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CATS Deliverable 2.3:
CATS Observation studies

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Summary

To support and prepare the introduction of Cyclist-AEB systems and the appropriate consumer tests of such systems, TNO has taken the initiative to set-up a project with passenger car manufacturers and suppliers and the support of Euro NCAP laboratories (such as BASt) to develop a testing system and test protocol for Cyclist-AEB systems: CATS, Cyclist-AEB Testing System.
The objective of the second work package of the CATS project (WP2, "*Test scenario definition*") is to construct car-to-cyclist accident test scenarios for the EU, based on the accident scenarios and accident parameters mainly obtained from various EU countries. In [4], relevant accident parameters for the 5 most dominant accidents scenarios defined in WP1 are described. One of these parameters is a view-blocking obstruction in a near-side car-cyclist crossing scenario. Accident data, even not from the most detailed databases, usually does not describe behaviour of bicyclist (or cars) in their approach of an intersection. Since these behavioural parameters (e.g. speed reduction, pedalling behaviour) are important parameters when describing a test scenario, an observation study has been performed.
This report describes the setup of such an observation study and the results of the study at 2 intersections with severe view-blocking obstruction in urban areas in the Netherlands. The velocity profiles of both cars and cyclists approaching the intersections were measured. Furthermore, for the cyclists, it was investigated what number of cyclists stops or continues pedalling when approaching the crossing, and in case they stopped pedal to determine the position of the legs (up-down or forward-rearward).
The results show that all bicyclists reduce their speed, while some cars do not reduce speed at all near severe view blocking obstructions. More than 80% of the cyclist stopped pedalling when approaching the intersection. The majority of this group stopped pedalling with on leg up and the other leg down. Results about cyclist behaviour obtained in this study are used in the specification of the bicyclist target in WP3 [12].

Contents

1 Introduction

The overall number of fatalities in road traffic accidents in Europe is decreasing. Unfortunately, the number of fatalities among cyclists does not follow this trend with the same rate [1]. A major share of killed cyclists in traffic accidents is the result of a collision with a motorized vehicle [2]. The automotive industry is making a significant effort in the development and implementation of safety systems in passenger cars to avoid or mitigate an imminent crash with vulnerable road users, and more specifically with cyclists. The current state-of-the-art of active safety systems, Autonomous Emergency Braking (AEB), is being widely introduced. A passenger car equipped with AEB makes use of on-board sensors such as cameras and radars to track and trace traffic participants that possibly interfere with the trajectory of the car. This information is used to warn the driver in case of a possibly critical situation and/or to brake in case the driver does not respond and the risk of collision does not decrease. To support and prepare the introduction of Cyclist-AEB systems and the appropriate consumer tests of such systems, TNO has taken the initiative to set-up a consortium of passenger car manufacturers and suppliers with the support of Euro NCAP laboratories (such as BASt) to develop a testing system and test protocol for Cyclist-AEB systems.

In work package WP2 of CATS, in-depth road accident studies have been performed to determine what accident scenarios are most relevant for car-to-cyclist collisions. Furthermore, for these accident scenarios the most common accident parameters are determined [4].
From accident analyses using databases from Germany, the Netherlands, Sweden, France, Italy, and the United Kingdom (converted to LHD) the percentage of seriously injured and fatalities covered by the most common scenarios has been determined.

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

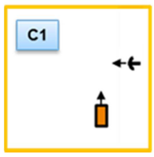
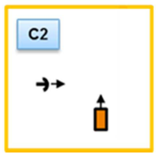
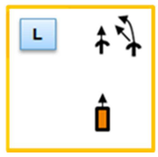
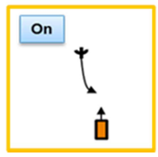
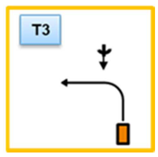
Scenario description and coverage in 6 studied countries (F, D, I, NL, S, UK):					
Seriously injured	28%	28%	7%	6%	5%
Fatalities	25%	29%	24%	8%	2%

Figure 1 shows possible testing scenarios to cover the C1 scenario from Table 1. In the C1 scenario, the car is driving straight while the cyclist is crossing the vehicle path from the near side. The test parameters to be selected for the tests are the passenger car speed, the bicycle speed, the direction of the bicycle crossing the car path, the contact point between bicycle and car in case of collision, and the possible presence, size and location of view-blocking obstructions.

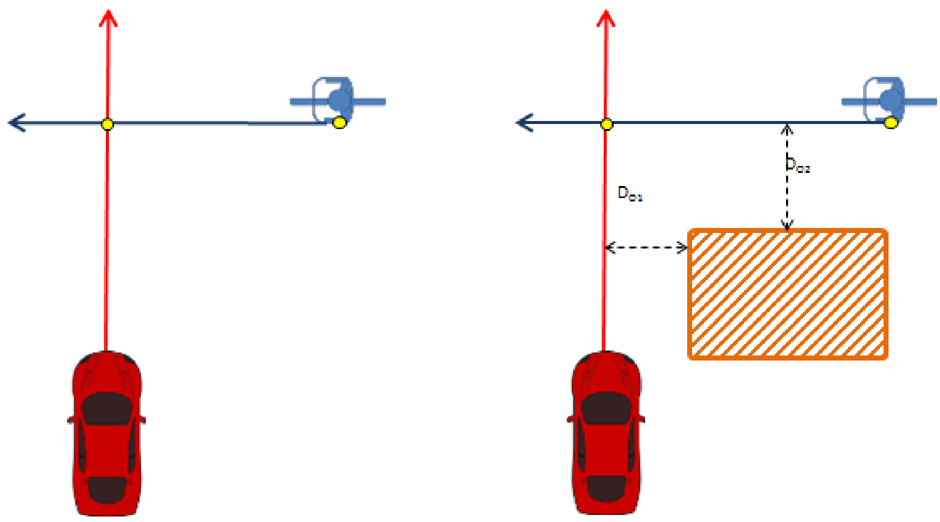


Figure 1 Different car-to-cyclist crossing scenarios. The right graph shows the presence of a view-blocking obstruction.

View-blocking obstructions can seriously hinder and delay the detection of an approaching bicycle from the perspective of the driver and car. Similarly, such an obstruction might limit the view from the bicyclist at the approaching vehicles. Late detection and identification of a bicycle because of a view-blocking obstruction, limits the probability for a driver or an automated braking system to avoid or mitigate the collision with a bicycle that appears from behind an obstruction. The size and the location of the obstruction determine the time at which the cyclist becomes visible, given the speed of both car and bicycle.
Looking at the separate dominant accident scenarios for both Germany and Sweden (Figure 2), it can be seen that view-blocking obstructions are more common in the crossing scenarios than in the other accident scenarios. Even between the crossing scenarios a difference is visible, where C1 (crossing bicycle from near-side, i.e. bicycle approaching from the right side in European mainland driving directions) occurs more often with a view-blocking obstruction than C2 (crossing bicycle from far-side). This might be explained by the fact that, since C1 is defined as a crossing scenario from the near side of the vehicle, it is more likely for the view on the bicycle to be blocked by an obstruction in the near side crossing scenario. In the C1 scenario a substantial part of the accidents (~40% to 50%) occur with a view-blocking obstruction, where the largest part is due to a permanent full view-blocking obstruction such as a building or a high hedge (fouling, vegetation). For this reason, it is proposed to specify one test scenario for cyclist-AEB tests with a well-defined full view-blocking obstruction for the near side (C1).

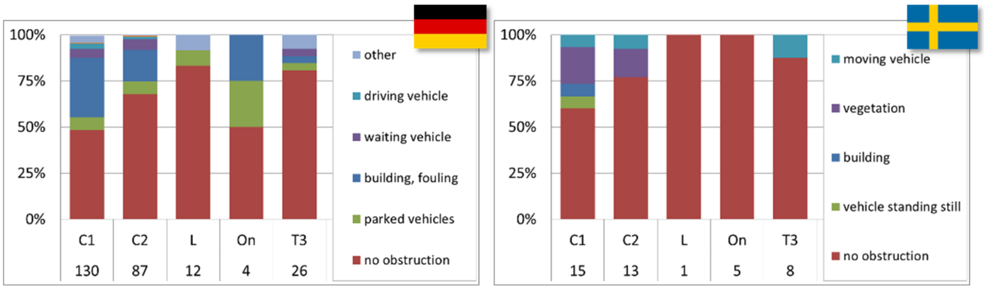


Figure 2 Type of obstruction in seriously injured accidents distributed over the different dominant scenarios. The left figure refers to data from Germany (GIDAS-PCM [6]), the right figure to data from Sweden [7]).

In contrast to pedestrian scenarios, where a pedestrian might wait at the road edge before deciding to start crossing the street, cyclists move more continuously towards the crossing and based on the traffic situation, priority rules and personal preferences either stop or continue to cross the intersection of roads. Information on such typical crossing behaviour or behaviour in the approach of an intersection is important for AEB-system development.

Based on the GIDAS-based PCM data [7], a cumulative distribution has been determined for the time-to-collision (TTC) at which the vehicle has been able to see the cyclist in case of accidents in crossing scenarios with a permanent view-blocking obstruction (Figure 3). In this project, TTC is computed by the ratio of the current distance to the impact point, divided by the current velocity, assuming that the heading of both car and cyclist is constant. This distribution covers passenger car-to-cyclist crossing accidents with a permanent view blocking obstruction and MAIS1+ injuries (n=38, C1=31, C2=7). Figure 3 shows that about 20% of these accidents occur when the vehicle is able to see the cyclist for 1 second or less before the crash. For TTC of 2 seconds or less it covers about 80% of the cyclist accidents. The median (50th percentile of the curve) of the cyclist accidents with a permanent view-blocking obstruction has a TTC of approximately 1.5 seconds at which the vehicle is able to “see” the cyclist (direct line of sight of the centre front of the car and the middle of the bicycle).

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

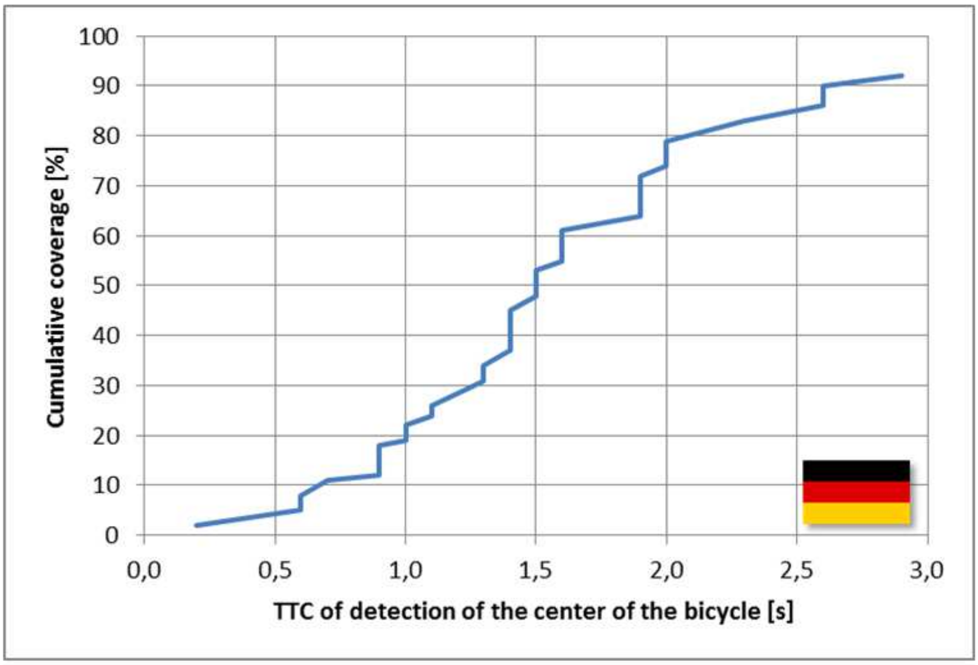


Figure 3 Cumulative distribution plot for the TTC of detection in case of accidents in which a permanent view-blocking obstruction was present.

The objective of such an observation study is to determine the influence of the presence of a view-blocking obstruction on the behaviour of cars and bicycles when approaching a crossing. Previous observation studies have shown that cyclists anticipate very well in traffic [8]. They continue pedalling and hardly decrease speed when riding on a priority bicycle lane crossing a road with a clear unobstructed view on the approaching vehicles. The hypothesis is that both bicyclists and car drivers reduce speed in case the view on the crossing is limited because of an obstruction (e.g. building, fouling, parked car). The more the view is limited, the larger the effect on speed reduction is expected to be.
To check this hypothesis, 2 bicycle crossings with a reasonably severe permanent view-blocking obstruction have been selected in the Eindhoven area. With a radar, the velocity as function of the distance to the crossing has been measured for a considerable number of passenger cars and bicycles. Interactions between bicycles and passenger cars are excluded from the results, as it is our intention to study the influence of an obstruction, not the braking of a cyclist once it detects an approaching car.

This report describes the observation study performed in the CATS project. The methodology used for this observation study is described in chapter 2, where the results for both test sites are discussed in chapter 3. Subsequently, conclusions and recommendations are given in chapter 4.

2 Method

2.1 Parameters to be measured

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

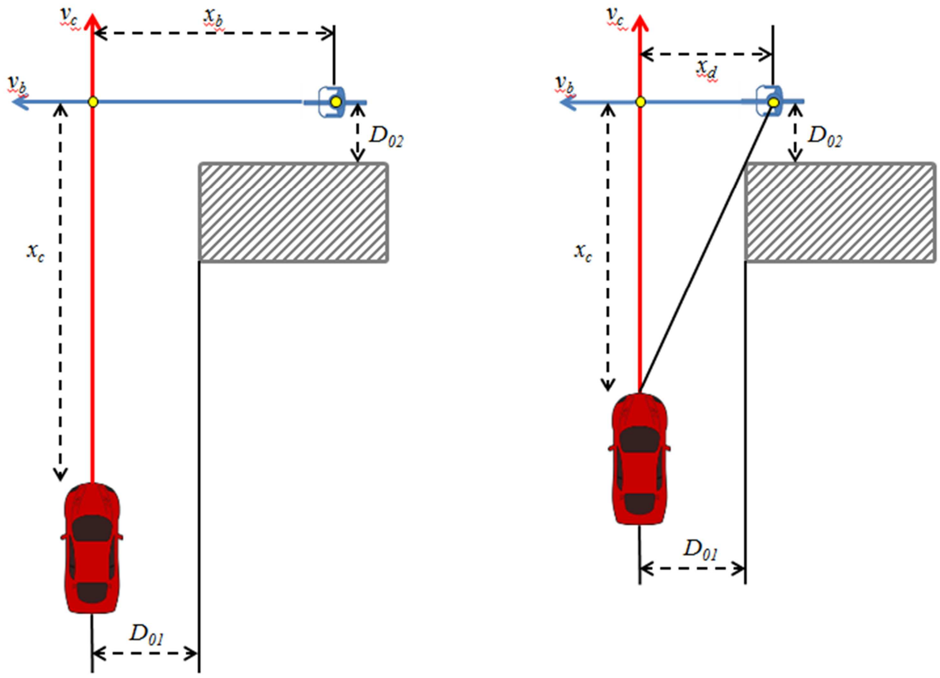


Figure 4 Definition of TTC in a car-to-cyclist crossing scenario in which x denotes distance and v velocity. The underscore b refers to the bicycle and c to the car.

$$TTC = \frac{x_b}{v_b} = \frac{x_c}{v_c} \quad (2.1)$$

$$TTC_d = \frac{x_d}{v_b} = \frac{D_{01} \cdot v_c + D_{02} \cdot v_b}{v_c \cdot v_b} \quad (2.2)$$

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

2.2 Measurement equipment

To perform a continuous speed measurement on traffic participants, an automotive radar that is able to detect bicycles and cars is used (Continental SSR 208). The short-range-radar with a field-of-view of +/- 20° and a range of 50 m is integrated in a road-side-unit which in addition to the radar consists of a platform to run filtering and target tracking algorithms, a data recorder, a wireless communication unit based on ITS-G5, and a battery [9]. Filtering is done based on lifetime of the detected objects (the time the object is in the detection range), the minimum velocity of the object, and by selecting a region of interest in which the important objects are expected. This filtering process is explained in more detail in paragraph 2.4.

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

In order not to influence the measurements in any way, the automotive radar and the platform connected to the radar are hidden into a garbage bin. Such a garbage bin often stands at the side of the road in urban areas, so it is less likely to be noticed by the approaching traffic participants, and consequently no influence from the presence of such equipment on the behaviour of traffic participants is expected.

The garbage bin with the radar is located at the road edge as much as possible in line with the direction of the approaching car. The radar is positioned opposite to the driving direction of the traffic that is being measured, at the opposite side of the crossing to have a reliable measurement of the speed up to the ‘collision point’, the point at which the car path and the bicycle path intersect. Moreover, the radar unit has been placed as much as possible in line with the driving direction of the bicycles or the cars, in order to achieve the highest possible accuracy.

Figure 5 shows how the radar is integrated into the garbage bin, and how the measurement direction is aligned.

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

Action cameras are mounted on traffic sign poles near the intersection to record the events at the intersection during the complete measurement session. In case of unexpected results in the measurements, the recorded video can be used to determine the cause for such event during the offline analyses of the measurement sessions. From the video footage, selections of cars and bicycles can be made in case radar measurements are disturbed.

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

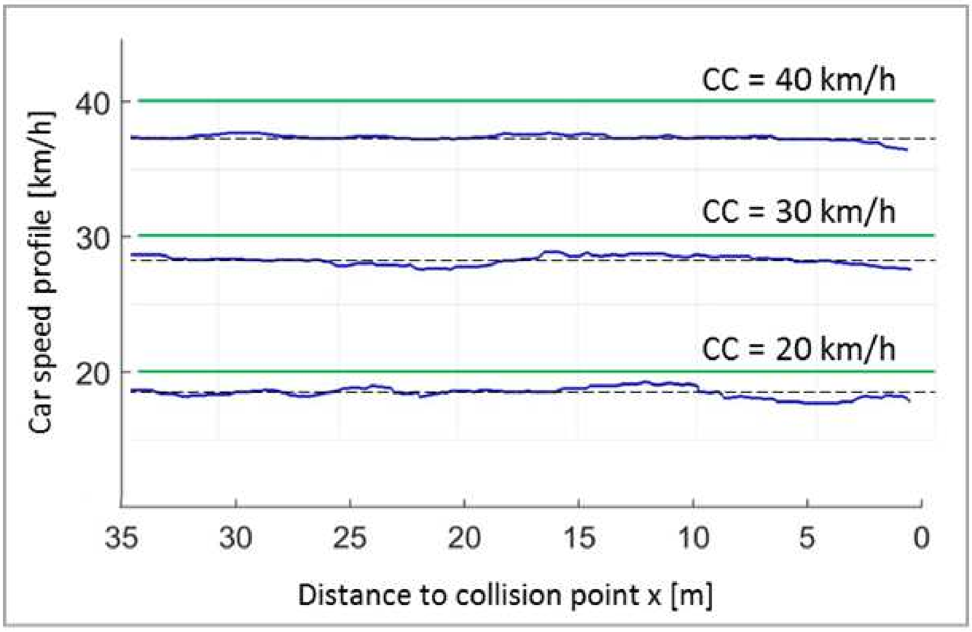


Figure 6 Measured speed with radar for car on cruise control.

For each bicyclist, camera images are used to determine whether or not the bicyclist stops pedalling and whether or not the bicyclist comes to a full stop before crossing.
Since the response of the car driver and cyclist to a view-blocking obstruction that limits the view on crossing traffic is to be determined, the speed profiles of individual cars approaching the crossing are being measured. The cars that have a path that interacts with other traffic on the same road, such as a car that needs to pass a bicycle driving in the same direction, need to be discarded from the results. The recorded videos are used for this purpose as well.

2.3 Selection of measurement sites

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

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

In [4] the location and size of a typical view-blocking obstruction is evaluated. The obstruction parameters are chosen such that it covers a major part of the obstructions found in accident data, while bearing in mind realistic measures of the road lay-out. For a rather severe view-blocking obstruction, where the car drives in the middle of its lane on a two-lane road with a pedestrian sidewalk, the value of D_{O1} (Figure 4) could be as low as 3.55 m. For a double cyclist lane bordered by a pedestrian sidewalk crossing this road, the value of D_{O2} would be around 4.80 m
The sites for the observation study should have a rather severe view-blocking obstruction, to determine the influence of such an obstruction on the velocity profile of both bicycles and cars. Hence an obstruction with values for D_{O1} and D_{O2} close to 3.55 and 4.80 m respectively is intended.

Starting from the criteria described above, two sites have been selected in the Eindhoven area in the Netherlands:

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

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

Figure 7 Top view and car view of selected crossing in Son en Breugel. Cyclists (orange arrow) approach the cars (red arrow) from the right, where the cyclists have right of way. Speed limit of the cars in this area is 30 km/h. The yellow sign at the right was not present during the measurement day.

Figure 8 Top view and camera overview of selected crossing in Eindhoven. Cyclists (orange arrow) approach the cars (red arrow) from the right, where the cyclists have right of way. Speed limit of the cars in this area is 30 km/h. The garbage bin containing the measurement equipment can be seen at the right side of the figure.

Additionally to the crossing in the Netherlands, similar crossings were found in Cologne, Germany, which also suited the selection criteria. At onsite inspection of the crossing however, the throughput volume of cyclists appeared very limited, making the crossings less suitable to perform measurement. These crossings were therefore not further taken into account in this study.

2.4 **Radar data processing**

Car velocity profiles are obtained from radar data. A list of the output fields of the raw radar data can be found in Appendix A. Four filtering steps are applied to the raw radar data in order to extract these velocity profiles: a region of interest filtering step, an object ID filtering step, a noise reduction step and finally an object classification step.

2.4.1 ROI filtering

In the first step, a region of interest (ROI) is applied to the raw dataset. This ROI excludes data outside a certain longitudinal and lateral distance with respect to the radar position. This first filtering step is illustrated in Figure 9.

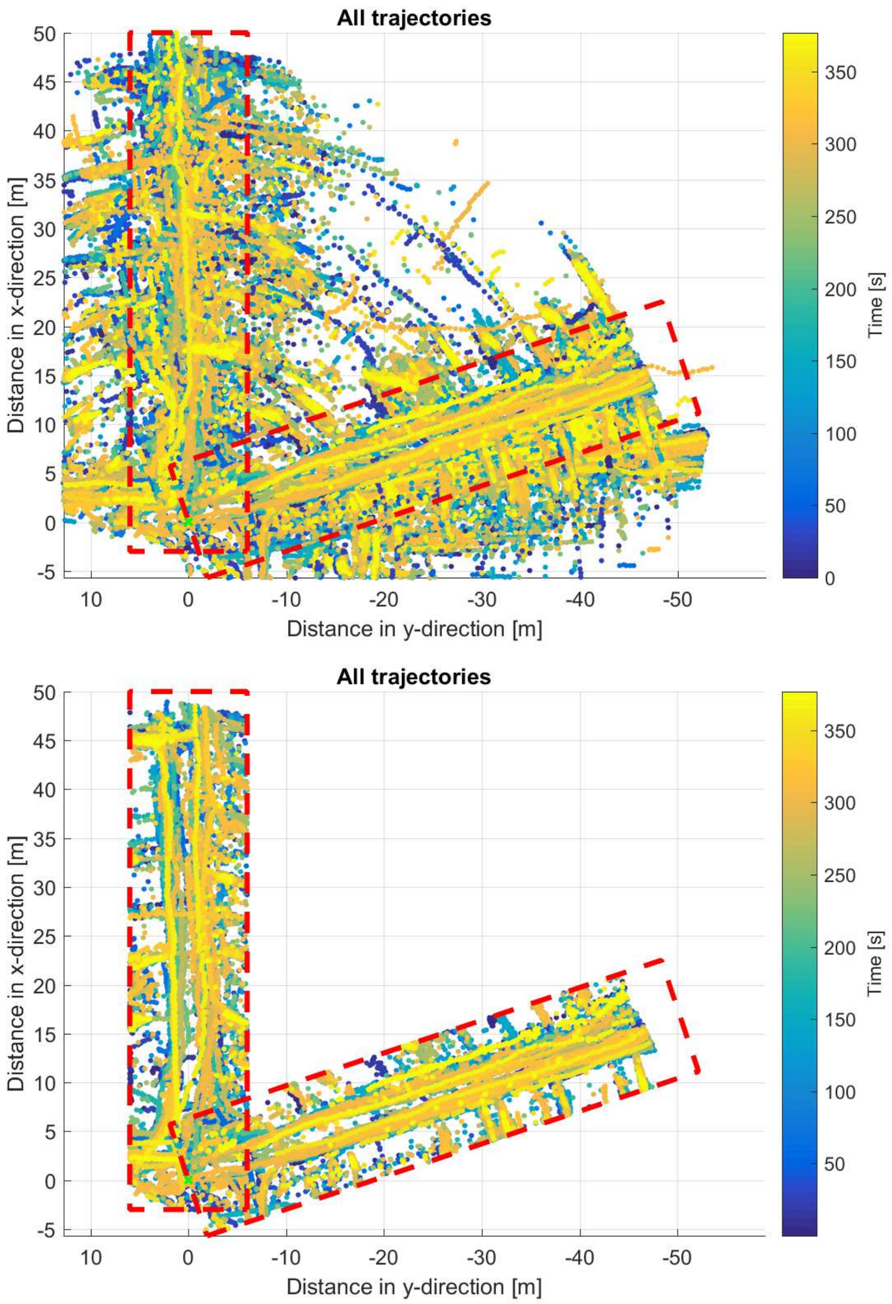


Figure 9 ROI filtering of radar data. TOP: raw radar dataset of approx. 6 minutes. Dashed red line shows the ROI's for the cyclist path (vertical) and car path (tilted horizontal). BOTTOM: data after ROI filter is applied.

2.4.2 Object ID filtering

The radar used in the study assign an ID to each object. These object ID's are used to split the radar data in one set per object. For this purpose, the following assumptions are made:

- If two different data points have different ID's, then the data points belong to different objects.
- If the time difference of two sequential data points with the same ID is more than 1 second, then the data points belong to different objects.

2.4.3 Classification

As a final step, criteria are imposed to classify objects in the dataset as being an object of interest (car or cyclist). The following criteria are used for classification:

- Number of data points in the track should be higher than 18, which equals 0.6s in case no radar data samples are lost (e.g. object should be present (and visible for radar) long enough).
- The average longitudinal velocity (with respect to the radar) should be higher than the average lateral velocity (w.r.t. radar) (e.g. object should move towards radar and not perpendicular to the radar)
- The distance between the first and last sample of the object trajectory should be more than 15 m for the cyclist path and 20m for the car path (e.g. the object should have covered a certain distance during the time it was present in the radar data).
- The maximum longitudinal velocity (with respect to the radar) should be higher than 2m/s for the cyclists' path and higher than 3 m/s for the car path.

Only objects that obey these criteria are used in the data analysis. Figure 10 shows the effect of this final classification step.

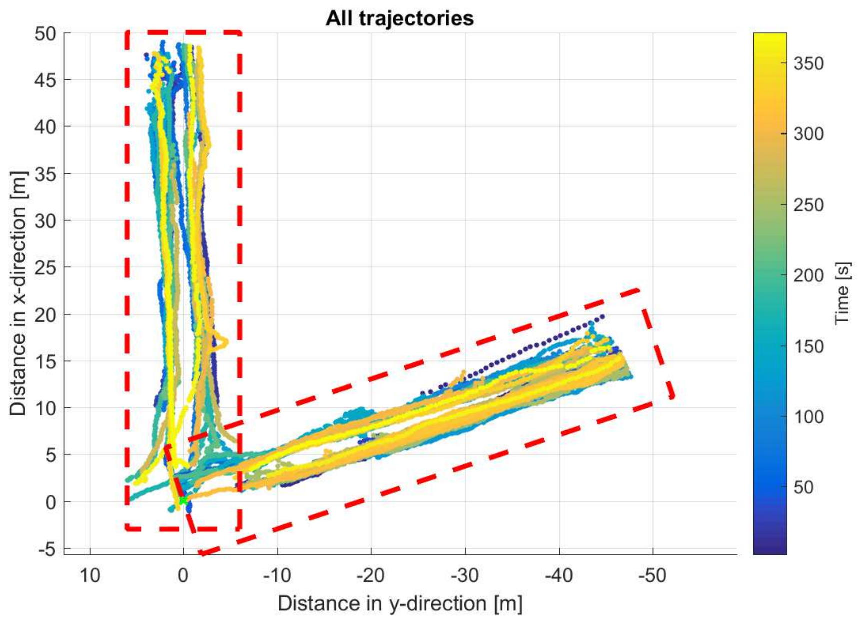


Figure 10 Classification step applied to the radar data. Only objects that obey the classification criteria mentioned in 2.4.3 are included in further data analysis.

2.5 **Cyclist behaviour**

Next to the velocity of the cars and bicyclists, also the behaviour of the cyclists approaching the intersection is monitored. Camera footage is used for this purpose. For each cyclist, the following questions are answered:

- What manoeuvre did the cyclist make? (go straight, turn left, turn right)
- Did the cyclist stop pedalling?
  - In case yes; what was the position of the legs? (up-down, front-rear)
- Did the cyclist made a full stop?
- Did the cyclist look at the cars?
- Did the cyclist adapt its speed to the situation?

The results coming from these observations have been used as input to the dummy cyclist design.

3 Results Son en Breugel

3.1 Results Son en Breugel

3.1.1 Description of measurement site

The first obstruction that has been studied is located in the village of *Son en Breugel*, about 10 km north of Eindhoven. The obstruction blocks the view from the cars driving on the *Boslaan*, a main road through the village centre, towards the *Esdoornlaan* bicyclist lane on the right. This part of the *Esdoornlaan* is a dead-end street for cars, which is frequently used by cyclists to go to the village centre, where schools, shops and other public buildings are found. The view-blocking obstruction consists of a high permanent (green) hedge, which borders the premises of the house at the corner of the *Boslaan* - *Esdoornlaan* intersection. The speed limit is 30 km/h. In Figure 11 a view on the site is given, both from the obstructed and unobstructed side. In this figure, the red arrow indicates the driving direction of the car and the orange arrow the driving direction of the bicycle (the blue arrow represents traffic from the side opposite to the bicycle path, unobstructed view).

Figure 11 Bicycle-crossing at *Boslaan* in *Son en Breugel* (left obstructed, right un-obstructed).

At this intersection, measurements were performed on a weekday in April 2015, from 8h00 till 12h30. It was partly cloudy without precipitation. GoPro cameras have been used to record the complete time of testing. In case a vehicle and a bicycle approached the crossing driving in the same direction or when cars turn onto the *Boslaan* from the side street, the radar could often not distinguish between the different objects, which resulted in a measurement that needed to be discarded. The video recordings were used to make the appropriate selection.
The dimensions of the crossing were measured using a measurement wheel. This includes the dimensions of the view-blocking obstruction, or more specifically the distance of the obstruction to both the assumed car path (D_{O1} = 4.5 m) and the

assumed bicycle path (D_{O2} = 5.0 m). Using these dimensions, the TTC_d is determined for the obstructed crossing as function of both the vehicle (v_c) and bicycle speed (v_b) and shown in Figure 12. The TTC_d values for the reference crossing (D_{01} = 3.55m, D_{02} = 4.80m) are plotted in the graph as well for comparison. This particular crossing provides the possibility to measure the speed profile of cars approaching from the opposite direction as well. The idea is to compare the speed profiles for the cars in the unobstructed case from those of the cars approaching the obstructed case.

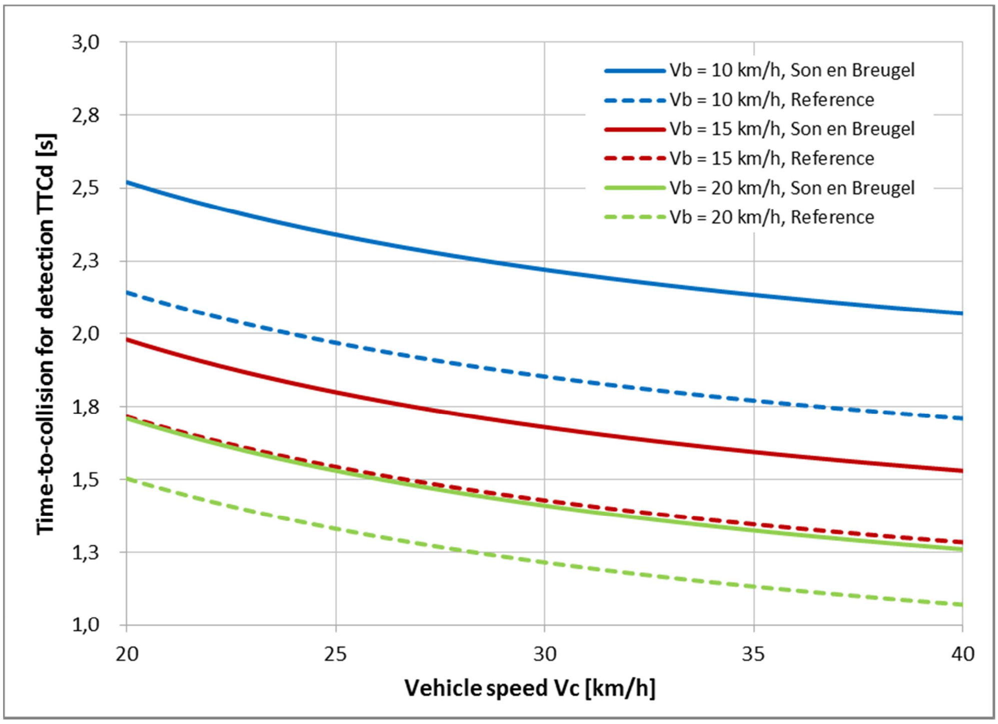


Figure 12 Time-to-collision for detection (*TTC_d*) at the obstructed crossing in *Son en Breugel*, as function of both bicycle speed v_b and vehicle speed v_c (solid lines) The graphs shows the TTC_d values for the reference crossing as well (D_{01} = 3.55m, D_{02} = 4.80m) (dashed lines).

3.1.2 Results bicycles

At the crossing in *Son en Breugel*, only the speed profile is measured for the cyclists approaching the *Boslaan* from the side where the obstruction is located. These cyclists have priority over the cars that approach the crossing from the left side. The view of the cyclists towards the cars coming from the right side is far less obstructed: TTC_d is roughly 0.75 sec larger for cars from the right than for cars from the left side (at an average bicycle speed of 15 km/h). During a typical weekday morning, the speed profile has been measured for 44 bicycles that approached the *Boslaan* from the side of the view-blocking obstruction. Using the video recordings and the speed profile measurements from the radar, the behaviour of the cyclists has been determined. A distinction was made between the trajectory of the cyclist (going straight, turning right, turning left) and the traffic conditions due to crossing cars during the cyclist's approach. This leads to the results as given in Table 2. From these results it can be seen that major part of the cyclists (over 85%) stop pedalling when approaching the intersection (from the direction as indicated in Figure 11).

Table 2 Results for bicycle measurements (*Son en Breugel*)

Bicycle manoeuvre		*Stopped pedalling*		*Continued pedalling, continued riding*	*Total*
		Continued	*Full stop*		
Straight	**total**	**20**	**9**	**4**	***33***
	no cars present	9			*9*
	car from left	8	2	2	*12*
	car from right	3	7		*10*
	car from both sides			2	*2*
Turning left	**total**	**4**	**6**	**2**	***12***
	no cars present	3	1	2	*6*
	car from left		2		*2*
	car from right		3		*3*
	car from both sides	1			*1*
Turning right	**total**	**1**	**0**	**0**	***1***
	no cars present				
	car from left				
	car from right				
	car from both sides	1			*1*
Total # bicycles		*25*	*15*	*6*	*46*

In Figure 13, the speed profiles of the cyclists as measured by the radar are plotted versus the distance to the ‘collision point’ (the point where the bicycle path crosses the vehicle path).

While most bicyclists stopped pedalling but continued riding, a decrease in the speed is seen for all bicycles. The 50th-percentile speed profile starts at a speed of almost 14 km/h (rather similar to the average bicycle speed found in accident studies [4], [11]) and a decrease in speed with almost 6 km/h has been measured in approach of the crossing with the view-blocking obstruction. No bicyclist during the measuring period maintains a speed higher than 10 km/h. It also seems at this intersection, that a larger speed reduction is found for faster driving bicycles.

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

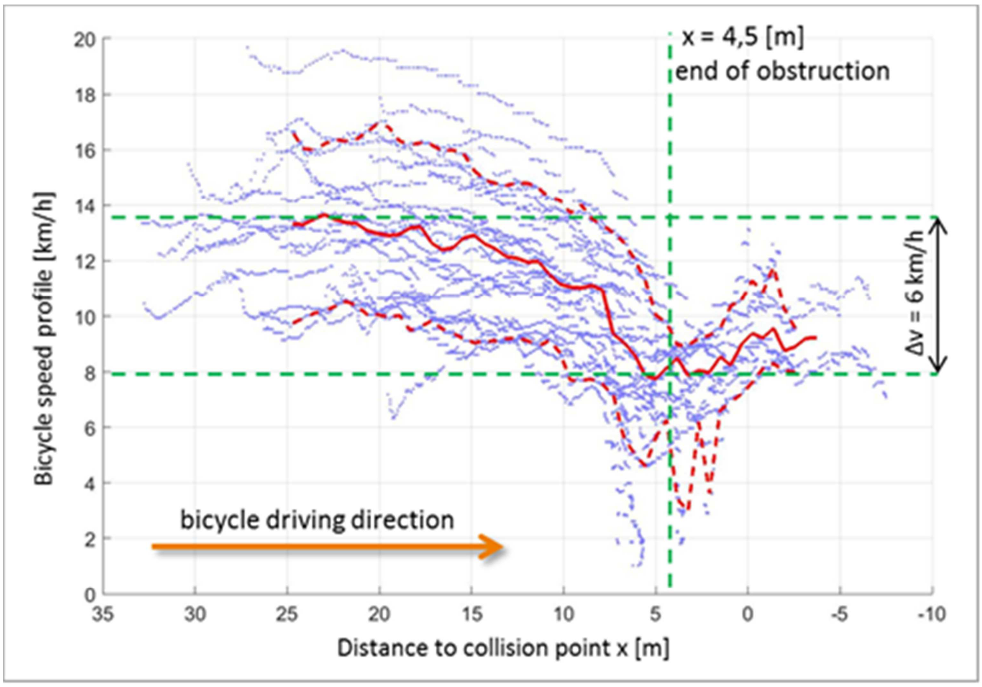


Figure 13 Measured bicycle velocity profiles near a severe view-blocking obstruction. In blue the different profiles for 27 cyclists that the radar could distinguish during the full approach of the crossing. The solid red curve indicates the 50th-percentile profile; the red dashed lines indicate the 10th and 90th-percentile curve.

3.1.3 Results passenger cars

In a similar way as for the cyclists, speed profiles have been determined for the passenger cars approaching this intersection. Also these measurements have been performed during a typical weekday morning. The speed profiles for 340 cars approaching the intersection from the direction with an obstructed view (Figure 11, left) have been determined. Subsequently, the profiles for 321 cars approaching the same crossing from the opposite side (with unobstructed view) have been measured (Figure 11, right). The results for the car speed profiles are shown in Figure 14.

The 50th-percentile curves (the solid red lines in both figures) show that the median approach speed from both sides is almost equal at 37 km/h. Similar velocities are found in accident data [4]. Where in the obstructed case, the speed during the approach is only reduced to 27 km/h (10 km/h speed reduction), in the unobstructed case, the speed reduction is approximately 15 km/h.
The larger median speed reduction for the situation where no view-blocking obstruction is present, is explained by the fact that cars approaching the non-obstructed side street, have to give yield to all traffic, not only cyclists but other cars as well. Since the traffic from the right is easily seen by the drivers, most cars reduce speed and in many cases even stop completely.

The village council of *Son en Breugel* placed a traffic sign (Figure 7) to specifically warn drivers for cyclists coming from the right at the intersection with the severe view blocking obstruction. At the time of the measurements, this traffic sign was <u>not</u> present. It had been removed for several months.

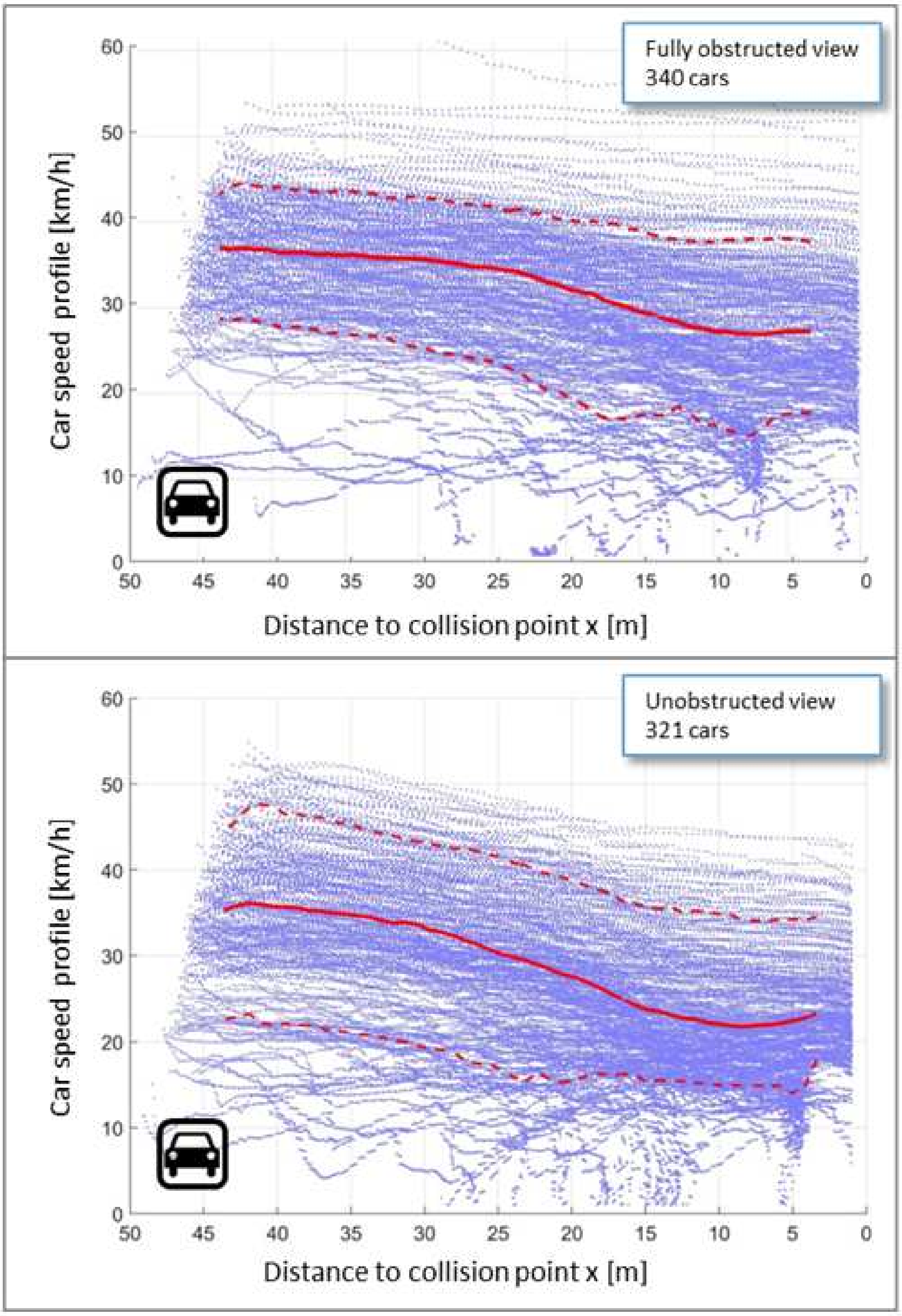


Figure 14 Radar measured speed profiles (blue curves) for cars crossing the intersection from the direction with view-blocking obstruction and the opposite direction without view-blocking obstruction. The solid red curve indicates the 50th-percentile profile; the red dashed lines indicate the 10th and 90th-percentile curve.

3.2 Results Eindhoven

3.2.1 Description of the measurement site

The second intersection with view-blocking obstruction has been studied in the centre of *Eindhoven*, corner *Hastelweg – Sint Trudostraat*. In this case, the permanent obstruction is a house, separated only from the road by a pedestrian sidewalk. It is a 4-armed crossing in a 30 km/h living area, with a significant amount of traffic. The obstruction is challenging as parked cars in the side street force bicycles (and other traffic) to drive close to the middle of this street. With dimensions D_{O1} = 4.3 m and D_{O2} = 4.9 m, this obstruction is slightly more severe (lower TTC_d for similar v_c and v_b) than the one in *Son en Breugel*. Figure 15 shows the TTC_d for a crossing scenario with these obstruction dimensions for varying car and cyclist velocity.

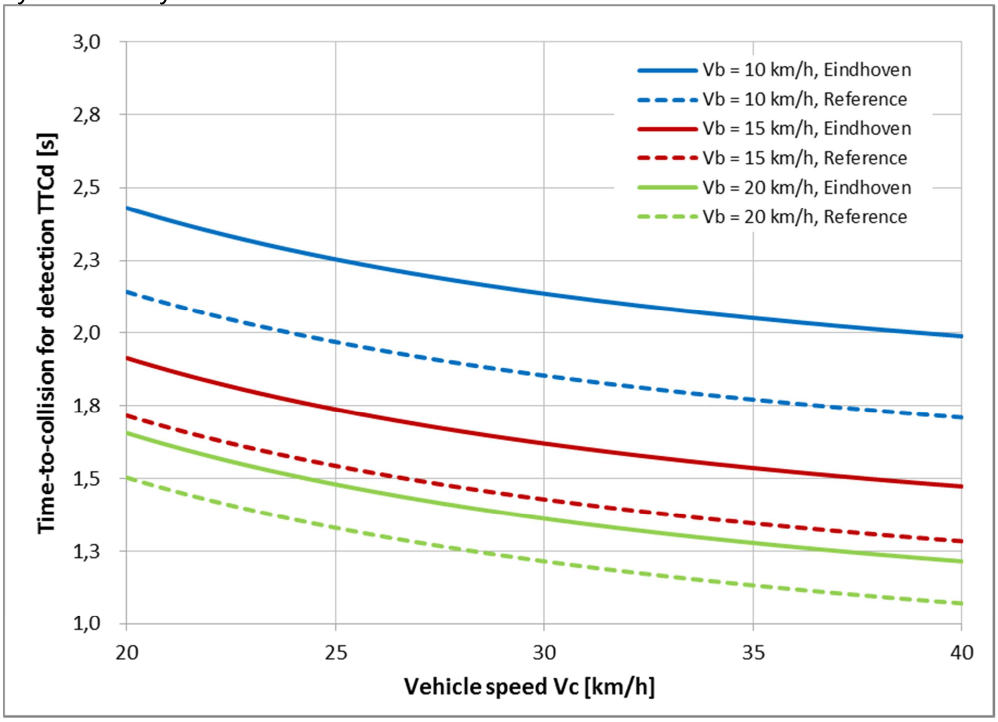


Figure 15 Time-to-collision for detection (*TTC_d*) at the obstructed crossing in *Eindhoven*, as function of both bicycle speed v_b and vehicle speed v_c (solid lines) The graphs shows the TTC_d values for the reference crossing as well (D_{01} = 3.55m, D_{02} = 4.80m) (dashed lines).

At this intersection, measurements were performed on a weekday in April 2015, from 7h15 till 11h15. It was a cold but sunny day, without precipitation.

Figure 16 Intersection at *Sint Trudostaat – Hastelweg Eindhoven* with a house as view-blocking obstruction

The intersection layout is shown in Figure 16. The orange arrow indicates the bicycle traffic coming from the right that has been studied, where the red arrow represents the car traffic that needs to give priority to all traffic (vehicles and bicycles) from the right. Although the road markings make this intersection look like a roundabout, it is not used as a roundabout. Neither the cyclists nor the passenger cars follow the circular pattern of the markings when making a turn. The very shallow speedbump that is integrated in the intersection does not challenge the speed of any traffic participant.
Due to the character of this intersection, in all directions a mixture of bicycles, cars and other traffic participants is found. During the measurement period of 4 hours in peak traffic in the morning (starting at 7:00), more than 500 cars and more than 200 bicycles were counted. In case of multiple objects being simultaneously present in the field-of-view of the radar, it appears difficult to distinguish the separate traffic partners over the full range of travel. For this reason, in this report only the behaviour of the bicyclists in approaching the intersection with the blocked view will be reported.

3.2.2 Results cyclists behaviour

Similar to the analyses in *Son en Breugel*, a distinction has been made for the behaviour of the bicyclists coming out of the side street. The intended direction of the bicyclist was recorded, as well as the shown behaviour: stop pedalling or continue pedalling, coming to a full stop or continue riding.
From 175 out of more than 200 cyclists, the pedalling- and stop/go-behaviour has been determined. For the cyclists going straight, more than 90% stopped pedalling (including cyclist that came to a full stop). Even with no cross-traffic, the vast majority of cyclists stops pedalling during the approach of the intersection. Only when a cyclist is turning right, hence no interaction with other traffic is expected, the number of cyclists that continue pedalling is twice the number of cyclists that stop pedalling. In all other cases, more cyclists stop pedalling than continue pedalling.
A quick check of the speed profiles for cyclists shows that also for Eindhoven a decrease in speed in approaching the crossing. Since distinguishing of cars and cyclists in the radar results is near impossible, the speed reduction could not be quantified accurately. However, a first estimate is between 4 and 5 km/h speed reduction for the cyclists.

Table 3 Results for bicycle measurements (Eindhoven)

Bicycle manoeuvre		*Stopped pedalling*		*Continued pedalling, continued riding*	*Total*
		Continued	*Full stop*		
Straight	**total**	**68**	**38**	**15**	***121***
	no cars present	25	0	4	*29*
	car from left	17	14	5	*36*
	car from right	14	13	6	*33*
	car from both sides	12	11	0	*23*
Turning left	**total**	**16**	**6**	**1**	***23***
	no cars present	5	0	0	*5*
	car from left	7	0	0	*7*
	car from right	3	3	1	*7*
	car from both sides	1	3	0	*4*
Turning right	**total**	**9**	**2**	**20**	***31***
	no cars present	2	0	10	*12*
	car from left	4	0	3	*7*
	car from right	2	0	6	*8*
	car from both sides	1	2	1	*4*
Total # bicycles		*93*	*46*	*36*	*175*

3.3 Results cyclists leg position

For the cyclists that stopped pedalling when approaching the intersection, the leg position was evaluated as well. Since leg position is not expected to be related to a specific crossing, but rather to a personal preference and/or intended manoeuvre of the cyclist, the results for both the *Son en Breugel* and *Eindhoven* observations are combined.
The leg position for cyclist that stop pedalling has been divided in three categories:

- *Up-down*: One leg up, other leg down; feet are in a (close to) vertical line.
- *Front-rear*: One leg positioned forward, other backwards; feet are in a (close to) horizontal line.
- *Intermediate*: Positioning of the legs in between up-down and front-rear; feet are in a (close to) diagonal line.

No distinction has been made between which leg was up, down, forward or backward.
The results of these observations can be found in Table 4. The up-down configuration was most common in the observation studies (around 66%, 62 out of 94). This information has been taken into account in the dummy cyclist design, where the up-down configuration has been selected [12].

Table 4 Positioning of the legs of cyclist that stopped pedalling when approaching the intersections investigated in this study, both in absolute numbers (TOP) as percentages (BOTTOM).

Bicycle manoeuvre	*Up-down*	*Front-rear*	*Between up-down and front-rear*	*Total*
Straight	49	18	4	71
Turning	13	9	1	23
Total # bicycles	62	27	5	94

Bicycle manoeuvre	*Up-down*	*Front-rear*	*Between up-down and front-rear*	*Total*
Straight	69%	25%	6%	100%
Turning	57%	39%	4%	100%
Total # bicycles	66%	29%	5%	100%

4 Conclusions and recommendations

The purpose of the observation study described in this report is to evaluate the behaviour of cyclists and cars when approaching an intersection where the view towards each other is obstructed (by for example a building or vegetation). Accident data usually does not describe behaviour of bicyclist (or cars) in their approach of an intersection, while these parameters (e.g. speed reduction, pedalling behaviour) are important when describing a test scenario.

Although the data collected for the intersection in *Eindhoven* has not been analysed to the same detail as that for the intersection in *Son en Breugel*, conclusions are drawn based on the observations in *Son en Breugel* and *Eindhoven*:

- Bicyclists appear to reduce their speed in the approach of an intersection, in case the view at the intersection is severely hindered by a permanent full view-blocking obstruction. Approximately 6 km/h of speed reduction was measured in one case, and in the other case the speed reduction was estimated at 4 to 5 km/h. A speed reduction always coincides with the fact that bicyclists stop pedalling. For all cyclists observed during this study, more than 80% stopped pedalling in approaching the intersection with view-blocking obstruction. For the cyclist that stopped pedalling, the majority (around 66%) stopped with one leg up and the other leg down.
- Also cars generally reduce speed in approaching the intersection. However, it appears to be very difficult to distinguish between the influence of the geometrical layout of an intersection and the interaction with other traffic participants, as these are interrelated, e.g. by traffic rules. Where for cyclists, a severe view-blocking obstruction prevents early anticipation on cross-traffic, a severe obstruction for car drivers might cause them to overlook the traffic from the right that might appear from behind the obstruction. This could explain the fact that the measured speed reduction for cars in the obstructed case was less (in average) than the speed reduction for the unobstructed case (*Son en Breugel*). However, based on the currently available information, no general conclusions can be drawn regarding the speed reduction of cars in the presence of a view-blocking obstruction.
- A speed reduction of the bicycle from 20 to 15 km/h results in an increase of the TTC to detection (TTC_d) of approximately 0.25 seconds. A further speed reduction from 15 to 10 km/h, would lead to an additional increase in TTC_d of approximately 0.50 seconds.

With a number of two crossings that have been studied to determine the influence of a view-blocking obstruction on the behaviour of cyclists and car drivers, the possibility to generalize these conclusions is rather limited. Moreover, both observed crossings are located within a radius of 10 km of each other in the Netherlands. Crossings according to the same selection criteria (Section 2.3) were found in Cologne, Germany, however these selected crossings appeared not to provide enough throughput of cyclists to be used as a feasible test site.

Based on the results of this observation study, the cyclist velocity in the obstructed crossing scenario (CVNBO) is set to 10 km/h (as a comparison, the cyclist velocity for the unobstructed crossing scenario (CVNBU) is set to 15 km/h).

The car velocity for the CVNBO scenario is varied between 10 and 40 km/h (20-60 km/h for CVNBU)

Non-pedalling legs are observed in a significant part of the bicyclist approaching crossings. For that reason it was decided to have non-pedalling legs in the CATS target. Moreover, the leg up-down configuration was most common and will therefore be used in the bicyclist target specification.

5 Signature

Helmond, September 2nd 2016

TNO

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7 Acknowledgements

The CATS project gratefully acknowledges the contributions from:

A Radar signal outputs

A list of the output signals from the Continental SSR 208 radar can be found in Table 5.

Table 5 Overview of outputs from the Continental SSR 208 radar as used in this study to measure velocities of cars and cyclists

	min	***max***	***unit***	***Rate/s***	***description***
CONTI_TRACK_ID	0	65535	-	~33	Unique track ID
CONTI_TRACK_INDEX	0	24	-	~33	Current index of the track in the track list
CONTI_TRACK_LONGDISP	0	51,1	m	~33	Longitudinal displacement
CONTI_TRACK_LATDISP	-51,1	51,2	m	~33	Lateral displacement
CONTI_TRACK_VRELLONG	-35	35	m/s	~33	Relative longitudinal velocity
CONTI_TRACK_VRELLAT	-32	31,75	m/s	~33	Relative lateral velocity
CONTI_TRACK_ROLLCOUNT	0	3	-	~33	The rolling counter is incremented with each valid message
CONTI_TRACK_RCSVALUE	-50	30	dBm^2	~33	Radar cross section
CONTI_TRACK_LIFETIME	0	6553,5	s	~33	The current lifetime of the track. In case the lifetime exceeds 6553.5 the value remains at this maximum value
CONTI_TRACK_INDEX2	0	24	-	~33	Current track list index of this track
CONTI_TRACK_ROLLCOUNT2	0	3	-	~33	The rolling counter is incremented with each valid message
CONTI_TRACK_STATUS_COUNT		25/255	-	~33	Number of measured tracks in this cycle
CONTI_TRACK_STATUS_ROLLCOUNT		65535	-	~33	The rolling counter is incremented with each valid message