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CATS Deliverable 2.2: CATS car-to-cyclist accident parameters and test scenarios

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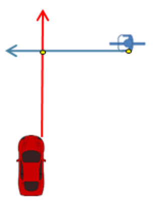
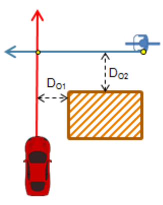
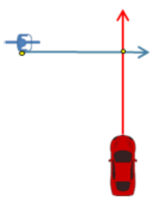
Summary

This report summarizes the work conducted within work package (WP) 2 “Test scenario definition” of the CATS project. It describes relevant accident parameters for the 5 most dominant accidents scenarios defined in WP1. The objective of this WP2 is to construct car-to-cyclist accident test scenarios for the EU, based on the accident scenarios and accident parameters mainly obtained from France, Germany, Italy, the Netherlands, Sweden, as well as the United Kingdom. The focus is hereby set on accidents with killed and seriously injured casualties rather than on the overall accident population. The result from this study will be used as an input for the creation of an AEB car-to-cyclist test protocol.

CATS will focus at the 3 dominant accident scenarios (C1: crossing bicycle from the near side, C2: crossing bicycle from the far-side and L: longitudinal scenario where car drives into the rear-side of a bicycle that rides in front of the vehicle in the same direction) only, for which at first DRAFT CATS scenarios are proposed. These accident scenarios together cover 63% and 78% of the seriously injured and fatal car-to-cyclist accidents for the investigated countries, respectively. Since the contribution to the coverage of On (Cyclist riding straight in the opposite (on-coming) direction) and T3 (Cyclist coming from the opposite direction, riding straight while car turning to far side) is relatively low and the On and T3 provide for essentially different scenarios, leading to additional test series, these accident scenarios are not taken into account at this moment in time.

In Table 1 the CATS matrix (DRAFT June 2015) is shown for the car-to-cyclist AEB test scenarios. It includes the C1 accident scenario as a crossing test scenario reference, but also with view blocking obstruction. In C1, also the hit-point on the car is varied. The C2 accident scenario is suggested to be used to vary cyclist speed. The L accident scenario is suggested to be divided over urban and rural (inter-urban) groups. The preparation and tolerances of the test scenario, test track, bicycle/cyclist dummy and vehicle are suggested to follow the Euro NCAP AEB VRU Test Protocol v1.0.1 [16]. At a later stage, after the verification tests in WP5, the final CATS matrix and test protocol will be provided.

Table 1. Draft CATS car-to-cyclist AEB test matrix (version June 2015)

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

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

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

- Car-to-VRU Nearside Bicyclist Unobstructed (**CVNBU**)
  a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the nearside and the frontal structure of the vehicle strikes the bicyclist at 0% 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 50% of the vehicle's width 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.

Contents

1 Introduction

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

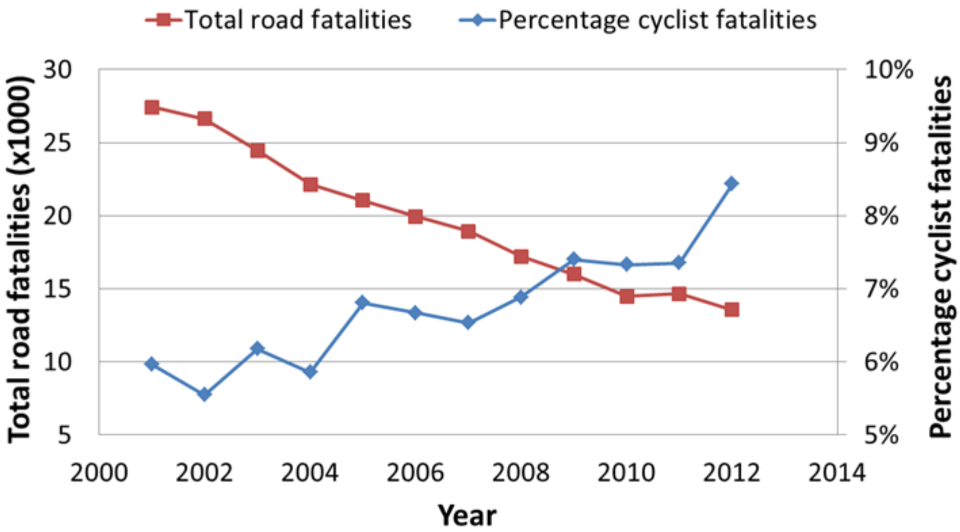


Figure 1-1. Trends of total road fatalities and cyclist fatalities for France, Germany, Italy, the Netherlands, Sweden plus the UK over the period of 2001 to 2012 [1].

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

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

This report summarizes the work conducted within work package (WP) 2, “test scenario definition”, of the CATS project. In the first work package of the project, the most dominant accident scenarios were determined using accident data from France, Germany, Italy, The Netherlands, Sweden and the United Kingdom [6]. For these accident scenarios the most common accident parameters are determined. The focus is hereby set on accidents with killed and seriously injured casualties rather than on the overall accident population. The scenarios and parameters together are used to define the first development test scenarios. At a later stage, after the tests in WP5, the final test matrix/ test protocol will provided.

2 Data selection

In this chapter relevant accident parameters with respect to the development of the test protocol are defined for the dominant accident scenarios determined in the first work package. Furthermore the data sources for these accident parameters are described. Just as for the accident scenarios the focus will be on the seriously injured and fatal accidents.

2.1 Dominant accident scenarios

From the first work package a top 5 of accident scenarios is provided as is shown in Figure 2-1 and described in Table 2 in order of relevance [6]. For both the seriously injured and fatal accidents the 2 crossing scenarios (from near and far side) were on average most dominant over the investigated countries covering about 50% in both categories. The longitudinal scenario was found to be dominating in the fatal accidents (about 25%), however it was also substantial in the seriously injured accidents (about 7%). The 2 crossing scenarios together with the longitudinal scenario were found to be the top 3 in each of the investigated countries. The fourth scenario, oncoming, was equally relevant in the fatal and seriously injured accident covering about 7%. The fifth scenario, T3 (where the vehicle makes a far side turn into an oncoming cyclist), was the most relevant turning scenario and was found to be mostly relevant in the seriously injured accidents covering about 5%. All other investigated scenarios had a coverage lower than 5% and was therefore not included here.

It was concluded that the test protocol should be developed at least for the scenarios C1, C2, and L. Because the oncoming and T3 scenario could still be considered in the future, these scenarios are also included in the parameter study described in this report.

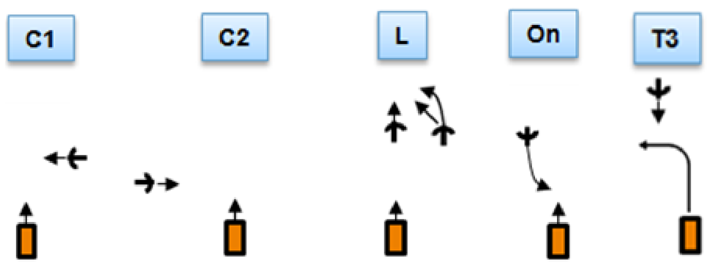


Figure 2-1 Top 5 of accident scenarios as identified in the first work package, “accident analysis”

Table 2. Description of top 5 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
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 • Cyclist coming in the opposite (on-coming) direction riding straight
T3	• Car turning to the left*, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight

* for left hand driven vehicles, opposite for right hand driven vehicles

2.2 Parameters

In order to create realistic test scenarios, the parameters of the accident scenarios need cover real-life accidents. To determine the test scenarios, the parameters for the vehicle, bicycle and accident scenario need to be defined. In Table 3 a list is shown of accident parameters deemed necessary for understanding of the accident scenarios and for the creation of the test scenarios. Some parameters for the test scenarios are captured within others and are discussed together when creating these test scenarios in the next chapter. For example, it is relevant to know the speed of the vehicle (parameter of one of the accident partners) at some time before the crash. However, since this is not always known, the speed limit (parameter of the accident scene) can also give an indication and is used there as well.

Table 3. List of relevant accident parameters

Accident scene	Accident partners
Precipitation	Cyclist speed
Lighting conditions	Cyclist age
Location	Cyclist size
Road layout, obstruction	Helmet use
Speed limit	Cyclist gender
Season	Vehicle Speed
	Vehicle braking
	Collision point

2.3 Data sources

In the first work package, six countries (France, Germany, Italy, The Netherlands, Sweden and the United Kingdom), were evaluated to determine the most dominating accident scenarios (The data from Italy was not used in the concluding averaging of the accident scenarios due to the low number of samples). For determining the accident parameters all available sources of these six countries are used. This is done since accident parameters unavailable in one data source might be available in another, making them complementary. An overview of the different data sources including the number of fatal and seriously injured accidents and the time frame selected for analysis is presented in Table 4. For completeness a short description of each used data source in the parameter study is given here:

France: Data are considered from LAB (*Laboratoire d'Accidentologie et de Biomécanique*) that use a database created for the French project called "VOIESUR" [7].The objective of this database is to have an intermediary level of detail between national data and in-depth data collection. 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, seriously injured (hospitalized for at least 24h) and slightly injured (received medical care but not admitted to hospital for more than 24h).

Germany: Two 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 Hannover 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 [8]).
GIDAS-based PCM [9]: By simulating the pre-crash scenario, additional and standardized data to describe the pre-crash-sequence of an accident in a very high detail is generated and documented in the GIDAS-based Pre-Crash-Matrix (PCM). The PCM contains major relevant data to reproduce the pre-crash-sequence of traffic accidents from the GIDAS database until 5 seconds before the first collision.

Italy: Fiat Group Automobiles enforces accident data collection from 2011. The in-depth accident database is an FIAT internal database [10] with the following information: accident circumstances, vehicle and injury severity (killed, injured, not injured; each injury is coded according to AIS [8]). For the CATS activities, a distinction is made between fatalities (killed) and injured (MAIS2+, 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 [11]. 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) [12]. 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.
Furthermore the Volvo Car company has its own internal database in cooperation with insurance company If - where all new Volvo cars are insured. The dataset cover crashes all over Sweden 2005-2012 with recent Volvo Car models, in total 252

collisions. 62 of these were recorded in STRADA Hospital and 54 in STRADA Police.

United Kingdom: The STATS19 Road Accident dataset is used for the UK as analysed for the AsPeCSS project [13]. 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.

Table 4. Overview of the available accident databases used in the parameter study

#	Country	Source	Killed		Seriously injured		Period
			Definition	*n*	*Definition*	*n*	
1	France 	LAB [7]	Fatal	72	Severely injured	620	2011
2a	Germany 	GIDAS-based PCM [9]	Fatal	11	MAIS2+	360	1999-2012
2b		GIDAS [14]	MAIS5+	15	MAIS2+	602	Until 12/2010
2c		GIDAS [14]	MAIS5+	28	MAIS2+	915	2000-2013
2d		GIDAS-based PCM [permanent obstructed crossing cases only] [9]	-	-	MAIS2+	14	1999-2012
3	Italy 	Internal FIAT [10]	Fatal	23	MAIS2+	17	2003-2014
4	Netherlands 	BRON [11]	Fatal	902	Seriously injured	10854	2000-2013
5a	Sweden 	STA/STRADA [12]	Fatal	104	MAIS2+	435	2005-2014 K 2010-2014 SI
5b		VCC internal	-	-	MAIS2+	61	2005-2012
6	UK 	STATS19 [13]	Fatal	116	Seriously injured	2699	2008-2010

The following limitations should be noted:

- Some of the sources contain in-depth data which can be used to distinguish the parameters for each scenario, where others contain higher level data only. Therefore, not for all sources the same level of detail is available.
- The time periods for the selected data vary. Limiting the data to a common timeframe would have reduced the data significantly and was therefore not done. When looking at all different GIDAS studies performed over several different time frames [6], it can be seen that accident scenarios do not seem to change with time. It is therefore assumed that there is no evolution on the car-to-cyclist accidents scenarios in the period from 2000-2013 and that using different time frames is allowed.
- Some of the data is based on police recorded records. Policemen are not necessarily experts in crash reconstruction and data is sometimes witness-based, thus data may contain subjective information.
- Not all databases use the same definitions for “killed” and “seriously injured”. A casualty might be listed under “killed” for one data source only when the victim died on the site of the accident where another database would list the casualty under “killed” also if the victim would have died no later than 30 days after the accident occurred. The same holds for “seriously injured”, though for most databases a severe injury for this study could be defined as an accident with MAIS 2+ injuries.
- The number of fatalities is low for some sources and must be regarded with care when trying to draw statistically relevant conclusions.
- It can be seen that, due to various reasons, the ration between killed and seriously injured are not the same between the different data sources. The 2 groups should therefore be examined separately.

For consistency, the dataset from the UK (STATS19) has been translated towards EU main land right-hand driving, to be able to make a direct comparison with the accident scenarios in the other countries.

3 Results

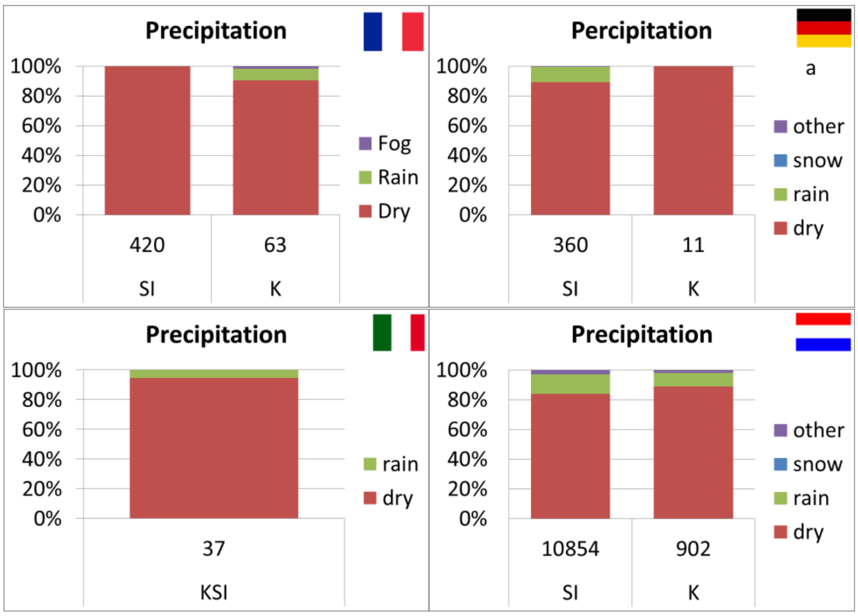
This chapter outlines the results of the collected accident parameters separated in the categories: accident scene and accident partners. In the figures the flags of the countries are shown in order to indicate where the data comes from. When more data sources per country exist (Germany and Sweden) and when these data sources are in line, a letter is added to indicate the data source used as defined in Table 4. Each figure also shows the number of cases on which each category is based upon. When for certain accidents in a data source the parameter is unknown it is removed from the data set (explaining the different number of cases between parameters from the same data source). For each parameter an overall figure is shown where only a subdivision for the injury severity (seriously injured (SI) and/or fatal (K)) is made, since most data sources are able to deliver this. After that, for the data sources where this is possible, it is further subdivided over the 5 most dominating scenarios: C1, C2, L, On and T3 (Figure 2-1). The data presented here will be used in the next chapter to construct test scenarios.

3.1 Accident scene

In this paragraph the parameters related to the accident scene are discussed, which will function as the preconditions for the construction of the test scenarios in the next chapter.

3.1.1 Precipitation

Figure 3-1 shows the percentage of cyclist accidents for different levels and types of precipitation. It shows that the majority, more than at least 80%, of these accidents occur when there is no precipitation (dry). The difference in precipitation between the seriously injured and fatal accidents is negligible. In France and Sweden a slightly higher percentage of some form of precipitation in the fatal accidents can be seen, whereas in the Netherlands and Germany the seriously injured accidents show a slightly higher percentage of some form of precipitation. Furthermore, when there is precipitation this is almost always classified as rain.



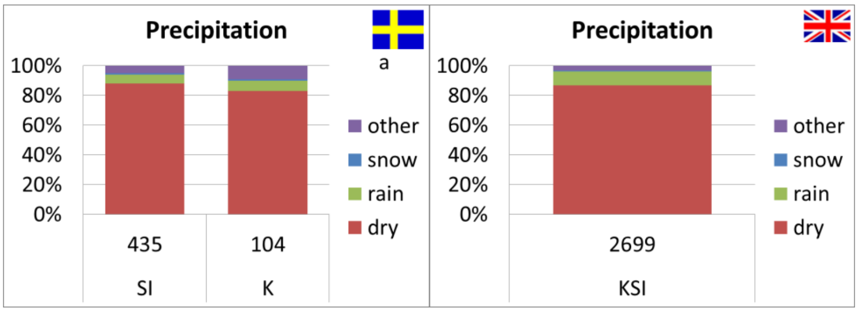


Figure 3-1 Overall overview of cyclist accidents in target population by precipitation. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

Figure 3-2 shows the precipitation divided over the 5 dominating accident scenarios for Germany (only seriously injured, since the fatal group is too small to be representative for the separate accident scenarios) and Sweden. No clear distinction can be found between the accident scenarios in both data sources and between the seriously injured and fatal accidents.

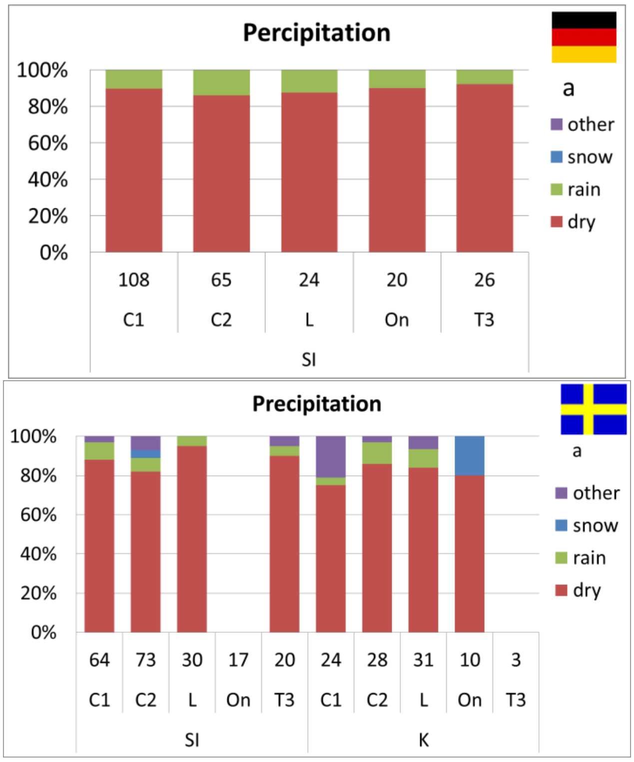


Figure 3-2 In-depth overview of cyclist accidents in target population by precipitation. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.1.2 Lighting conditions

In Figure 3-3 the percentage of cyclist accidents are shown by different types of lighting conditions. It can be seen that for all data sources the fatal accidents occur more often in low lighting conditions than the seriously injured accidents. 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 should be 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 lighting.

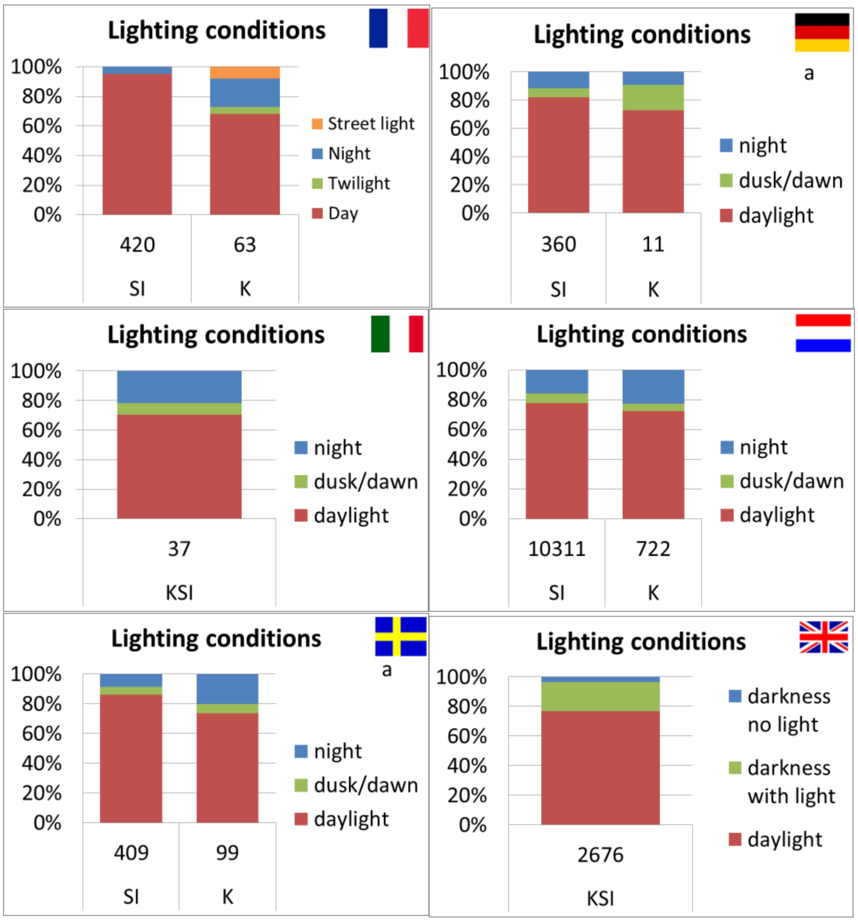


Figure 3-3 Overall overview of cyclist accidents in target population by lighting conditions. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

Figure 3-4 shows the lighting conditions for the 5 dominating accident scenarios for Germany and Sweden. For Germany 2 data sources are shown since they provided a slightly different result. In the seriously injured accidents there is little difference in the lighting conditions between the scenarios, however in the other data source from Germany (c) it can be seen that the longitudinal scenario occurs more often during at night (dusk/dawn portion is similar). This can be explained by the observation that fatal accidents occur more often in low lighting conditions and the different definition of seriously injured, where in the second German data source this includes fatal accidents. Especially combined with the low number of samples this can have a visible effect.

In the fatal accidents from Sweden it can be seen that in Sweden the oncoming scenario occurs mostly at night. However caution is advised due to the low number of cases (10) and the fact that data for the oncoming scenarios in the seriously injured accidents and data for the T3 scenario in the fatal accidents are missing. Furthermore a higher portion occurs at night for the C2 scenario when compared to the C1 scenario.

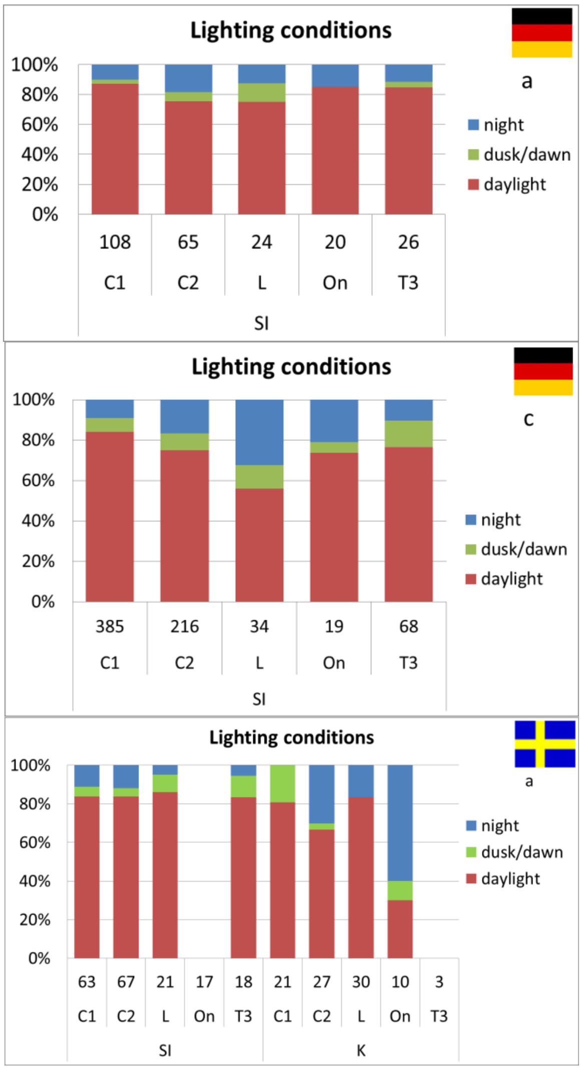


Figure 3-4 In-depth overview of cyclist accidents in target population by lighting conditions. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.1.3 Location

Figure 3-5 shows the cyclist accidents by location which is divided into urban and rural areas. Even clearer than for the lighting conditions there is a distinction between the seriously injured and fatal accidents, where in all data sources the fatal accidents occur more often in rural areas. These parameters are most likely not independent. One can imagine that rural areas are more likely to have no artificial lighting during the night. Furthermore, in most cases, the speed limit and therefore the speed of the vehicle is higher in rural areas, making a cyclist accident to be more likely to become fatal than in lower speed situations. When considering all data sources, the majority (~70%-90%) of the seriously injured accidents occur in urban areas. The fatal accidents occur on average (~40%-60%) evenly in urban and rural areas.

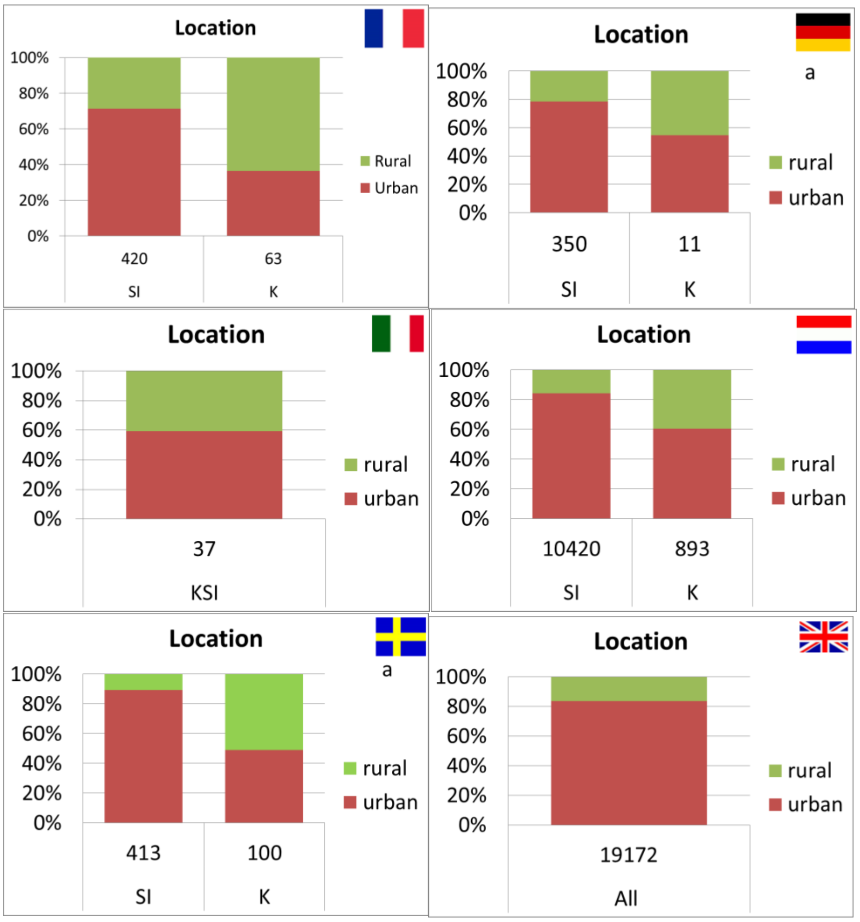


Figure 3-5 Overall overview of cyclist accidents in target population by location. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

Figure 3-6 shows the location for the separate accident scenarios for France, Germany and Sweden. The overall conclusion that fatal accidents occur more often in rural areas is also true for each separate accident scenario. However it is also clear that the crossing scenarios occur more in urban areas for both the seriously injured (~60%-95%) and fatal accidents (~50%-65%), than the longitudinal scenario (~50%-60% for the seriously injured and ~15%-25% for the fatal accidents). Especially the fatal accidents in the longitudinal scenarios clearly occur more often in rural areas. Also the oncoming and T3 accident scenario occurs mostly in urban areas in the seriously injured accidents (~80%-100%). For the fatal accidents caution is advised to draw any conclusion due to the low number of cases in some accident scenarios.

Figure 3-6 In-depth overview of cyclist accidents in target population by location. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.1.4 Road layout

Figure 3-7 shows the road layout for the cyclist accidents. It is divided in junctions, straight roads, bends in roads and roundabouts. The majority (~55% -70%) of the seriously injured accidents occur on a junction. The second largest road layout is a straight, which occurs relatively more often in Sweden (~35%) than in Germany (~10%) for the seriously injured accidents. An even larger difference is seen in the fatal accidents where the straight road layout is dominant in Sweden (~65%), while in Germany it is similar to the seriously injured accidents (~15%). However caution is advised since the German fatal accidents are only based on 11 accidents. Furthermore (part of) the difference between Germany and Sweden can also originate from the definition of a junction and a straight road layout in each data source, since this is not as straight forward as for example urban and rural locations (note that this does not change the differences found in seriously injured and fatal accidents between the 2 countries).

The road layout for the separate dominating accident scenarios can be found in Figure 3-8. It shows that the crossing scenarios and the T3 scenario occur more on junctions and the oncoming and longitudinal scenarios more on a straight road layout. This makes sense, since for a crossing or T3 scenario it is needed to be on some kind of intersection (even though if it is classified as a straight road layout), where this is not a prerequisite for the oncoming or longitudinal accident scenario. Furthermore for the fatal accidents in Sweden in the oncoming and longitudinal accident scenarios the large majority either occurs on a straight or bend road layout and none at a junction.

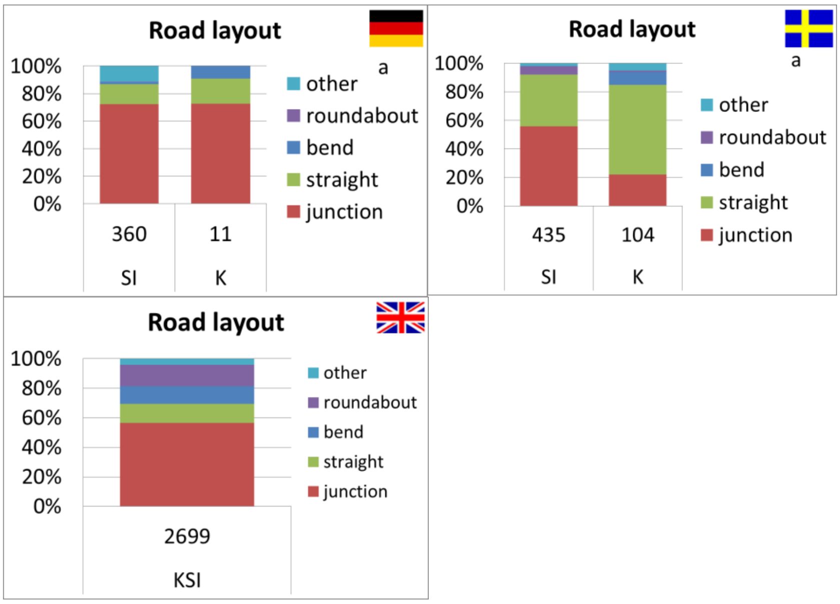


Figure 3-7 Overall overview of cyclist accidents in target population by road layout. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

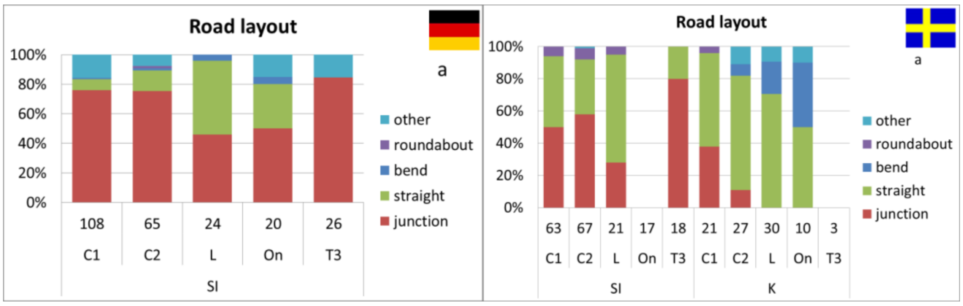


Figure 3-8 In-depth overview of cyclist accidents in target population by road layout. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.1.5 Speed limit

Some data sources delivered actual vehicle speeds while others have provided the speed limit at the location of the accident. Both will be used in order to construct test scenarios, however they will be discussed separately since they do deliver different insights. Figure 3-9 shows for the cyclist accidents the speed limit for The Netherlands and Sweden. Both countries show the same distribution for the seriously injured accidents, where the majority (~80%) of the accidents occur with a speed limit of 50 or 60 km/h. The fatal accidents occur at a higher speed limit than the seriously injured accidents in both countries. This correlated well with the location of the accidents described in paragraph 3.1.3, where the rural (higher expected speed limit) accidents were more common in the fatal accidents. Still the majority (~40%-60%) of the accidents occur with the 50 or 60 km/h speed limit in both countries. There is however a difference visible in the speed limits between both countries for the fatal accidents. Where in the Netherlands no fatal accidents were found with a speed limit of 90 km/h or above, this is a substantial part of the Swedish fatal accidents (~25%). The reason is that in The Netherlands, there can be no possible conflict between vehicles and bicycle for speeds over 80 km/h and alternative solutions are mandatory (separated lanes, bridges, tunnels, etc.). This does not apply to Sweden.

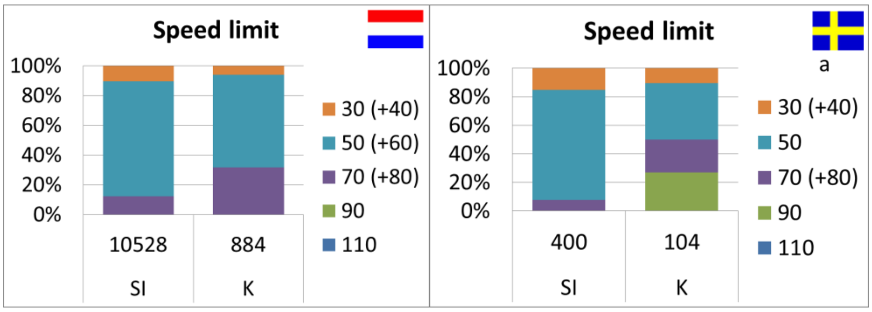


Figure 3-9 Overall overview of cyclist accidents in target population by speed limit (km/h). Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

Figure 3-10 shows the speed limit for the separate dominating scenarios for Sweden. Especially the crossing and T3 scenarios occur at a 50 km/h speed limit for the seriously injured accidents. Furthermore, it shows that in both the seriously injured and fatal accidents the longitudinal scenario occurs at a higher speed limit than the other accident scenarios. Furthermore all accidents scenarios show that the fatal accidents occur more often at higher speed limits.

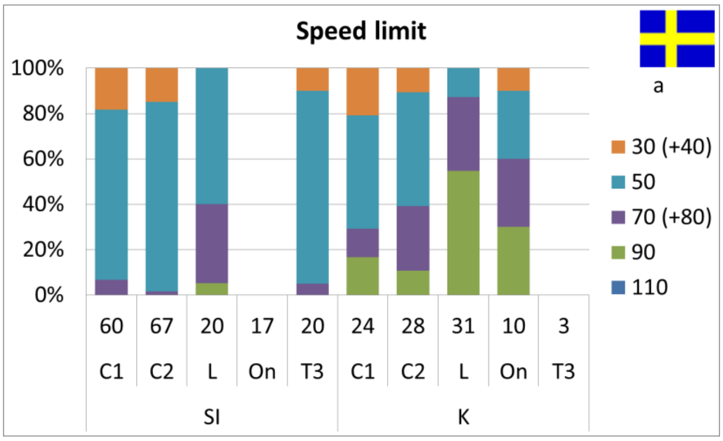


Figure 3-10 In-depth overview of cyclist accidents in target population by speed limit (km/h). Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.1.6 Season

Figure 3-11 shows the month of the year in which the seriously injured and fatal cyclist accidents occur for Germany, The Netherlands and Sweden. A difference can be seen between Germany and Sweden on the one hand and The Netherlands on the other. Germany and Sweden show a normal distribution where the most accidents occur in the middle (summer) of the year and less towards the beginning and end (winter). In the Netherlands the number of accidents (seriously injured and fatal) is spread evenly throughout the year. This is probably best explained by a cultural difference, where the people in The Netherlands are using the bicycle during any kind of weather and the people in Germany and Sweden are more likely to use the bicycle when the weather is good. Furthermore, winters in Germany and Sweden are more likely to be colder than in The Netherlands.

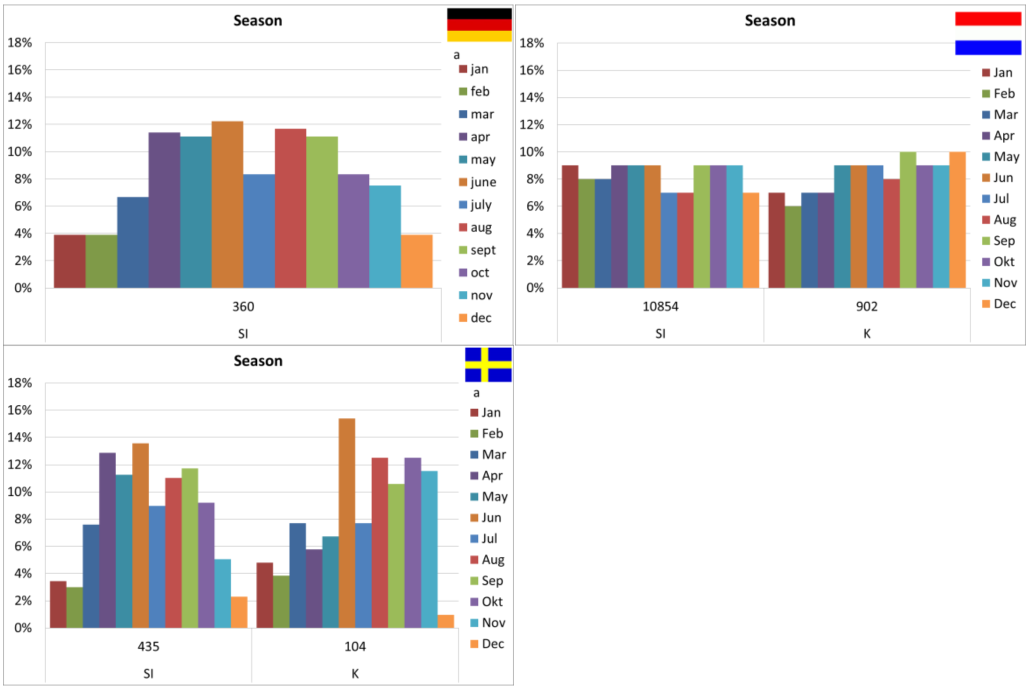


Figure 3-11 Overall overview of cyclist accidents in target population by the month of the year. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.1.7 View blocking obstruction

View blocking obstructions can prevent and delay the detection of the bicycle by the (occupant of the) vehicle prior to the accident. This makes it more difficult for the vehicle to avoid or mitigate the accidents. Figure 3-12 shows an example of such a view blocking obstruction in a crossing scenario.

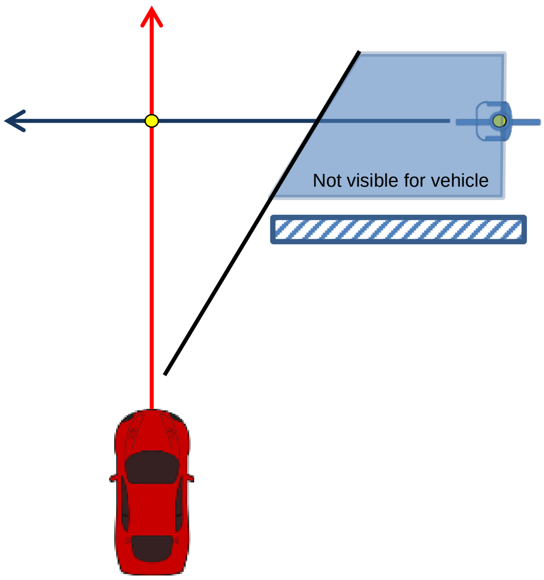


Figure 3-12 schematic example of a view blocking obstruction which prevents early detection of the bicycle by the occupant of the vehicle

Figure 3-13 shows the view blocking obstructions for the vehicle during a cyclist accident for Germany and Sweden (2 data sources are used for seriously injured and fatal accidents). Depending on the data source, the presence of a view blocking obstruction turns up in retrospective driver interview or accident reconstruction where the vehicle was unable to detect the cyclist prior to the accident (no TTC is provided). It shows that in the majority (~65%-80%) of the accidents no obstruction was present in both the seriously injured and fatal accidents. When an obstruction is present, it is most likely a permanent obstruction (building, vegetation, …). When looking at the separate dominant accident scenarios in Figure 3-14, for both Germany and Sweden 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 occurs more often with a view blocking obstruction than C2. 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 bicycle to be visibly blocked by an obstruction. 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. Figure 3-15 shows based on the GIDAS-based PCM the cumulative distribution of the time to collision (TTC) when the front, middle of the vehicle was able to see 50% of the cyclist for accidents in the crossing scenarios with a permanent view blocking obstruction for all MAIS1+ injuries (n=38, C1=31, C2=7) It shows that about 20% of these accidents occur when the vehicle was 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 viewing obstruction have a TTC of about 1.5 seconds when the vehicle is able to see the cyclist.

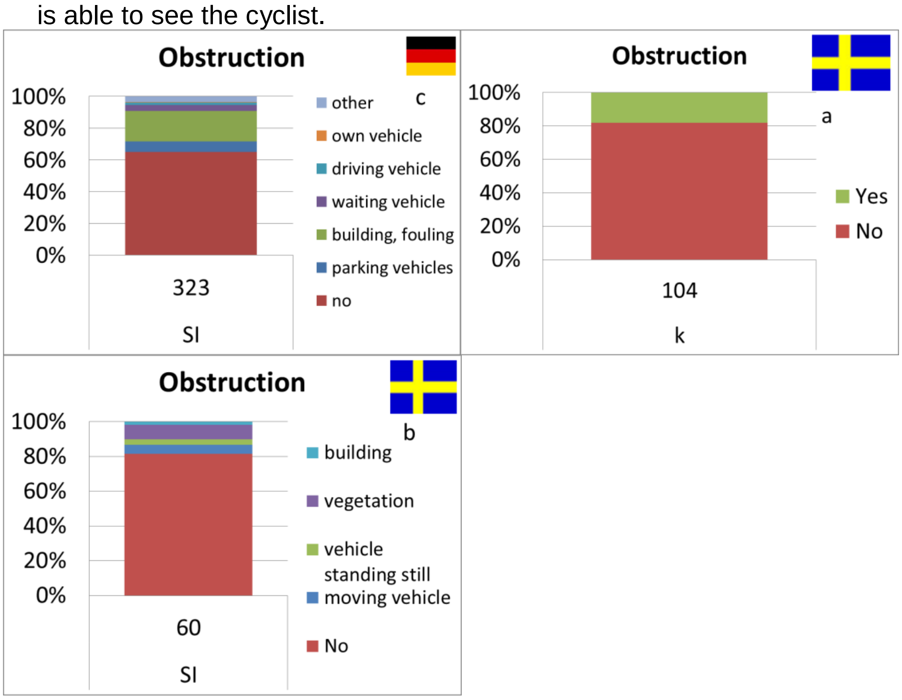


Figure 3-13 Overall overview of cyclist accidents in target population by a view blocking obstruction for the vehicle. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

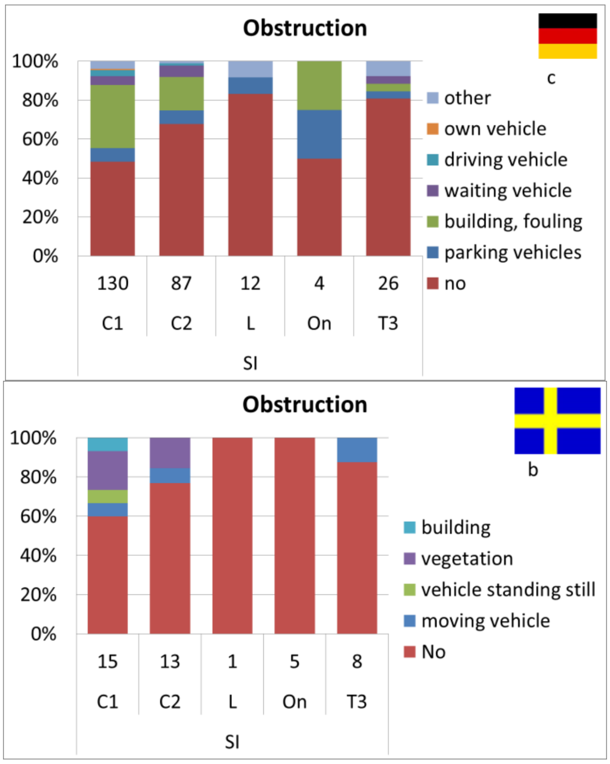


Figure 3-14 In-depth overview of cyclist accidents in target population by a view blocking obstruction for the vehicle. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

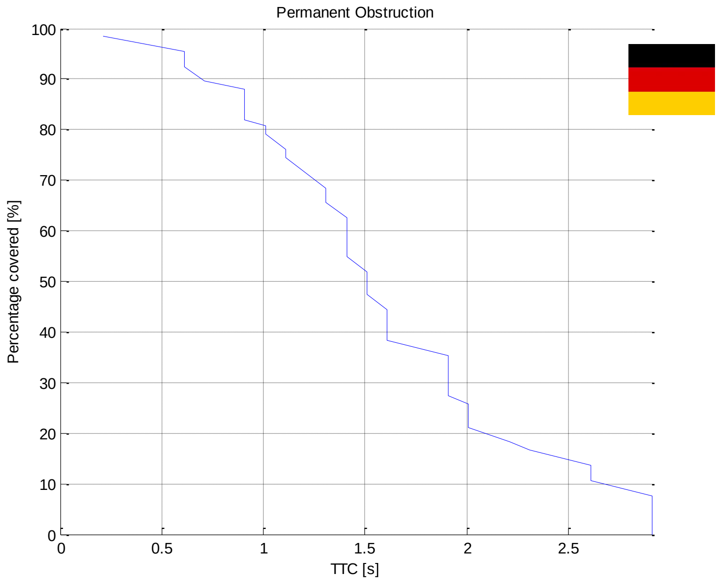


Figure 3-15 cumulative distribution plot for the TTC at which point the middle of the cyclist can be seen by the front, middle of the vehicle for the permanent obstructions in the crossing scenarios for MAIS1+ injuries (n=38,C1=31,C2=7))

3.2 Accident partners

In this paragraph the parameters related to the accident partners are discussed, of which most will function as the preconditions for the construction of the test scenarios in the next chapter. The rest can be used in the construction of the cyclist dummy.

3.2.1 Initial Cyclist and Vehicle Speed

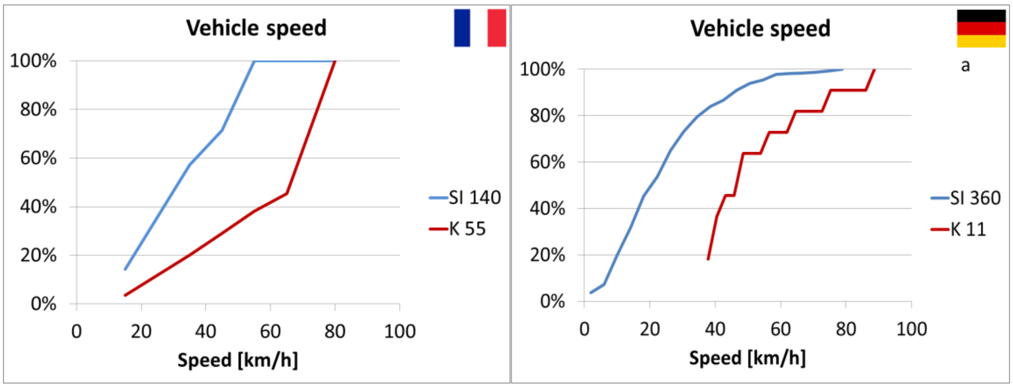
In this section both the initial vehicle speed, the initial cyclist speed and the combination will be presented.

Initial vehicle speed

Figure 3-16 shows the cumulative distribution plots of the vehicle speeds in the seriously injured and fatal accidents for which data are found from France, Germany and Italy. Since this is one of the most relevant parameters for the test scenarios both German data sources, for which this data is available are shown.

Just as for the speed limit described in paragraph 3.1.5, it can be seen that the fatal accidents occur at a higher speed than the seriously injured accidents except for Italy. Furthermore the 2 German and France data sources match well for the seriously injured accidents. The fatal accidents occur at higher initial vehicle speeds in both countries, however the median initial vehicle speed is higher in France. The initial vehicle speed in the fatal accidents for Italy is in line with the 2 German data sources. The initial vehicle speedy in the seriously injured accidents for Italy is different and follows more initial vehicle speed in the fatal accidents. The reason for this is that the portion of longitudinal accidents in the seriously injured accidents, which already occur at a higher speed, is much larger in Italy. Combined with the low number of samples and the unrealistic ratio between the fatal and seriously injured accidents results in a similar initial vehicle speed in the seriously injured and fatal accidents.

Unlike many other parameters, speed will be varied over a certain range. The 50th and 90th percentile vehicle speed of the seriously injured accidents (excluding Italy) is 20-30 km/h and 50-55 km/h respectively. The 50th and 90th percentile speed of the fatal accidents is 50-60 km/h and 70-80 km/h respectively.



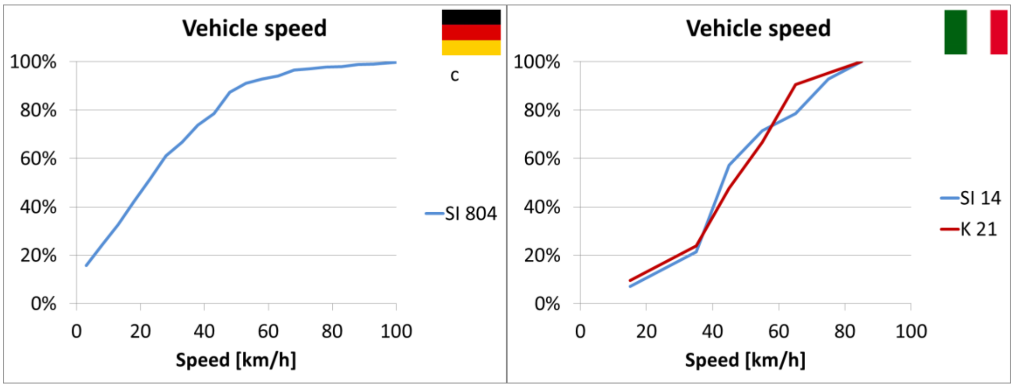


Figure 3-16 Overall overview of cyclist accidents in target population by vehicle speed. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

In Figure 3-17 the cumulative distributions of the initial vehicle speed are shown for the separate dominant accident scenarios for the seriously injured and fatal accidents combined based on the 2 German data sources

Both plots are well aligned for the crossing, longitudinal and T3 scenarios. Both show that in the longitudinal scenario the highest vehicle speeds are found. The T3 scenario shows the lowest speeds. For the On scenario the distributions are not well aligned. This is most likely due to the low number of samples in both data sources for the oncoming scenario. This curve above the 70th percentile is only based on 3 cases. This data is far from converged which results in two distributions that are not aligned. Conclusions should be drawn with care for the vehicle speed in the On scenario.

The 50th and 90th percentile of the initial vehicle speeds of the separate accident scenarios can be found in Table 5.

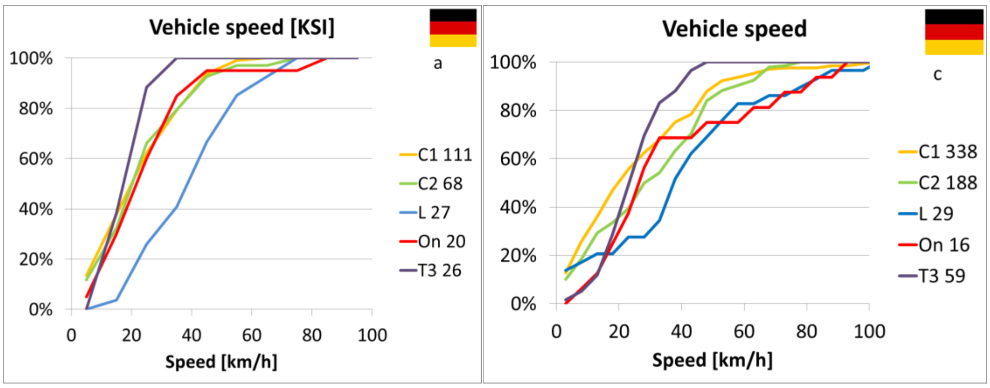
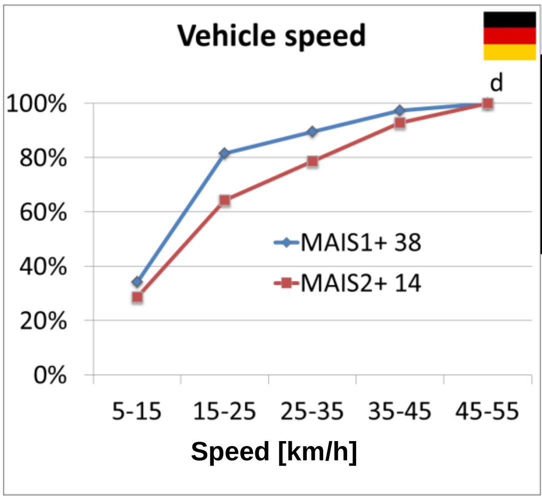


Figure 3-17 In-depth overview of cyclist accidents in target population by vehicle speed, including the number of cases

Table 5. 50th and 90th percentile of the vehicle speed distribution for the separate dominant 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
On	~20-25	~40-80
T3	~20	~25-35

Figure 3-18 shows the joint distribution of the TTC at detection of the cyclist and vehicle speed and the marginal cumulative distribution of the vehicle speed around a permanent view blocking obstruction of the crossing car-to-cyclist accidents described in in 3.1.7 and visualized in Figure 3-15. Firstly, when looking at the marginal distribution of the vehicle speed it can be seen that the vehicle speed is higher for the MAIS2+ cases compared to the MAIS1+ cases. Furthermore, here no vehicle speed is higher than 45-55 km/h and thus substantially lower than the values in Table 5 (50th percentile of ~15 km/h and 90th percentile of ~40 km/h for MAIS2+ cases). Secondly, although the data density is low, there seem to be no indication of a relation between the vehicle speed and the TTC when detection of the cyclist is possible.



TTC [s]	Vehicle speed 5-15	15-25	25-35	35-45	45-55
0.6-0.8	2	1			
0.8-1.0		3		1	1
1.0-1.2		2			
1.2-1.4	1	4			
1.4-1.6	3	3			
1.6-1.8					
1.8-2.0	3		1	1	
>2.0	4	5	2	1	

TTC [s]	Vehicle speed 5-15	15-25	25-35	35-45	45-55
0.6-0.8		3			1
0.8-1.0		1			
1.0-1.2		1			
1.2-1.4	2				
1.4-1.6					
1.6-1.8	2		1	1	
1.8-2.0					
>2.0			1	1	

Figure 3-18 Joint distributions (right) of the vehicle speed (km/h) and the TTC at which the cyclist is visible and the marginal distribution (left) of vehicle speed in permanent view blocking obstruction accidents of the data presented in Figure 3-15 including the MAIS2+ accidents.

Initial cyclist speed

Figure 3-19 shows the cumulative distributions of the initial cyclist speeds for France (only shows the cyclist speed for the fatal accidents, since the speed for the seriously injured accidents was not accurate enough), Germany (again both data sources) and Italy. All curves match well between the different data sources. In all sources a similar distribution of the cyclist speed is found. The cyclist speed does not seem to have an influence on the severity of the accident.

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.

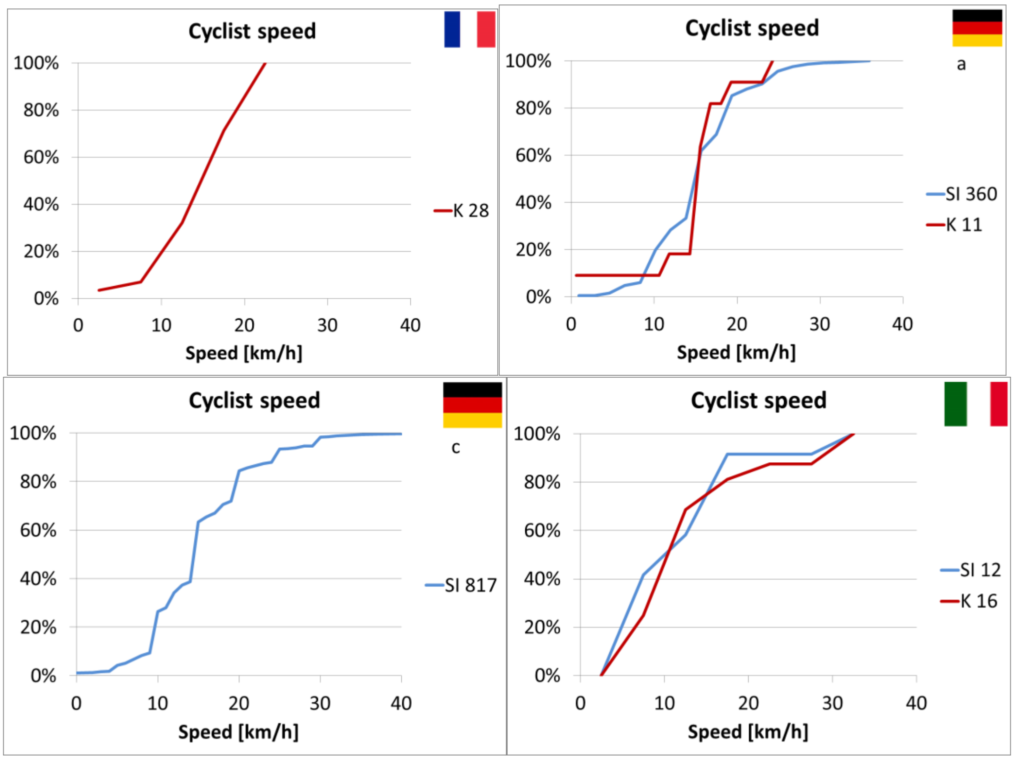


Figure 3-19 Overall overview of cyclist accidents in target population by cyclist speed. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

In Figure 3-20 the cumulative distributions are shown for the separate dominant accident scenarios for the seriously injured and fatal accidents in the 2 German data sources combined. It can be seen that there is no discrimination of the cyclist speed between the separate accident scenarios and all show more or less the same distribution. Only the oncoming scenario in the second German data source could be regarded as different. However that conclusion is only based on a low number of samples in this group.

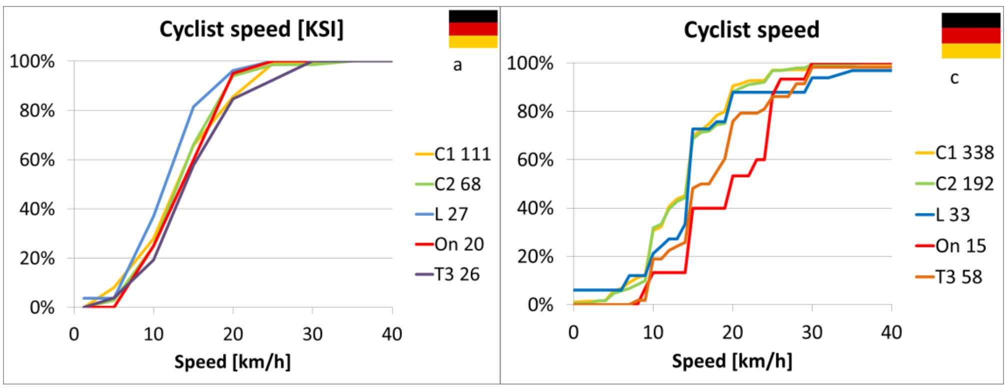
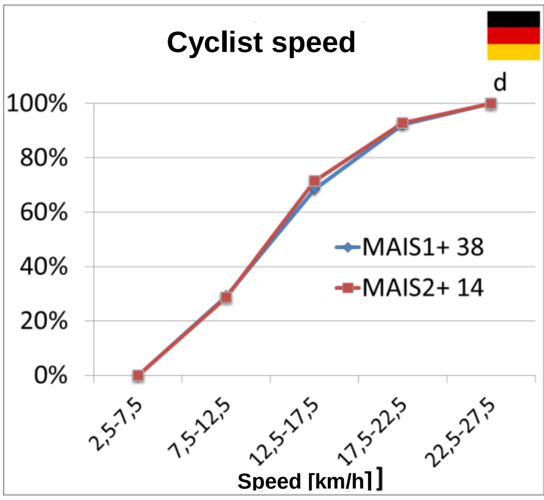


Figure 3-20 In-depth overview of cyclist accidents in target population by cyclist speed. Including the number of cases

Figure 3-21 shows the joint distribution of the TTC at detection of the cyclist and cyclist speed and the marginal cumulative distribution of the cyclist speed around a permanent view blocking obstruction of the crossing car-to-cyclist accidents described in in 3.1.7 and visualized in Figure 3-15. Firstly, when looking at the marginal distribution of the cyclist speed it can be seen that the cyclist speed is similar for the MAIS2+ cases compared to the MAIS1+ cases. Furthermore the distribution is similar to the cyclist speed distribution were all crossing MAIS2+ accidents are included (50th percentile of ~13-14 km/h, 90th percentile of ~20 km/h). Secondly, although the data density is low, there seem to be no indication of a relation between the cyclist speed and the TTC when detection of the cyclist is possible.



TTC [s]	Cyclist speed 2.5-7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5
0.6-0.8		1		2	
0.8-1.0		1	4		
1.0-1.2			1		1
1.2-1.4		1	3	1	
1.4-1.6		2	1	3	
1.6-1.8					
1.8-2.0		3		1	1
>2.0		3	6	2	1

TTC [s]	Cyclist speed 2,5-7,5	7,5-12,5	12,5-17,5	17,5-22,5	22,5-27,5
0.6-0.8					
0.8-1.0		1	3		
1.0-1.2			1		
1.2-1.4				1	
1.4-1.6			1	1	
1.6-1.8					
1.8-2.0		2		1	1
>2.0		1	1		

Figure 3-21 Joint distributions (right) of the cyclist speed (km/h) and the TTC at which the cyclist is visible and the marginal distribution (left) of the cyclist speed in permanent view blocking obstruction accidents of the data presented in Figure 3-15 including the MAIS2+ accidents.

Combined Initial vehicle and cyclist speeds

In this section it is checked if there exists a correlation of the initial vehicle speed and initial cyclist speed. Figure 3-22 show the joint distribution tables of the initial vehicle and cyclist speed for the Germany. It can be seen that for the 2 crossing, On and T3 scenarios no dependency exist between the vehicle and cyclist speed. In the longitudinal scenario a dependency seems to exist where the initial cyclist speed increases with the initial 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 number of samples, and it should be noted that no accidents can occur above the red line (in the figure below: when the cyclist speed is larger than the vehicle speed there can be no impact).

Joint speed distribution (vehcile and cyclist) — C1 KSI 111 — a

Vehicle speed \ Cyclist speed	1,25	5	10	15	20	25	30	35	40
5	0	2	2	3	5	3	0	0	0
15	0	2	5	11	5	3	0	1	0
25	0	0	6	10	7	4	0	0	0
35	0	2	5	7	3	2	0	0	0
45	0	1	3	8	1	3	0	0	0
55	0	2	1	2	1	0	0	0	0
65	0	0	0	1	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0

Joint speed distribution (vehcile and cyclist) — C2 KSI 68 — a

Vehicle speed \ Cyclist speed	1,25	5	10	15	20	25	30	35	40
5	0	0	0	4	2	1	0	1	0
15	0	0	3	7	3	1	0	0	0
25	0	0	9	3	11	0	0	0	0
35	0	0	2	6	1	0	0	0	0
45	0	0	0	6	2	1	0	0	0
55	0	2	0	1	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0
75	0	0	1	1	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0

Joint speed distribution (vehcile and cyclist) — L KSI 27 — a

Vehicle speed \ Cyclist speed	1,25	5	10	15	20	25	30	35	40
5	0	0	0	0	0	0	0	0	0
15	0	0	0	1	0	0	0	0	0
25	0	0	5	1	0	0	0	0	0
35	0	0	0	4	0	0	0	0	0
45	1	0	2	3	1	0	0	0	0
55	0	0	1	3	0	1	0	0	0
65	0	0	1	0	1	0	0	0	0
75	0	0	0	0	2	0	0	0	0
85	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0

Joint speed distribution (vehcile and cyclist) — On KSI 20 — a

Vehicle speed \ Cyclist speed	1,25	5	10	15	20	25	30	35	40
5	0	0	0	0	0	1	0	0	0
15	0	0	2	1	2	0	0	0	0
25	0	0	0	4	2	0	0	0	0
35	0	0	1	2	2	0	0	0	0
45	0	0	1	0	1	0	0	0	0
55	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0
85	0	0	1	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0

Joint speed distribution (vehcile and cyclist) — T3 KSI 26 — a

Vehicle speed \ Cyclist speed	1,25	5	10	15	20	25	30	35	40
5	0	0	0	0	0	0	0	0	0
15	0	0	2	6	1	0	1	0	0
25	0	1	1	3	6	1	1	0	0
35	0	0	1	1	0	1	0	0	0
45	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0

Figure 3-22 Overview per accident scenario of cyclist accidents in target population by the joint distribution of the vehicle and cyclist speed.

3.2.2 *Vehicle braking*

In Figure 3-23 the vehicle braking behaviour is shown for all the separated dominant accident scenarios in Germany. It can be seen that the vehicle is performing an emergency braking action (>7m/s²) in about 20% of the cases in the crossing and longitudinal scenarios and in 40% and 10% in the oncoming and T3 scenario respectively. No braking action to a low braking action (<4m/s²) is found to be the majority (~60%-70%) in all accident scenarios expected oncoming where in the majority (~60%) of the case there was at least a moderate braking action (> 4m/s²).

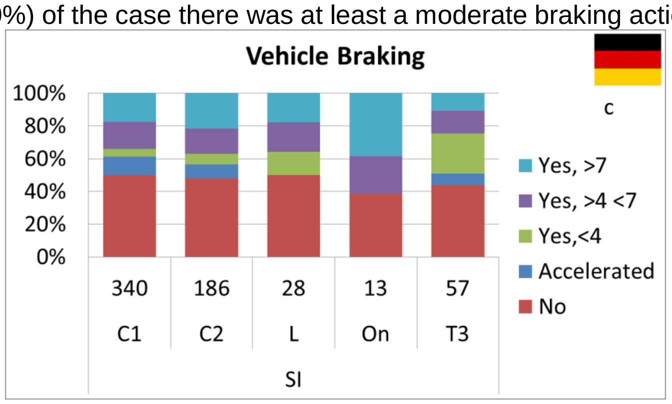


Figure 3-23 In-depth overview of cyclist accidents in target population by vehicle braking, separated in seriously injured (SI) and fatal (K) where possible including the number of cases. Values are in m/s²

3.2.3 *Collision point*

The definition of collision point can be found in appendix A. In that definition the location of the impact on the cyclist is included, which allows the collision point to be lower than 0% and higher than 100%. In Figure 3-24 where the collision points for the crossing and longitudinal accident scenario can be found, the impact location on the cyclist is not included and only based on the width of the vehicle.

For the crossing scenarios it can be seen that it is most likely that the cyclist is impacted at the middle of the car in the seriously injured/fatal accidents. It can also be seen that the lower percentage collision points are substantially more likely than the higher percentage collision points. Both the seriously injured/fatal accidents and lower injury severity accidents with more cases show a similar distribution.

For the longitudinal scenario it shows that the bicycle is more likely to be impacted by the near side of the vehicle. This is the side of the road where the bicycles are riding. 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. However, as can be seen in Figure 3-24, if the bicycle is impacted less than 20%, the chance of the cyclist being seriously injured or killed becomes lower. A likely reason for this could be that in this case all the energy of the impact is not transferred to the cyclist anymore.

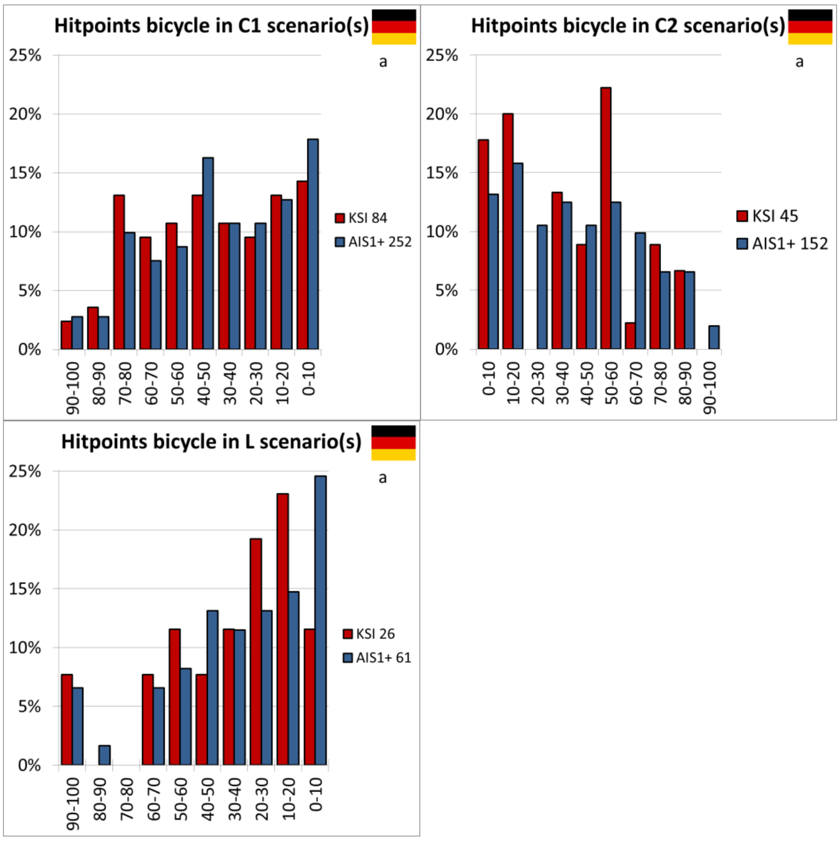


Figure 3-24 Overall overview of cyclist accidents in target population by collision point for the crossing and longitudinal accident scenarios for both the low severity injuries (MAIS1+) and the seriously injured/fatal (KSI) accidents including the number of cases

3.2.4 Cyclist gender

As can be seen in Figure 3-25, for Germany, The Netherlands and Sweden the distribution between male and female cyclists in seriously injured accidents is almost evenly distributed, where a slightly higher portion of males are present (~50%-60%). For both The Netherlands and Sweden it can be seen that in the fatal accident the male portion is slightly higher (~65%-70%) when compared to the seriously injured accidents.

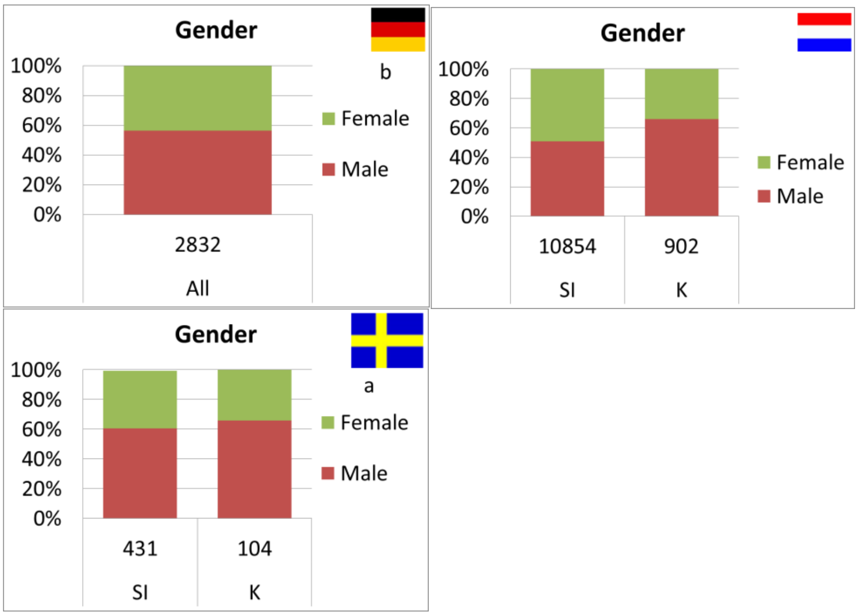


Figure 3-25 Overall overview of cyclist accidents in target population by cyclist gender. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.2.5 Cyclist Age

Figure 3-26 shows the distribution of the cyclist age in Germany, The Netherlands, Sweden and the United Kingdom. The first thing that can be noticed is that in the fatal accidents the cyclist age is higher. It is unlikely that older people are more involved in rural, low lighting and other increased parameters fatal accidents (perhaps even less). Thus this can most likely be explained by the fact that older people are more likely to be killed in a similar accident than younger people due to being more fragile. In the seriously injured accidents the cyclist age is further mostly evenly distributed.

In Figure 3-27 the cyclist age can be seen for each of the separate accident scenarios. From that figure it can be seen that the raised cyclist age in the fatal accidents mostly originates from the crossing scenarios since the other accident scenarios do not show that substantial increase. The portion of 70+ cyclist age is not different in the seriously injured and fatal accidents (~20%) in the longitudinal scenario.

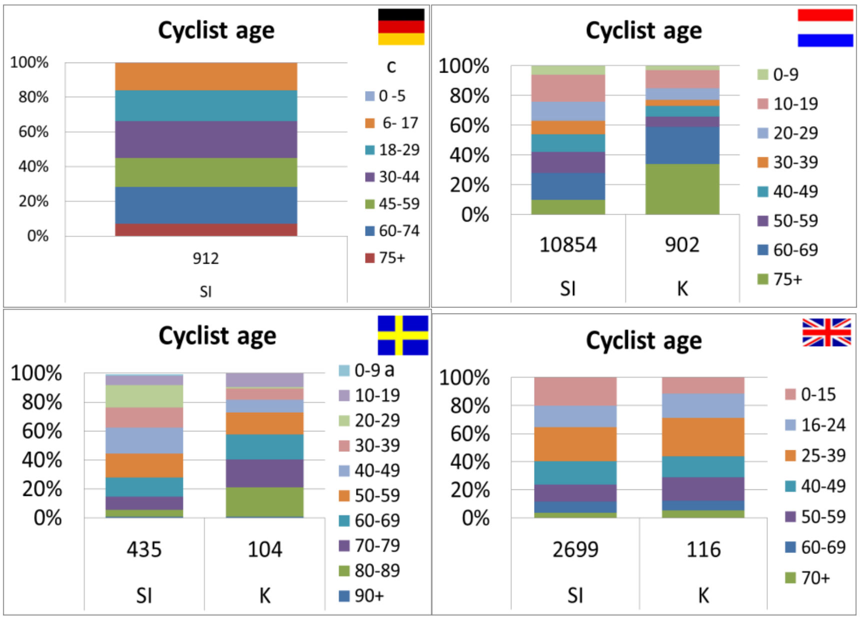


Figure 3-26 Overall overview of cyclist accidents in target population by cyclist age. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

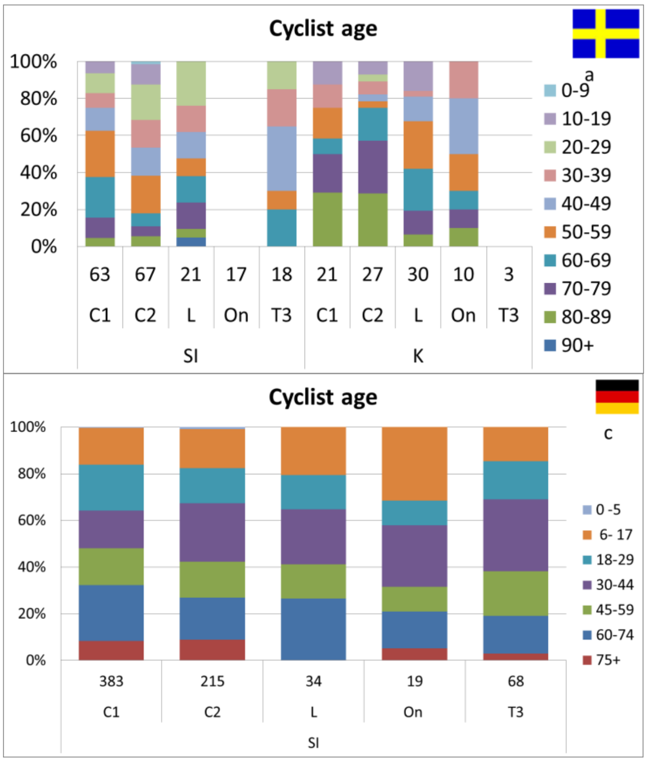


Figure 3-27 In-depth overview of cyclist accidents in target population by cyclist age for the vehicle. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

3.2.6 Cyclist height

In Figure 3-28 the cumulative distribution of the cyclist height can be seen in the seriously injured accidents in Germany. The figure shows that only about 5% of the cyclist is below a height of 150cm. The median (50th percentile) part of the curve is around 170cm. The mode (height with the largest frequency, steepest part of the curve) is around 175cm.

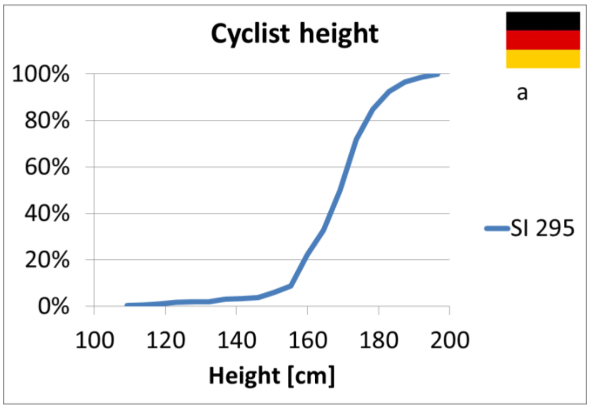


Figure 3-28 Overall overview of cyclist accidents in target population by cyclist height including the number of cases

3.2.7 Helmet use

The overall helmet use in the cyclist accidents is shown in Figure 3-29 for Germany, Sweden and the United Kingdom. It can be seen that in the majority of the accidents no helmet is worm by the cyclist in both the seriously injured (~70%-90%) and fatal accidents (~90%). The smaller portion of helmet use in the fatal accidents in Sweden compared to the seriously injured accident can be seen as an indication that helmet use does lower injury risk.

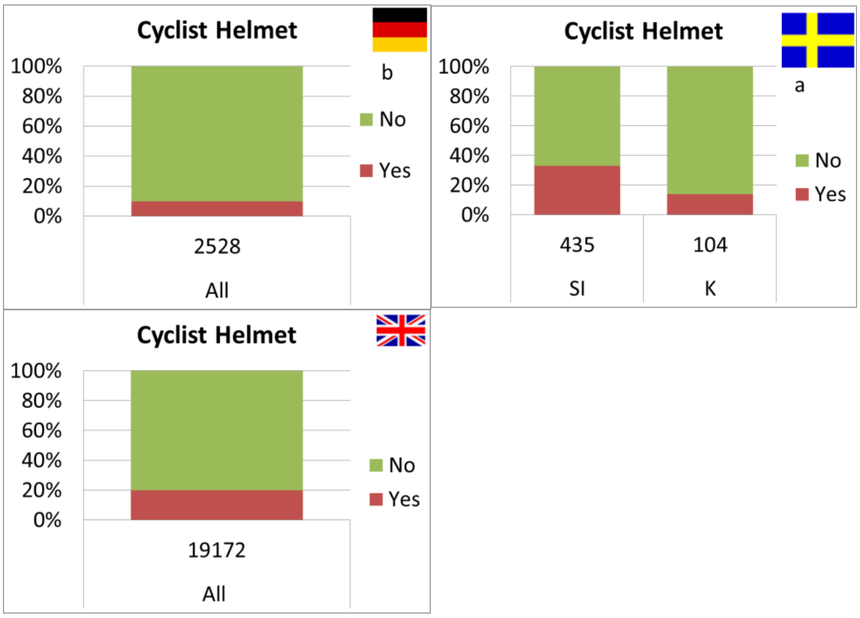
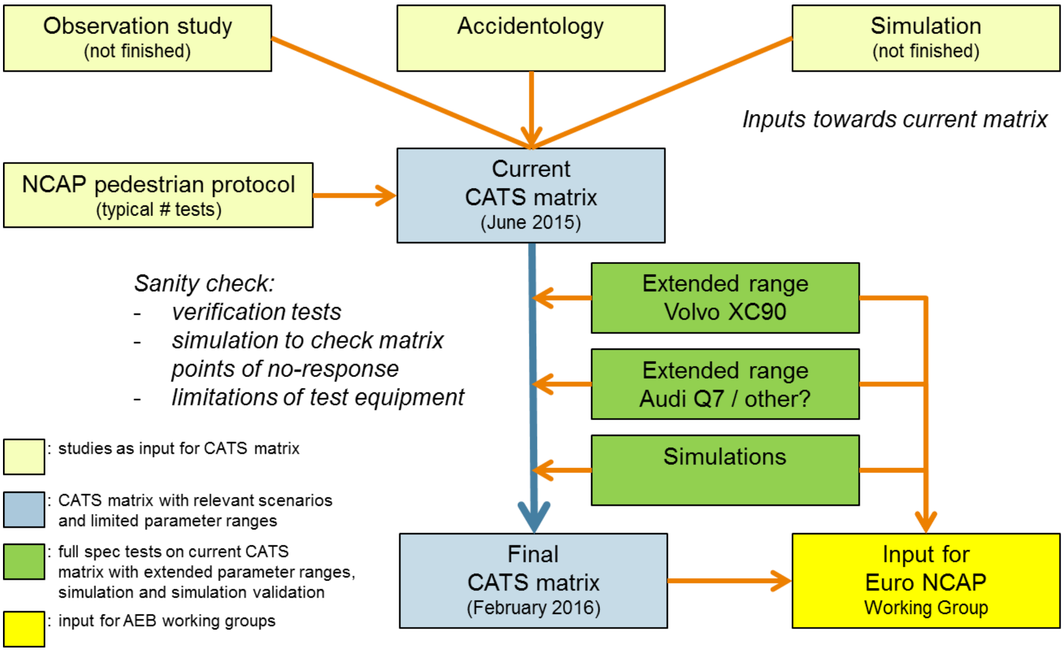


Figure 3-29 Overall overview of cyclist accidents in target population by cyclist helmet use. Separated in seriously injured (SI) and fatal (K) where possible including the number of cases

4 CATS test matrix (DRAFT June 2015)

In this chapter, the preliminary test scenarios are deduced from the accident scenarios and the accident parameters. The approach according to the scheme below is used:



Information from the simulation study and the observation study (both reported in separate documents) is included as input into the CATS scenario matrix. This DRAFT version will be used as a basis for the verification tests, e.g. with the new Volvo XC90. Moreover, the Euro NCAP AEB VRU Test Protocol v1.0.1 is used to match the CATS proposal to, especially regarding to the typical number of tests that are expected.
As is seen from the scheme above, the results of the verification tests and further simulations are used to further fine-tune the matrix into a final version of the cyclist-AEB test protocol (expected for February 2016).

The philosophy, conditions and construction of the test scenarios will follow as much as possible the current version of the Euro NCAP AEB VRU Test Protocol v1.0.1 [16]. Also the recommendations of the AsPeCSS deliverable for cyclist AEB test scenarios [13] will be used to provide additional information. At this point in time (June 2015) the suggested test scenarios are to be used as an input in WP5 where verification tests are to be performed. This will provide an indication of the feasibility and the effectiveness of the suggested test scenarios. Furthermore the suggested test scenarios will be evaluated using a simulation tool developed by the BASt [27].

So far, CATS will focus at the 3 dominant accident scenarios (C1, C2 and L) for which in the end a complete test scenario will be proposed. These scenarios cover 63% and 78% of the seriously injured and fatal car-to-cyclist accidents for the investigated countries, respectively. For the On and T3 scenario, no detailed scenario description will be proposed so far. First tests will be performed for C1, C2 and L; at the end of CATS (Q1 2016), it will be discussed how to deal with On and

T3 when after gaining experience in tests with the developed setup. Moreover, C1, C2 and L already cover a large fraction of all seriously injured and fatal accidents. It should be discussed how sensible it is to extend the protocol with tests for the On and T3 scenario.

The bicycle and cyclist dummy are developed in WP3 and WP4 of the CATS project. These separate deliverables will not be discussed with the test scenarios in this chapter. The relevant results from the study in WP1 and WP2 will be used as input for the dummy and propulsion setup in WP3 and WP4.

First boundary conditions to the tests will be presented. Thereafter, the development test scenarios for each selected accident scenario will be described. Finally a test matrix will be proposed covering the C1, C2 and L accident scenarios.

4.1 Boundary conditions

The environmental parameters will be identical for all test scenarios. As shown in paragraph 3.1, the vast majority of the bicycle accidents occur with good weather regardless of accident scenario. Therefore, no configuration is suggested for the test scenarios which would cover precipitation. When looking at the lighting condition, the majority (scenario dependent 65-90%) occurs during daytime or good lighting conditions. Therefore it is suggested for now to continue with daylight lighting conditions.

To ensure a repeatable and robust test method, the following boundary conditions should be met before and during testing just as described in Euro NCAP AEB VRU Test Protocol v1.0.[16]:

- Test start (TTC of 4s).
  - This ensures that there exists an equilibrium well before any systems should be activated, identical as in Euro NCAP AEB VRU Test Protocol v1.0.1 [16] (crossing) and Euro NCAP AEB Test Protocol v1.1 [17] (longitudinal).Euro NCAP AEB VRU Test Protocol v1.0.1.
- Bicycle should have constant speed when in field of view vehicle.
  - This is not possible for the longitudinal scenario, and thus assumed that the accelerating phase is far away enough to not interfere with the test scenario
- The test ends when one of the following criteria is met:
  - Speed of vehicle is 0 km/h
  - Contact between vehicle and any part of bicycle and /or cyclist dummy
  - Complete bicycle dummy has left vehicle path (due to braking)

4.2 Scenario C1: crossing cyclist from nearside

For the C1 crossing scenario it is suggested to specify an unobstructed well as a view obstructed test scenario:

CVNBU: Car-to-VRU Nearside Bicyclist Unobstructed. A collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the nearside and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.

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

In summary the schematic overview of the two C1 test scenarios can be seen in Figure 4-1. Each of the test parameters will be discussed below.

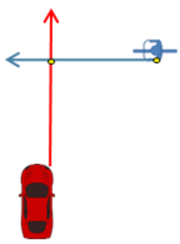
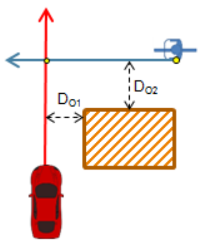
DRAFT JUNE 2015	CVNBU		CVNBO	
Vehicle speed	20 – 60 km/h	Δv = 5 km/h, similar to pedestrian protocol	10 – 40 km/h	Δv = 5 km/h, similar to pedestrian protocol
Cyclist speed	15 km/h	~50-percentile	10 km/h	Input from observation study
Obstruction	Without	50 – 60% of C1 accidents happen without view blocking obstruction	With D_{O1}=3.55m D_{O2}=4.80m	40 – 50% of C1 is at an obstruction. Dimensions taken from typical layout in Netherlands.
Overlap hitpoint	0 %	Slightly more collisions to near side front	50 %	Mid car – mid bicyclist
AEB / FCW	AEB		AEB	
# tests	9		7	
Layout sketch				

Figure 4-1 Schematic overview of the CNVBU and CVNBO test scenario

4.2.1 Vehicle speed

The first relevant parameter for any test scenario is the speed range of the vehicle. For the unobstructed scenario (CVNBU), it is suggested to start with a vehicle range of 20 km/h to 60 km/h with incremental steps of 5 km/h. From Table 5 and Figure 3-17 it can be found that this covers a range of about 45%-95% of all vehicle speeds in this accident scenario. This is a similar coverage that has been proposed for the pedestrian accidents in the AsPeCSS project [13] [18]. Furthermore this speed range aligns perfectly with what has been selected for the Euro NCAP AEB VRU Test Protocol v1.0.1 [16].

4.2.2 Cyclist speed

For the cyclist speed, a single characteristic speed is suggested of 15 km/h. As can be seen in Figure 3-20 this is about equal to the 50[th] percentile for both the seriously injured and fatal accidents in the C1 scenario. Higher cyclist speeds are suggested to be tested in the test scenario for C2 described in the next paragraph.

4.2.3 Collision point

As can be seen from Figure 3-24 a 50% collision point (assumed middle car/middle bicycle) can be taken as a nominal value in both the C1 and C2 crossing accident scenarios. From the same figure it becomes clear that the collision on the vehicle front tends more to take place at the side where the bicycle approaches from. The 0

– 20% region shows even higher percentages for occurrence than the 40 – 60% region.

It is therefore proposed to use a collision point of 0% in the unobstructed C1 case: CVNBU. For the obstructed case CVNBO, the nominal value of 50% is proposed for the collision point. For the C2 scenario, also a collision point of 50% will be proposed. Then a good variety of the collision point over the different tests dealing with crossing scenarios is achieved.

4.2.4 View blocking obstruction

From Figure 3-14 it is clear that in the crossing scenarios a substantial portion of the accidents occur when a view blocking obstruction is present. In the crossing scenarios it is the C1 accident scenario that occurs most often with an obstructed view (40%-50%) where the majority is a full permanent obstruction. It is therefore proposed to also include a view blocking obstruction in this test scenario. Tests without this view blocking obstruction are proposed as a reference case. Based on Figure 3-18, it is suggested to have a maximum vehicle speed of 40 km/h instead of 60 km/h and a minimum speed of 10 km/h instead of 20 km/h in the obstructed test scenario. Figure 3-21 does not show that the cyclist speed is influenced by a permanent view obstruction.

Figure 3-15 shows that when a permanent view blocking obstruction is present the vehicle is most likely able to detect the cyclist 1.5s prior to the impact (where the slope is steepest) (mid front vehicle to middle bicycle). To have a high coverage of the accidents with a permanent view blocking obstruction, it is preferred to have a TTC at detection range in the test scenario around this 1.5s. It is suggested to use this TTC in combination with the 50th percentile cyclist speed of 15 km/h as found in accidentology to compute the optimal location of the view blocking obstruction.

Furthermore, for practical reasons it is suggested to use one location of the view blocking obstruction for all vehicle speeds in the test scenario. This does mean that the TTC for detection of the cyclist will be larger for lower vehicle speeds and smaller for higher vehicle speeds (as explained in appendix B), where from accidentology no link is visible between TTC at detection of the cyclist and the vehicle speed.

To define a representative location for the view blocking obstruction, with keeping in mind the desired TTC for cyclist detection, a characteristic approach is chosen. In the table below Dutch guidelines for the width of road layout designs can be found [19][20][21][22].

Table 6. Dutch guidelines for the width of road layout designs

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

For the test scenario a vehicle lane with a pedestrian path is selected next to the vehicle path. The cyclist will be in a cycling lane or one way street next to a pedestrian sidewalk. This scenario is shown in Figure 4-2 where D_{O1} and D_{O2} represent the location of the obstruction with respect to the impact point and vehicle and bicycle path respectively. For the two way road a width of 7.0m is chosen since the vehicle does have to be able to drive 40 km/h comfortably. Also for the pedestrian sidewalk and bicycle lane the maximum design dimension is chosen. This leads to the following distances to define the location of the view blocking obstruction:

- D_{O1} = 3.55m
- D_{O2} = 4.80m

Figure 4-3 shows an example of such a situation and accident scenario in The Netherlands. This crossing at Noordeinde – Rapenburg in Leiden has the view blocking obstruction at 3.3m and 3.6m for D_{O1} and D_{O2} respectively. The maximum speed at the crossing is 30 km/h. These parameters are comparable to the scenario derived above (D_{O2} is somewhat smaller in the example). This crossing experienced 7 vehicle to car accidents from 2008-2012 resulting in 3 hospitalized cyclists, showing that this test scenario is relevant for real life cases [23].Note that at this crossing, the car has priority over the cyclist. The presence of a zebra pedestrian crossing might be confusing for car drivers regarding priorities for vulnerable road users.

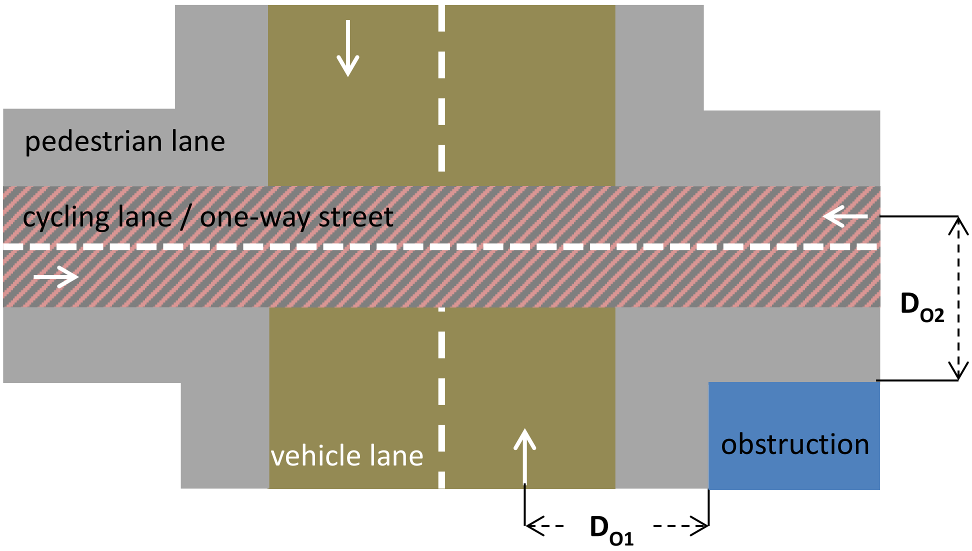


Figure 4-2 characteristic scenario for permanent view blocking obstruction

Accidents 2008-2012	7
Injured / only material damage	3 / 4
D_{O1}	3,3 m
D_{O2}	3,6 m

Figure 4-3 example of a characteristic city obstruction scenario (low speed). Noordeinde – Rapenburg (Leiden, The Netherlands). The red arrow indicates the path of the vehicle and the blue arrow indicates the path of the bicycle

As shown in Appendix B, the TTC at the moment of possible detection (mid front vehicle to middle bicycle) can be computed when the location of the view blocking obstruction, the speed of the bicycle and the speed range of the vehicle is known. Figure 4-4 shows the TTC at possible detection (mid front vehicle to middle bicycle against the vehicle speed. It can be seen that it ranges from 2.58s at 10 km/h to 1.28 at 40 km/h for the cyclist speed of 15 km/h. Based on Figure 3-15, this corresponds to a coverage of about 58% (10% to 68%).

An observation study [26] investigating the effect of a view blocking obstructing on the cyclist and vehicle speed show a substantial decrease of the cyclist speed in approaching the obstruction. Based on these observations, considering the fact that the number of cases for accidentology in Figure 3-21 is limited, it is proposed to use a cyclist speed of 10 km/h. Despite the fact that a speed of 10 km/h for a cyclist makes the speed rather similar to high pedestrian speeds, it is expected to be a representative speed for a cyclist approaching a crossing with bad or no view on the crossing traffic. The results of the final observation study are used to fine tune the cyclist speed for CVNBO when necessary.

The additional advantage is, that with a cyclist speed of 20 km/h in the C2 scenario, a good variety of cyclist speeds is found in the different tests. When changing the cyclist speed to 10 km/h the TTC at possible detection changes to 3.01 at 10 km/h to 1.71s at 40 km/h as can be seen in Figure 4-4. Even though this will not cover the same range as for a cyclist speed of 15 km/h, it is for this moment not proposed to change the location, but to use it as a starting point for the test series planned in WP5 to check feasibility.

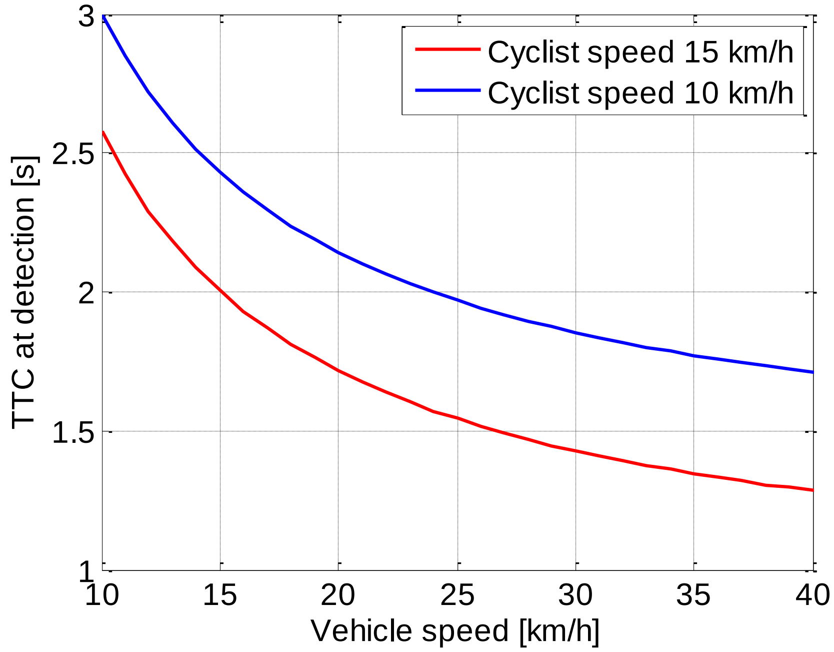


Figure 4-4 TTC at detection against vehicle speed for characteristic city obstruction scenario (lower speed), for two cyclist speeds.

4.3 Scenario C2: crossing cyclist from far side

For the C2 crossing test scenario it is suggested to develop it as a test scenario to evaluate vehicle viewing angles for cyclist detection, by varying mostly the cyclist speed. Also the collision point could be varied, but this has already been included in the CVNBU test (C1 unobstructed scenario that is rather similar to a C2 scenario). For the C2 scenario, currently only one configuration of cyclist speed and collision point is being proposed:

CVFB: Car-to-VRU Farside Bicyclist. 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 50% of the vehicle's width when no braking action is applied.

A schematic overview of the C2 scenario is given in Figure 4-5, including the proposed ranges for its parameters. Each parameter will be discussed below.

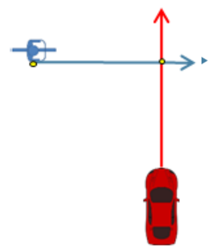
DRAFT JUNE 2015	CVFB	
Vehicle speed	20 – 60 km/h	Δv = 5 km/h, similar to pedestrian protocol
Cyclist speed	20 km/h	~90-percentile
Obstruction	Without	Most C2 accidents happen without view blocking obstruction
Overlap hitpoint	50 %	Nominal collision point
AEB / FCW	AEB	
# tests	9	
Layout sketch		

Figure 4-5 schematic overview of the CVFB test scenario

4.3.1 Vehicle speed

Table 5 and Figure 3-17 show that the initial vehicle speed distribution difference between the C1 and C2 accident scenarios is negligible. It is thus proposed to test the C2 (CVFB) scenario with the same speed range and incremental steps as for the unobstructed C1 test scenario (CVNBU), being 20 km/h to 60 km/h with 5 km/h incremental steps.

4.3.2 Cyclist speed

The C1 test scenario is mostly designed for a standard and obstructed situation with the 50th percentile cyclist speed of 15 km/h for the unobstructed case, and 10 km/h for the obstructed case. By increasing the cyclist speed, the vehicle needs to have a wider view (larger view angle). It is therefore suggested to test the unobstructed crossing scenario both with a cyclist speed of 15 km/h (50th-percentile) and 20 km/h (90th-percentile). The 15 km/h cyclist speed is already used for the unobstructed C1 case. Consequently, it is proposed to run the CVFB test with a cyclist speed of 20 km/h.

4.3.3 Collision point

As can be seen in Figure 3-24 a 50% (assumed middle car/middle bicycle) collision point is most common in both crossing accident scenarios. It was also seen that lower percentage collision points are also common in the crossing scenarios. Tests with a lower percentage collision point increase the needed vehicle viewing angle for bicycle detection. As a 0% collision point is proposed for the unobstructed C1 scenario (CVNBU), it is suggested to implement a 50% collision point for the unobstructed C2 scenario (CVFB).

4.4 Scenario L: Car and cyclist driving in the same direction

The longitudinal scenario in which a bicycle driving in the same direction as the car approaching the bicycle from the rear occurs frequently in urban and inter-urban areas. Two speed ranges, one covering a typical urban and one a typical inter-urban accident scenario are being proposed.

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

The schematic overview of the CVLB test scenario is given in Figure 4-6, with the proposed parameter ranges:

DRAFT JUNE 2015	CVLB*			
Vehicle speed	30 – 60 km/h	Δv = 5 km/h, similar to pedestrian protocol	65 - 80 km/h	Δv = 5 km/h, similar to pedestrian protocol
Cyclist speed	15 km/h	~50-percentile	20 km/h	Higher bicycle speed in inter-urban areas is more common.
Obstruction	Without		Without	
Overlap hitpoint	50%	Mid car – bicyclist	20%	More collisions to near side front of car.
AEB / FCW	AEB	Urban areas, with relatively low vehicle speeds.	FCW	Inter-urban areas having a higher vehicle speed regime. No AEB.
# tests	7		4	
Layout sketch				

Figure 4-6 schematic overview of the CVLB test scenario

4.4.1 Vehicle speed

As can be seen in Table 5 and Figure 3-17 the average vehicle speed is higher in the longitudinal scenario than in the other accident scenarios. Two speed ranges for 2 essentially different tests are suggested: a low vehicle speed test scenario (30 to 60 km/h) for FCW and AEB for L-scenarios in urban areas and a high vehicle speed range to assess FCW (no braking) for L-scenarios in rural areas. As a warning is expected to be much more effective on inter-urban roads than AEB for typical L scenarios, no AEB is tested for a speed range between 60 and 80 km/h. In the CVLB-scenario, both the vehicle and bicycle travel in the same direction. To keep the test scenario representative for seriously injured and fatal accidents, a lower boundary speed of 30 km/h for the vehicle speed range is proposed. The 30 – 80 km/h vehicle speed range covers about 60% (30^{th}- to 90^{th} percentile) of the seriously injured and fatal accidents. Here also an incremental step of 5 km/h is proposed, as to not deviate from previous scenarios.

4.4.2 Cyclist speed

From Figure 3-22 it can be seen that the cyclist speed is higher for higher vehicle speeds. It is therefore suggested to select a the cyclist speed of 15 km/h (50^{th} percentile) for the lower vehicle speeds up to 60 km/h and a cyclist speed of 20 km/h (90^{th} percentile) for the higher vehicle speeds. This is in agreement with the expectation that bicycles in inter-urban areas on average ride faster than bicycles in the urban areas.

4.4.3 Collision point

As can be seen in Figure 3-24, the collision point for the bicycle on the vehicle is distributed over the width of the vehicle where the median is to the near side. Since most of the seriously injured and fatal accidents occur with a collision point of 20% and because the severity of the accidents seems to go down with smaller collision points (towards 0%, Figure 3-24), a collision point of 20% is suggested to be used in the CVLB test scenario as the upper boundary. For the lower speed range, a collision point of 50% is suggested as a characteristic value. This collision point range covers over 60% of the seriously injured and fatal accidents (30^{th}- to 90^{th} percentile). In this choice, it is assumed that lower percentage collision point cases occur more in inter-urban environments with higher vehicle speeds, and higher speed differences between vehicles and bicycles, resulting in more severe injuries. Higher percentage collision point cases (50%) are assumed to occur more often in urban environments with lower vehicle speeds.

4.5 **Test start**

For all test scenarios, a test start at TTC= 4 sec. is selected, identical to the current Euro NCAP AEB VRU Test Protocol v1.0.1 [16]. In general this implies that conditions from TTC=4 sec. until the end of the test (either the moment of contact between car and cyclist dummy, or time at which the collision is avoided) are kept constant. Practically, it means that a reproducible initial state is taken as a starting point for the test in which both the bicycle and the car have come to a constant speed.

For the crossing scenarios without obstruction (CVNBU, CVFB), this implies that the cyclist dummy will accelerate up to the test speed behind an obstruction, and that the cyclist dummy will appear from behind the obstruction at TTC = 4 sec, i.e. the centre of the bicycle will appear from behind the obstruction at TTC = 4 sec. This means that the vehicle needs to have reached the constant test speed 1.67 sec. and 2.22 sec. sooner for the 15 km/h and 20 km/h test speed, respectively (in order to trigger the dummy movement and to accelerate the dummy to the desired cyclist speed). The minimum dimensions of the obstruction, and the placement of the obstruction depending on choices for the test parameters is given in Figure 4-7 and Table 7. A practical distance of 1 meter is proposed for placing the obstruction away from the path of the cyclist dummy. This does mean that the vehicle will, in theory, be able to detect the cyclist dummy slightly sooner than 4s before collision. Depending on viewing angle, vehicle speed and bicycle speed.

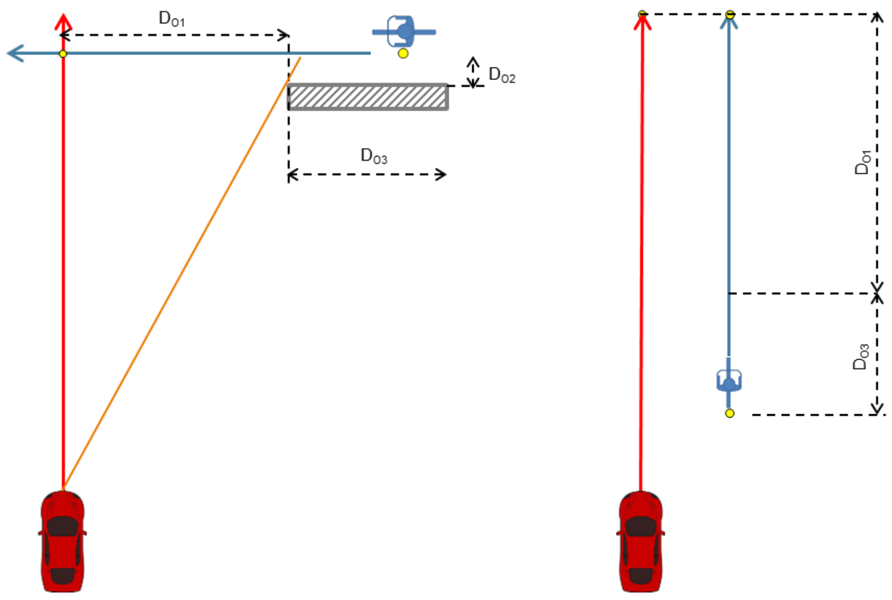


Figure 4-7 schematic overview of obstruction dimensions for crossing tests (left) and the longitudinal tests (right)

Table 7. Typical obstruction dimensions based on test parameters for the crossing tests

	Cyclist speed 15 km/h	**Cyclist speed 20 km/h**	
D_{O1} [m]	16,7	22,2	TTC start = 4 sec.
D_{O2} [m]	1,0	1,0	Choice
a_b [m/s^2]	2,5	2,5	Typical acceleration of cyclist dummy
D_{O3} [m]	3,5	6,2	Required obstruction/acceleration length

For the longitudinal scenarios, it is not possible to construct a setup where the cyclist dummy appears from behind an obstruction at TTC = 4 sec. The same constraint holds that the dummy needs to be at constant test velocity at TTC = 4 sec. The view from the car to the cyclist dummy will in this case not be obstructed during the acceleration phase of the car and the dummy. The situation is viewed in Figure 4-7 (right side).

Table 8. Typical dimensions based on test parameters for the longitudinal tests

	Cyclist speed 15 km/h	**Cyclist speed 20 km/h**	
D_{O1} [m]	16,7	22,2	TTC start = 4 sec.
a_b [m/s^2]	2,5	2,5	Typical acceleration of cyclist dummy
D_{O3} [m]	3,5	6,2	Required acceleration length
$D_{car\text{-}cyclist}$ [m]	16,7	50,0	Shortest distance to cyclist at TTC = 4 s.
$D_{car\text{-}cyclist}$ [m]	50,0	66,7	Largest distance to cyclist at TTC = 4 s.

5 Analytical feasibility of test scenarios

This chapter provides an indication on the feasibility of the suggested test scenarios. This is done by providing, for each suggested test scenario, the needed braking TTC for stopping and avoidance and the minimal needed vehicle viewing angle (except for the L-scenario where this is not expected to be an issue) based on simplified and maximum vehicle characteristics. Note that values provided here are theoretical and should only be used as an indication of the feasibility. A more in-depth simulation study is performed by BASt using a dedicated simulation tool [27].

In all computations the vehicle is represented by a straight front end only characterized by its width. The bicycle is only characterized by its length and the width is assumed negligible. Furthermore for simplicity, in this chapter the width of the vehicle and the length of the bicycle are chosen identical with a characteristic value of 1.80m. The collision point ranges therefore from -50% and 150% as explained in appendix A.

Furthermore, braking is assumed to be instantaneous and with a (maximum) deceleration of 10 m/s^2. Therefore all values found can be regarded as the theoretical lowest or latest.

Time To Collision (TTC) is always defined as the momentary relative distance divided by the momentary relative speed. When results are given based on the TTC, it is always done in the part where the vehicle velocity is still constant (no braking).

5.1 Scenario C1: crossing cyclist from near side

5.1.1 Braking TTC for stopping and avoidance

In this section it is checked for the C1 test scenario at which TTC the vehicle needs to start braking in order to avoid the collision while using the maximum instantaneous deceleration. One possibility for the vehicle to avoid the collision is to come to a complete stop before the impact point. The computation for this TTC is shown in appendix D and finalized in equation D.18. It is shown that this TTC is linearly dependent on the vehicle speed.

However, in order to avoid the collision the vehicle does not always need to come to a complete stop. From a certain speed, given by equation D.28, the vehicle just needs to lower its speed enough for the cyclist to pass the impact zone. Both the speed from which this is possible and the speed reduction needed is dependent on the vehicle and cyclist speed as well as the collision point.

For the C1 test scenario 15 km/h for the cyclist speed and 0% collision point have been suggested for the unobstructed test scenario (**CVNBU**) and 10 km/h cyclist speed and 50% collision point for the obstructed test scenario (**CVNBO)**. Using these values provides a speed for the vehicle of 47 km/h and 47 km/h from which the vehicle does not need to come to a complete stop anymore to avoid the collision when instantaneously braking with 10 m/s^2 for CVNBU and CVNBO, respectively. Since for the obstructed test scenario the vehicle speed is not higher than 40 km/h this is not relevant and the vehicle always needs to come to a complete stop to avoid the collision. The latest TTC for braking to avoid the collision (green) and the latest TTC for braking to come to a complete stop before the impact point (blue) as a function of the vehicle speed can be seen in Figure 5-1 for the unobstructed C1 test scenario.

It can be seen that at 60 km/h the latest TTC to come to a complete stop is about 12ms sooner (~1.5% difference) than the latest TTC for braking to avoid the collision.

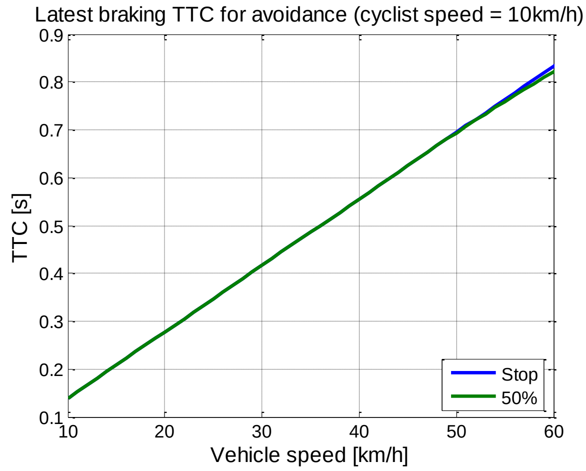


Figure 5-1 Latest TTC for braking to come to a complete stop before the impact point (blue) and to avoid the collision (green) for the unobstructed C1 test scenario (CVNBU, cyclist speed 15 km/h and a 0% collision point)

For the C1 accident scenario with a view blocking obstruction, a characteristic location (3.55m lateral and 4.80m longitudinal) is suggested as a starting point. Using appendix B, Figure 5-2 shows the effect of changing the 2 variables of the location (lateral [D_{01}] and longitudinal [D_{02}], Figure 4-1) relative to the starting point on the TTC of detection of the cyclist. Changing the lateral distance will result in an offset of the TTC detection of the cyclist as a function of the vehicle speed, whereas changing the longitudinal distance results in a scaling.

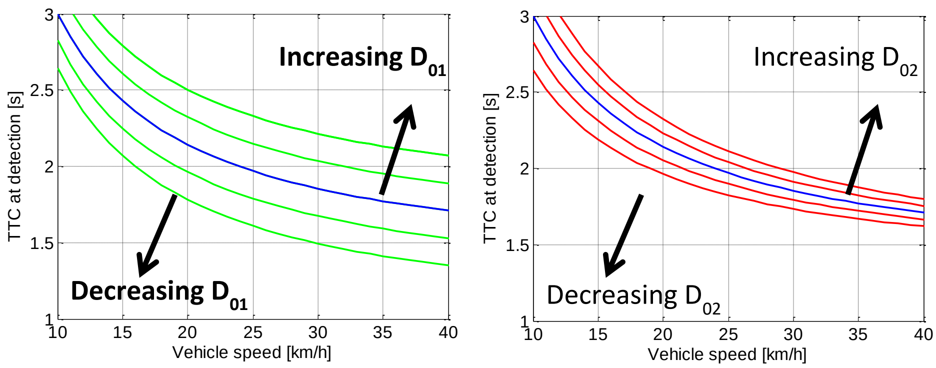


Figure 5-2 Effects of changing the location of the view blocking obstruction relative to the suggested starting point with respect to the TTC for detection of the cyclist as a function of the vehicle speed.(reference Figure 4-1, green and red line represent -1.0m,-0.5m,+0.5m and +1.0m)

When the latest braking TTC for avoidance is subtracted from the TTC where detection is possible, the result is the maximum time left for classification of the cyclist, waiting for a driver response after issuing a warning, deciding to brake and engaging the brakes in order to still avoid the collision (with maximum braking characteristics). This maximum is shown in Figure 5-3. It can be seen that the maximum time left after possible detection for avoidance ranges from about 2.85 to 1.15s for 10 and 40 km/h, respectively.

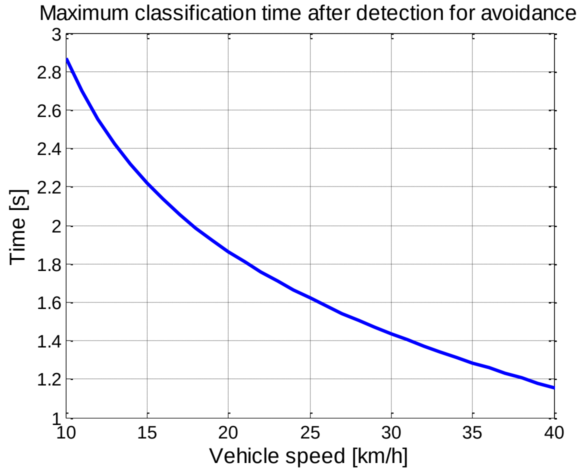


Figure 5-3 maximum time left after possible detection while still avoiding a collision using maximum braking characteristics.

5.1.2 Vehicle viewing angle

In the default case the minimal needed vehicle viewing angle is computed from the middle of the front of the vehicle to the middle of the cyclist. This will provide a conservative estimate since sensors further back on the vehicle and observing the front of the cyclist will both lower the vehicle viewing angle. Appendix C shows how to compute the needed sensor angle as a function of the TTC. When the observing part of the cyclist will impact the sensing middle of the front of the vehicle, the minimal needed viewing angle will remain constant as a function of the TTC. Figure 5-4 shows the minimal vehicle viewing angle for the test scenarios, CVNBU and CVNBO, for the default case, a sensor 0.9m back on the vehicle, observing front of cyclist (0.9m forward) and both. The most challenging needed viewing angle in the default case of CVNBU is with a vehicle speed of 20 km/h which ranges from ~36° at TTC is 4 seconds to ~41° at TTC is 1 second. For the CVNBO this is with a with a vehicle speed of 20 km/h and has a constant viewing angle of 45°.

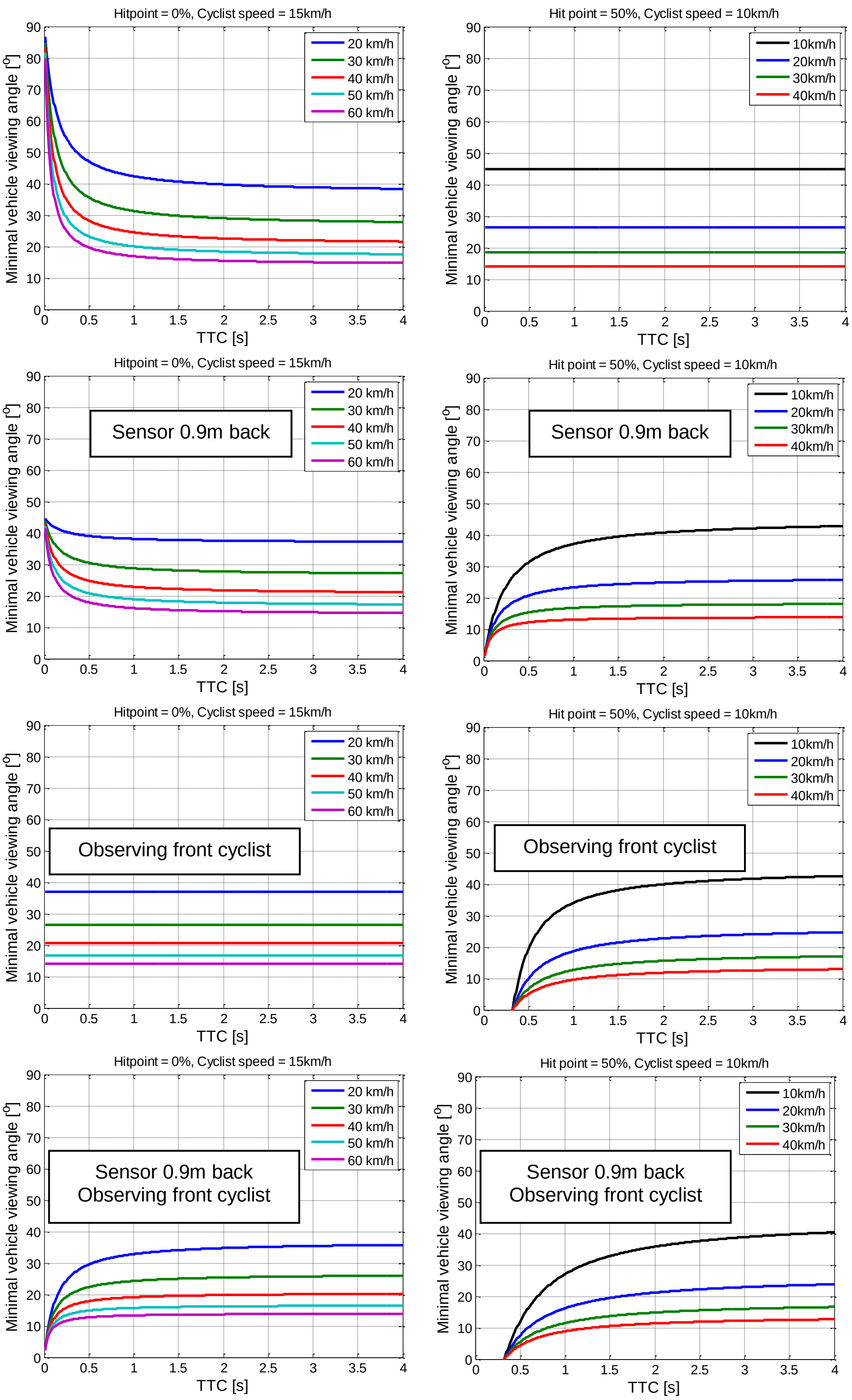


Figure 5-4 minimal needed viewing angle for CVNBU (left) and CVNBO (right) for the default case (middle front vehicle to middle cyclist)(top), sensor 0.9 back on vehicle (2nd row), observing front of cyclist (3rd row) and both (bottom).

5.2 Scenario C2: crossing cyclist from far side

5.2.1 Braking TTC for stopping and avoidance

Just as for the C1 test scenario the latest braking TTC for avoidance using maximum braking characteristics can be computed for the C2 test scenario. At this moment the cyclist speed is in the C2 test scenario is considered to be 20 km/h and the collision point is considered to be 50%. Figure 5-5 shows the latest braking TTC for stopping and avoidance as computed by equation D.18 and D.28.

At a vehicle speed of 23 km/h the vehicle does not need to come to a complete stop anymore to avoid the collision when instantaneously braking with 10 m/s^2 for. The latest TTC for braking to avoid the collision (green) and the latest TTC for braking to come to a complete stop before the impact point (blue) as a function of the vehicle speed can be seen in Figure 5-5. Furthermore It can be seen that at 60 km/h the latest TTC to come to a complete stop is about 120ms sooner (~15% difference) than the latest TTC for braking to avoid the collision.

Where in the C1 test scenario the difference between stopping TTC and avoidance TTC is limited, in this scenario it is substantial, most likely also with actual braking systems. This also makes sense, since with the higher speed and larger collision point the cyclist needs less time to move out of the impact zone.

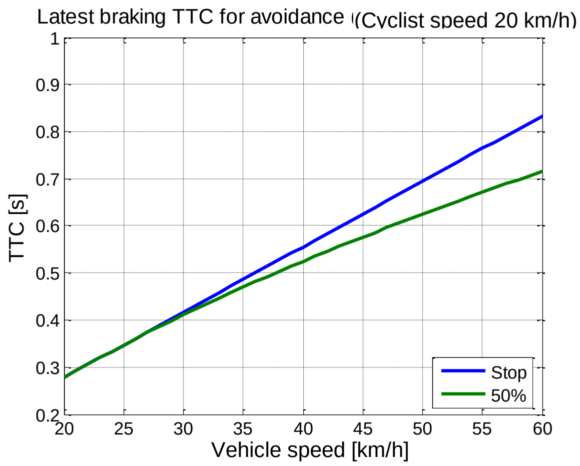


Figure 5-5 Latest TTC for braking to come to a complete stop before the impact point and to avoid the collision for several different collision points for the C2 test scenario (cyclist speed 20 km/h)

5.2.2 Vehicle viewing angle

As explained in the previous paragraph, in the case of a 50% collision point where the middle of the front of the vehicle and middle of the cyclist is used, this minimal vehicle viewing angle remains constant as a function of the TTC which is the case in this test scenario. In the default case the minimal needed vehicle viewing angle is computed from the middle of the front of the vehicle to the middle of the cyclist. This will provide a conservative estimate since sensors further back on the vehicle and observing the front of the cyclist will both lower the vehicle viewing angle. Appendix C shows how to compute the needed sensor angle as a function of the TTC. Figure 5-6 shows the minimal vehicle viewing angle for the test scenarios, CVNBU and CVNBO, for the default case, a sensor 0.9m back on the vehicle, observing front of cyclist (0.9m forward) and both. The most challenging needed viewing angle is in the default case of CVNBU with a vehicle speed of 20 km/h which is 45° and remains constant over the entire TTC range.

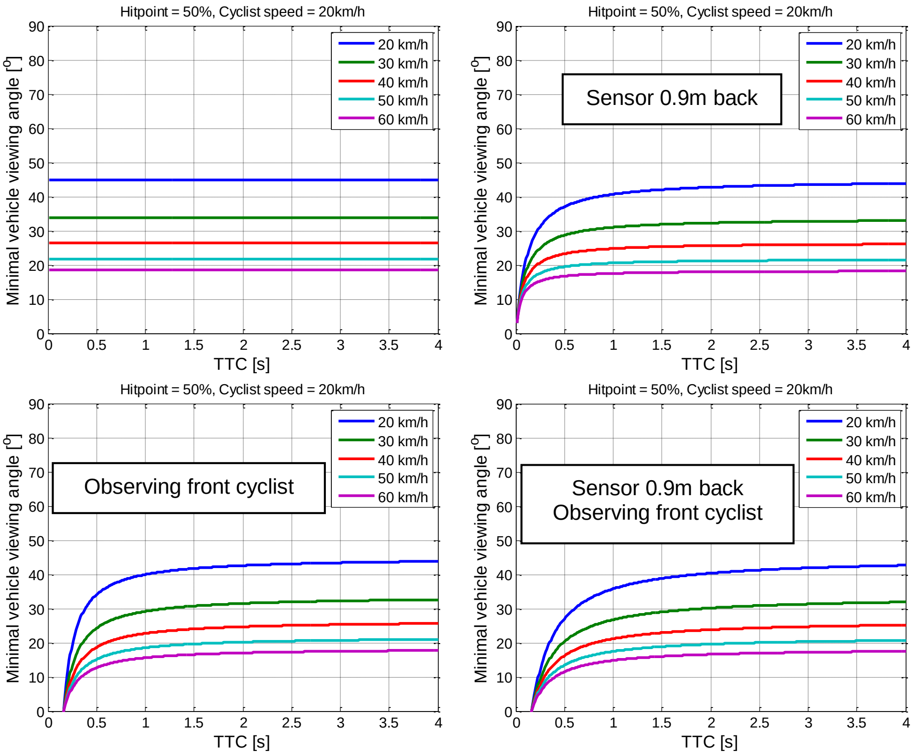


Figure 5-6. The needed vehicle viewing angles for the C2 test scenario as a function of the TTC. Top left: default case. Top right: sensor 0.9m back on vehicle. Bottom right: observing the front of the cyclist. Bottom right: both sensor back on vehicle and observing front of cyclist.

5.3 Scenario L: Car and cyclist driving in the same direction

5.3.1 Braking TTC for stopping and avoidance

The latest braking TTC for avoidance using maximum braking characteristics in the longitudinal test scenario is relatively simple, because the cyclist will never move out of the impact zone. Appendix E explains how to compute this and is comparable to the stopping TTC in the crossing scenarios. It is linearly dependent on the relative speed between the vehicle and the cyclist. Figure 5-7 shows the latest braking TTC for avoidance in the suggested test scenarios defined where an AEB action is required (vehicle speed from 30 to 60 km/h). It ranges from 0.21s for 30 km/h to 0.62s for 60 km/h.

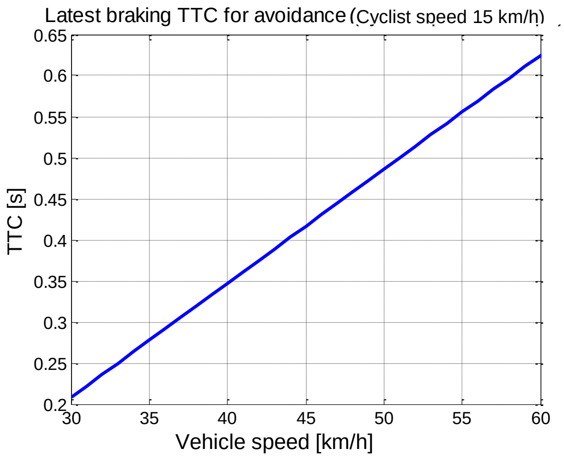


Figure 5-7 Latest TTC for braking to come to avoid the collision in the L scenario (cyclist speed 15 km/h)

6 Conclusions and Recommendations

From the accident scenario investigation in WP1 the 5 most dominant accident scenarios are derived (C1, C2, L, On and T3) covering 75% and 87% of the seriously injured and fatal car-to-cyclist accidents for the investigated countries, respectively. For these 5 dominant accident scenarios the accident parameters are investigated in order to construct the first development test scenarios. Since the contribution to the coverage of On and T3 is relatively low and the On and T3 provide for essentially different scenarios, leading to additional test series, CATS will first focus at the 3 dominant accident scenarios (C1, C2 and L only) for which complete development test scenarios are proposed. These accident scenarios together cover 63% and 78% of the seriously injured and fatal car-to-cyclist accidents for the investigated countries, respectively.

In Table 9 the complete summarized suggested test matrix, as defined June 2015, is shown for the development of the vehicle to cyclist AEB test scenarios. The suggested test scenarios will also be evaluated by BASt using a dedicated simulation tool [27]. At a later stage, after the verification tests in WP5, the final test matrix/test protocol will provided.

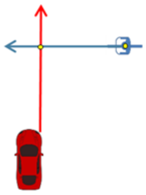
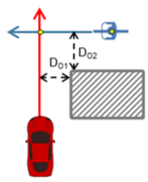
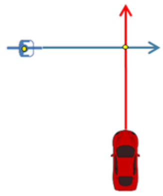
It is suggested to use the C1 accident scenario for a crossing test scenario with 50th percentile cyclist speed and a 0% collision point (CVNBU), but also for a test scenario with a view blocking obstruction since this occurred most in this accident scenario (CVNBO). Based on accidentology the maximum car speed in the test scenario with the view blocking obstruction will be lower (40 km/h) than in the reference test scenario. Moreover, a lower cyclist speed of 10 km/h is selected which is supported by an observation study toward vehicle and cyclist speeds around a viewing obstruction [26].

For the C2 accident scenario it is suggested to vary the cyclist speed according to the found accident parameters (CVFB). A cyclist speed of 20 km/h is proposed as this covers currently 90-percent of cyclist speeds, keeping in mind that it is expected that average cyclist speed will slowly rise the coming years due to the increased popularity of electric bikes. Actually, electric bikes (for which speed can easily go up to 25 km/h) have not been considered in the current study, but these will influence cycling traffic in the near future [24]. The change in cyclist speed will have the effect that the car needs to have a broader view to be able to detect the cyclist at the same time.

For the L scenario (CVLB) it is suggested to divide it into an urban and inter-urban group. In the urban group the vehicle and cyclist speed is lower up to 60 km/h and 15 km/h respectively and will be tested on FCW and AEB with a 50% collision point. As a check, it is proposed to make AEB system eligible for evaluation in the CVLB tests, in case the AEB system is able to reduce speed in the CVLB [30-60 km/h car speed range] with a 20% overlap (instead of 50%).
For the inter-urban group with vehicle speeds from 60 km/h up to 80 km/h, a cyclist speed of 20 km/h and a 20% collision point only FCW will be evaluated.

It is further suggested that the preparation and tolerances of the test scenarios, test track, bicycle/cyclist dummy and vehicle will follow the Euro NCAP AEB VRU Test Protocol v1.0.1 [16].

Table 9. Draft CATS car-to-cyclist AEB test matrix (version June 2015)

DRAFT JUNE 2015	CVNBU	CVNBO	CVFB	CVLB*	
Vehicle speed	20 – 60 km/h	10 – 40 km/h	20 – 60 km/h	30 – 60 km/h	65 - 80 km/h
Cyclist speed	15 km/h	10 km/h	20 km/h	15 km/h	20 km/h
Obstruction	Without	With D1=3.55m, D2=4.80m	Without	Without	Without
Overlap hitpoint	0 %	50 %	50 %	50%	20%
AEB / FCW	AEB	AEB	AEB	AEB	FCW
# tests [36]	9	7	9	7	4
Layout sketch					

This provides the proposed test matrix according to Table 10, resulting is a maximum of 36 + 1 tests for cyclist AEB systems.

Table 10. Draft test matrix for car-to-cyclist AEB tests (version June 2015), 36+1 test in total.

Vehicle speed	CVNBU	CVNBO	CVFB	CVLB*
10 km/h		10 km/h - 50%		
15 km/h		10 km/h - 50%		
20 km/h	15 km/h - 0%	10 km/h - 50%	20 km/h - 50%	
25 km/h	15 km/h - 0%	10 km/h - 50%	20 km/h - 50%	
30 km/h	15 km/h - 0%	10 km/h - 50%	20 km/h - 50%	15 km/h - 50 %
35 km/h	15 km/h - 0%	10 km/h - 50%	20 km/h - 50%	15 km/h - 50 %
40 km/h	15 km/h - 0%	10 km/h - 50%	20 km/h - 50%	15 km/h - 50 %
45 km/h	15 km/h - 0%		20 km/h - 50%	15 km/h - 50 %
50 km/h	15 km/h - 0%		20 km/h - 50%	15 km/h - 50 %
55 km/h	15 km/h - 0%		20 km/h - 50%	15 km/h - 50 %
60 km/h	15 km/h - 0%		20 km/h - 50%	15 km/h - 50 %
65 km/h				20 km/h - 20 % | FCW
70 km/h				20 km/h - 20 % | FCW
75 km/h				20 km/h - 20 % | FCW
80 km/h				20 km/h - 20 % | FCW
# of tests	9	7	9	11
* To be eligible for evaluation in AEB VRU Cyclist Longitudinal, the AEB system must reduce speed in CVLB - [30-60] km/h scenario with 20 % overlap.				

7 Signature

Helmond, September 2nd 2016

TNO

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9 Acknowledgements

The CATS consortium gratefully acknowledges the contributions from:

A Definition of collision point

For the definition of the collision point several aspects are chosen:

- The vehicle width is used as a reference
- The collision point where the middle of the vehicle impacts the middle of the cyclist is 50%
- In the crossing scenarios the direction where the cyclist comes from is selected as the starting point
- In the longitudinal scenarios the near side is chosen as the starting point

For the longitudinal scenario the collision point range is from 0 to 100 % when assuming the width of the cyclist to be negligible. For the crossing scenarios this will lead to the following collision point range defined by de width of the vehicle (W_v) and the length of the cyclist (L_c):

$$HP = 0 - \frac{L_c}{2 \cdot W_v} \Leftrightarrow 1 + \frac{L_c}{2 \cdot W_v} \qquad \text{(A 1)}$$

These aspects lead to the following collision point definition for C1, C2 and L where the width of the vehicle is the dame as the length of the cyclist.

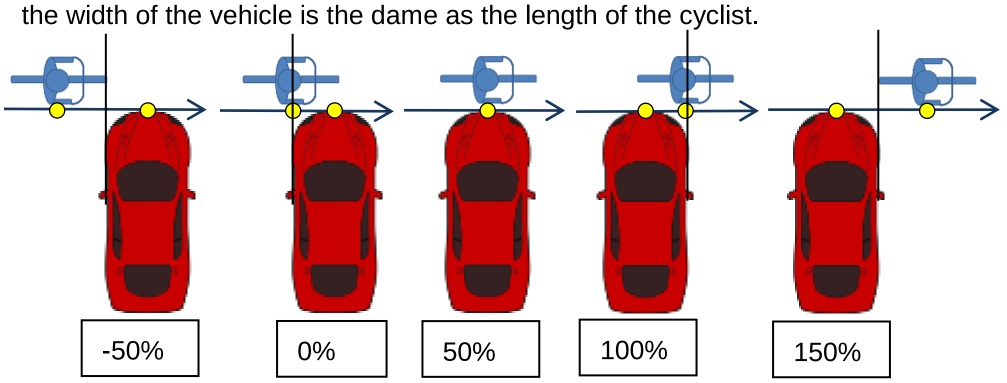

Figure 9-1 Collision point definition in the C2 test scenario (vehicle width is identical to cyclist length)

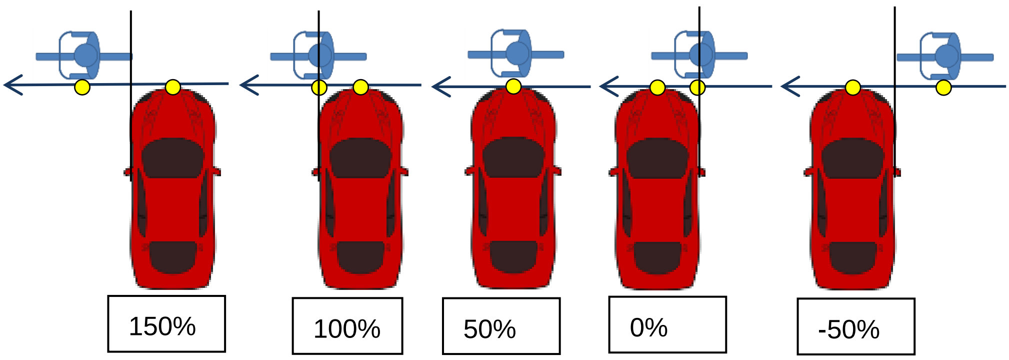

Figure 9-2 Collision point definition in the C1 test scenario (vehicle width is identical to cyclist length)

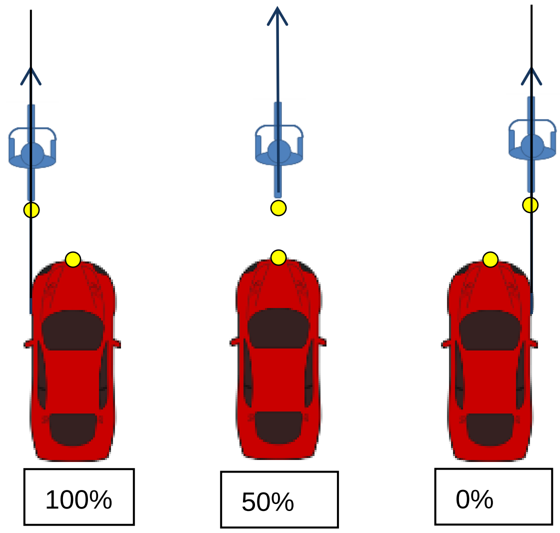

Figure 9-3 Collision point definition in the L test scenario

B Computation of detection TTC in obstructed C1 (near side crossing) scenario

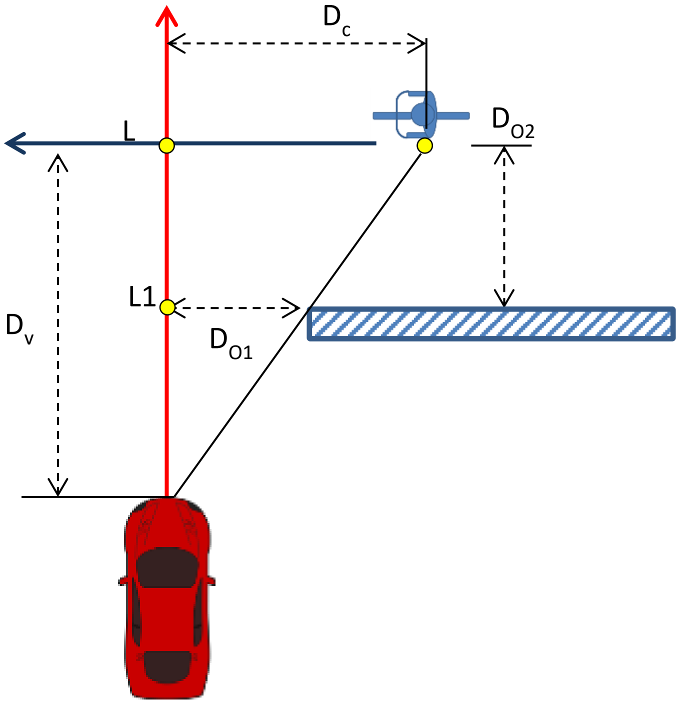

Figure 9-4 schematic overview of the C1 scenario at point of possible detection

Detection is possible at the moment as shown in Figure 9-4.

At that moment 2 right triangles with the same ratio can be observed:

- The large triangle; Vehicle-impact point (L)-cyclist
- The small triangle; Vehicle-obstruction point (L1) – obstruction

Due to this the following equation can be formulated:

$$\frac{D_c}{D_v} = \frac{D_{O1}}{(D_v - D_{O2})} \tag{B 2}$$

Since the vehicle and the cyclist are going to be at the impact point at the same time the following equations can be formulated:

$$D_v = V_v \cdot TTC \tag{B 3}$$

$$D_c = V_c \cdot TTC \tag{B 4}$$

Filling in B.3 and B.4 in B.2 gives:

$$\frac{V_c \cdot TTC}{V_v \cdot TTC} = \frac{D_{O1}}{\left(V_v \cdot TTC - D_{O2}\right)} \qquad \text{(B 5)}$$

This will give an answer of TTC =0 (which makes sense) and the following formula:

$$\frac{V_c}{V_v} = \frac{D_{O1}}{\left(V_v \cdot TTC - D_{O2}\right)} \qquad \text{(B 6)}$$

Solving this for TTC gives:

$$TTC = \frac{V_c \cdot D_{O2} + V_v \cdot D_{O1}}{\left(V_v \cdot V_c\right)} \qquad \text{(B 7)}$$

C Computation of vehicle viewing angle in C2 (far side crossing) scenario

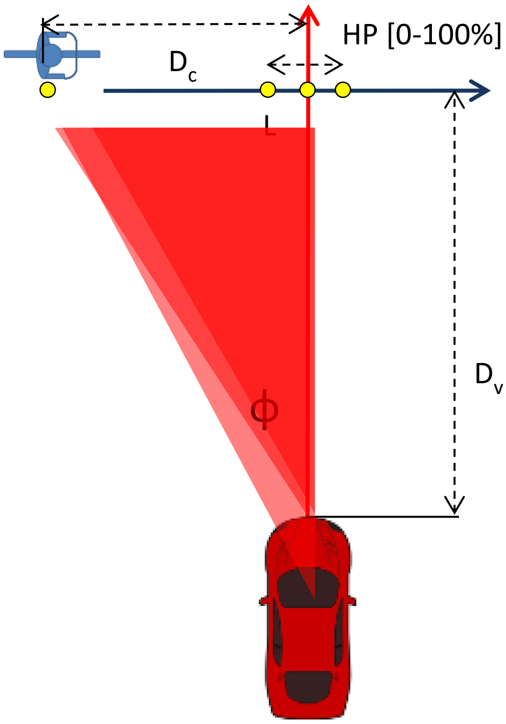

Figure 9-5 schematic overview of the C2 scenario at an arbitrary point during the test. Vehicle viewing angle can be defined here at any point on the middle of the vehicle to any point on the cyclist

The vehicle viewing angle is defined as the angle between the motion of travel of the vehicle and the line from a point on the middle of the vehicle to a point on the cyclist.

The vehicle viewing angle can be computed by:

$$\Phi = a\tan\left(\frac{D_c + offset\_cyclist}{D_v + offset\_vehicle}\right) \quad \text{(C 8)}$$

Where offset_cyclist can be seen as the observation point on the cyclist for the vehicle and offset_vehicle the location of the sensor on the car. When a 50% collision point is chosen (middle vehicle impacts middle cyclist) and since the vehicle and the cyclist are going to be at the impact point at the same time the following equations can be formulated:

$$D_v = V_v \cdot TTC \quad \text{(C 9)}$$

$$D_c = V_c \cdot TTC \quad \text{(C 10)}$$

However the middle of the cyclist can also be impacted on a different location on the vehicle, as defined in the previous chapter. When the collision point value is not 50% a correction is needed on equation B.9 based on the collision point (CP) and width of the vehicle (W_v) (shown for scenario C2):

$$D_c = V_c \cdot TTC + W_c \cdot (0.5 - CP) \qquad \text{(C 11)}$$

Combing equation C.8 with C.9 and C.11 results in a vehicle viewing angle based on the vehicle speed, cyclist speed, collision point, sensor location, observation point on cyclist and TTC.

$$\Phi = a\tan\left(\frac{V_c \cdot TTC + offset\_cyclsit + W_v \cdot (0.5 - CP)}{V_v \cdot TTC + offset\_vehicle}\right) \qquad \text{(C 12)}$$

D Computation of avoidance braking TTC for C1 and C2 (near and far side crossing)

In this section the following formulas of motion are used:

$$X = X_0 + V_0 \cdot t - \frac{1}{2} a \cdot t^2 \quad \text{(D 13)}$$

$$V = V_0 - a \cdot t \quad \text{(D 14)}$$

Where X is the distance, X_0 the initial distance, V_0 the initial speed, t the time, a is the (immediate) deceleration and V the speed. Eliminating the time by combing D.13 with D.14 gives:

$$V^2 = V_0^2 - 2 \cdot a \cdot (X - X_0) \quad \text{(D 15)}$$

When it is desired to stop the vehicle (V=0) before it reaches the impact point, it needs to start braking at a distance of:

$$X_{stop} = \frac{V_v^2}{2 \cdot a} \quad \text{(D 16)}$$

Where V_v is the initial vehicle speed.

The Time To Collision (TTC) is defined as:

$$TTC = \frac{X}{V_v} \quad \text{(D 17)}$$

Combing D.16 and D.17 gives a stopping TTC of:

$$TTC_{stop} = \frac{V_v}{2 \cdot a} \quad \text{(D 18)}$$

However the vehicle does not need to stop completely in all cases to avoid a collision. The limit for avoidance in the crossing scenarios is when the entire length of the cyclist (L_c) is just out of the impact zone (width vehicle W_c) when the vehicle reaches the path of the cyclist (width cyclist is assumed zero) regardless of the vehicle speed at that moment. This is shown in Figure 9-6.

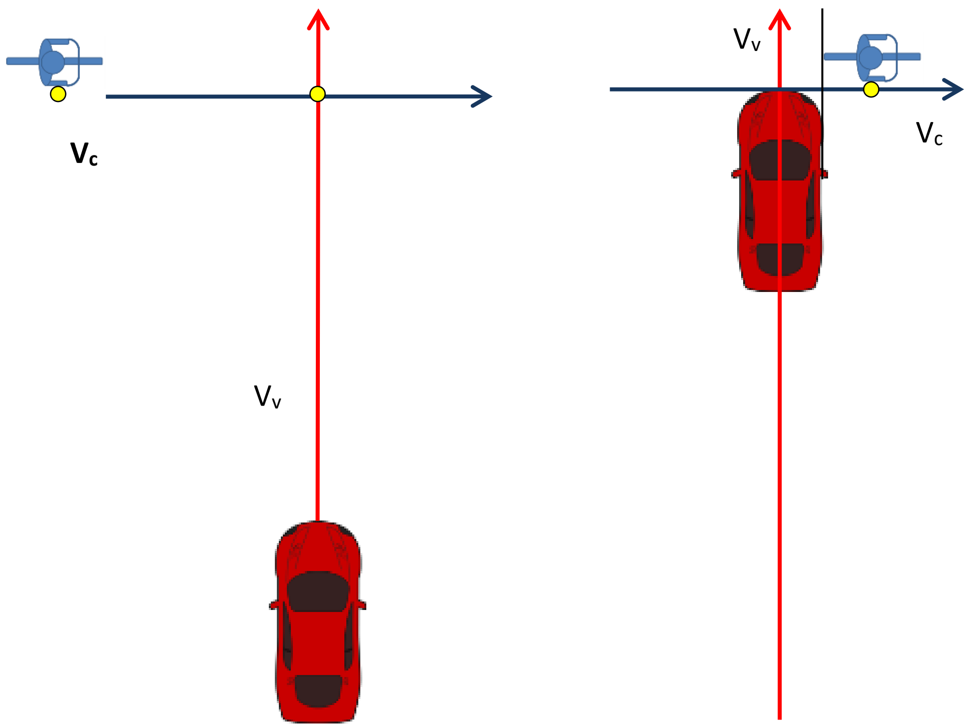

Figure 9-6 schematic overview of avoidance in the crossing scenario. Left: initial set up. Right: vehicle brake at the lasts moment for the cyclist to move out of the way. Here C2 is shown, but this is identical in C1.

First the distance needed for the cyclist to move out of the impact zone (X_{c_ex}) is computed using the collision point (CP) range defined in B.12:

$$X_{c\_ex} = W_v \cdot \left(\frac{L_c}{2 \cdot W_v} + (1 - CP)\right) \quad \text{(D 19)}$$

The extra time the cyclist needs to move out of the impact zone is computed by dividing this distance by the cyclist speed (V_c):

$$t_{ex} = \frac{X_{c\_ex}}{V_c} \quad \text{(D 20)}$$

This is also the extra time the vehicle needs to be later at the impact point.

The distance the vehicle still needs to travel at the moment braking is applied is given by:

$$X_{v\_brake} = V_v \cdot TTC_{brake} \quad \text{(D 21)}$$

It should travel this distance in the time it takes the cyclist to move out of the impact zone, which is

$$X_{v\_brake} = V_v \cdot (TTC_{brake} + t_{ex}) - \frac{1}{2} a \cdot (TTC_{brake} + t_{ex})^2 \quad \text{(D 22)}$$

Combining D.21 and D.22 gives a latest brake TTC of:

$$TTC_{brake} = \sqrt{\frac{2 \cdot V_v \cdot t_{ex}}{a}} - t_{ex} \qquad \text{(D 23)}$$

However this is only valid if the time for the car to come to a stop (at impact point) is larger than the time for the cyclist to move out of the impact zone:

$$\frac{V_v}{a} > TTC_{stop} + t_{ex} \qquad \text{(D 24)}$$

Simplifying D.24 gives, using D.18:

$$V_v > 2 \cdot a \cdot t_{ex} \qquad \text{(D 25)}$$

If the speed of the vehicle is smaller than this, the car needs to come to a stop to avoid the collision (formula D.18).

E Computation of avoidance braking TTC for the L scenario

The accident in the longitudinal scenario is avoided when the vehicle (V_v) reaches the speed of the cyclist (V_c) before impact due to braking. In other words the relative speed (V_{rel}) should become zero just before impact.

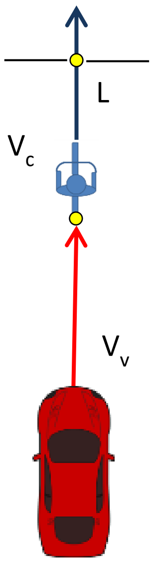

Figure 9-7 schematic overview of the L scenario

$$V_{rel} = V_v - V_c \tag{E 26}$$

$$V_{rel} = V_{rel\_0} - at \tag{E 27}$$

$$X_{rel} = V_{rel\_0} t - \frac{1}{2} a t^2 \tag{E 28}$$

$$TTC = \frac{X_{rel}}{V_{rel}} \tag{E 29}$$

Combing the above formulas gives the latest TTC at which braking should start to avoid collision:

$$TTC_{brake} = \frac{V_{rel\_0}}{2 \cdot a} \tag{E 30}$$