decrease in speed in approaching the crossing. Since cars and cyclists could not easily be distinguished in the radar results, the speed reduction cannot be quantified accurately. However, a first estimate is between 4 and 5 km/h speed reduction for the cyclists.

Table 4: Results for bicycle measurements (Eindhoven)

Bicycle manouevre		*Stopped pedaling*		*Continued pedaling*
		Continued riding	*Full stop*	*Continued riding*
Straight	**total**	**68**	**38**	**15**
	no cars present	25	0	4
	car from left	17	14	5
	car from right	14	13	6
	cars from both sides	12	11	0
Turning left	**total**	**16**	**6**	**1**
	no cars present	5	0	0
	car from left	7	0	0
	car from right	3	3	1
	cars from both sides	1	3	0
Turning right	**total**	**9**	**2**	**20**
	no cars present	2	0	10
	car from left	4	0	3
	car from right	2	0	6
	cars from both sides	1	2	1
Total # bicycles		93	46	36

5. CONCLUSIONS AND RECOMMENDATIONS

The method and measurement device that has been developed to perform observation studies into the behaviour of bicycles and passenger cars has served its purpose. It has been possible to measure the velocity profile for bicycles and cars on two intersections. However, it appears to be difficult to distinguish bicycles and cars automatically, so that manual selection in an offline analysis is required. To simplify such selection, a manual triggering device is added to the setup, which the test operator can use to trigger observations that are automatically time-stamped and synchronized with the radar loggings.

Although the observation study for the intersection in *Eindhoven* has not been concluded, first conclusions can be drawn based on the observations in *Son en Breugel* and *Eindhoven* so far:

- Bicycles appear to reduce their speed in the approach of an intersection, in case the view at the intersection is severely hindered by a permanent full view-blocking obstruction. Approximately 6 km/h of speed reduction was measured in one case, and in the other case the speed reduction was estimated at 4 to 5 km/h. The speed reduction always coincides with the fact that bicyclists stop pedaling. For all cyclists observed during this study, more than 80% stopped pedaling in approaching the intersection with view-blocking obstruction. The usual early anticipation by bicyclists on cross-traffic [8] does not seem to be possible in case the view on this cross-traffic is severely hindered.
- Also cars generally reduce speed in approaching the intersection. However, it appears to be very difficult to distinguish between the influence of the geometrical layout of an intersection and the interaction with other traffic participants, as these are interrelated, e.g. by traffic rules. Where for cyclists, a severe view-blocking obstruction prevents early anticipation on cross-traffic, a severe obstruction for car drivers might cause them to overlook the traffic from the right that might appear from behind the obstruction. This could explain the fact that the measured speed reduction for cars in the obstructed case was less (in average) than the speed reduction for the unobstructed case (*Son en Breugel*). However, based on the currently available information, no general conclusions can be drawn regarding the speed reduction of cars in the presence of a view-blocking obstruction.
- A speed reduction of the bicycle from 20 to 15 km/h results in an increase of the TTC to detection of approximately 0.25 seconds. A further speed reduction from 15 to 10 km/h, would lead to an additional increase in TTC_d of approximately 0.50 seconds.

With a number of two crossings that have been studied to determine the influence of a view-blocking obstruction on the behaviour of cyclists and car drivers, the possibility to generalize these conclusions is rather limited. Moreover, both observed crossings are located within a radius of 10 km in the Netherlands. It is recommended to finish the analyses of the observations at the crossing in Eindhoven, and to perform a similar study at typical intersections with severe view-blocking obstructions in Germany. Due to the expected smaller number of bicycles per unit of time, it is expected that such an observation study needs to be performed for at least one day per crossing. As additional parameter in the study, difference in culture, especially regarding traffic rules, will appear in case a similar study is performed in Germany.

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Specification of a cyclist target and test setup for the evaluation of Cyclist-AEB systems

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Abstract

From 2018, AEB systems dedicated to avoid or mitigate car-to-cyclist collisions will be included in the safety assessment by Euro NCAP [1] & [2]. To test such systems, appropriate equipment and a test procedure are being developed in the project CATS “Cyclist-AEB Testing System”. Accidentology was used to determine the most common car-to-cyclist accident scenarios in the EU [3]. The testing setup has been developed to deal with the 3 most relevant scenarios: a cyclist crossing the path of the car from the nearside, a cyclist crossing the path of the car from the farside, and a longitudinal scenario in which the car and cyclist are driving in the same direction, and the car drives into the cyclist from the rear. The test equipment should be capable to deal with these 3 scenarios.

Apart from the scenarios, the typical AEB systems and the applied sensors by the car manufacturers should recognize the dummy as a real cyclist on a bike, which puts important requirements regarding dummy visual and radar characteristics. Finally, requirements to the design of the testing system and dummy result from practical testing constraints: during testing, possible collisions between car and dummy should be mild to limit damage for the dummy and the vehicle under test, and not to compromise the testing.

The paper describes how the translation is made from accident data to a test setup.

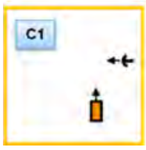
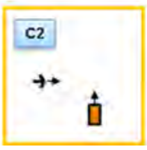
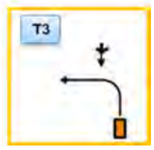
Keywords: Autonomous Emergency Braking, AEB, bicyclist, bike, dummy, target, testing system.

Introduction

The overall number of fatalities in road traffic accidents in Europe is decreasing. Unfortunately, the number of fatalities among cyclists does not follow this trend with the same rate [4]. A major share of killed cyclists in traffic accidents is the result of a collision with a motorized vehicle [5]. The automotive industry is making a significant effort in the development and implementation of safety systems in passenger cars to avoid or mitigate an imminent crash with vulnerable road users, and more specifically with cyclists. The current state-of-the-art of active safety systems, Autonomous Emergency Braking (AEB), is being widely introduced. A passenger car equipped with AEB makes use of on-board sensors such as cameras and radars to track and trace traffic participants that possibly interfere with the trajectory of the car. This information is used to warn the driver in case of a possibly critical situation and/or to brake in case the driver does not respond and the risk of collision does not decrease. To support and prepare the introduction of Cyclist-AEB systems and the appropriate consumer tests of such systems, TNO has taken the initiative to set-up a consortium of passenger car manufacturers and suppliers with the support of Euro NCAP laboratories (such as BASt) to develop a testing system and test protocol for Cyclist-AEB systems.

Within CATS, in-depth road accident studies have been performed to determine what accident scenarios are most relevant for car-to-cyclist collisions [3]. From accident analyses using databases from Germany, the Netherlands, Sweden, France, Italy, and the United Kingdom the percentage of seriously injured and fatalities covered by the most common scenarios has been determined, see Table 1.

Table 1 Percentage of fatalities and seriously injured covered by the 5 most common accident scenarios (the orange box represents a passenger car and the other symbol a bicycle, the arrows indicate the direction of movement)

Scenario description and coverage in 6 studied countries (F, D, I, NL, S, UK):					
Seriously injured	28%	28%	7%	6%	5%
Fatalities	25%	29%	24%	8%	2%

Scenarios in which the bicyclist crosses the trajectory of a car in an approximately perpendicular direction is most relevant in all studied countries, covering well over 50% of the seriously injured and fatal car-to-cyclist accidents (crossing nearside C1 & crossing farside C2) in Table 1. The longitudinal scenario, in which the vehicle approaches the cyclist from the rear has particularly a large contribution to the number of fatalities. The cumulative overview of car-cyclist scenarios can be found in Figure 1

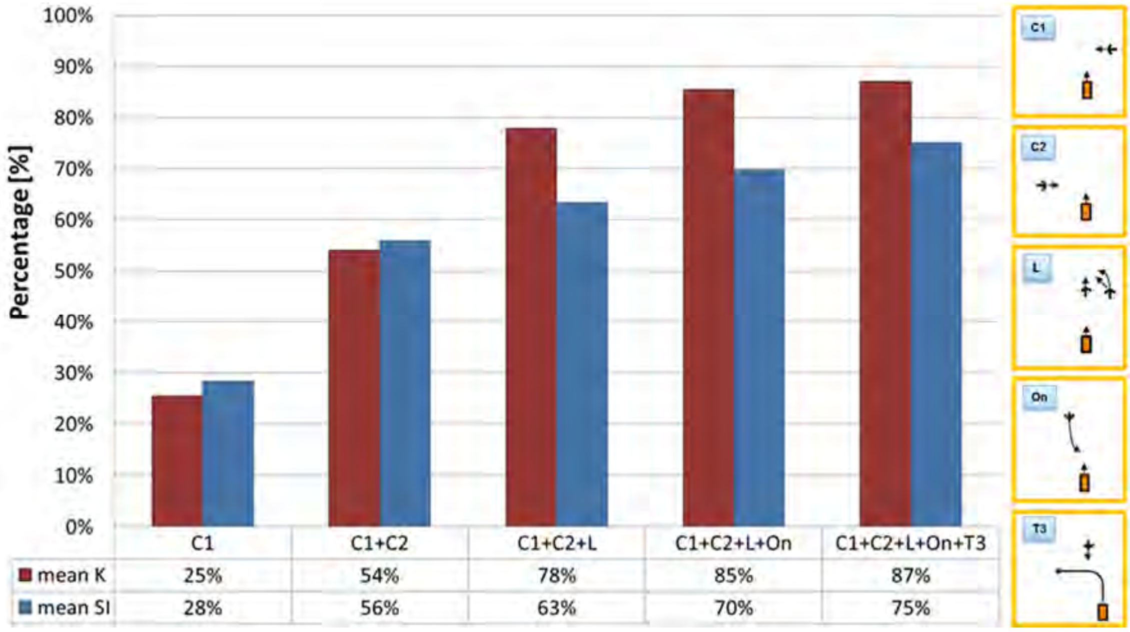


Figure 1 Overview of car-cyclist scenarios in EU

CATS focusses on the 3 most dominant scenarios in EU, nearside crossing, farside crossing & longitudinal.

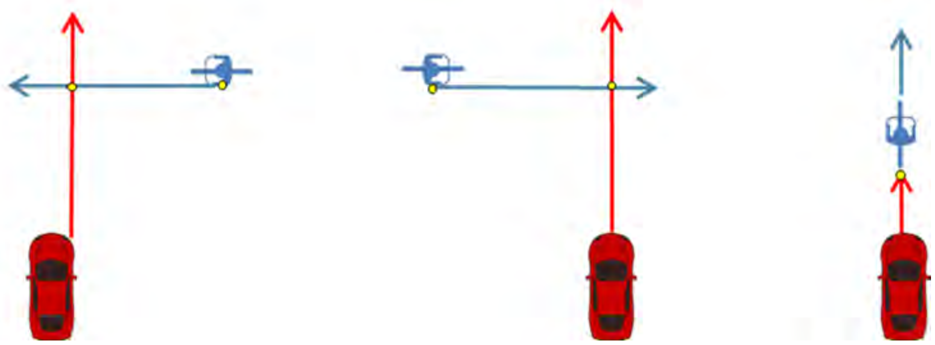


Figure 2 Three dominant EU scenarios: nearside crossing, farside crossing & longitudinal

Within the CATS project detailed test parameters are determined for the tests shown in Figure 2, including passenger car speed, bicycle speed, direction of the bicycle crossing the car path, contact point between bicycle and car in case of collision, and possible presence, size and location of view-blocking obstructions.

In order to be able to test these test cyclist-AEB systems in these scenarios a bicyclist and bike target, which represent the human bicyclist and bike attributes in relation to the sensors used in vehicles, will need to be defined and realised. The CATS consortium defines the technical specification for bicyclist and bike target, as well as the requirements for the propulsion system to move the target. 4activeSystems GmbH will develop a propulsion system, bicyclist and bike target meeting the requirements defined by the CATS consortium.

The technical specifications focus on the three dominant scenarios: nearside crossing, farside crossing and longitudinal. Alternative scenarios like on-coming scenarios and scenarios in which a collision results from the presence of a bicycle in a vehicles blind-spot will be monitored for possible later consideration.

The technical specifications will be aligned where possible with existing protocols and target definition for AEB VRU testing, like ACEA [6], Euro NCAP [7], [8] ISO/TC 22/WG 16 [8] and vFSS [9] to improve and secure global conformity.

Specifications

Bicyclist and bike target

The bicyclist and bike target (BT) described in this paper represent an average human bicyclist on an average standard utility bike (Figure 6) in relation to the vulnerable road users (VRU) detection sensors used in vehicles. The requirements relate, insofar not specified otherwise, to the BT including a platform, which is needed to keep the bike and bicyclist upright during all tests. The BT is designed to work with the following types of automotive sensors technologies: RADAR (24 and 77 GHz), Video, Laser, PMD and Near-IR-based system similar to the ACEA TF-NCAP EG AD Pedestrian Target Specifications [6].

Features/properties

The fitment of various features of the bicyclist and bike have been evaluated as well as possible clothing of the bicyclist to check relevance for inclusion in the bicyclist and bike target (BT). Wearing reflective clothing or a helmet are both not mandatory under all conditions for bicyclists in any of the EU28 countries. For that reason neither reflective clothing nor a helmet will be part of the BT specification. Both however could be retrofitted on the BT as optional feature.

Front, rear, pedal and wheel reflectors are mandatory in many of the EU28 countries and are therefore included in the specifications of the BT. The specification for the reflectors are not uniform over the EU28 countries, but the most common ones have been selected for the BT specifications. The front, rear and all four pedal reflectors (left – right and front - rear) should be marked BS6102/2 (or equivalent) and coloured respectively white (front), red (rear) and amber (pedals). The front and rear reflector should be located on the bike target between 350mm and 900mm from the ground level, with the white front reflector positioned between most forward point of bike target and point 4 in Figure 4 facing forward. The red rear reflector is positioned between most rearward point of the bike target and point 5 in Figure 4 facing rearward. The amber coloured pedal reflectors should be on the front and rear side of both left and right pedal. The wheel reflectors will be white reflective strips on both sides of the rims or tyres. Examples of reflectors are shown in Figure 3.

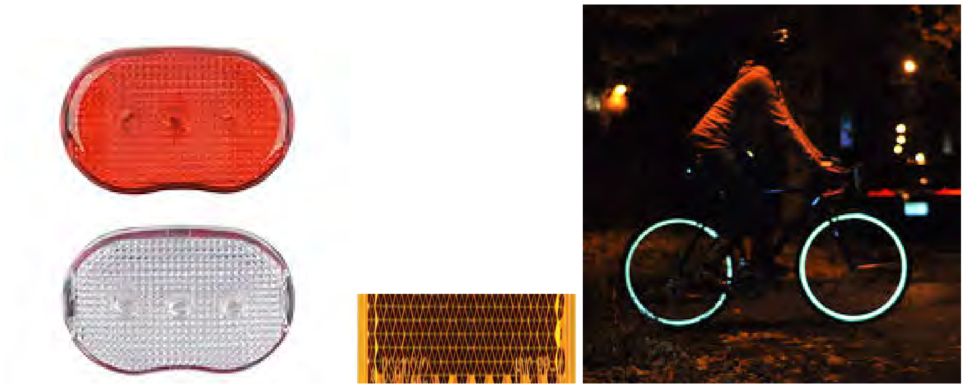


Figure 3 Bike Target: Rear and Front reflector, Pedal reflector and Wheel reflector

As mudguards, gear cases and luggage racks are fitted on most bikes in the EU, therefore they are included in the BT specifications.

Besides that fact that currently proposed CATS scenarios only includes daytime tests and the fact that front and rear light are not mandatory in most EU countries during daylight, front and rear lights are not included in the bike target requirements. However the defined front and rear reflectors have been selected in such a way that they can be easily replaced with front and rear lights that include reflectors. In that way the front and rear light can be offered as optional to the bike target.

For a realistic representation with respect to the micro-Doppler effect the bike target (BT) is fitted with rotating wheels. Both wheels are in contact with the ground to make sure that the wheel rotational speed is in agreement with the actual bike speed (as induced by the propulsion system). More information on the radar properties of the target is provided in the paragraph dedicated to radar properties.

The inclusion of rotating pedals and moving legs has been considered, however forward motion on a bicycle does not necessarily require moving pedals nor legs. An observation study on bicyclist behaviour showed that a significant part of the bicyclists stop pedalling when approaching a crossing [9]. Therefor nor rotating pedals nor moving legs are included in the proposed specifications of bike and bicyclist target. Rotating pedals and/or moving legs could be implemented in a later phase or as an option to the target.

Similar to the ACEA TF-NCAP EG AD Pedestrian Target Specifications [6] the bicyclist target should be coated with a closed textile outer cover.

Dimensions and posture

The bike target is based on a standard utility bike, as shown in Figure 6, and has a double triangle frame shape as shown in orange in Figure 4.

The dimensions of the bike target are based on an average Dutch utility bike for average male according to data from TU Delft ([10] and [12]) with additional dimensions taken from a standard Dutch utility bike (Gazelle Paris Pure male size 57) to complete the dimension specifications. Also alternative European bikes have been taken into account. Typical dimensions include dimensions indicated in Figure 4. Exact dimensions and tolerance are defined in Table 2.

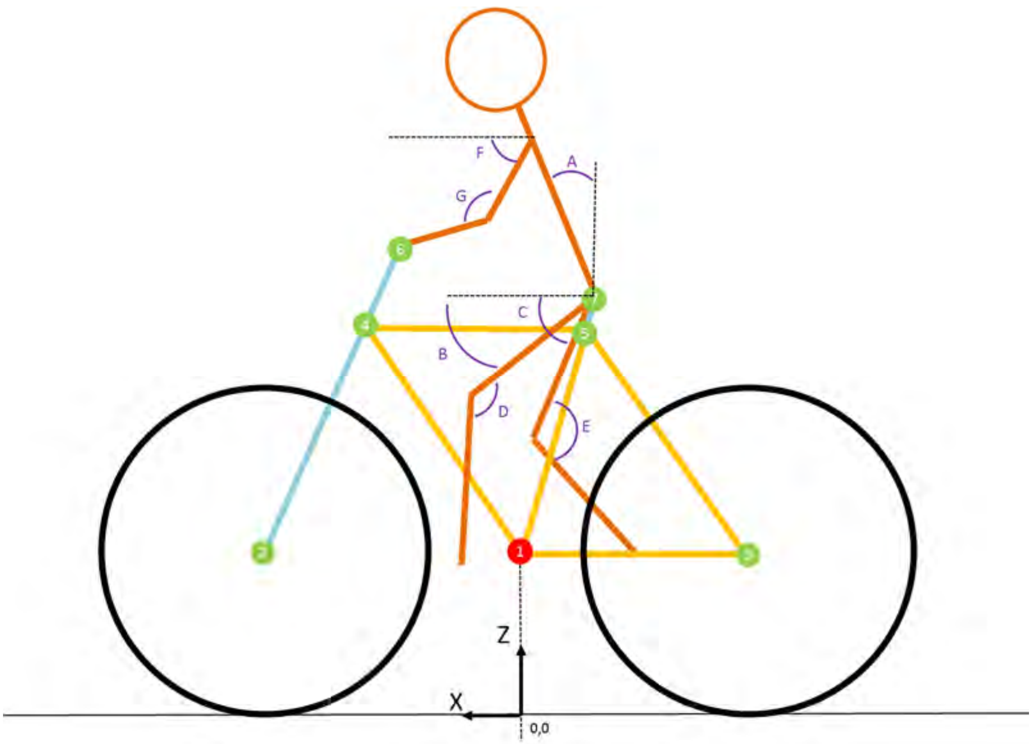


Figure 4 Bike target dimensions

Table 2 Bike target dimensions

Segment	Dimension (X, Z)	Unit	Tolerance	Unit
1 Centre of bottom bracket of bike	0, 260	mm	± 10	mm
2 Centre axis front wheel	690, 350	mm	± 10	mm
3 Centre axis rear wheel	-510, 350	mm	± 10	mm
4 Front top frame	430, 870	mm	± 10	mm
5 Rear top frame	-240, 870	mm	± 10	mm
6 Handle bars	290, 1200	mm	± 10	mm
7 Saddle	-270, 930	mm	± 10	mm

The centre of the bottom bracket (crank shaft) of the bike target (red circle Figure 4) will be used as reference 0-point in X-direction and floor level is reference 0-point in Z-direction.

The dimensions of the bicyclist target are based on an adult pedestrian target described in ACEA TF-NCAP EG AD Pedestrian Target Specifications [6] representing average (50th %-ile) male. The shape of the adult bicyclist target has to comply in its contours with the 50% RAMSIS Bodybuilder based on the RAMSIS version 3.8.30 to a permitted tolerance of ± 20mm [6].

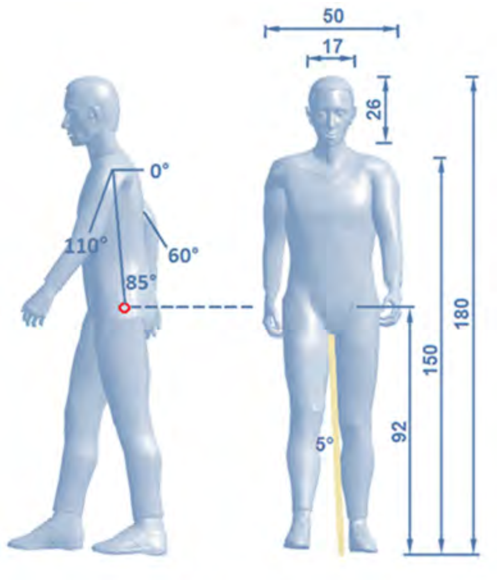


Figure 5 Bicyclist target dimensions in standing posture

Table 3 Bicyclist target dimensions in standing posture

Segment	Dimension / Angle	Unit	Tolerance	Unit
Body height (incl. shoes)	1800	mm	± 20	mm
H-Point height	920	mm	± 20	mm
Shoulder width	500	mm	± 20	mm
Shoulder height	1500	mm	± 20	mm
Head width	170	mm	± 10	mm
Head height	260	mm	± 10	mm
Torso depth	240	mm	± 10	mm
Torso angle	85	°	± 2	°
L Upper arm angle	60	°	± 2	°
R Upper arm angle	110	°	± 2	°

The posture of bicyclist target represents a natural driving position, facing forward, both hands on the steering wheel, with the peddles at same level and left foot forward. The same dummy posture is used for all driving directions. The posture definition includes: torso angle, hip angles, knee angles, shoulder angles and elbow angles, according to
Table 4.

Table 4 Bicyclist target posture

Bicyclist angles	Angle	Unit	Tolerance	Unit
A Torso angle	10	°	± 2	°
B Hip angle left leg	30	°	± 2	°
C Hip angle right leg	60	°	± 2	°
D Knee angle left leg	130	°	± 2	°
E Knee angle right leg	100	°	± 2	°
F Shoulder angle (left & right)	55	°	± 2	°
G Elbow angle (left & right)	170	°	± 2	°

There must be a possibility to check and correct the body posture and angle of legs and arms in an easy and practical way corresponding to the defined tolerances e.g. with the help of a tool with a reference shape. This tool is under development, awaiting the final harmonized specifications.

Visual and infrared

The bicyclist target will have the same visual and infrared requirements as defined in ACEA TF-NCAP EG AD Pedestrian Target Specifications [6]. The bicyclist target shall look like clothed with a long-sleeved shirt and shoes in the colour black [colour space XYZ(2.6, 2.8, 3.0)] and long trousers in blue [colour space XYZ(11.0,13.3,32.2)]. The clothing has to be made from tear-proof and water-resistant material. The “skin” surface parts (face and hands) have to be finished with a non-reflective flesh-coloured texture or paintwork [colour space XYZ(37.6, 38.8, 31.0)]. The head hairs should also be black [colour space XYZ(2.6, 2.8, 3.0)]. The tolerances of the colour specifications are ±2%.

The infrared (IR) reflectivity (within 850-910nm wavelength) of the clothes and “skin” shall be within 40-60% and for the hair this shall be within 20-60%, similar to ACEA TF-NCAP EG AD Pedestrian Target Specifications [6].

Textile specification outer cover as defined in ACEA TF-NCAP EG AD Pedestrian Target Specifications [6]:

- Area weight: < 300 g/m²
- Water resistance (AATCC 127): > 600 mm
- Strength (ASTM D5034): > 350 lbs
- Light fastness (AATCC 169): > 6000 h
- Wear resistance ASTM (D3884): > 500 cycles

The bike target will have a frame, mudguards, luggage rack and tires in black. The gear case and rims are grey. The BT is currently in final verification phase and IR properties of BT will have to be defined for the different components of the bicyclist target.

The colour of stiffening ropes or other supports must be light grey or transparent and be of low optical reflectivity.

Radar

The radar reflective characteristics for ADAS relevant radar frequencies (24Ghz and 77Ghz) of the bicyclist and bike target (BT) should be comparable to a real human bicyclist and bike of the same size. The requirement boundaries are also based on measurement spread of real human bicyclist and bikes.

Within the FP7 AsPeCSS project 360° RCS measurements have been performed in an RF anechoic chamber on a bike with bicyclist for radar frequencies 24Ghz and 77Ghz. In those tests pedestrian and bicyclists have been place on a rotating pedestal and RCS signatures have been determined from a fixed distance [10]. For the bicyclist evaluation a standard utility bike with an average bicyclist has been used, see figure below. It is noted that for the 360° RCS measurements, the wheels of the bike are not rotating.

Figure 6 AsPeCSS 360° RCS test set-up

The AsPeCSS 360° RCS measurements have been used as basis for the RCS properties of the bicyclist and bike target (BT). After this a series of development and verification workshops, in which OEM's and suppliers could evaluate the BT, have been performed. During those workshops both real and target bicyclist and bike were available for comparison. Based on the feedback from those workshops the BT has been adjusted in different development stages to better match the visual and RCS responses of a real bike and bicyclist. During those workshops both static and moving real and target bicyclist and bike have been used to also take into account the micro-Doppler signatures. The BT is currently in final verification phase and final RCS properties of BT will be defined including corridors.

For the final target definition three configurations will be used to evaluate the RCS signature of the target. This is done to ensure that RCS characteristics of the BT match a real human bicyclist and bike from relevant different distances and angles.

The three RCS configurations are shown in Figure 7.

1. 360° degree static BT (24Ghz & 77Ghz)
   Reference measurement of BT in a well-controlled environment for overall RCS property definition, similar to 360° RCS measurements performed during AsPeCSS project.
2. Static BT (left, rear and right) with moving automotive radar (24Ghz & 77Ghz)
   Measurements with automotive radar sensors moving towards the stationary BT, to take into account the RCS properties at different distances.

3. Moving BT (left to right, right to left, ?rear?) with static automotive radar (24Ghz & 77Ghz) Measurements with automotive radar sensors at fixed location and moving BT, crossing and longitudinal, to measure response at different BT angles and distances and micro-Doppler effect of rotating wheels.

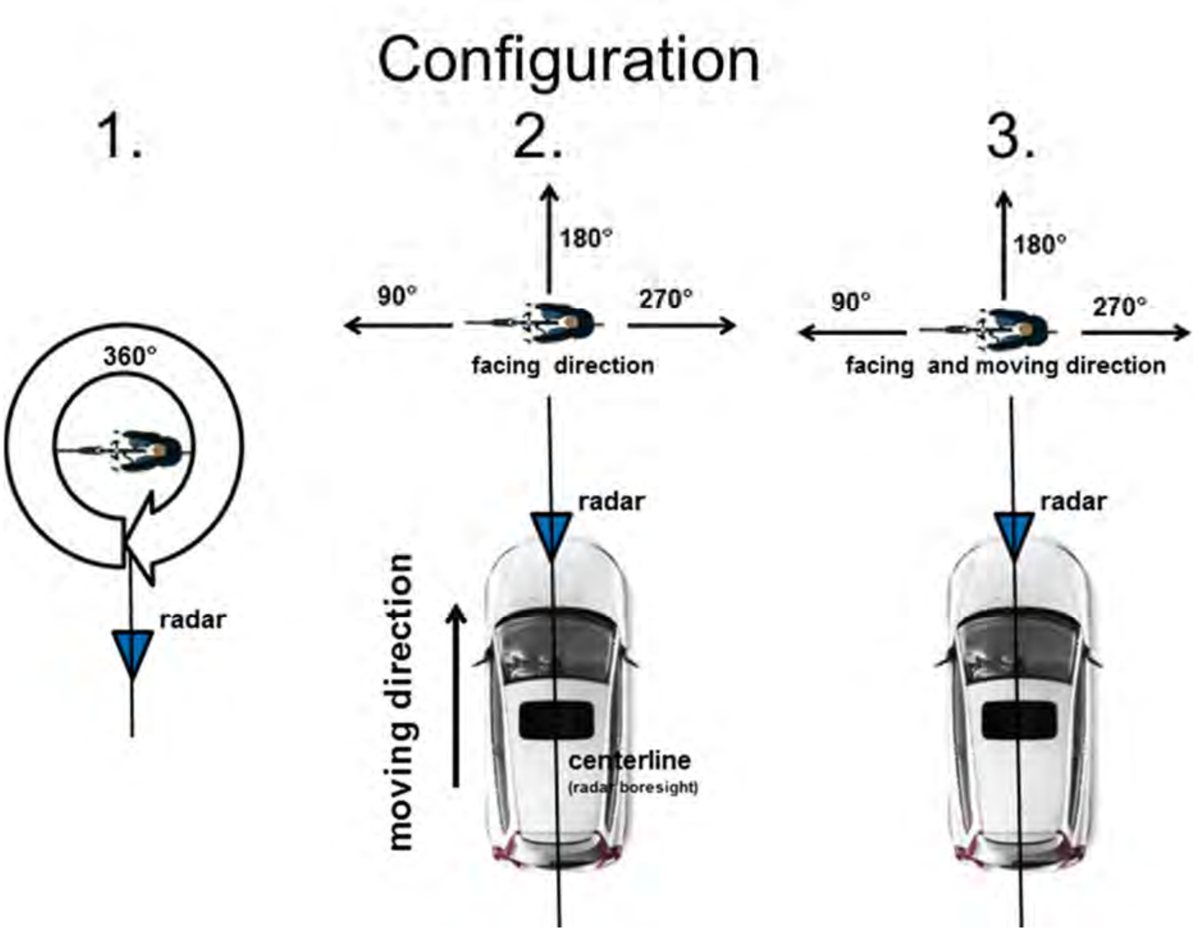


Figure 7 Radar verification configurations

RCS measurement configuration 1 is intended as baseline RCS measurement in well-controlled environment. RCS measurement configurations 2 and 3 can also be used as verification tests during testing, to ensure the target RCS properties are still within the set corridors.

The radar profile of stiffening ropes or other supports must be low and not affect the overall radar profile of the BT.

Stability

The bicyclist and bike target (BT) should have limited lateral (relative to moving direction of BT) oscillations during testing. A sideward motion up to +/- 5° is acceptable, similar to ACEA TF-NCAP EG AD Pedestrian Target Specifications [6].

Crashworthiness

The bicyclist and bike target (BT) should have limited weight (max. 10kg) and lack any hard impact points to prevent damage of the Vehicle Under Test (VUT). It should be possible to repair damage to both VUT and BT related to impact speeds (up to 60km/h for crossing scenarios and 45km/h for longitudinal scenarios) with limited time and costs. Any repair to the BT should not affect the properties related to representation of real bicyclist & bike, nor the stability, as described above.

Environmental conditions

The bicyclist and bike target (BT) shall fulfil all requirements in a temperature range of -5ºC to +40ºC. The BT shall not deteriorate under storage temperatures in the range of -20ºC to +80ºC when properly stored.

Wind speeds up to 10m/s should not have a significant influence on the characteristics of the BT, similar to ACEA TF-NCAP EG AD Pedestrian Target Specifications [6].

Propulsion system

Also for the propulsion system specifications have been defined for the three dominant EU scenarios, crossing nearside, crossing farside and longitudinal.

It should be possible to perform tests with vehicle under test (VUT) speeds from 10km/h up to 80km/h and bicyclist and bike target (BT) speeds from 10km/h up to 25km/h. The speed of the BT should be remained constant for at least 30m in crossing and 45m in longitudinal scenarios with a tolerance of ± 0.2km/h, similar to Euro NCAP AEB VRU protocol [7]. An exact and reproducible positioning of the BT has to be guaranteed. The required tolerances for the path control in lateral and longitudinal direction are currently evaluated.

The propulsion system should not interfere with the vehicle under test up to the point of impact. All visible parts of the BT mounting, guidance and propulsion system must be coloured in grey or silver shades. Any supporting ropes, tubes for fixing the dummies position and or BT mounting must be designed not to interfere with the vehicle under test and in particular with its bicyclist emergency braking system.

The rotating wheels of the BT should be in constant contact with the road surface to ensure that the wheel speed matches the forward speed of the BT.

An active unlocking system is required to release the BT immediately just before impact to prevent/reduce severe damage during a collision between vehicle and target.

Realisation

The next chapter will describe the propulsion system with bicyclist and bike target (BT) that 4activeSystems GmbH realised based on the specifications described previously in this paper. The BT version described below is version v5.

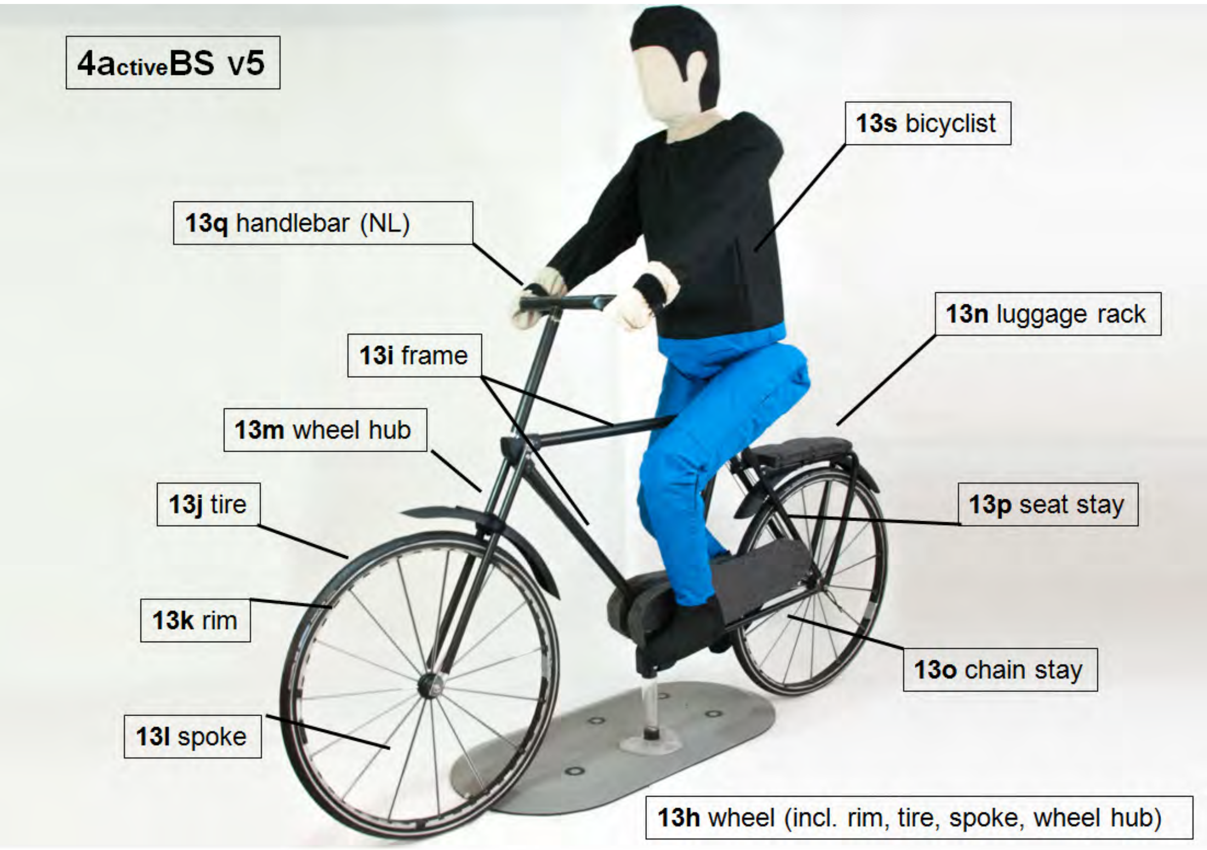


Figure 8 Components of 4activeBS v5

List of components of 4activeBS v5 ($13a_5$):

13h wheel (incl. rim, tire, spoke, wheel hub)
13i frame
13j tire, original bike tire are used
13k rim
13l spoke (10 pcs.)
13m wheel hub
13n luggage rack
13o chain stay
13p seat stay
13q handle bar (NL)
13r handle bar (EU)
13s bicyclist

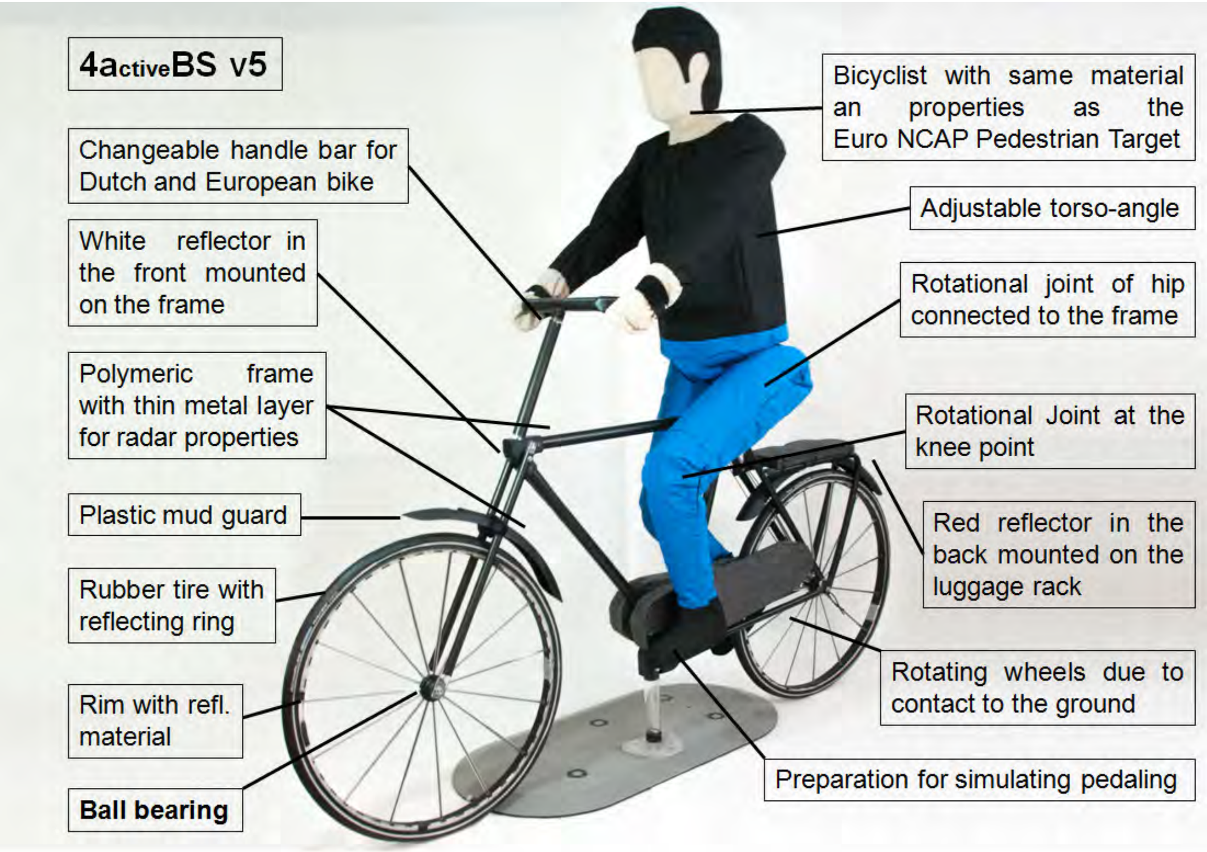


Figure 9 description of different components of the 4activeBS v5

The following picture show the 4activeBS v5 from different viewing points.

Figure 10 pictures of 4activeBS v5 from different viewing points (90°-45°-0°-315°-270°)

Figure 11 Dimensions and posture of 4activeBS v5

Table 5 Table of dimension and posture of 4activeBS v5

Segment	Dimension (X, Z)	Unit	Tolerance	Unit
1 Centre of bottom bracket of bike	0, 26	cm	± 1	cm
2 Centre axis front wheel	69, 35	cm	± 1	cm
3 Centre axis rear wheel	-51, 35	cm	± 1	cm
4 Front top frame	43, 87	cm	± 1	cm
5 Rear top frame	-24, 87	cm	± 1	cm
6a Handle bar - Dutch Bike	29, 120	cm	± 1	cm
6b Handle bar - European Bike	41, 106	cm	± 1	cm
7 Saddle	-27, 93	cm	± 1	cm
A Torso angle	10	°	± 2	°
B Hip angle left leg	30	°	± 2	°
C Hip angle right leg	60	°	± 2	°
D Knee angle left leg	130	°	± 2	°
E Knee angle right leg	100	°	± 2	°
F Shoulder angle (left & right)	55	°	± 2	°
G Elbow angle (left & right)	170	°	± 2	°

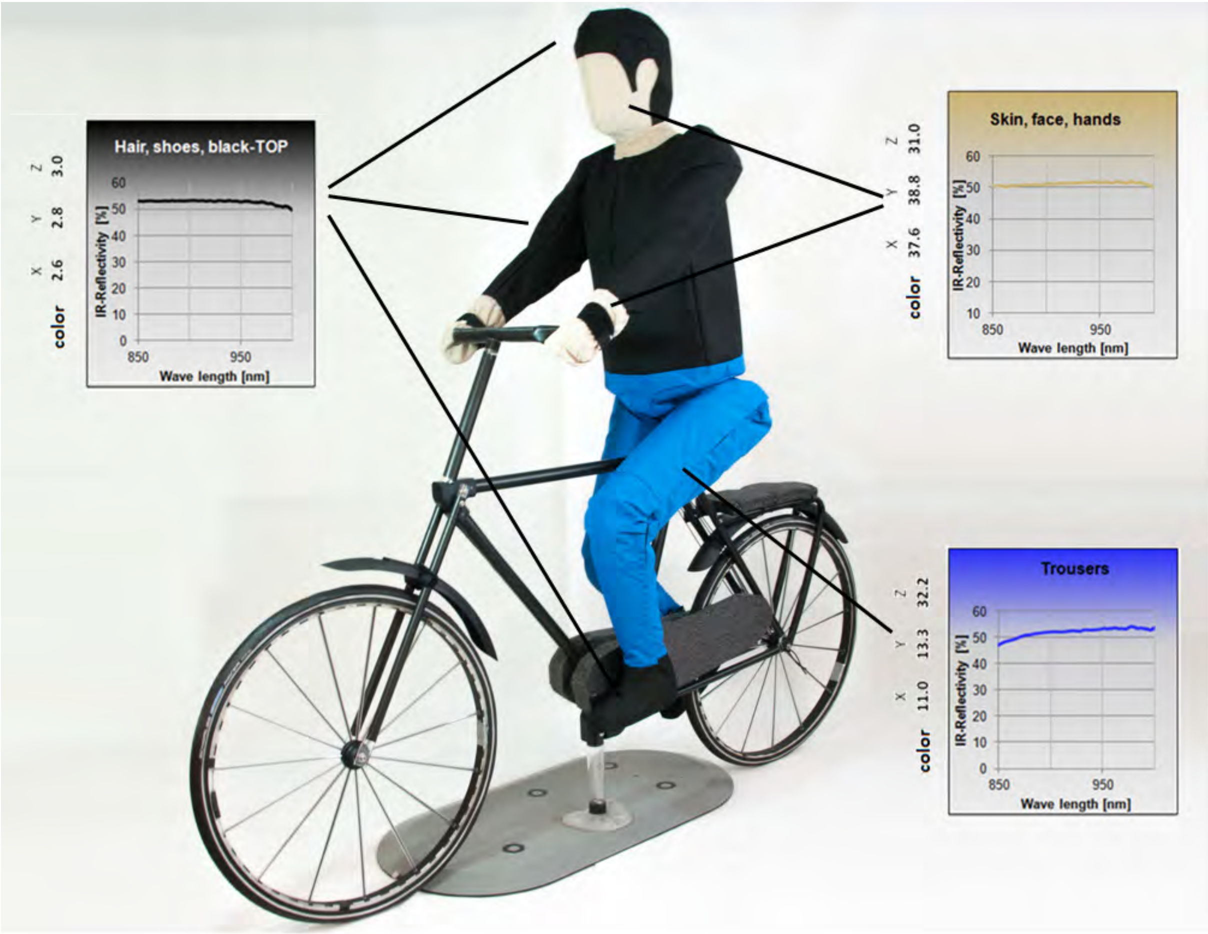


Figure 12 IR-Properties of the bicyclist and bike of 4activeBS v5.

The outer surface of the tyres, wheels and frame are from the same materials as on real bike.

Propulsion system

The basis for the propulsion system is the 4activeSystems pedestrian propulsion system, which is being used by various labs for AEB VRU pedestrian tests according Euro NCAP protocol [7]. A more powerful system has been manufactured for the cyclist scenarios to facilitate the heavier target at higher target speed covering longer distances. For the longitudinal scenario the existing propulsion system has been adopted to a single belt configuration.

CONCLUSIONS

CATS consortium has defined the basic specifications for a bicyclist and bike target with a propulsion system to facilitate the scenarios for evaluation of cyclists-AEB systems. For some RCS and IR properties more detailed specifications are needed and those will be defined in the coming months.

4activeSystems GmbH manufactured a bicyclist and bike target with propulsion system meeting the set requirements.

Possible additions, beyond the CATS project, could include: adjustable dummy torso angle representing more sporty bicyclist position, inclusion of helmet, moving pedals and legs, Long Wave IR (thermal radiation from bicyclist), active lights on bike target, representation of electric bikes.

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