Delivery Report for

MeBeSafe

Measures for behaving safely in traffic

Deliverable Title	Report simulation environment
Deliverable	D2.2
WP	WP2 In-vehicle nudging solutions
Task	Task 2.5 Solution selection

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Abstract

This report describes the simulation studies that are conducted to find the most promising in-vehicle nudging solution to direct the attention of drivers of passenger cars towards potentially hazardous situations.

Therefore different simulation studies have been carried out.

- Study on different human machine interface (HMI) designs with 24 volunteers:six different designs have been tested with 12 female and 12 male participants and all of them hold a driving license.
- Driving simulator study to compare the driver behaviour without a nudging HMI with the behaviour using some different nudging HMIs.
- The driving simulator experiment was on nudging HMI used a within-subject-design, in which each of the 30 participants was exposed to different test conditions in the different driving scenarios.
- Simulation study on the static hazard model.
- Simulation study to support the development of the dynamic hazard model.

The virtual test environment and driving simulator will be used to perform optimization and for tuning the system parameters.

Based on the results (will be included in D2.3), the most promising nudging solution to direct the attention of drivers to potentially hazardous situations including an appropriate HMI will be implemented into the (FIAT 500X) test car for validation in a field test (WP5).

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1 Introduction

1.1 MeBeSafe and Work Package 2

The aim of the MeBeSafe project is to develop, implement and validate measures that direct road users towards safer behaviour in common traffic situations. MeBeSafe is planning to do this by changing habitual traffic behaviour using 'nudging' and coaching, with the aim of improving driving behaviour. Nudging is a technique that subconsciously stimulates drivers to drive safer, while with coaching, drivers are given feedback on their driving behaviour by a coach in order to learn about their own driving behaviour and enhance driving performance. The main aim of WP2 is the development and implementation of in-vehicle hardware and software solutions to nudge drivers of passenger cars to show safer behaviour. Moreover, an interface to in-vehicle sensor systems, e.g. to provide an off-line coaching scheme with the necessary information, will be implemented in WP2.

MeBeSafe is organised in altogether 6 Work Packages (WPs), as shown in Figure 1.

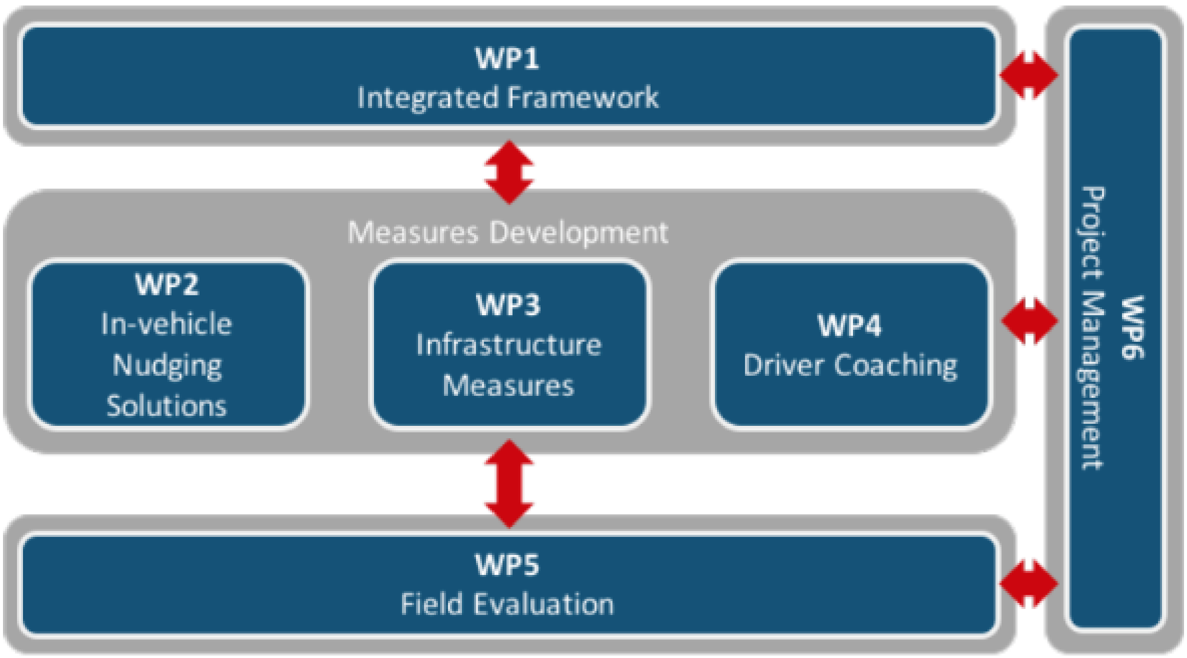


Figure 1 Work packages in MeBeSafe.

The in-vehicle solutions are mainly dedicated to drivers of passenger cars, with a focus on stimulating the use of safety functions, particularly Adaptive Cruise Control, and directing the driver's attention to potential hazards. In this report (D2.1), different possible solution concepts will be proposed. As development and implementation of a prototype solution into a vehicle (up to a level that the vehicle is allowed to drive on the road) is very costly, an evaluation funnel is developed in T2.5. With the evaluation funnel, consisting of a combination of driving simulator tests and virtual simulation tests, the most promising solution will be selected for implementation.

WP2 targets solutions to meet the following MeBeSafe objectives:

- **O2: Increase the use of Adaptive Cruise Control systems** throughout the journey to prevent close following. Insufficient distance between vehicles in close following are a direct causation in 10% of road accidents [2].
- **O3: Direct the attention of the driver to potential hazards** to increase the timely perception of actual hazards. "Failure to look properly" has been shown to be a major causation factor in 30% of accidents [4].

1.2 Description of Tasks

Task 2.1 – Sensing driver and vehicle state

Interfaces will be defined and implemented with the sensors that provide information on the driver and vehicle state:

- Interface to the driver drowsiness state sensor as implemented in VCC cars including a definition and implementation of data transfer to a VCC coaching app.
- Interface to the driver direction of attention sensor that is used during the tests to evaluate the different solutions to influence the drivers direction of attention.
- Interface to get information regarding the vehicle state such as current speed, heading, and acceleration, and whether ACC is switched on or not.

Task 2.2 – Sensing and predicting cyclist intent

To provide the appropriate nudging information towards the driver in an earlier stage than when a critical situation is imminent, information on the intent of cyclists that might interfere with the path of the host vehicle needs to be available some seconds before the critical situation occurs. This information comes available from the interpretation of the vehicle's sensor system. Based on the view of the bicycle's trajectory over the last few seconds, a prediction is made over the intended trajectory for the coming seconds. The prediction will come with an estimated probability for the cyclist's manoeuvre. To develop such a sensing and prediction system requires the following tasks:

- Develop a probabilistic cyclist's intent prediction model for the most common interaction scenarios between cyclists and passenger cars on a typical intersection.
- Perform an observation study to determine typical bicycle-to-car manoeuvres and to estimate the model parameters.
- Perform a sensor study to determine the accuracy of path prediction of a cyclist, based on in-vehicle sensor observations. In this way, the detections made in the observation study are coupled to the paths as monitored from the car.

Task 2.3 – Hazard perception and prediction

Current Autonomous Emergency Braking systems only brake when a collision with a (cyclist) target is imminent. The AEB decision logic and control law uses the relative position and movement of the target to make this judgement. Nudging responses to the driver need to occur at a larger distance from the (potential) targets, whose positions and intended manoeuvres with respect to the car need to be known (or estimated), considering the local relevant traffic rules and infrastructure layout. The objective of T2.3 is to build a world model based on an available map (public domain), the localization of the host vehicle on this map and the location and intended manoeuvres of surrounding cyclist targets from the vehicle's sensor information. The world model consists at each point in time of all relevant information for the decision logic and control law to respond with appropriate nudging actions. The development of the world model includes:

- Interfacing to a GPS-based map, using the GPS position of the host vehicle and the corresponding driving direction.
- Sensing possibly hazardous situations from fusion of sensor data (obstructions e.g. by parked cars) and the world map regarding possible traffic crossing the host vehicle path. Relevant information from the UDRIVE project [1] will be utilised.
- Integration with the target intent models to provide a complete picture of potential hazards and probability measures. A simulation application is built as a development tool to carry out stochastic simulations in order to support the development. Its purpose is to determine the difference between actual hazard and perceived hazard.

Task 2.4 – In vehicle nudges

The information on a possibly hazardous situation is input to nudge the driver several seconds before a cyclist is crossing the path of the host vehicle. The nudge is intended to avoid any critical situation. Should a critical situation occur (i.e. a Time-to-Collision of < 2 sec), then the available advanced driver assistance system (ADAS) should be triggered in addition to the nudge. The objective of T2.4 is to design the decision logic and control law of the nudging system according to the framework of WP1. Output from these systems is provided to a human-machine-interface (HMI), which is also developed and implemented in this task.

For the Adaptive Cruise Control (ACC) awareness nudging, the main approach is to present the driver with information on current percentage of ACC usage (by the driver) over a certain prior time period in such a way that usage of ACC is encouraged.

For the intersection conflict nudge, information on possibly hazardous situations will be presented several seconds before they are predicted to escalate (e.g. a cyclist is crossing the path of the host vehicle), in order to nudge the driver towards adaptation of larger safety margins, and hence avoid the potentially critical situations.

The actions to be undertaken within this task are:

- o Decision logic and control law development and implementation;
- o HMI development for Directing the Driver Attention towards possibly hazardous situations involving crossing bicycles;
- o HMI development for ACC Awareness;
- o HMI implementation for evaluation in a virtual test environment and for testing in the driving simulators at FIAT Chrysler Automobiles (FCA) and Volvo Car Company (VCC).

Task 2.5 – Solution selection

A task in which different options for in-vehicle nudging solutions as proposed and developed in tasks T2.2, T2.3 and T2.4 will be evaluated in driving simulator tests, and by means of virtual simulations. It is the objective of task T2.5 to select the most promising and feasible option for implementation in the test vehicles for testing in WP5.

Task 2.6 – Implementation of the nudge solution in the test vehicles

Based on the results of task T2.5, the nudging system and corresponding HMI will be implemented into the test vehicles for validation in a field trial (WP5). The vehicles will be prepared to run a field trial. Results out of the field trial will be used to update and optimize the system.

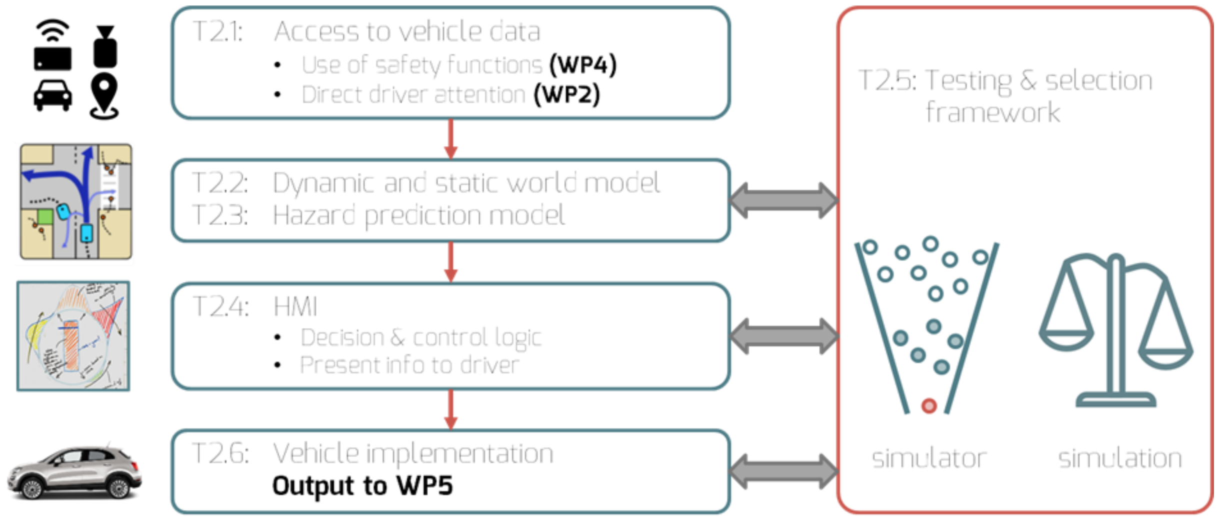


Figure 2 Schematic overview of tasks and their relations in WP2.

1.3 Structure of deliverable and contribution by partners

In this deliverable we, focus to select the most promising and feasible option for implementation in the test vehicles for testing in WP5.. Therefor the next sections show which activities have been performed to achieve these objectives. The different studies are used to optimize different parts of the solution: HMI via questionnaire to limit the number of options towards a simulator study to optimize the timing and visuals. Virtual simulations are used to finetune and calibrate the parameters in both the static and the dynamic hazard model.

Requested output: One solution for implementation in a vehicle. A solution consists of a hazard model (enriched with a cyclist prediction model) and an HMI that based on the estimated hazard level (evolution) provides a nudge to the driver.

OFFIS focussed on:

- HMI design for the Directing Driver attention use case
- Design study based on questionary with participants to find the most pomising design solutions for further analyses in the driving simulator study

CRF focussed on:

- Evaluating the different MeBeSafe in-vehicle nudging solutions. Evalation was done in the CRF Virtual Reality Driving Simulator and the simulator was chosen as the testing facility solutions as it guarantees the possibility to manipulate both the presentation of different visual nudging stimuli and critical road scenarios in a controlled, repeatable and safe environment.
- The study conducted in the CRF Virtual Driving Simulator compares driving scenarios with and without novel in-vehicle nudging HMI solutions in order to assess their hypothesized impact on driving behavior

Virtual Vehicle focussed on:

- Simulation study on the static hazard model, especially setting up and running simulations for a plausibility analysis of the static hazard model parameters. In contrast to the simulator study and the dynamic hazard model study, this study does not consider any driver reactions. Furthermore it produces data equivalent to a time period of one year which hardly is not feasible using a driving simutator
- The simulation study performed by Virtual Vehicle is used to examine the sensitivity of parameters in the static hazard prediction model, in order to calibrate the model such, that an intuitively reliable hazard evolution (with time or distance to the intersection) in the approach of the cyclist crossing results

BMW focused on:

- Simulation study on the dynamic hazard model.
- Four different simulation studies have been conducted:
  - Study on the likelihood of detection in case of a visual obstruction;
  - Study on the likelihood of a collision depending on reaction time point;
  - Study on the required speed reduction in order to achieve a certain post encroachment time (PET);
- Study on the effectiveness of different activation thresholds of the dynamic hazard model.

2 Executive Summary

This report describes the simulation studies to find the most promising in-vehicle nudging solution to direct the attention of drivers of passenger cars towards potentially hazardous situations. These solution will be implemented in one FIAT vehicle for evaluation in the field test of WP5. For the planned systems it is necessary to analyse the best parameters and design because it is just possible to implement the most promising system. With the simulation and the simulator studies, MeBeSafe analyses different ideas and design of systems. Within the simulation it was possible to investigate a lot of different parameters and also a large number on accident possibilities based on UDRIVE naturalistic driving studies.

Simulation/simulator are used because:

- No hardware and software implementation of the full nudging system is needed to get access to the performance of such a system;
- A huge number of different use cases can be efficiently compared;
- Test matrix can be extended to use cases that cannot or can hardly be tested in the real world;
- Parameter studies can be performed with more efficient use of resources (cost and time) compared to other evaluation methods.

In virtual simulation, thousands of variations on tests are performed, needed to check whether the system responds technically correct in all possible circumstances. Such a virtual simulation environment is however not appropriate to check the response of a human driver to an HMI design. For such human-in-the-loop tests, where an actual implementation in a vehicle is lacking, driving simulator tests are proposed, as the human participant in the test is put in a reasonably realistic environment (a mock-up of a vehicle) in which different designs of the HMI can be implemented without facing the difficulties of true integration in a vehicle that is allowed for driving on the road. In a driving simulator, sensors can be directed towards the driver to measure the response of the driver quantitatively, in addition to subjected results that are acquired from questionnaires that are completed by the participants.

The final check on the effectiveness of a system involving an HMI requires a field operational test (FOT), with a vehicle in which the solution has been implemented is driven on the road by naïve drivers. Only such tests show the realistic environment with other road users that are needed for a solid conclusion on the effectiveness of a system. This cannot be achieved in any type of simulation study. In the MeBeSafe project, the complete spectrum of tests in parallel to system development has been used to come to the best possible and feasible solution. The design of the FOT is provided in D5.4 whereas the results of the FOT are given in D5.5.

2.1 First solution selection – Questionnaire study OFFIS

The HMI design phase of WP2 led to six different design variants (which was the result of MeBeSafe workshop in January 2018 at OFFIS in Oldenburg) applicable in the MeBeSafe context for the Directing Driver attention use case. The design variants have been described in MeBeSafe Deliverable D2.1. This first evaluation was based on a digital questionnaire study. The questionnaire started by showing 18 different pictures in randomized order and the participants got no explanation in the first step. Subsequently, each design was explained to the participants and the participants were asked to state their behavior when seeing a picture showing a hazardous situation. The participants were additionally asked to answer questions derived from System Usability Scale.

2.2 Driving Simulator study CRF

The CRF Virtual Reality Driving Simulator was chosen as testing facility for evaluating the different MeBeSafe nudging solutions because it guarantees the possibility to manipulate both, the presentation of different visual nudging stimuli and critical road scenarios in a controlled, repeatable and safe environment. The scenario considered is a urban one and during the trial, data are registered, such as driving behaviour, eye movements and subjective measures with the purpose of evaluating the designed MeBeSafe nudging HMIs. The task of the study was to compare the driver behaviour without a nudging HMI with the behaviour when different nudging HMIs are applied to evaluate the added value of a nudging stimulus in not influencing the driver behavior negatively.

2.3 Simulation study on the static hazard model Virtual Vehicle

The focus of this simulation study lies on the static hazard model, especially setting up and running simulations for a plausibility analysis of the static hazard model parameters. The simulation is used to evaluate the output of the static hazard model in an intersection scenario. The parameters in the hazard model are varied to understand the sensitivity of the computed hazard evolution in the approach of an intersection. Based on the outcome, a set of parameters is selected to fit the hazard evolution to what may be expected in such an approach.

2.4 Simulation study on the dynamic hazard model BMW

Additional simulation studies have been conducted in order to support the development of the dynamic hazard model. Four simulation studies have been conducted:

A. Study on the likelihood of detection in case of a visual obstruction;
B. Study on the likelihood of a collision depending on the time of response by the approaching car;
C. Study on the required speed reduction in order to achieve a certain post encroachment time (PET);
D. Study on the effectiveness of different activation thresholds of the dynamic hazard model.

Since the scope of the studies for the dynamic hazard model differs, the test design is not common among the studies. Therefore, test design is described for each separately. The studies follow the simulation approach known from the simulation based safety impact assessment.

3 Description of Tasks

This Task focused on the analyses of different HMI`S and finetuning the static and dynamic hazard model that is essential input for the HMI. The most promising nuging solution should be used for the field trial in WP5.In a virtual environment, a first selection of promising options is made. The virtual test environment is also used to perform optimization and tuning of the system parameters.. The selected options are tested in a driving simulator study. In this study, volunteers are recruited to test the performance of the different variants of the feedback measures. Based on a first evaluation in the simulator, the parameters in the system are further adjusted and optimised. In a second evaluation, a selection is made of the system to be implemented in a test car. Based on the results, the feedback measures and corresponding HMI will be implemented into the (FCA and TNO) test cars for validation in a field test (WP5).

This task includes the following actions:

- Implementation of models of the different options of the nudging system into a virtual test environment. This includes a representation of the sensors, the world model and the path prediction (where relevant) and a representing model for the nudge system actuation.
- Typical test cases to trigger the system are used as input to the virtual test environment for validation and testing. Scenarios are either build from typical Euro NCAP test cases, from typical scenarios found in the observation study (T2.2) and from UDRIVE (SWOV) naturalistic driving studies.
        - Simulation studies are used to finetune the static and dynamic hazard model that is essential input for the HMI
    - Driving simulator tests:
        - Design tests to be performed in the driving simulator, and preparation of the scenarios to be used in the driving simulator.
        - Implementation of the hardware/software solution into the driving simulator.

  - Recruiting volunteers to test several options in the driving simulator and perform driving simulator tests.
  - Provide feedback to the system engineers for optimizing the system parameters.
  - Simulator studies are performed to select the best HMI to direct driver attention.
- Select the option for implementation in the vehicle to be evaluated in WP5 (field trial).

4 First HMI solution selection – Questionnaire study (OFFIS)

The HMI design phase of WP2 led to six different design variants applicable in the MeBeSafe context for the Directing Driver attention use case. The design variants have been described in D2.1 and are shown in Figure 3 .

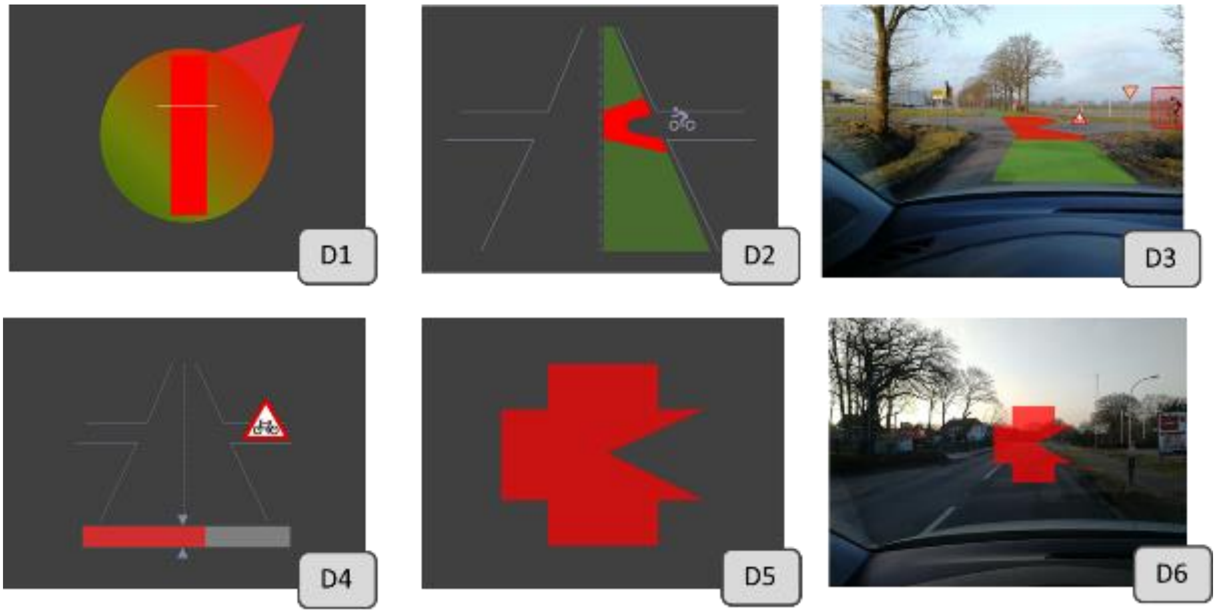


Figure 3 Concept designs for the HMI to direct driver attention to potential hazards.

As n = 6 design variants are too many to be tested in a *within-subjects-design* in the driving simulator, OFFIS conducted a first empirical study to reduce the number of designs to be tested in the simulator study. This first evaluation was based on a questionnaire study. The next section describes the design and purpose of the questionnaire followed by the sample description.

4.1 Participants

N = 24 participants (12 female) with a mean age of M = 30.96 years (SD=13.66, range: 19 – 58 years) took part in the study. Two of them had a visual impairment influencing their color vision. They were not excluded as all designs mind visual color impairment by double-coding information (e.g. by presenting the same information via color <u>and</u> shape). All participants hold a driving license since 13.54 years (SD=13.03, range: 3 – 40 yers). Most participants had medium driving experience and drive around 5.000 – 10.000 km per year.

Since the participants are only asked to provide their impressions regarding the different visual HMI options, and no response to the HMI is expected, no specific bias in the selection of participants is required to include more participants representing the risk groups in traffic, such as young men and seniors at 70+ years. The possible degradation in visual perception by seniors is taken into account appropriately by including two participants with a visual impairment regarding specifically the perception of color.

Since the investigated HMI concepts are based on low-level psychological human vision traits, which are not dependent on the level of education, no specific selection criteria for educational level of the participants have been considered.

4.2 Questionnaire design

OFFIS made a digital questionnaire using the google forms tool (extract shown in Figure 4).

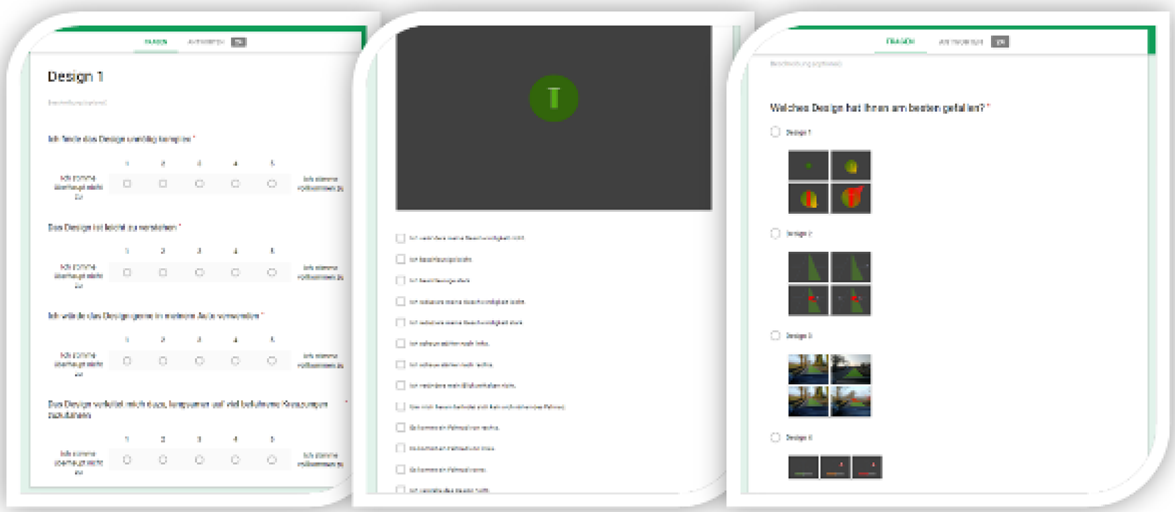


Figure 4 Questionnaire (visual impression).

The questionnaire provided a mixture of own questions (to assess participants reaction to design pictures) and derived questions from standardized questionnaires (SUS) [20]. The questionnaire started by explaining the situation (approaching an intersection) and by showing n = 18 different design pictures accompanying this situation in randomized order. These pictures showed the different design variants – as presented in the prior section in Figure 2 - in n = 3 different situations: One situation showing a non-hazardous situation, one example showing a medium hazardous situation and one example showing a hazardous situation. This is exemplarily shown in Figure 5 for Design D5.

Figure 5 Pictures showing different hazard-levels for design D5.

The participants were allowed to choose none of the given answers in case none of the answers was applicable for them.

With this, OFFIS assessed in how far participants adapt their behavior intuitively in response to the pictures with regard to the speed and gaze behavior as asked in the questions. Other behavioural adjustments were not examined.

After this, each design was explained to the participants. After getting the explanation, they were again asked to state their behavior when seeing a picture showing a hazardous situation. With this question, OFFIS assessed how participants adapt their behavior after having received an instruction on how to interpret the designs

Furthermore they were asked to answer the following questions (derived from SUS (System Usability Scale) [20]) for each design using a 5-point Likert (from 1=totally disagree to 5=totally agree) scale:

- I think the design is too complex.
- The design is easy to understand.
- I would like to use the design in my car.

At the end the participants were asked to select their favorite design.

This selection was made because the focus was on assessing intuitive understanding. We assumed that further questions of the SUS like "I would imagine that most people would learn to use the systemvery quickly" could not be answered with certainty by the participants after the short use of the designs.

Details about the participants and the results are given in the subsequent sections.

4.3 Results

The results are subdivided into the reaction of the participants before explanation, their reaction after explanation, the design complexity and understanding and design preference of the participants:

4.3.1 Reaction (before Explanation)

With the n = 18 pictures showed in random order at the beginning of the questionnaire, we captured data about participant's reaction. As no design explanation has been given to the participants, we hypothesize that their reactions reflect the intuitive response when seeing the display. This can be further subdivided answers given with regard to speed adaptation and with regard to gaze behavior adjustment.

Speed Reduction

We evaluated the participants answers on how to adapt speed in the different situations. The design is aimed to nudge the driver to slow down speed in hazardous situations. We evaluated if the stated participants reaction was correct with regard to the hazard level of the situation shown in the picture (with 0 totally wrong to 1 totally right). Figure 6 shows the mean correctness level of the reaction for the different designs 1-6 (as shown in Figure 2).

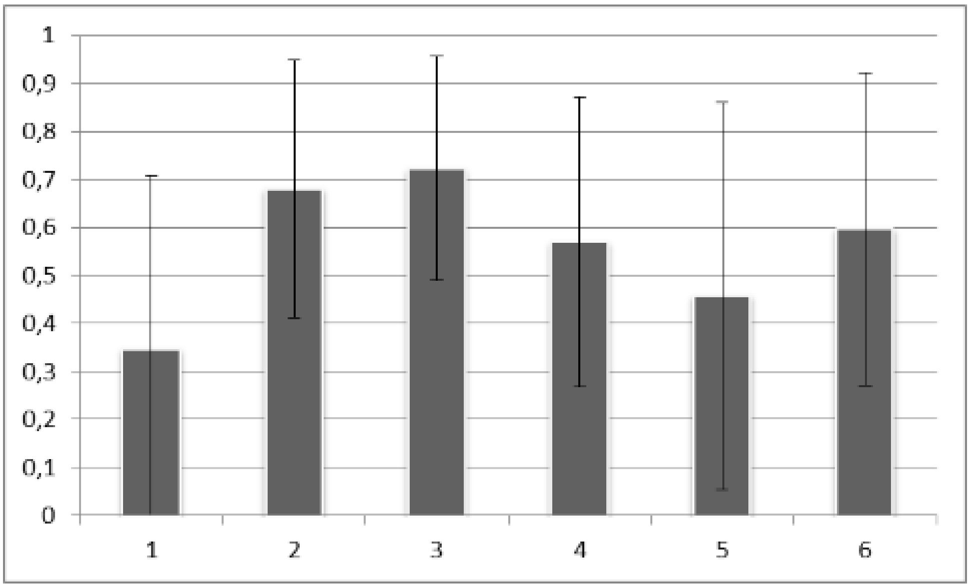


Figure 6 Mean correctness of speed adjustment for 6 different designs.

The exact values are given in the table below.

Design	D1	D2	D3	D4	D5	D6
Mean Correctness	0.34	0.68	0.72	0.57	0.46	0.6

Table 1 Values for correctness level for adapting speed in the situation.

An ANOVA (F (2,3) = 4.57, p < .001.) reveals that there are significant differences between the results. Thus, we compared the designs pairwise using T-Tests. The resulting p-values are shown in the upcoming table (orange indicates that there is a significant difference with p<0.05 (based on Fisher Criterion).

	D1	D2	D3	D4	D5	D6
D1		0.001	<0.001	0.0074	0.125	0.01
D2	0.001		0.266	0.08	0.006	0.077
D3	<0.001	0.266		0.19	<0.001	0.0585
D4	0.0074	0.08	0.019		0.115	0.372
D5	0.125	0.006	<0.001	0.115		0.052
D6	0.01	0.077	0.0585	0.372	0.052	

Table 2 Resulting p-values for speed reduction.

Gaze Behaviour Adjustment

Similar to the stated speed reduction, we analyzed the correctness of the adjusted gaze behavior. This is shown in Figure 7.

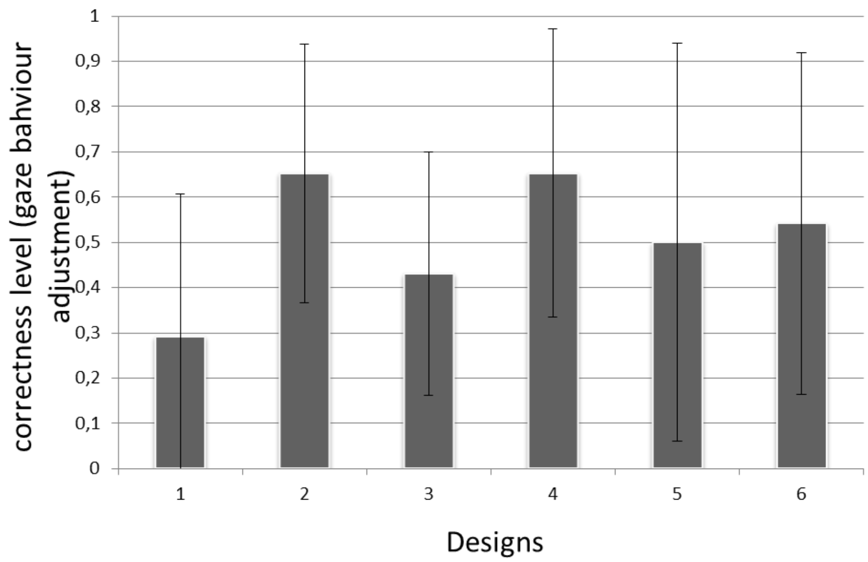


Figure 7 Correctness of gaze behaviour adjustment (before explanation).

The exact values are given in the table below.

Design	D1	D2	D3	D4	D5	D6
Mean Correctness	0.29	0.65	0.43	0.65	0.5	0.54

Table 3 Results gaze behaviour.

The ANOVA-Test again revealed that there are significant differences between the designs ($F(2.28) = 3.99$, $p < .05$). The results of the T-Tests are as follows:

	D1	D2	D3	D4	D5	D6
D1		<0.001	0.0397	<0.001	0.01	0.005
D2	<0.001		0.002	0.5	0.03	0.0719
D3	0.04	0.002		0.003	0.18	0.043
D4	<0.001	0.5	0.003		0.062	0.12
D5	0.01	0.03	0.18	0.062		0.223
D6	0.005	0.0719	0.043	0.12	0.223	

Table 4 Results of T-Tests.

4.3.2 Reaction (after Explanation)

After explaining the design concepts the reaction changed as follows:

Speed Reduction

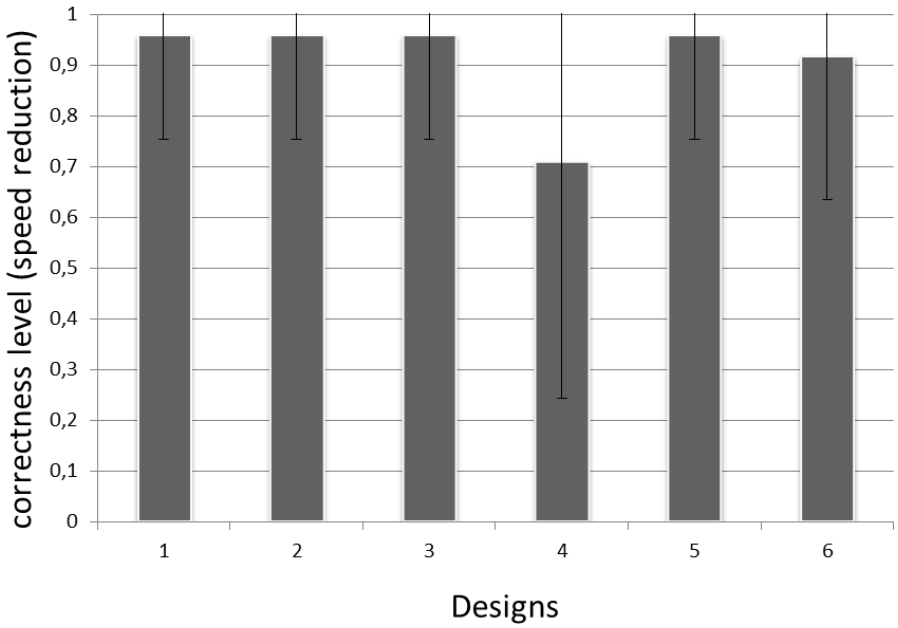


Figure 8 Correctness of speed adjustment (after explanation).

Figure 8 shows the mean correctness of the speed adjustment after the explanation of the design. The exact values are as follows:

Design	D1	D2	D3	D4	D5	D6
Mean Correctness	0.96	0.96	0.96	0.71	0.96	0.92

Table 5 Values of speed adjustment.

The ANOVA-Test showed that there exist significant differences between designs ($F(2,28) = 3.12$, $p < .05$). The T-Tests revealed that there is no significant difference between D5 and D6 ($p=0.16$) but between all other designs to D4 (e.g. D6 to D4 results in $p=0.028$).

Gaze Behaviour Adjustment

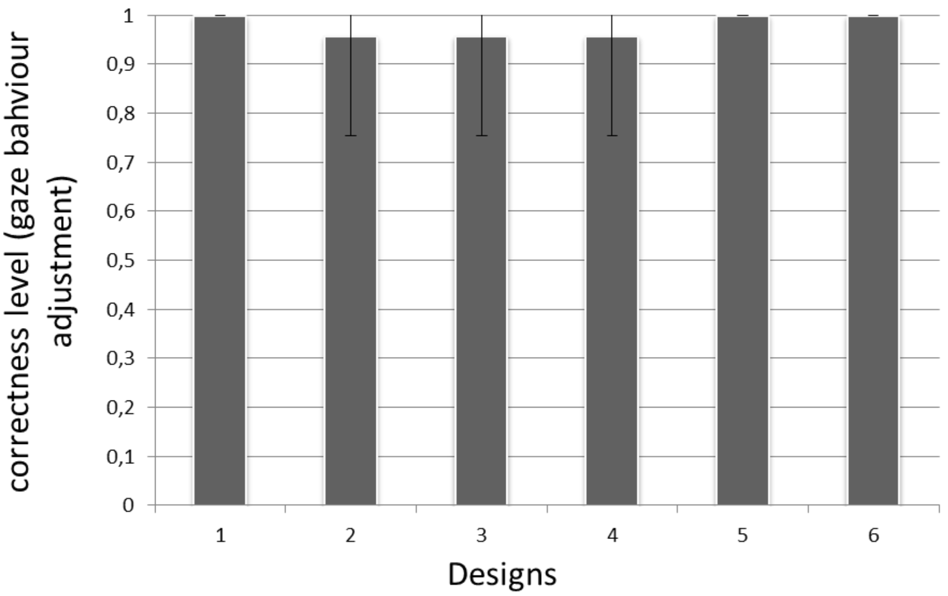


Figure 9 Correctness of gaze behaviour adjustment (after explanation).

Figure 9 shows the mean correctness of the adjustment of the gaze behaviour for the different designs. The exact values are:

Design	D1	D2	D3	D4	D5	D6
Mean Correctness	1	0.96	0.96	0.96	1	1

Table 6 Values of gaze behaviour adjustment.

The ANOVA-Test indicated that there are no significant differences between the design variants ($F(2,28) = 0.6$, $p=0.7$).

4.3.3 Design Complexity and Understanding

As stated before, we asked the participants to indicate via 5-point Likert (from 1=totally disagree to 5=totally agree) scale if they think that the design is too complex and if it is easy to understand.

With regard to the first statement ("I think the design is too complex"), the participants answers are shown in Figure 10 and with regard to the second question ("The design is easy to understand"), the participants answers are shown in Figure 11 .

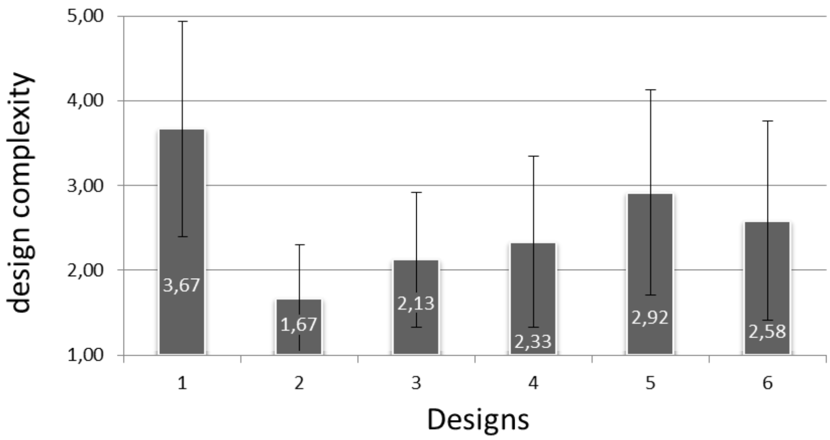


Figure 10 Mean rating of design complexity.

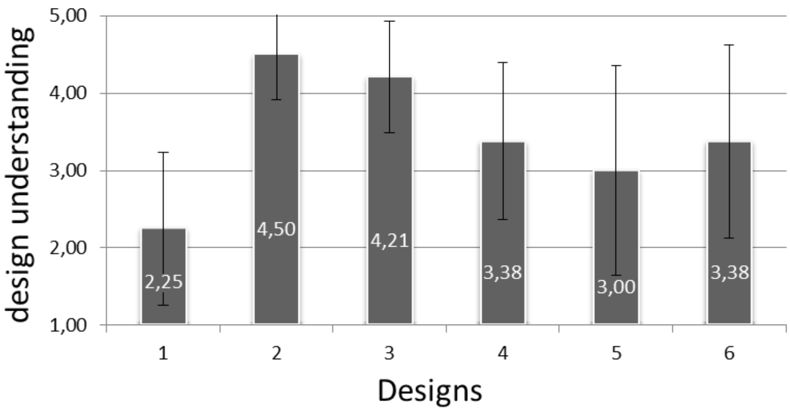


Figure 11 Mean rating of design understanding.

4.3.4 Preferred Design

The participants were asked to state if they would use the design based on a 5-Point Likert scale (from 1=totally disagree to 5=totally agree). The results are shown in Figure 12 .

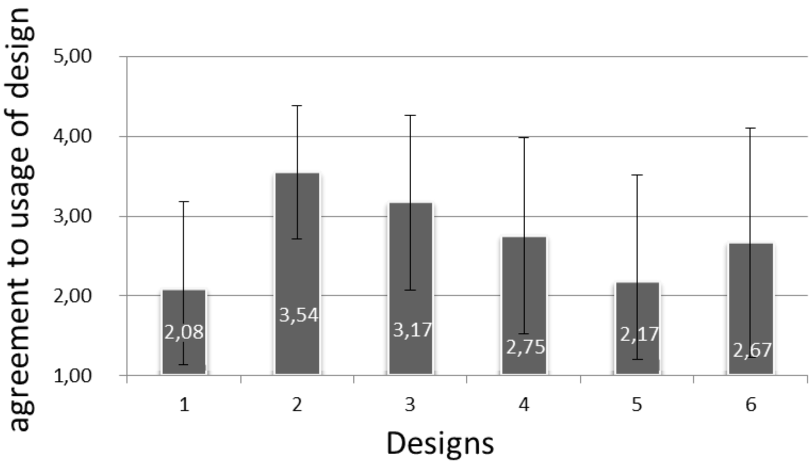


Figure 12 Mean agreement to usage of design.

At the end, each participant had to state his or her favorite/preferred design. The result of this question is given in Figure 13 .

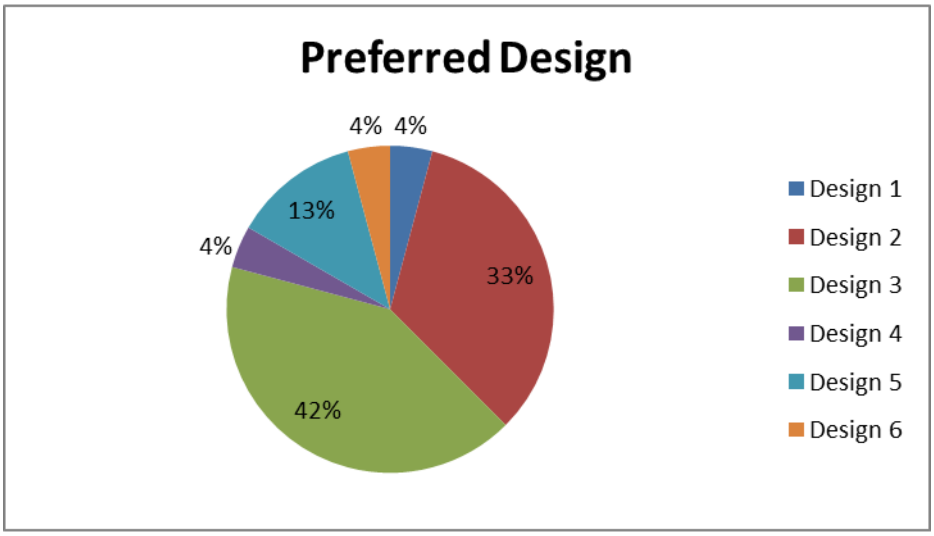


Figure 13 Preferred design.

4.4 Discussion

The results described previously revealed that the more abstract designs (D1, D5, D6) lead to higher complexity in understanding (c.f. Figure 10) . Especially in case of D1 (most abstract one), this results in poor correctness for adjusting speed and gaze behavior (c.f. Figure 6 and Figure 7). After explanation, this problem is solved and participants adjusted their behavior correctly (as required by the hazard level of the shown situation) (c.f. Figure 8 and Figure 9). Due to the high complexity, D1 was less preferred than all other designs (c.f. Figure 13).

An interesting aspect is, that – after design explanation – all designs lead to the correct adjustment of speed behavior despite of D4. All other designs were significantly better than D4 (c.f. Table 2). Based on some comments the participants made, we assume that this is based on the "warning symbol". The participants might have underestimated the warning sign. They are used to see this warning signs quite often at roadside and "learned" that in most cases no accident and problem occurred. Thus they are less willing to adapt their speed.

When looking at the preferred designs of the participants (c.f. Figure 13), the favorite designs become quite obvious: The participants strongly preferred design D2 and D3 which are nearly the same (as D2 is the cockpit display variant and D3 the head-up display variant of the same design concept). This is based on the low complexity and easy understandability of the concept (c.f. section 3.3). An interesting result ist, that D5 resulted in a high preference (13%) even though it was quite complex.

4.5 Conclusion

Based on the results, we are interested in further testing D2/D3 (most promising concept) but also one more abstract design concept (D5(most promising abstract concept)) in the simulator study conducted by CRF in the upcoming chapter An overview of the output is given in the upcoming Figure 14.

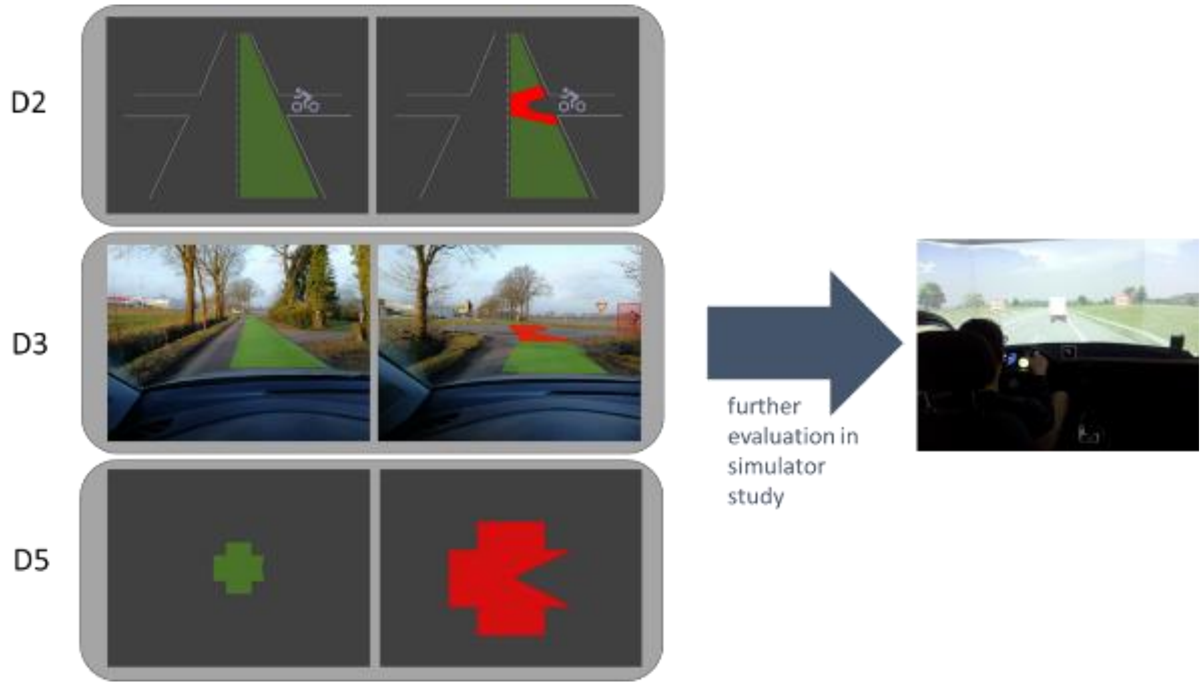


Figure 14 Inout designs for simulator study.

5 Simulator study on HMI selection (CRF)

5.1 Introduction

The MeBeSafe European Project is to develop, implement and validate interventions that direct road users (mainly drivers and cyclists) towards safer behaviour in common traffic situations which carry a high risk. More specifically, the Project aims at changing habitual traffic behaviour using different nudging measures to offer to the drivers an *ad hoc* designed HMI (Human Machine Interface) to predispose them to follow a safer behavioural choice, without a dangerous situation occurring, preserving this way their safety margins in driving. The CRF Virtual Reality Driving Simulator was chosen as the testing facility for evaluating the different MeBeSafe in-vehicle nudging solutions as it guarantees the possibility to manipulate both the presentation of different visual nudging stimuli and critical road scenarios in a controlled, repeatable and safe environment. Drivers had to drive in a urban scenario, with several crossroads. Sometimes at crossroads there was an incoming cyclist and, moreover, some crossroads were occluded by a building. During the study amongst others the following parameters are being observed and collected: driving behaviour, eye movements and subjective measures.

5.1.1 Aim

The study conducted in the CRF Virtual Driving Simulator compares driving scenarios with and without novel in-vehicle nudging HMI solutions in order to assess their hypothesized impact on driving behavior.

5.1.2 Research questions

The research questions relevant to the study are:

- Are there any differences in the driving performance with and without the visual nudging HMIs presentation? When the nudging HMI is displayed, is the driving performance more correct and improves road safety, in respect to situations in which the nudging is not displayed?

- Which of the different visual HMI proposals is the best in guaranteeing a more correct driving performance, in particular near the crossroads?

5.2 Method

5.2.1 Participants

Participants were recruited by an external agency. In particular, N = 30 participants (15 female) with a mean age of M = 44.7 years (SD=13.6, range: 25 - 67 years) took part in the study. In choosing the participants' sample characteristics, the criteria that the driver attention direction could be affected by factors as the driving experience (years, km driven per year) and the visual characteristics tied to e.g. growing age were followed.

The sample age that is representative of car drivers' age (FCA internal data) allowed to include in the experiment people with different visual characteristics due to their different ages (e.g. accommodation, etc.). This was done because the tested HMI was visual and located both in the near view field (instrument cluster) and in the far view field (augmented reality).

77% of the participants had a high school diploma, while 23% of them had a university degree. The participants' sample of CRF driving simulator experiment is representative for people buying a vehicle in Italy regarding their level of education (FCA internal data).

All participants hold a driving licence since 25,4 years on average (SD=13,62, range: 6-48 years). Participants drove a mean of M = 16.000 kilometers per year (km/y) (SD = 7331.9, range: 5000 - 40000 km/y) in mixed types of roads. 40% of participants drove more than 4 days per week on highway, 96% of participants drove more than 4/5 days per week on urban roads and 46% of them drove more than 4/5 days per week on extraurban roads.

The sample includes both, the less experienced drivers (7 less or equal than 10 years of driving licence, a small number of driven km/year, 8 less or equal than

10.000 km/year) and the most experienced ones (12 more or equal than 30 years of driving licence, some ten of thousands driven km/year: 8 more or equal to 20.000 km/year). This allows to make the experiment in the driving simulator involving people with different risk on driving due to the different driving experience.

23% of participants owned small segment cars, 23% owned medium segment cars, 23% owned small Sport Utility Vehicle (SUV) and 30% owned medium SUV. Moreover, participants drove bikes (37%) or motorbikes (20%) or both (6%).

Only participants with an adequate score in the CRF Motion Sickness Questionnaire (which measures if motion sickness problems are foreseen) were recruited. Moreover, half of the sample had high experience with technology, according to a CRF questionnaire based on the use of technology devices.

In the recruited sample both the critical age groups and the other intermediate ages were represented, so to have a heterogeneous distribution, representative of drivers.

This segmentation can well represent the visual behavior of the different ages without creating any bias caused by the heterogeneity of the sample. Moreover, it was important to take care of the different reactions to the MeBeSafe nudging HMIs to allow a design useful for the majority of the drivers.

5.2.2 Apparatus: CRF Virtual Driving Simulator

The CRF Virtual Driving Simulator is based on a six degrees of freedom (surge, sway, heave, roll, pitch, yaw) dynamic platform.

Other characteristics of the CRF driving simulator are the highly realistic vehicle dynamic models and a flexible and configurable vehicular traffic model, allowing for the implementation of critical traffic situations.

The system includes:

1. An I-Space with:

  a. 3 orthogonal rear projected screens, 3m tall and 3m wideallowing for a a ±45° vertical, and ±135 horizontal field of view
  b. 6 projectors (2 per screen) which allow stereoscopic visualization
2. A 6-degrees of freedom mechanical motion platform by Bosch-Rexroth (model HSE-6-MS-15-C-3E) with the following characteristics:
  a. Payload: 1000 kg
  b. Excursions: surge, sway +/-270 mm; heave +/-200 mm; roll, pitch: +/-18°; yaw +/- 23°
  c. Accelerations: surge, sway, heave +/- 0.75 g ; roll, pitch +/- 300 °/s2; yaw +/- 600 °/s2
3. A physical mock-up mounted on the mobile platform. This mock-up includes:
  a. An automotive seat, adjustable in longitudinal and tilting way
  b. A steering-wheel with force feedback
  c. Brake and accelerator pedals
  d. Automatic or Selespeed gearshift
4. A surrounding audio system, including a subwoofer and 4 tweeters mounted on the mock-up
5. A motion tracking system that measures and provides the driver head position within the I-Space
6. A PC cluster that manages accurate simulation of the graphics, the dynamic platform, and the vehicle dynamics (6 degrees of freedom)

The functional features of this system are:

1. 3D scenario and vehicle interiors rendering
2. Head motion tracking (continuous graphic visualization updating, based on the driver head positions)
3. The reproduction of the dynamic platform of:
  a. Vibrations simulating the road roughness and engine activity
  b. Car body motions (pitch and roll)

   c. Motion cueing, which are the inertial forces perceived by the driver during braking/accelerating manoeuvres, during a bend and during specific situations that happen while driving on low friction road conditions

4. Force feedback through the steering-wheel based on the dynamic condition of the vehicle

In the Virtual Reality Driving simulator there is also an eye tracker installed. The eye tracker FOVIO from Seeing Machines is a fully portable device suitable to be used in several environment and in the High Fidelity Simulator too (Figure 15). The FOVIO cylinder gaze angular range is -30° to 30° (Horizontal) and -15° to 30° (Vertical).

The FOVIO eye tracker is in bundle with software EyeWorks™ developed by EyeTracking, Inc.

Thanks to the EyeWorks™ software suite, it is possible for example to record all data and view video during data collection. The parameters detected are left/right eye intersected screen (0=no screen intersected), left/right gaze data quality (0=invalid, 3=most accurate), left/right eyeball rotation (X,Y,Z), left/right eyeball position (X,Y,Z), distance from eft/right eye to eye tracker.

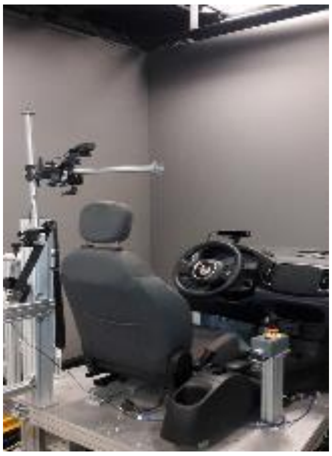


Figure 15 FOVIO eye tracker setup.

5.2.3 Scenarios for testing definition

The goal of this phase was to identify critical scenarios from accidents databases, selecting them on their frequency and severity and analysing the main aspects that characterize them. A literature review (Annex C: Scenarios selection) was done to understand previous efforts in defining prototypical accident scenarios based of specific criteria, like recurrent aspects or typical dynamics. The literature analysis shows an almost clear framework of what are the constant variables that influence the accident scenarios.

The accidents that involve cars and cyclists are still growing in number, even though the overall number of road accidents is decreasing. It seems that the specific typology of accident has a peculiar number of dynamic variables that influences each agent involved in the accident scenario and the overall scenario as a whole. Many research works and projects addressed the analysis of accident scenarios in the last years. One example is the research, conducted by the German Insurers Accident Research, of Kuehn and colleagues (2015) [13], that selected accidents with personal injury from the 2002 to 2010 describing how and under what circumstances cyclist-car accidents occur. They selected for their analysis an overall number of 407 accidents (basing the selection on the typology of injury and on the total claim amount), stating that in the 84% of the cases the impact between the bicycle and the car occurred at the front part of the vehicle (Figure 16).

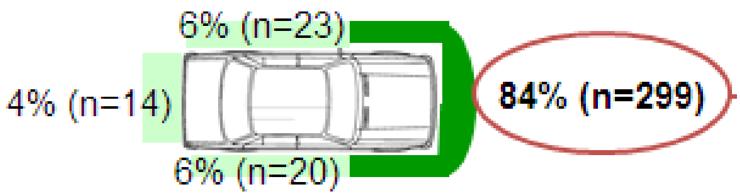


Figure 16 Impact distribution on car's part (from Kuehn et al., 2015 [13]).

Starting from the frontal impact scenarios they described also the frequency of the different impact dynamics in the set of accidents taken in exam. They discovered that the 76% of the cases selected described a perpendicular impact with the bicycle coming from the right (42%) or from the left (34%) of the car, while the 13% of the impacts where found to involve cyclist approaching head-on, and the 11% involved bicycle moving in the same direction of the car. The authors analysed the perpendicular accident set finding three specific configurations that seems to describe the highest proportion of frequency, describing also the most common characteristics. The results are synthetized in the Figure 17 . They describe the junction scenario as the most common between the analysed cases and they describe other aspects like the car average speed for each peculiar scenario, information about weather and road conditions in each context. The results show that the majority of the accidents in the selected dataset happened in daylight condition, with a dry road surface and with a car speed that does not exceed the 30 km/h, with the car braking only in half of the cases.

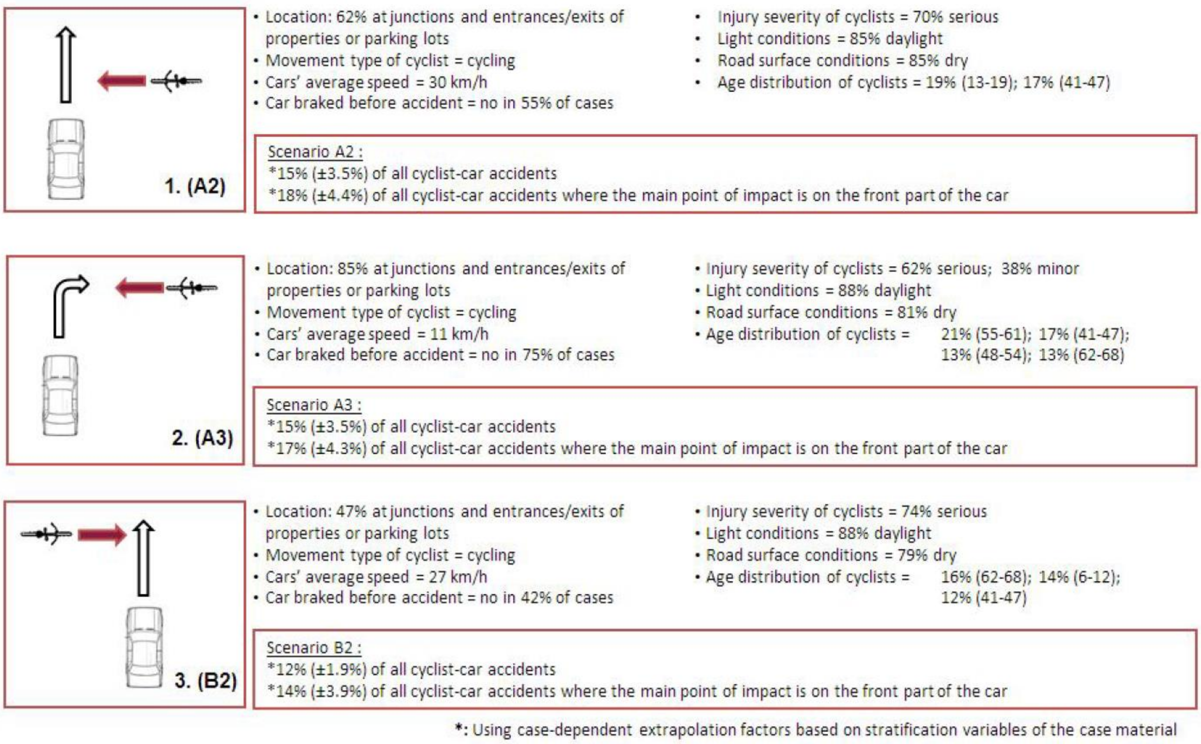


Figure 17 Characteristics of the most common accidents scenarios (from Kuehn et al., 2015, [13]).

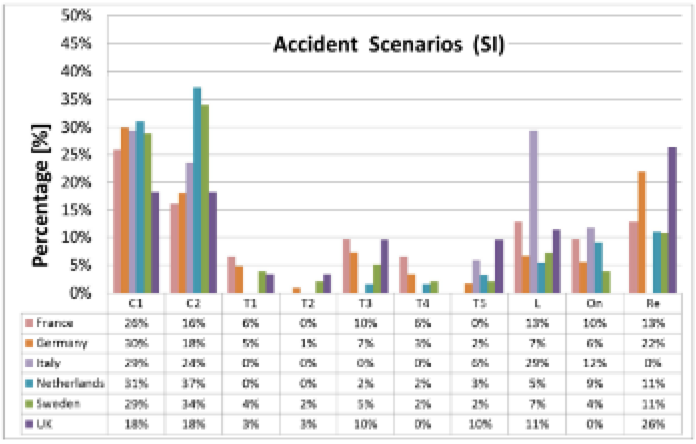
Research in the US by the Insurance Institute for Highway Safety (MacAlister and Zuby, 2015, [14]) took into account records crossing two different American databases, the National Highway Traffic Safety Administration (NHTSA) and the National Automotive Sampling System General Estimates System (NASS GES), in the file from 2008 to 2012. They analysed only the accidents involving one car and one cyclist, selecting

274.000 cases. In recent Italian research, Prati and colleagues (2017) 95[15] studied all the bicycle crashes that occurred in Italy during the 2011-2013 period (from ISTAT Database). Using a latent class analysis, they segmented 19 classes which represent 19 bicycle crash types (Figure 18). They identified 35246 accidents that involved cars and bicycles, the 71% of the total cyclist accidents.

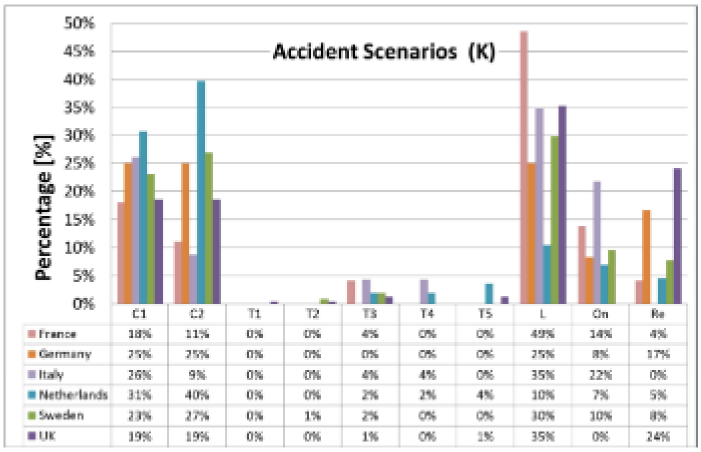
Figure 18 Scenarios of latent class analysis (from Prati et al., 2017, [15]).

In the project CATS (Op den Camp e.a. 2017 [16]), a thorough analysis was carried out on 16211 scenarios through a very large database (LAB-France, GIDAS based PCM-Germany, Fiat Internal-Italy, BRON-Netherlands, STA / STRADA-Sweden, STATS19-UK).

The selection criteria were: All the car to bicycles accident scenarios that happened in the European Union and led to death or serious injuries could be prevented by the adoption of AEB systems on cars. Results were weighted on national incidence and divided in Fatal (K) and Seriously Injured (SI) incidents. Percentages based on K and SI have been calculated. Through this method they analyzed 10 different scenarios, describing also their frequencies, probabilities and direction of impact (Figure 19).



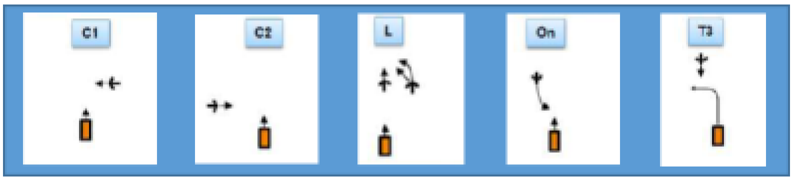
Distribution of seriously injured over the 9 main accident scenarios that are distinguished for 6 EU countries.



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

Figure 19 Percentage of car-cyclist accident scenarios in the different countries.

They analyzed the distribution of the accidents in the different databases, analyzing also the consistency of each scenarios with the implementation of possible driving aids. The results of the analysis generated a scenario list for a deeper understanding (Figure 20).



Scenario	Description	% covered for K	% covered for SI
C1	• Car driving straight • Cyclist crossing the vehicle path from the right	25	29
C2	• Car driving straight • Cyclist crossing the vehicle path from the left	29	28
L L1 L2	• Car and cyclist driving in the same direction • Cyclist riding straight and being hit by the car from behind • Cyclist swerving to the left in front of the car and being hit by the car from behind	24	7
On	• Car driving straight • Cyclist riding straight in the opposite (on-coming) direction	8	6
T3	• Car turning to the left • Cyclist coming from the opposite direction, riding straight	2	5

Figure 20 Scenarios selected for MeBeSafe.

Starting from this analysis, we selected the use cases taken from the CATS project to start the development phase of the scenarios to be involved in the "Driver attention direction" test in MeBeSafe Project. In fact, these scenarios are substantially overlapping to all the previous analyzed research. They involve predominantly frontal scenarios (cfr. Kuehn et al., 2015, [13]95), with almost the same crossing situations; also analysing the classes selected by Prati and collegues (ibidem) [15], taking into account only the scenarios involving one car and one cyclist, only the scenarios with the same dynamics of those selected by CATS remain.

During this phase a feasibility study of the scenarios was also done starting from the critical data obtained by the CATS database that describe also speed range (always in consistency with the other database), distance and other technical measure to be set in the experimental setup. From all the analyzed data we took for granted the weather (sunny), timing (daylight) and the road condition (dry).

In accordance with all the carried out analyses, the scenarios that had greater impact are those considered as the basis for the MeBeSafe project. Moreover, the selected scenarios are coherent with the other MeBeSafe partners analysis on critical scenarios.

In the "Driver attention direction" test done in June 2018 in the CRF Driving Simulator (Annex C: Sensing driver and vehicle state (CRF) all the scenarios described in Figure 21 (C1, C2, L, On and T3) were tested acquiring drivers eye movement through FOVIO eye tracking system, in order to evaluate the driver attention direction in presence and absence of cyclist, with cyclist that gave or did not give priority at crossroads.

In that experiments a *within-subjects-design* was used in which all 10 participants drove in all the 5 previous mentioned scenarios (Figure 21).

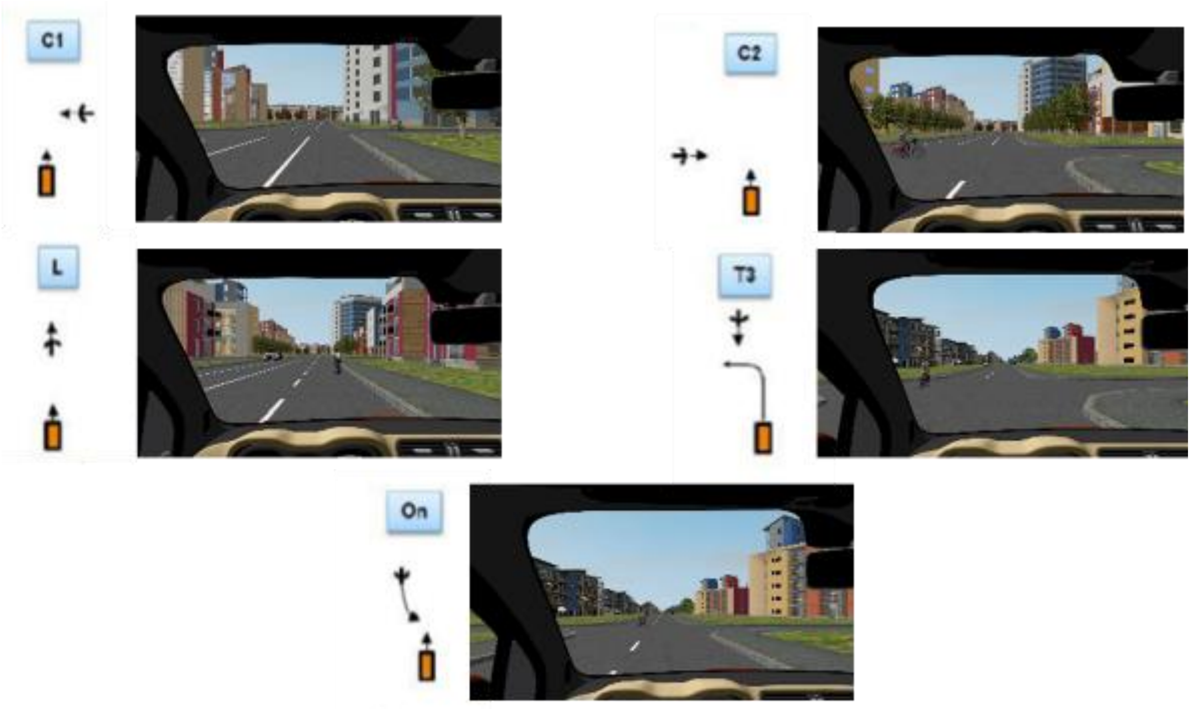


Figure 21 June 2018 CRF "Driver attention direction" test scenarios.

On data acquired during this test, an analysis of gaze direction and indicators related to glances was done, using as reference "ISO 15007-1:2014 Road vehicles - Measurement of driver visual behaviour with respect to transport information and control systems", comparing data during intersection approaching with and without cyclists. This analysis showed that the presence of cyclists in scenarios C1 and C2 shows a higher impact on the direction of attention of the driver than in the other 3 scenarios. This is due to the fact that in scenarios L, On and T3 the cyclist is inside or very near to the main driver attention direction focus, that is on the road in front of him/her (and partially on the left in T3 scenarios, where the driver has to turn left).

In the next figures gaze direction in X during intersection approaching in absence and in presence of a cyclist is shown.

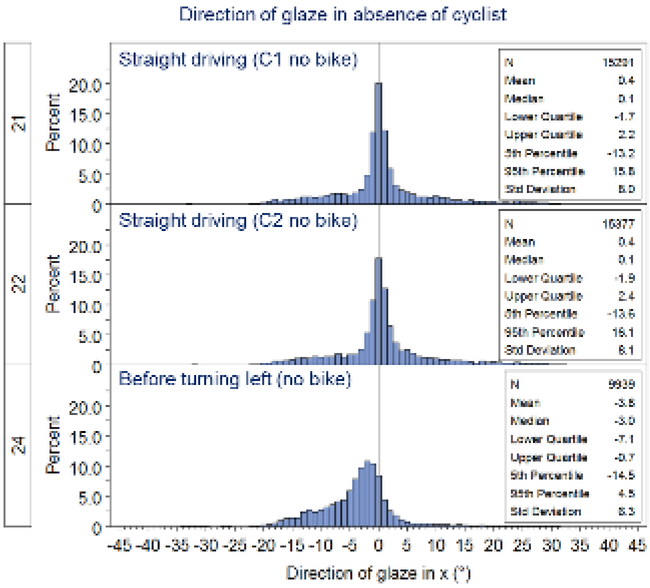


Figure 22 June 2018 CRF "Driver attention direction" test: Direction of glaze in absence of cyclist.

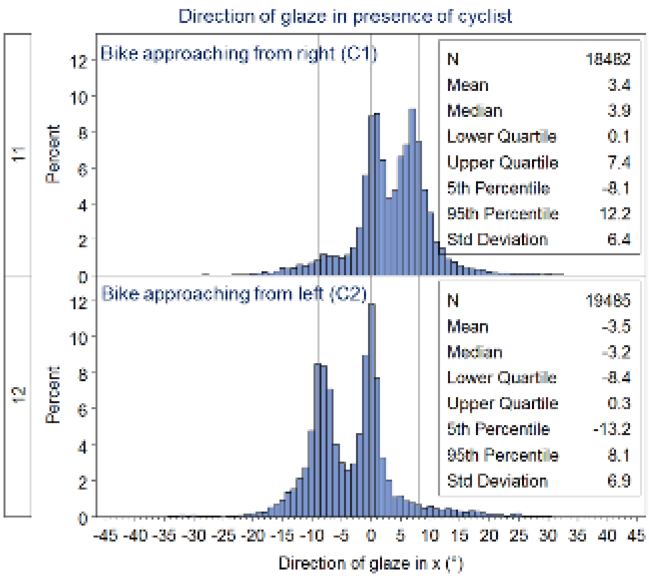


Figure 23 June 2018 CRF "Driver attention direction" test: Direction of glaze in presence of cyclist: scenarios C1 and C2.

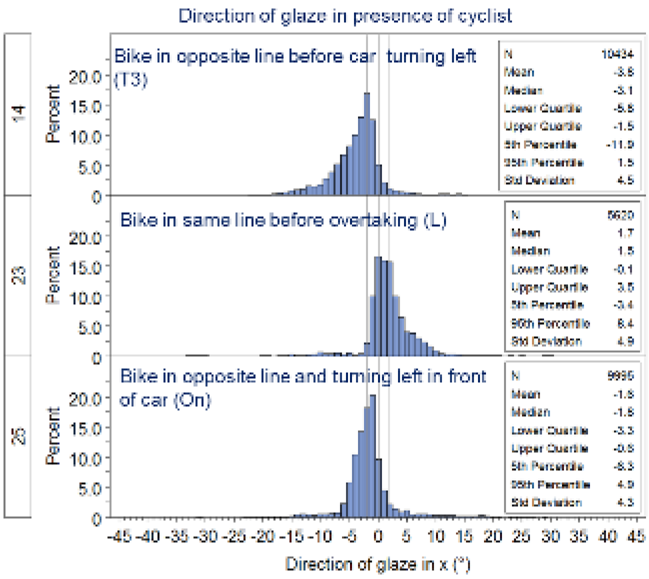


Figure 24 June 2018 CRF "Driver attention direction" test: Direction of glaze in presence of cyclist: scenarios L, On and T.

5.2.4 Experimental scenario

The previous described analysis on driver attention direction, (Annex C: Sensing driver and vehicle state - CRF contribution), and considerations on percentage of covered Fatal (K) and Seriously Injured (SI) incidents (Figure 1.6) allowed to focus the CRF driving simulator experiment on nudging HMIs designed proposals on the following urban scenarios:

- C1 (car driving straight and cyclist crossing the vehicle path from the right). In this case the cyclist had always priority, because the road in which the participant had to drive was a road without right of way
- C2 (car driving straight and cyclist crossing the vehicle path from the left). In this case the cyclist could give or not priority to the ego-vehicle

The cyclist speed was around 15 km/h.

In both C1 and C2 scenarios there was surrounding traffic constituted by other cars present to make the driving experience more realistic and less annoying.

Moreover, both in C1 and C2 scenarios some crossroads could be obstructed by a building or not (

Figure 25 and Figure 26) to evaluate the impact of the nudging HMI.

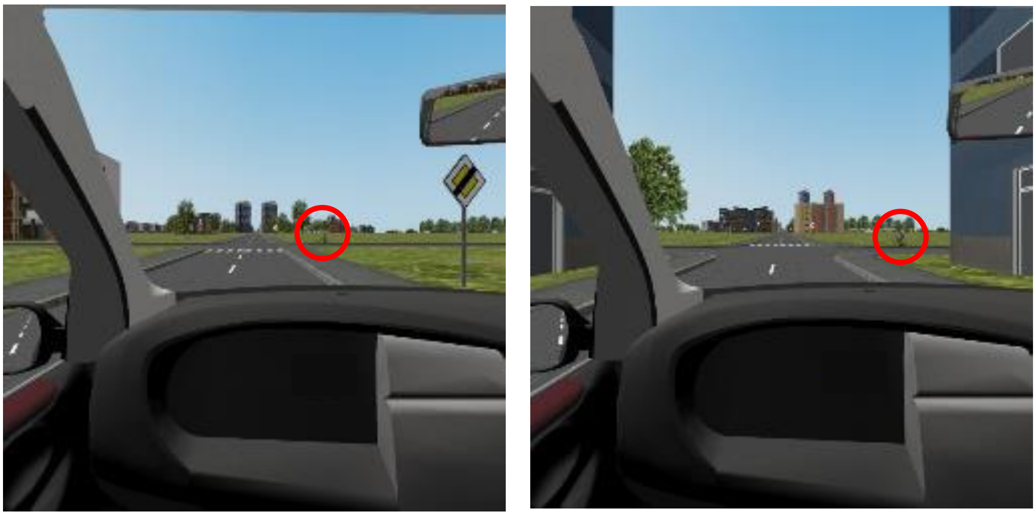


Figure 25 CRF driving simulator C1 scenario with and without obstruction.

Figure 26 CRF driving simulator C2 scenario with and without obstruction.

5.2.5 Stimuli and test conditions

The nudging visual stimuli tested in the CRF Virtual Driving Simulator study were defined and selected, among several initial proposals, in previous tasks of the Project thanks to a Project choral Workshop and to the activity of a MeBeSafe partner.

Moreover, to optimize the D2, D3, D5 nudging HMI graphics to be shown in the CRF Virtual Driving Simulator a preliminary test was conducted. This test was done using the same apparatus (CRF driving simulator), driving scenarios and experimental design described in this chapter. N=10 participants (CRF employees not involved in HMI and Advanced Driver Assistance Systems activities) were involved in this preliminar study and recruited with the same characteristics range of the second study.. The study was within-subjects, in which all participants experienced all test conditions in the different driving scenarios as explained in the next paragraph.

After the trials, participants were interviewed on the the nudging HMIs experienced during their driving and verbalized comments were used to slightly adjust graphics to adapt them better to the visualization in the driving simulator.

Following possible participants comments, D2, D3, D5 HMI solutions were adjusted accordingly, if necessary, and these results will be described in the Deliverable 2.3.

Then in the second study, these three different nudging HMI optimized solutions were tested. Each of them showed three different states of nudging, according to the correct level of warning, through different colors (green, amber, red) and slightly changing graphics due to obstacle presence and cyclist direction (Figure 27).

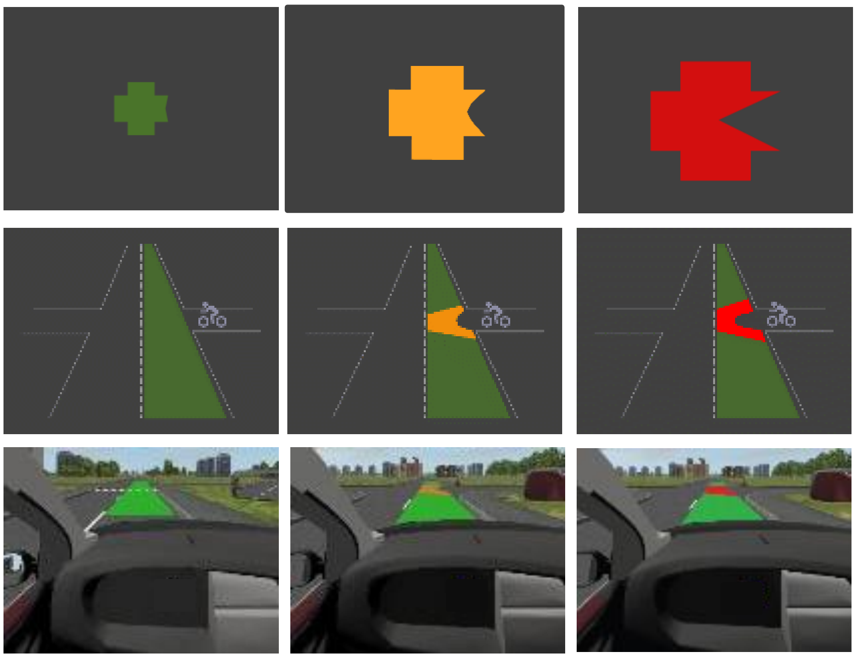


Figure 27 MeBeSafe nudging HMI (D2, D3, D5 graphic versions) with different warning levels.

Four different conditions were evaluated:

- o Absence of nudging visual HMI
- o D5 visual nudging HMI
- o D2 visual nudging HMI
- o shown on the instrument panel, that was done with a 16:9 7-inches display (1024x600 resolution at 150 pixels per inch) with a width of 15.50 cm and a height of 8.72 cm
- o One visual nudging HMI (D3) displayed as Augmented Reality on the scenario (e.g. Head-Up display), creating a great immersion sensation

The importance of the position of the visual nudging HMI in the frontal central driver field of view was confirmed by the analysis of data acquired during the June 2018 CRF "Driver Attention Direction experiment" (Annex C).

These test results, in fact, showed that the main focus of the driver attention is the central area in front of the driver. This area is the main focus in absence of cyclists and remains the second driver attention direction, with around 20% of time on this AOI (Area of Interest), also in presence of an identified cyclist. The Figure 28 reports main indicators of glances in this area in presence and absence of cyclist during approaching a C1 or C2 crossroad.

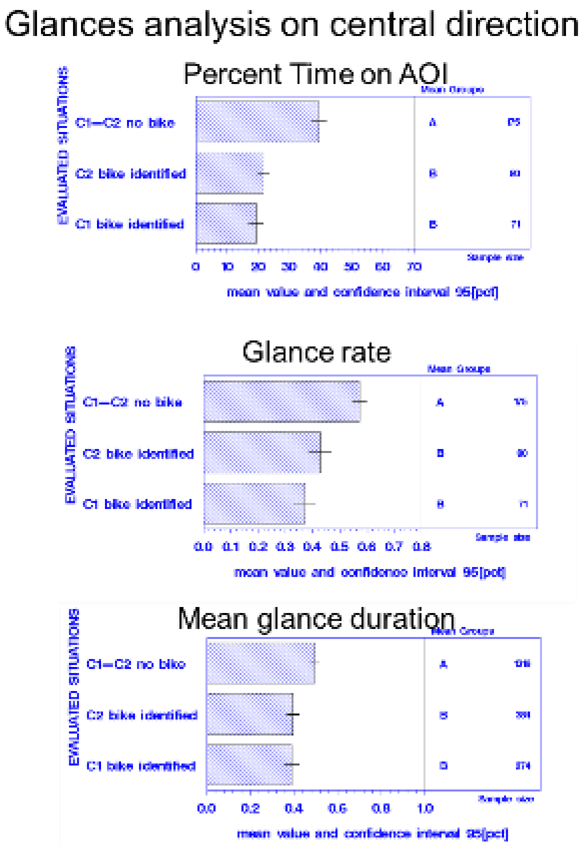


Figure 28 June 2018 CRF "Driver attention direction" test: Glances on central area in front of the driver.

The instrument panel is anyway a significant area for driver attention during the driving task to be tested due to the presence of fundamental information (e.g. speedometer, failure icons/messages…) and moreover it is always present even if the Head-Up Display is not present in a car.

5.2.6 Experimental Design

The CRF experiment on nudging HMI used a *within-subjects-design*, in which each of the N = 30 participants was exposed to all test conditions in the different driving scenarios to acquire data to be able to answer to the research questions (see 5.1.2).

The experiment consisted of five driving sessions in both C1 and C2 scenarios.

All participants experienced the baseline (driving without nudging and approaching cyclist at crossroads) always as first session of the test, in order to identify the individual driving performance and the usual direction of attention near the crossroad.

In the other four driving sessions, the test conditions (no nudging HMI and 3 different nudging HMIs displayed to support the driver) were presented in a random order, to avoid sequence and order effects. In these four sessions the approaching cyclist and the crossroad view obstruction (building) were sometimes present and sometimes not. Moreover, in the C2 scenario the approaching cyclist could or not give priority to the ego-vehicle, to create a more challenging and not repetitive situation.

In particular, each session included 18 crossroads in randomized order (8 without approaching cyclist and 2 repetitions for the 5 conditions obtained by different combination of C1, C2 vs. obstruction vs. cyclist giving priority).

Participants drove in an urban context on a road without right of way and they were asked to not exceed 50 km/h and to respect all the driving rules.

5.2.7 Procedure

After a five minutes practice drive with the driving simulator to get acquainted with the system and to guarantee each user the same level of basic expertise in driving the Virtual Reality Simulator, participants started with the driving sessions (baseline and 4 test conditions as previously described). At the end of each session, participants were asked to answer the questionnaire ratings with their driving experience and the tested nudging HMI (when present).

At the end of all the driving sessions, participants were asked to fill out a questionnaire to compare the different nudging modalities tested and to give a final evaluation of the nudging HMI in presence of crossroads view obstruction.

Then participants were asked to fill in a demographic and driving habits questionnaire. Finally, participants were greeted and thanked by the experimenter for the collaboration.

5.2.8 Questionnaires

Subjective evaluations were collected by questionnaires administered to participants at the end of each driving session and at the end of the experiment.

At the end of each driving session, questionnaires assessed the participants' evaluation of their driving tasks, their feeling during the test and the displayed nudging HMI (if present).

Moreover, open questions related to nudging comprehension and usage intention were asked.

In the final questionnaire, participants were asked to sort the preferred proposals and interviewed on the nudging tested solutions in presence of crossroad view obstruction.

The last questionnaire participants filled in was a demographic and driving habits one (age, gender, education qualification, year of driving licence, km driven per year, type of driven vehicle, frequency of driving in differend road types, frequency of riding bikes).

5.2.9 Variables

In the experimental design the following ***independent variables*** are considered:

- Nudging HMI: three different visual nudging HMI (see 5.2.5) and absence of nudging HMI (baseline condition)
- Type of scenario: Scenario C1 and C2 in urban environment with or without visual obstructions at intersections, with and without approaching cyclist and different manoeuvres performed by cyclists in C2 scenario (see 5.2.4)

Three main categories of ***dependent variables*** were collected during the study: driving performance measures, driver direction of attention and subjective evaluations.

From the log files of the driving simulator, a number of objective measures describing drivers' behaviour and reactions to the different stimuli such as distance among cyclist and car, car speed, pedals and steering-wheel usage behaviour, etc. are calculated. The standard analysis of these signals allows to evaluate the number of possible accidents and also the impact of the presence/absence and of the type of proposed nudging interfaces on driver behaviour in terms of driving performance at crossroad and cyclist approaching.

In addition, participants' eye movements during the various tests, including the baseline, collected by FOVIO can be analysed to capture driver direction of attention. The test done in July 2018 was useful to verify the instrumental integration of the eye tracking system FOVIO and the possibility to determine the direction of attention by the driver; moreover this experiment was useful to implement indicators suggested by "ISO 15007-1:2014 Road vehicles - Measurement of driver visual behavior with respect to transport information and control systems" and evaluate the difference on them due to different situations: different types of scenarios and presence/absence of cyclist. The same indicators can be used to test the impact of presence/absence and type of proposed interface in the final test.

5.3 Results

Analyses of the simulator study measurement is still under process and the data will be evaluated and prepared for the field test. The results will be included in Deliverable D2.3 in the selection of the HMI for implementation of the FIAT 500X vehicle that is used in WP5 for field test evaluation.

6 Simulation study on static hazard model (Virtual Vehicle)

The focus of this simulation study lies on the static hazard model as defined in [2], especially setting up and running simulations for a plausibility analysis of the static hazard model parameters. In contrast to the simulator study and the dynamic hazard model study, this study does not consider any driver reactions. Furthermore it produces data equivalent to a time period of one year which hardly is not feasible using a driving simutator.

The (in-vehicle) hazard model estimates the hazard level and the direction from which the hazard might be expected for a passenger car approaching an urban intersection. The type of hazard considers a cyclist crossing the path of the approaching vehicle and possibly colliding with this vehicle. A distinction is made between a dynamic and static hazard model. The dynamic hazard model considers the hazard of a cyclist that is in view of the car or the driver; the hazard is high in case the cyclist is at collision course with the car and the time-to-collision is decreasing. The hazard decreases in case the paths of car and cyclist do not appear to cross.

The static model estimates the possible hazard in case there is no direct view on a cyclist, but the road layout and usual traffic flow indicate that a cyclist might be approaching from behind a view-blocking obstruction. The hazard is usually increasing, with decreasing distance of the car to the potential point of collision, until distance is so small, that the driver can have a look around the view blocking obstruction. Then the static hazard drops down to zero. In case a cyclist is actually approaching, the dynamic hazard model will estimate the actual hazard from the cyclist manoeuvre.

In this example it becomes clear that both, the static and dynamic hazard model are required to get a reliable estimation of the hazard at any point in time during the approach of an intersection of a car with a cyclist (or actually any other road user – though focus is on cyclists in WP2 of MeBeSafe).

The present simulation study performed by Virtual Vehicle is used to examine the sensitivity of parameters in the static hazard prediction model, in order to calibrate the model such, that an intuitively reliable hazard evolution (with time or distance to the intersection) in the approach of the cyclist crossing results. Different approaching scenarios are simulated and results are visualised to enable a subjective assessment of the hazard evolution in relation to the situation on the road. Simulations are performed in both critical (cyclist on collision course) and non-critical situations (cyclist far from a collision with the approaching car).

6.1 Design of tests

Simulation is used to evaluate the output of the static hazard model in potentially critical situations in an intersection scenario. A four armed intersection with mixed car and cylist traffic is used for the investigation. The simulation is then used to generate both critical and non-critical situations. For each situation the static hazard level is determined. Furthermore, a visualisation of selected situations from driver's view are created to be able to visually assess the criticality of the situation. As a final step, the static hazard output is compared to the (subjective) assessment of the situation based on the visualisation.

6.2 Set up of the simulation environment

The simulations are performed by using SUMO (v1.0.1) [1], a microscopic traffic simulation software. The simulation is set up to log all situations with possible interaction between a cyclist and a car. Such situations are identified by either time to collision (TTC) <= 3s or post encroachment time (PET) <= 2s. For each critical situation the trajectories (positions and velocities) of the involved traffic participants are logged as well as the minimal values for TTC and PET. This information is required for determining the static hazard level and for creating the visualisation.

The static hazard level is calculated as defined in [2]. The calculation is done in a postprocessing step using a python implementation, as the driver reaction is not included in this simulation. The static hazard level calculation uses the following parameters (definitions can be found in [2]) as baseline:

Input parameters for R:

- abrake = 4.0 (characteristic constant deceleration when applying the brake. [m/s2])
- CT = 3 (characteristic needed time to react to cyclist before applying brakes [s])

Input parameters for p:

- D1 = 4.65 (lateral distance to obstruction [m])
- D2 = 7.5 (longitudinal distance to obstruction [m])
- Wv = 1.8 (vehicle width [m])
- Wc = 1.8 (cyclist length [m])
- S = 0.5 (safety distance[m])

Input parameters for Cr:

- b = 0.1 (Initial Cr at cyclist flow of zero)
- a = 0.9 (Cr at the moment of Cc)
- Cc = 1.0 (Cyclist flow at the moment of Cr of a)

The visualisation is done as a postprocessing step using the 3D-modelling and rendering software Blender (v2.79b) [3], the environment (roads, buldings etc.) is generated based on OpenStreetMap [4]. The static hazard level is visualised using a red circle in the driver's field of view. The circle size is related to the static hazard level (between level= 0 (minimum), no circle visible; to level=1 (maximum), circle with 200mm diameter).

6.3 Test matrix

The chosen location is an intersection in Eindhoven where measurements of the cyclist and car traffic have already been performed by TNO [5]. These measurements are used to create daytime and weekday dependent flows of cylists in the simulation.

In detail, the cyclist traffic is set up as follows:

For each hour of one week the number of cyclists coming from each of the 4 directions is known as well as where they go. Based on that information 12 stochastic cyclist flows (from 1 to 2,3,4, from 2 to 1,3,4 and so on, see Figure 29) are generated for each hour so that they reproduce the measured cyclist traffic in numbers.

The car traffic is set to a constant probability of 125 cars per hour driving from 1 to 3 (along Hastel Road). All cyclists and cars follow the „right before left" rule for this intersection.

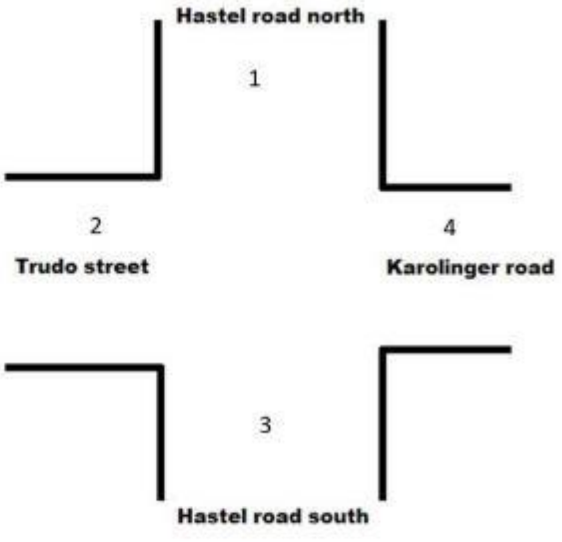


Figure 29 The simplified intersection with the 4 directions cylcist can come from and go to.

A schematic overview of the intersection and the measured distances from lane center to visual obstructions can be found in Figure 30. However, the recorded distances could not be reproduced in the simulation. They were set to D1 = 4.65m (instead of 4.45m), D2 = 7.5m (instead of 6.35m) as input parameters for the static hazard level model.

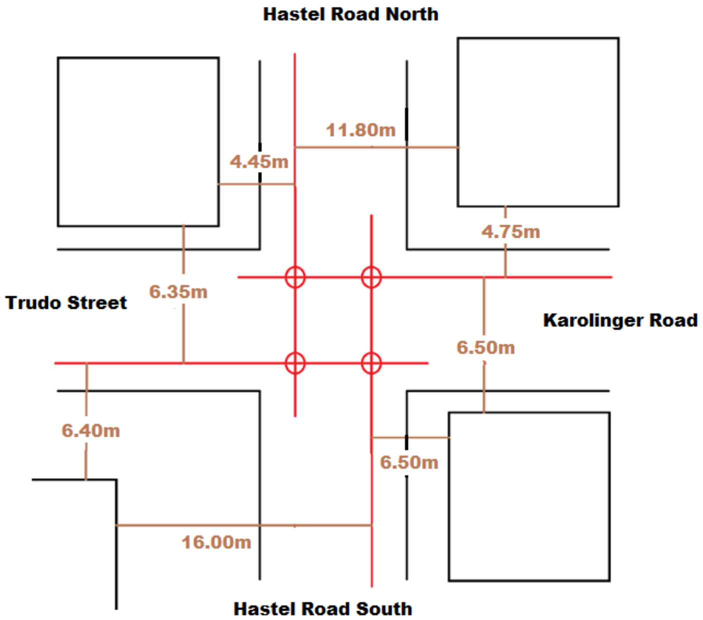


Figure 30 Sketch of the investigated intersect ion in Eindhoven, taken from [2].

Figure 31 Aerial photo of the intersection with overlay of the SUMO net file including polygons for the most relevant buildings.

6.4 Results

In a first step, we verified that the generated cyclist traffic represents the real world cyclist traffic. Since the flow of cyclists is based on a stochastic approach, 52 weeks of traffic have been simulated with different seeds for the random generator but identical appearance probabilities for the cyclists. An evaluation of the cyclist counts can be found in Table 7 .

	From 1	From 2	From 3	From 4
Measurement:	4077	2386	4154	1251
Simulation (average):	4079	2401	4161	1279
Relative difference:	0%	+1%	0%	+2%

Table 7 Summarised results of cyclist counts over one week coming from all 4 directions for measurement and simulation as well as the relative difference between them.

The speed profiles of the simulated cylists approaching the intersection from Trudo Street can be found in Figure 32. Figure 33 shows measured cyclist speed profiles for a similar intersection as comparison.

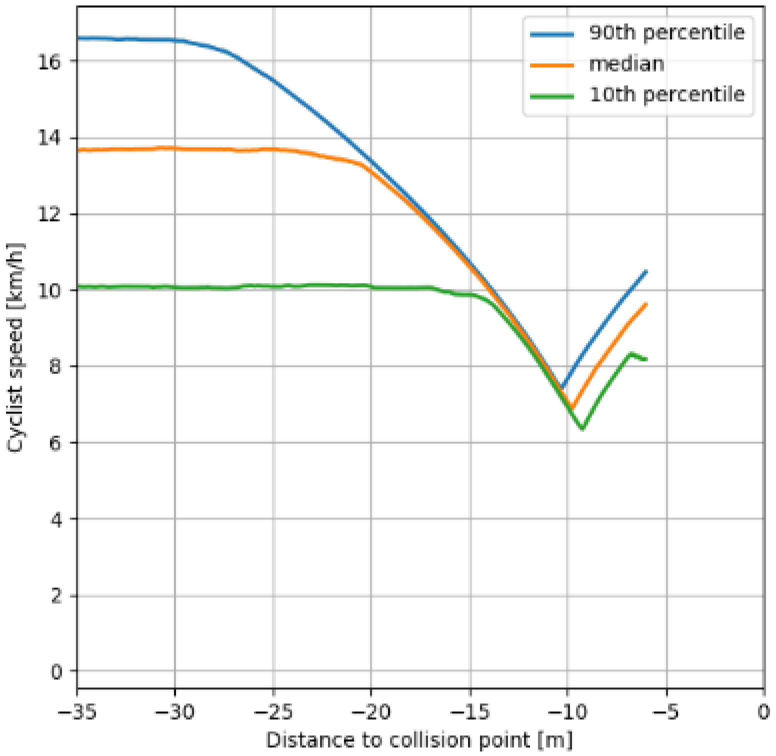


Figure 32 Distribution of the speed profiles of the cyclists coming from Trudo Street.

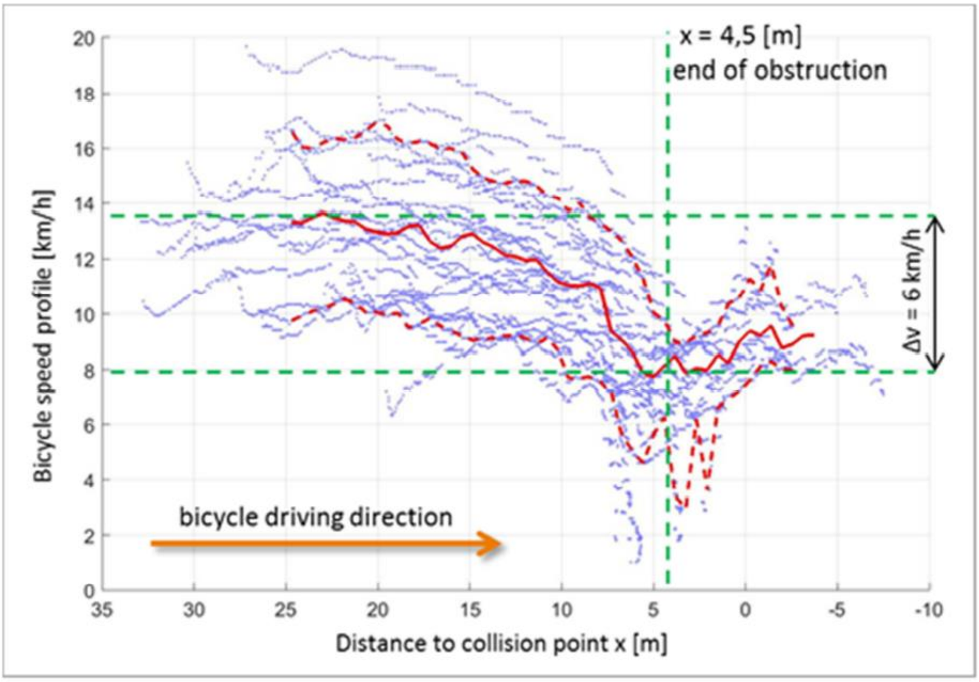


Figure 13 Measured bicycle velocity profiles near a severe view-blocking obstruction. In blue the different profiles for 27 cyclists that the radar could distinguish during the full approach of the crossing. The solid red curve indicates the 50th-percentile profile; the red dashed lines indicate the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

Figure 33 Measured speed profiles of cyclists approaching an intersection with view blocking obstruction taken from [6].

Source: CATS Deliverable 2.3 CATS Observation Studies

Figure 34 shows the speed profiles of the simulated cars coming from Hastel Road North. Figure 35 shows measurement results from a similar intersection as comparison.

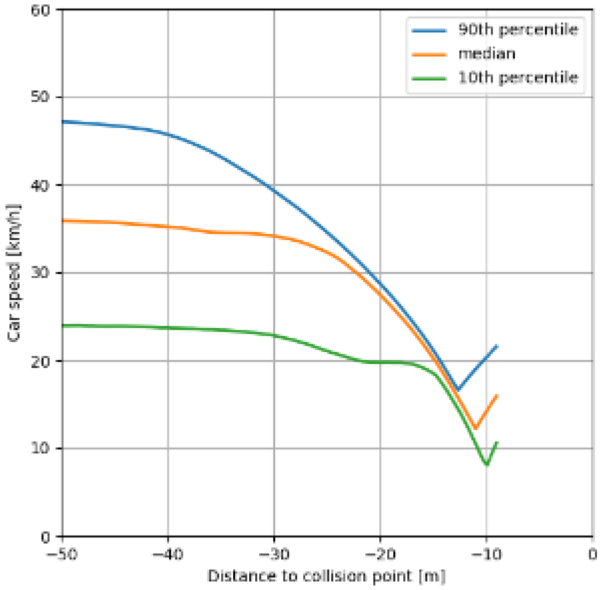


Figure 34 Distribution of the speed profiles of the cars coming from Hastel Road North.

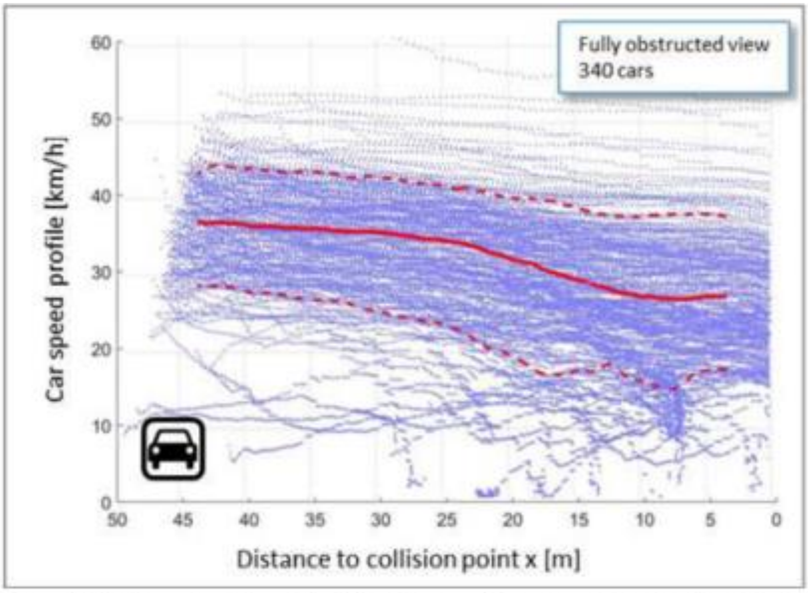


Figure 14 Radar measured speed profiles (blue curves) for cars crossing the intersection from the direction with view-blocking obstruction and the opposite direction without view-blocking obstruction. The solid red curve indicates the 50th-percentile profile; the red dashed lines indicate the 10th and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

Figure 35 Measured speed profiles of cars approaching an intersection with view blocking obstruction taken from [6].

Source: CATS Deliverable 2.3 CATS Observation Studies

6.4.1 Hazard level evaluation

Within the 52 weeks of simulation, 22342 conflict situations occurred of wich 11532 conflict situations were due to a PET (Post Encroachment Time) equal or smaller than 2.0s and 17982 conflict situations due to a minimal TTC equal or smaller than 3.0s. The calculated hazard levels for the conflict situations ranged from 0 to 0.364 in the PET conflict situations and from 0 to 0.601 in the minimal TTC conflict situations.

Figure 36 shows the distributions of PET and maximal static hazard level as well as a scatter plot of PET versus maximal static hazard level for all PET conflict situations. Figure 37 shows the distributions of minimal TTC and maximal static hazard level as well as a scatter plot of minimal TTC versus maximal static hazard level for all minimal TTC conflict situations. No correlation can be seen between the actual criticality of the situation and the static hazard level. This result is somewhat expected, since the static hazard level is not sensitive to a cyclist actually appearing but only on their appearance probability.

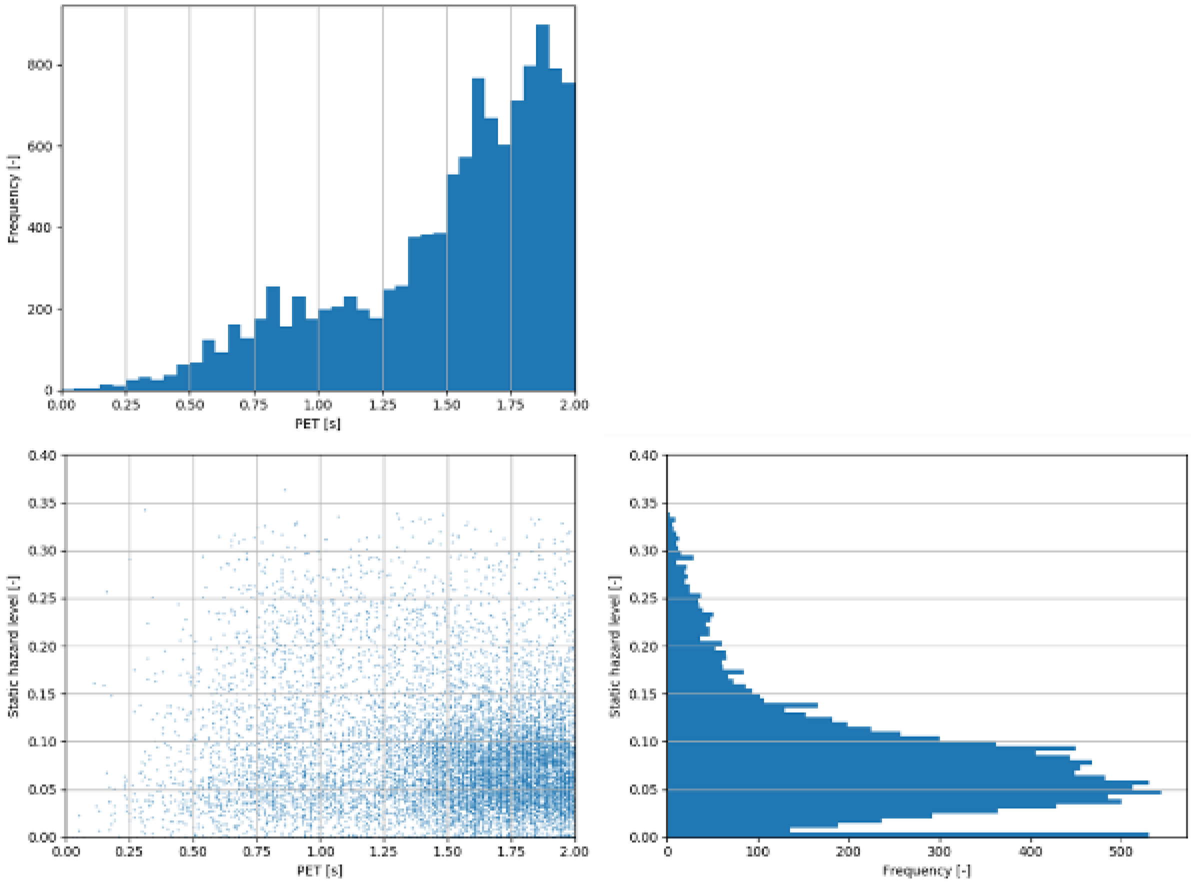


Figure 36 Distribtions of PET (top left), static hazard level (bottom right) and scatter plot of PET vs static hazard level.

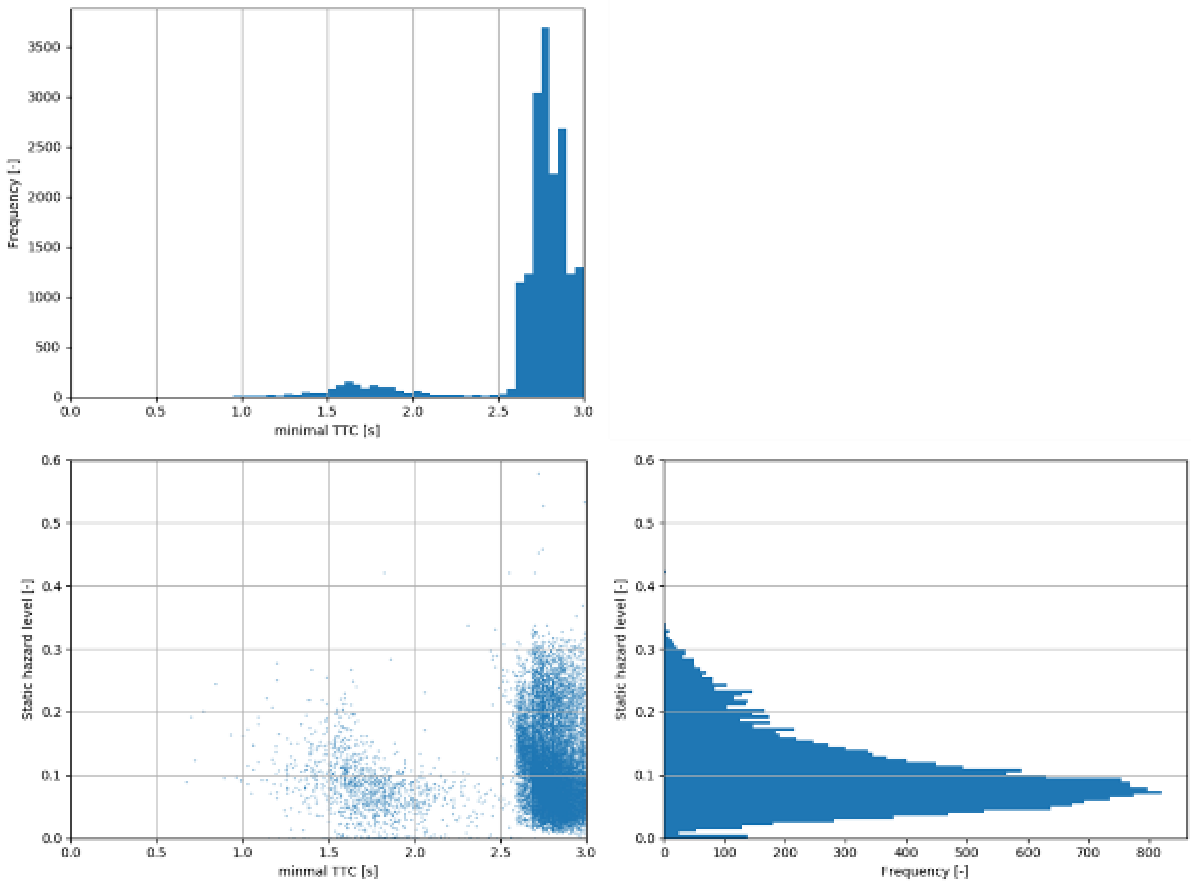


Figure 37 Distribtions of minimal TTC (top left), static hazard level (bottom right) and scatter plot of minimal TTC vs static hazard level.

6.4.2 Driver experienced situation

Finally, visualisations were made of some representative conflict situations. The first conflict situation is a PET conflict with a PET of 0.86s and a hazard level 0.364. Figure 38 shows the respective trajectories, static hazard level and car speed over distance to conflict point. Figure 39 is part of a video created to be able to subjectively assess the situation. It shows the situation at the highest static hazard level shortly before the cyclist appears from the right side.

The second conflict situation is a minimal TTC conflict with a hazard level 0.601 and a minimal TTC of 2.62s. Figure 40 show the respective plots and visualisation.

Finally, a conflict situation with hazard level 0 is analysed. This is a conflict with PET = 0.03s. Figure 42 shows the respective plots and Figure 41 shows a visualisation of the situation at the time where the cyclist is fully visible for the first time.

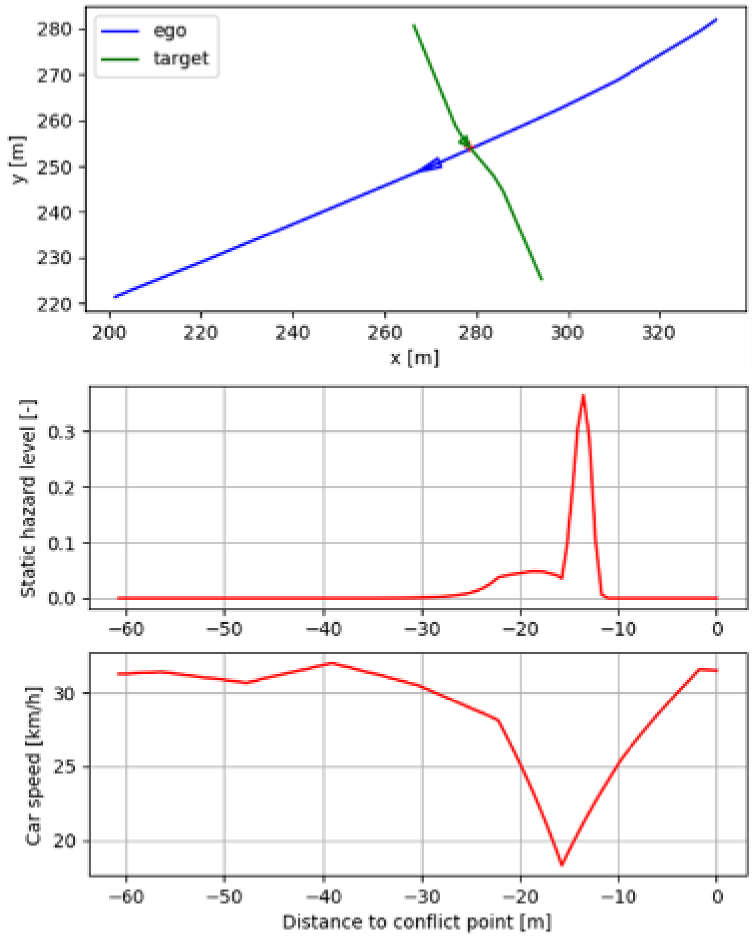


Figure 38 Trajectories (top), static hazard level (middle), car speed (bottom) for a PET conflict (PET = 0.86s).

Figure 39 Visualisation of a PET conflict (PET=0.86s) from a driver's point of view at the point in time of the highest static hazard level. The size of the red dot represents the static hazard level. This image is taken from a video showing the whole time range of the conflict.

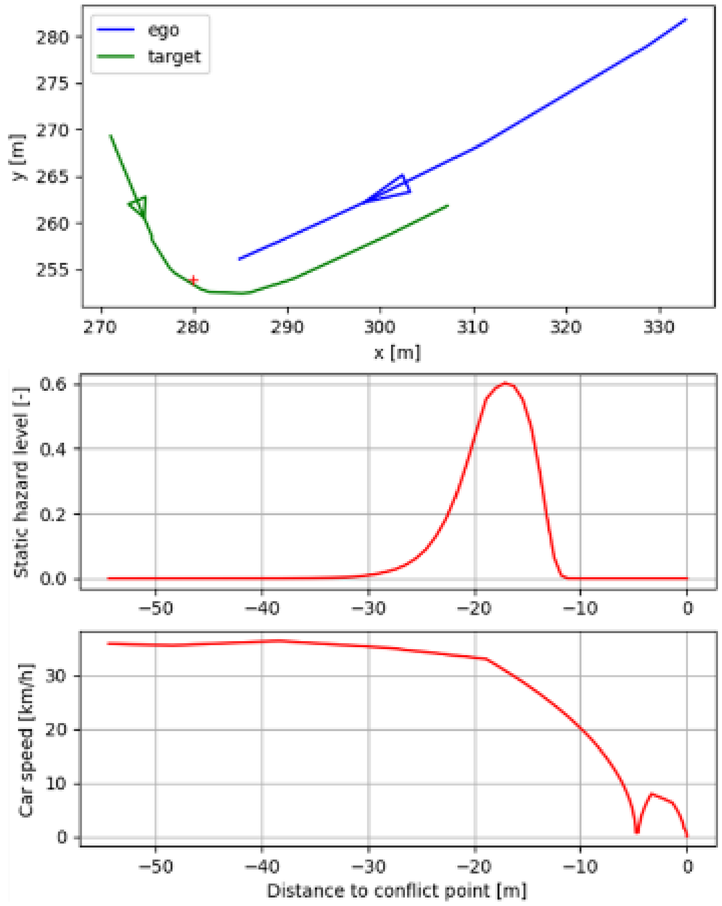


Figure 40 Trajectories (top), static hazard level (middle), car speed (bottom) for a minimal TTC conflict (minimal TTC = 2.62s).

Figure 41 Visualisation of a minimal TTC conflict (minimal TTC = 2.62s) from a driver's point of view at the point in time of the highest static hazard level. The size of the red dot represents the static hazard level. This image is taken from a video showing the whole time range of the conflict.

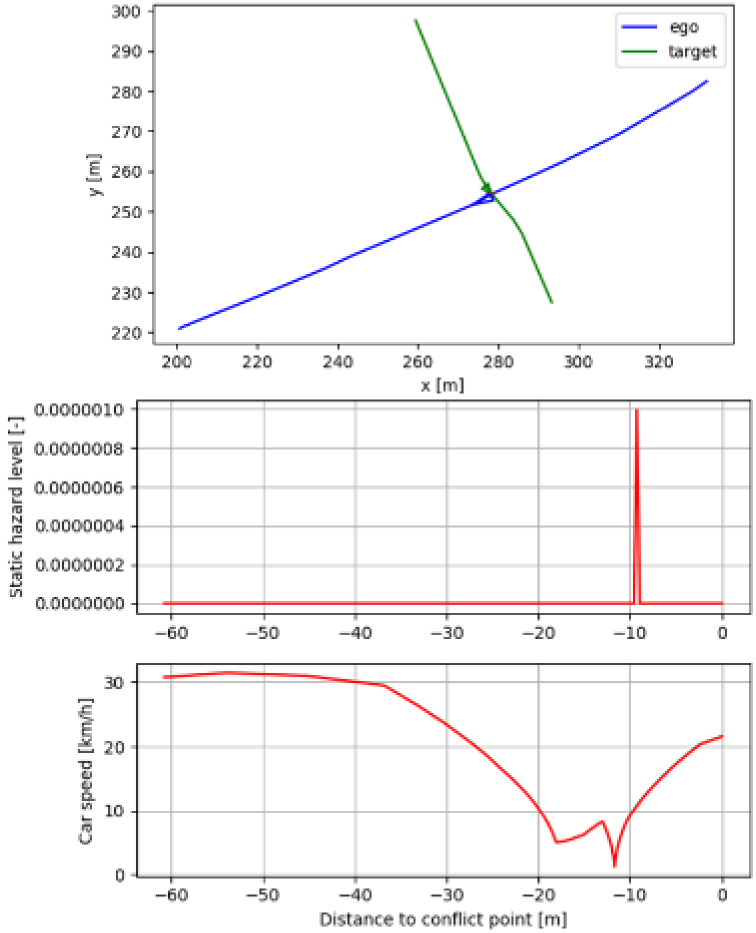


Figure 42 Trajectories (top), static hazard level (middle), car speed (bottom) for a PET conflict (PET = 0.03s).

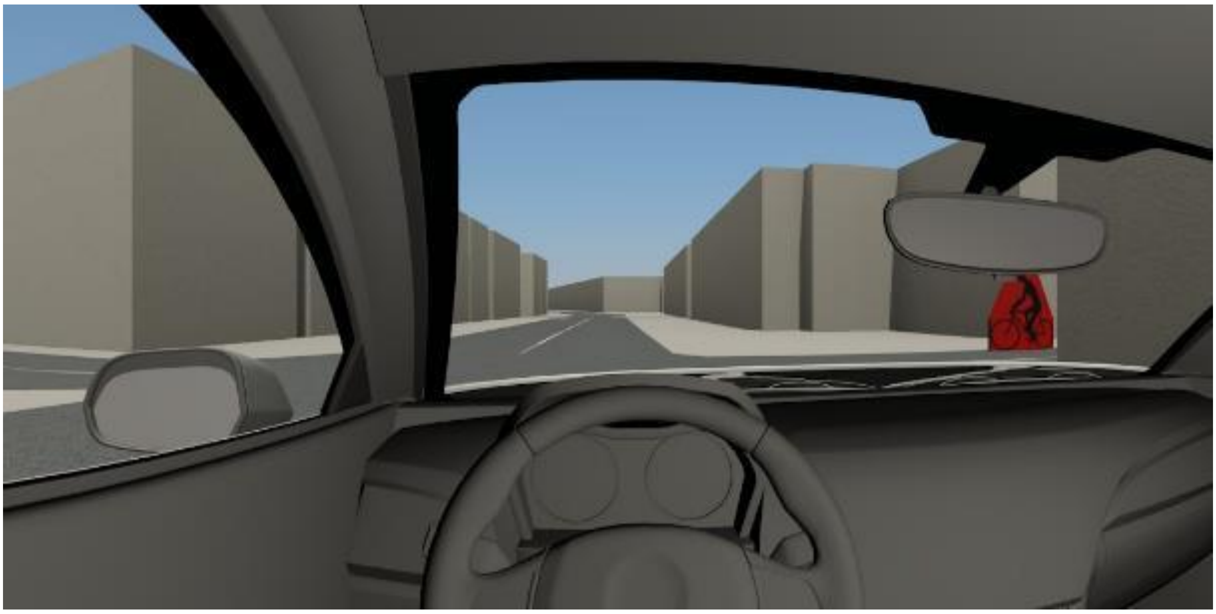


Figure 43 Visualisation of a PET conflict (PET=0.03s) from a driver's point of view at the point in time where the cyclist is fully visible for the first time. This image is taken from a video showing the whole time range of the conflict.

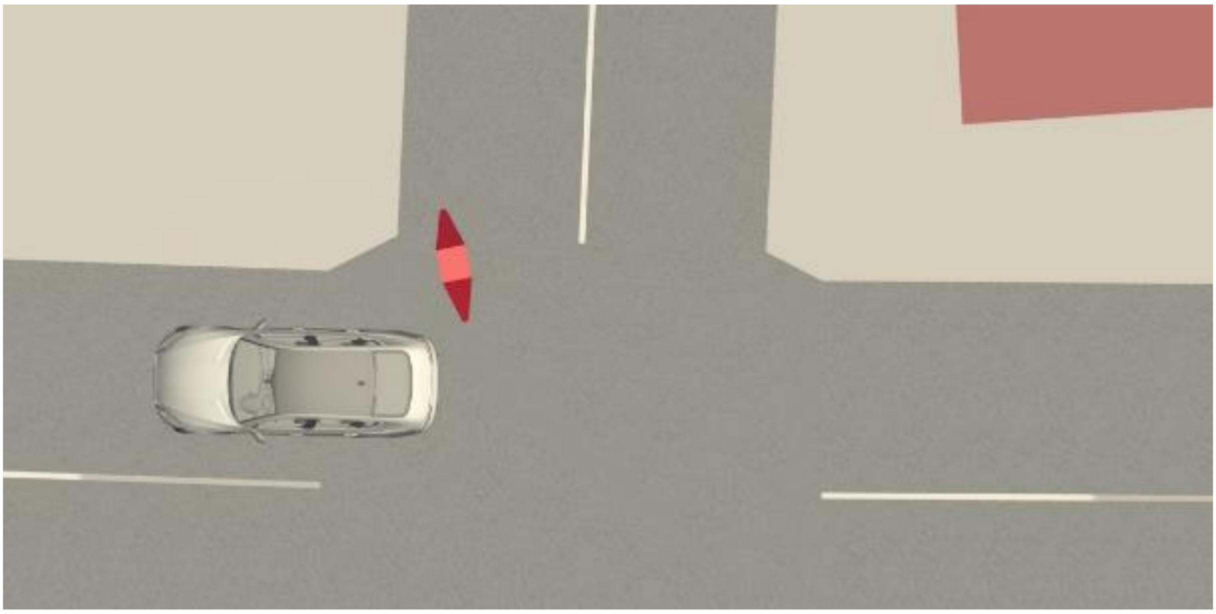


Figure 44 Visualisation of a PET conflict (PET=0.03s) from a bird's-eye view at the point of minimal PET.

6.5 Discussion

The static hazard levels in critical situations did not reach the maximum value of 1 but stayed below a maximum value of 0.6. The assumed reason for this is the fact that the simulated car drivers show "safe driving" behaviour and considerably slow down before the "right before left rule" intersection, thus reducing the possible static hazard level. This especially applies to the case where the hazard level is zero while also PET is very low. Here the miminal PET value is reached when the vehicle leaves the intersection (see Figure 44). The low PET value indicates high criticality of the situatution due to the small time-distance between the car leaving and the cyclist entering the intersection (see Figure 44). As both move at low speeds (not taken into account by PET criterion) the subjective assessment of this situation would result in a lower criticality.

6.6 Conclusion

So far only safe driving of the car drivers is considered. As a next step, also unsafe driving (no or little deceleration when approaching the intersection) will be looked at to get a broader view. With both safe and unsafe driving behaviour available the static hazard model parameters can be further adapted. Furthermore, a sensitivity study for the parameters of the static hazard model will be carried out. It will help in improving the final static hazard model setup in the pilot vehicle. It will be used to show the influence of the model parameters on maximum static hazarad level as well as when this maximum level is reached in typical intersection approaching situations.

7 Simulation study on dynamic hazard model (BMW)

Next to the previously described computer simulations, which focuses on the static hazard model, this chapter reports on the computer simulation studies that have been conducted in order to support the development of the dynamic hazard model. Overall, four different simulation studies have been conducted:

A. Study on the likelihood of detection in case of a visual obstruction;
B. Study on the likelihood of a collision depending on reaction time point;
C. Study on the required speed reduction in order to achieve a certain post encroachment time (PET);
D. Study on the effectiveness of different activation thresholds of the dynamic hazard model.

In the following section report on these four studies.

7.1 Design of tests

The test design of each of the computer simulation study for the development of the dynamic hazard model is described separately in the following. Although there are some common aspect among the conducted studies, the different scopes of the four studies requires individual adaptation for each study.

The main common aspect for the studies is that they follow the simulation approach known from the simulation based safety impact assessment (7) (8). The safety impact assessment approach is to applying stochastic agent based computer simulations for relevant driving scenarios. A further common aspect among the studies is that for the simulation in the studies two agents (combination of driver and vehicle respectively bicycle) are considered.

7.1.1 Study A: Likelihood of detection in case of a visual obstruction

Study A investigates how early the vehicle can detect the cyclist in case of a visual obstruction. The basic scenario is a 90° intersection conflict in which the cyclist is approaching the vehicle from the right side. The vehicle and the cyclist are intending to cross the intersection straight ahead. The velocity of both agents is varied in each simulation run. The trajectory are set up in a way that with the given velocity both traffic participants are on a collision course. The target collision point is also varied in each simulation run. Since in this simulation the vehicle and cyclist agent do need just to follow the pre-calculated trajectory, no sophisticated driver behaviour model is used in this simulation.

In addition, this study requires obviously the presence of a visual obstruction. The visual obstruction is simulated by a rectangle, see Figure 45. The positon of the rectangle is defined by the gap to the vehicle (longitudinal gap) and the gap to the cyclist (lateral gap). The longitudinal gap is varied in each simulation run, whereas the lateral gap is kept constant for a series of simulation run (simulation set) and only varied for the different simulation set.

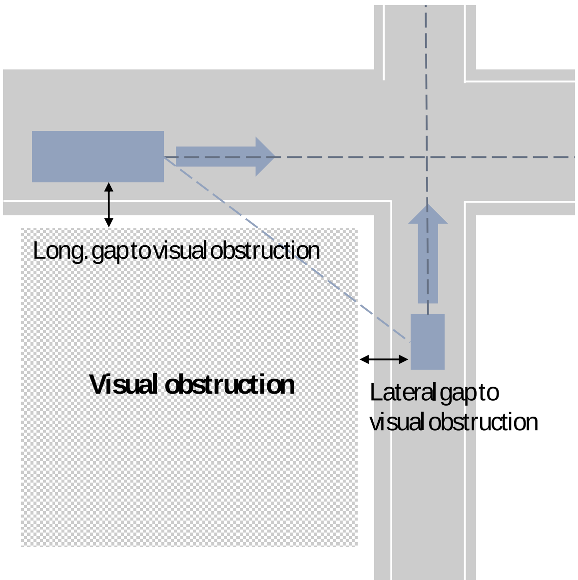


Figure 45 Test scenario of study A.

Overall, ten different simulation sets with different lateral gaps (gap between the cyclist's outer side to the visual obstruction) are analysed in this study. The analysed lateral gaps are 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 15 m, 20 m, 25 m and 30 m. Each simulation set constist of 1000 simulation runs. An overview on the varied parameters that define the starting conditions for each simulation run are provided by.

Parameter	Distribution type	Parameter A	Parameter B
Velocity vehicle	Uniform	Lower Boundary: 10 km/h	Upper Boundary: 65 km/h
Velocity cyclist	Combination of 2 normal distributions (70% 1st; 30% 2nd)	Mean 1st: 25.2 km/h Mean 2nd: 18 km/h	SD 1st: 3.6 km/h SD 2nd: 1.8 km/h
Targeted collision point	Uniform	Lower Boundary: -0.9 m	Upper Boundary: 1.8 m
Longitudinal gap	Uniform	Lower Boundary: 1 m	Upper Boundary: 10 m

Table 8 Overview of parameters varied for each simulation run in study A.

For the analysis at each time point Figure 45, the view from the vehicle to the cyclist is blocked by the visual obstruction or not. In a second step the first point of time at which the vehicle can see the cyclist is determined. With this information the remaining time to collision (TTC) is calculated for this time point. Finally, with this information given for each simulation runs the probability that the cyclist is visible at a certain TTC for the vehicle is calculated.

7.1.2 Study B: Likelihood of a collision depending on reaction time point

The second study analyzes how likely a collision is if the driver of the vehicle or the cyclist reacts to the situation. The design of the second study follows the basic concept of the first study. Figure 46 gives an overview of the simulated scenario for second study.

Thus, there is a passenger car and a cyclist, which are on collision course at 90° four arm intersection. The cyclist approaches the vehicle from the right side. The initial velocities of both traffic participants as well as the targeted collisions point are again stochastically varied for each simulation run.

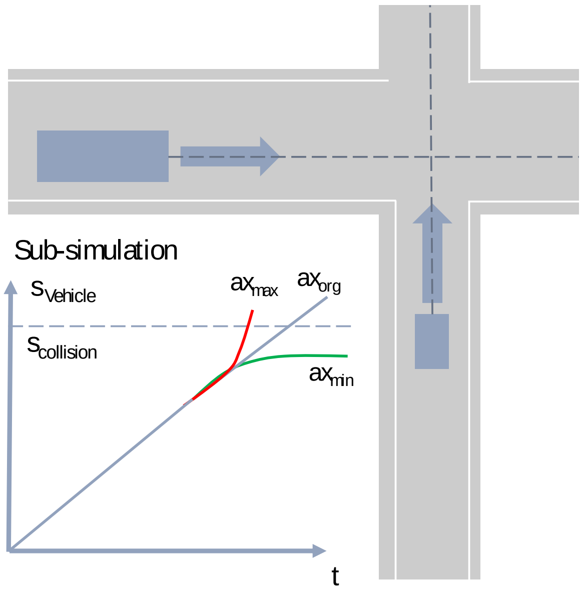


Figure 46 Test scenario of study B.

However, due to the scope of this study some adaptions are required compared to the first study. First, this study requires no visual obstruction. Therefore, the visual obstruction is not taken into account for this study. The second adaptation is that the study must consider different driver reactions for vehicle and cyclist at different locations. For this purpose the basic simulation is stopped after 60 m and then every 2.5 m that the vehicle moves. At these points the given constellation is taken and a sub-simulation is started. In the sub-simulation stochastically chosen accelerations are assigned to both traffic participants. The chosen accelerations are in the range of normal driving and should simulated that one participant or even both decide to react to the given situation. With the new acceleration a series of forward simulation runs are conducted. Once the sub-simulation are finished the basic simulation is continued until it is stopped again. This process continues until a collision in the basic simulation occurs. Since the trajectory in the basic simulation and the acceleration for the sub-simulation are predetermined, also this simulation study does not require a detailed driver behaviour model. Table 9

Parameter	Distribution type	Parameter A	Parameter B
Velocity vehicle	Uniform	Lower Boundary: 10 km/h	Upper Boundary: 65 km/h
Velocity cyclist	Combination of 2 normal distributions (70% 1st; 30% 2nd)	Mean 1st: 25.2 km/h Mean 2nd: 18 km/h	SD 1st: 3.6 km/h SD 2nd: 1.8 km/h
Targeted collision point	Uniform	Lower Boundary: -0.9 m	Upper Boundary: 1.8 m
Long. acceleration vehicle (sub-simulation)	Uniform	Lower Boundary: -3 m/s^2	Upper Boundary: 1 m/s^2
Long. acceleration vehicle (sub-simulation)	Uniform	Lower Boundary: -2 m/s^2	Upper Boundary: 0 m/s^2

Table 9 gives an overview on the varied parameters for the basic simulation and sub-simulation.

Parameter	Distribution type	Parameter A	Parameter B
Velocity vehicle	Uniform	Lower Boundary: 10 km/h	Upper Boundary: 65 km/h
Velocity cyclist	Combination of 2 normal distributions (70% 1st; 30% 2nd)	Mean 1st: 25.2 km/h Mean 2nd: 18 km/h	SD 1st: 3.6 km/h SD 2nd: 1.8 km/h
Targeted collision point	Uniform	Lower Boundary: -0.9 m	Upper Boundary: 1.8 m
Long. acceleration vehicle (sub-simulation)	Uniform	Lower Boundary: -3 m/s^2	Upper Boundary: 1 m/s^2

Parameter	Distribution type	Parameter A	Parameter B
Long. acceleration vehicle (sub-simulation)	Uniform	Lower Boundary: -2 m/s^2	Upper Boundary: 0 m/s^2

Table 9 Overview of parameters varied for each simulation run in study B.

7.1.3 Study C: Required speed reduction in order to achive a certain PET

The third study aims to investigate, how much speed reduction is required to ensure a certain PET depending on the start of the intervention. The analysed scenario and taken approach in the third study differs from the previous two. Here, actual real world accidents between passenger cars and cyclists are re-simulated. For this purpose relevant accidents have been identified in the Pre-Crash-Matrix (PCM) database [9]. The PCM is a subset of the German In-Depth Accident Study (GIDAS) database [10].

In the PCM database certain GIDAS accident cases have been reconstructed until 5 s before the collision. Thus, the PCM database provides the trajectories of the in the accident involved traffic participants including all relevant kinematic parameters. Overall, 539 accidents between a passenger car and cyclist have been identified and are analysed in this study.

For the study each of the 539 accidents is simulated in order to detect the required reduction in speed. The required speed reduction depends on the PET that should be achieved and the point of time at which the deceleration starts. The PET that should be achieved range from 3 s to 1 s in 0.5 s. The deceleration manoeuvre is triggered at the following remaining time to collisions 1 s, 1.5 s, 2 s, 2.5 s, 3 s, 3.5 s and 4 s. The options for the PET and the seven options for the TTC result overall in 35 different configuration that are analysed in this study.

The calculated speed reduction considers two parts of braking manoeuvre. In the first part the deceleration is build up. In the second part the deceleration is kept constant. Furthermore, the deceleration is limited to the maximum possible deceleration.

7.1.4 Study D: Effectiveness of different activation thresholds of the dynamic hazard model

The last study analyses the different thresholds for the activation of the dynamic hazard model. For this purpose different types of threshold are analysed – namely the time to brake (TTB), the time to collision (TTC) and the required acceleration to avoid the collision ($a_{x\ required}$) – as well as different values of the threshold are analysed. In order to determine the effectiveness of a nudge that is issued by the dynamic hazard model every simulation run is conducted once without the system (baseline) and once with the system (treatment). By means of the relative comparison between the number of accidents in the baseline and treatment the effectiveness is calculated for each analysed threshold.

For study D the same crossing scenario as in study A and B is simulated. The vehicle intends to cross an intersection while a cyclist is approach from the right, who is also intending to cross the intersection. The scenario is simulated with and without a visual obstruction. The velocity of the ego vehicle is kept constant at 30 km/h. The velocity of the cyclist is varied (Normal Distribution, Mean: 15.64 km/h, SD: 5.61 km/h) as well as the target collision point.

For this study the vehicle agent must be capable of reacting to the nudge that is issued by the dynamic hazard model as well as to the given situation. Therefore, a driver behaviour model has been implemented for the vehicle agent. The driver behaviour is a modified version of the intelligent driver model [19], for which mainly the information acquisition process has been updated. This update enables the driver to look at different areas around the vehicle and only receiving the information from the area, at which he / she is look at. The direction at which the driver is looking as well as the duration how long the driver looking is chosen stochasticaly. The second update is required in order to react to the nudge. Once a nudge is given, first the likelihood of a reaction towards the nudge is calculated in each time step. This represents time that the driver needs to notice the nudge. If the driver has noticed the nudge, a randomly chosen reaction time is applied (Normal Distribution, Mean: 0.9 s, SD: 0.1 s). Figure 48 shows the distribution of the overall reaction times covering both process (notice and react) for the three analysed intensities of the nudge. Once the reaction time has finished, the view direction of the driver is changed towards directions of the cyclist independent at which are the driver has been looking before. Afterwards the reaction to the given situation is calculated by means of the driver behaviour model.

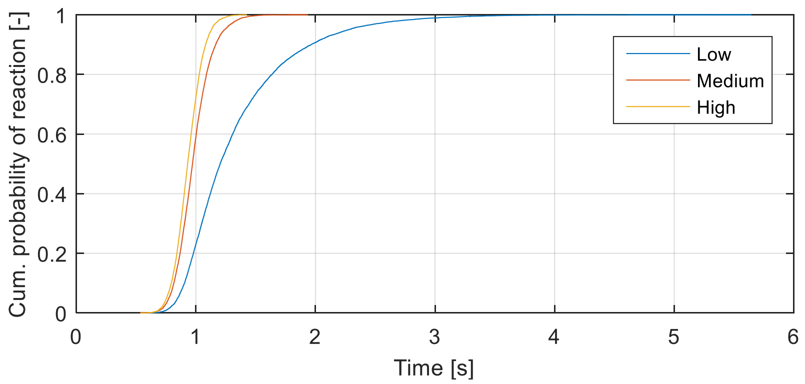


Figure 47 Overall reaction time to the nudge that is issued by dynamic hazard model for three different intensities.

The cyclist does not react to situation at all and continues the pre-calculated trajectory. There are two reasons for this decision: 1. limit the stochastic variations 2. simulate only critical cases, in which the driver is forced to solve the situation. Therefore, for the cyclist no driver behavior model is required.

The dynamic hazard model in this study is a simplified generic version of the later to be implemented model, because for this study a flexible in terms of the applied threshold is needed. The dynamic hazard model calculates, whether the threshold is met or not. For this purpose the system determines based on the position of the vehicle and cyclist the relative distance and relative velocity between both objects. This information is used to calculate the the current value of the analysed metric (TTB, TTC or $a_{x\ required}$) and compare it with the applied threshold. The analysed thresholds are given in Table 10:

	With Obstruction ($p_{Obstruction}$ = 0.5)	Without Obstruction ($p_{Obstruction}$ = 0)
TTB	2 s, 3 s, 4 s, 5 s @ a_x =5 m/s^2	1 s, 1.5 s, 2 s, 3 s, 4 s, 5 s @ a_x =3 m/s^2, 5 m/s^2, 9 m/s^2
TTC	1 s, 1.5 s, 2 s, 3 s, 4 s, 5 s	1 s, 1.5 s, 2 s, 3 s, 4 s, 5s
a_x required	-	-1 m/s^2, -1.5 m/s^2, -2 m/s^2, -3 m/s^2

Table 10 Applied thresholds for the dynamic hazard model in study D.

Once the threshold is met the dynamic hazard model would in reality lead to a certain HMI output. For the simulation the output of the dynamic hazard model is basically just a flag indicating that the nudge is active. Since the study in the simulator have been finished, when this study has been carried out, assumptions had to be made on how likely a reaction of the driver on the nudge is. In order to cover a boarder range three different likelihoods for driver reaction have been analysed:

- Low likelihood of reaction on nudge (p = 0.1023);
- Medium likelihood of reaction on nudge (p = 0.3721);
- High likelihood of reaction on nudge (p = 0.5879).

7.2 Set up of the simulation environment

The agent-based simulation of all four studies are conducted in MATLAB 2015b. For the studies A, B and C simple forward simulation without any driver behaviour model are conducted. Here, the trajectories of the involved traffic participants are pre-calculated including possible reactions. Hence, no feedback loop is required, which results in the requirement for a more sophisticated driver behaviour model.

In terms of the analysed scenario, study C differs from the remaining three, since here real accidents are analysed and simulated. Thus, the simple setup of the intersection as for the other studies does not apply. For the other studies the scenario is always 90° intersection conflict with a cyclist approach the vehicle from the right. The only difference between the different simulations is the presentation of a visual obstruction. The scenario from the right side has been selected because it is expected that this scenario is more challenging than a driving scenario in which the cyclist approaches the vehicle from the left – in particular in case of a visual obstruction.

For the study D the taken approach differs from the other studies. Here, each simulation run is simulated without (baseline) and with a nudging system (treatment) in order to investigate the effect of the dynamic hazard model. Therefore, the simulation in this study must be conducted with a driver behaviour model and a simplified model of the dynamic hazard model. The driver behaviour model controls the input to the vehicle model, which translates the driver command into movement of the vehicle.

During the simulations all relevant measures for the vehicle and cyclist are logged. Based on the logged data each simulation run is evaluated by means of the chosen metric (e.g. occurrence of collision). A visualization of the simulation has also been implemented.

7.3 Test matrix

As described in the previous section in all studies two traffic participant- a passenger car and a cyclist – are simulated in intersection conflict. The relevant parameters that are simulated have been also described. Therefore this chapter focuses on the amount of simulation conducted in each studies.

In terms of simulation runs two criteria are relevant. The first and main criteria is to get reasonable results. Due to the stochastic approach that is applied in the studies A, B and D the number of simulation runs must be high enough to get to sable results. For study C the situation differs, since the amount of simulated scenarios is limited by the available number of real world accidents. The second criteria is that the simulation effort needs to be limited to a reasonable amount and cannot be increased arbitrarily. The taken compromise for for the studies in terms of conducted simulation runs is given in Table 11.

Study	Test approach	Overall number of simulation runs [-]
A	10 simulation sets with 1000 simulation runs	10 000
B	100 basic simulations with 1000 sub-simulations at 25 locations	2 500 000
C	35 configurations in 539 accident cases	18 865
D	108 simulation sets with 1000 runs for the baseline and for the treatment	216 000

Table 11 Number of conducted simulation runs in each study.

For the study C 35 different configurations of the PET and the TTC are analysed. Since in the following only the configuration number is present, Table 12 provides the configuration ID in order to identify which PET and TTC have been used in each configuration.

Configuration ID		TTC @ start of braking						
		1.0 s	1.5 s	2.0 s	2.5 s	3.0 s	3.5 s	4.0 s
PET	1.0 s	1	6	11	16	21	26	31
	1.5 s	2	7	12	17	22	27	32
	2.0 s	3	8	13	18	23	28	33
	2.5 s	4	9	14	19	24	29	34
	3.0 s	5	10	15	20	25	30	35

Table 12 Configuration ID of study C.

7.4 Simulation procedure

All simulations for the four studies have been carried out according to the described test design (see chapter 7.1) and the test matrix (see chapter Table 13). An overview of the expected results and used metrics for the analysis is given in the following table.

Study	Expected result	Metric
A	Identify how early a nudge by the dynamic hazard model can be issued in case of a visual obstruction.	Probability of collision.
B	Identify how likely a collision is depending on reactions of both involved traffic participant at different remaining time to collision.	Probability of collision.
C	Determine which reduction invelocity must be achieved to ensure a certain PET depending on different reaction start points.	Required speed reduction.
D	Identify how effective different thresholds for the activation of the dynamic hazard model are in terms of accident prevention.	Relative change of the collision probability between baseline and treatment simulation.

Table 13 Overview of the expected results and used metric for the studies on the dynamic hazard model.

7.5 Results

The results of the conducted simulation studies should support the later design of the MeBeSafe implemented nudging systems in terms of finding the right parameter set for the dynamic hazard model. It must be noted that the selection of the final parameters for the nudging is a rather complex process which will be continued under consideration of the here presented results. Thus, the studies do not provide a final set of parameters, but next to the other studies the basis for selecting the right parameters, which will be reported in the upcoming deliverable. Since the process of selecting the right parameters is ongoing it is concentrated on describing the results.

The results of each study are reported separately.

7.5.1 Study A: Likelihood of detection in case of a visual obstruction

The result of the first study are given in Figure 45. The results show that in particular if the lateral gap between the visual obstruction and the cyclist is small (less than 10 m) it is hardly possible to detect a cyclist 4 s before the collision. Furthermore, in 50% of the case for the small gaps the first detection is below a TTC of 2 s. These results indicated that the dynamic hazard model is limited in case of a visual obstruction on aspect, how early a nudge can be given. This limitation should be taken into account, when design the nudging system.

It must also be noted that the simulation considers cases in which both participants do not react to the imminent threat. Thus, a constant velocity is presumed for the traffic participants. However, if one of the traffic participant starts to react and to slow down the remaining time to collision will increase.

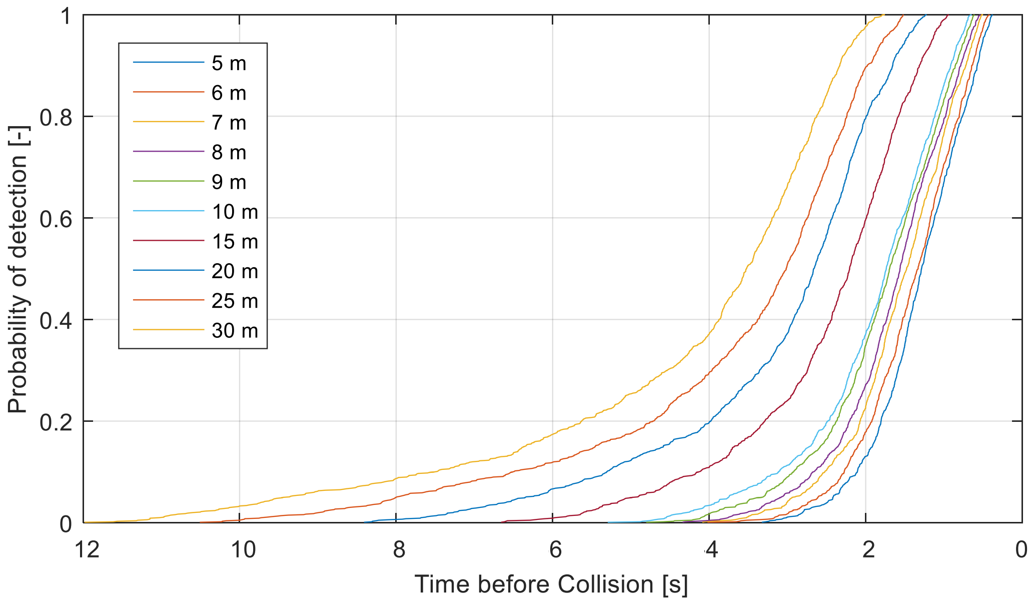


Figure 48 Results of the study to investigate the likelihood of detection in case of a visual obstruction.

7.5.2 Study B: Likelihood of a collision depending on reaction time point

The results of the simulation and sub-simulation of the study B are given in Figure 49. The results show that up to remain time to collision of 3 s the likelihood of a collision considering the applied acceleration distributions is about approx. 25%. Of course, thís number changes in case other acceleration distribution are applied. Nevertheless, this result indicates that if the traffic participants are on collision course, there are still many options to solve the situation without an accident. If the reaction start earlier, the likelihood of a collision decreases. On the other hand if the reaction happens later, there is strong increase of the likelihood of an accident.

For the dynamic hazard module these results should be taken into account when defining the activation threshold. A too early activation might lead to many activations in situations in which the driver might consider any hint as not required. For these situation it is then up to the design of the nudging system as well as to the temper of human driver, whether the hint by the system is consider as irritating or not.

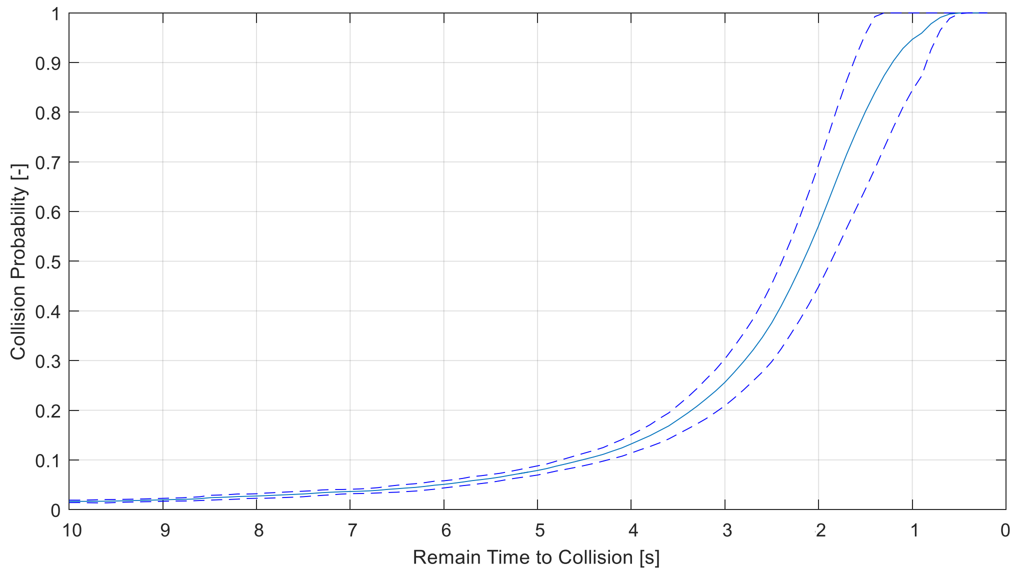


Figure 49 Results of the study to investigate the likelihood of a collision depending on reaction time point (line: mean value; dashed line: mean +/- SD).

7.5.3 Study C: Required speed reduction in order to achieve a certain PET

In the study C 539 accidents of the PCM-Matrix have been re-simulated and analysed with respect to the required speed reduction in order to achieve a pre-defined PET. The results that are given in Figure 50 as well as in more detailed form in the annex A show that the required speed difference depend strongly on the PET and TTC at which the braking starts. The larger the PET that should be achieved, the less the required speed reduction is. The same applies for a earlier start of the braking manoeuvre (increased TTC at which the reaction starts).

Thus, the lowest speed reduction is detected for configuration 31. For this case the mean speed reduction is approx. 14 km/h. The results show a high variation in general and very high required speed reduction for some cases. This is an indication that for re-simulated accident an avoidance is hardly possible, which lead to the question, whether these even can be targeted by a dynamic hazard model.

In general a drawback of the study is that the PCM consists only of accidents that have led to injury. Due to this, the accident in this database are rather severe. Critical situation or minor accidents, which would require less speed reductions, are not considered in the study due to missing data. Thus, in the end the results are biased towards larger required speed reductions. Hence, it is hard to draw specific conclusions on how many speed reductions would be required to achieve a certain PET.

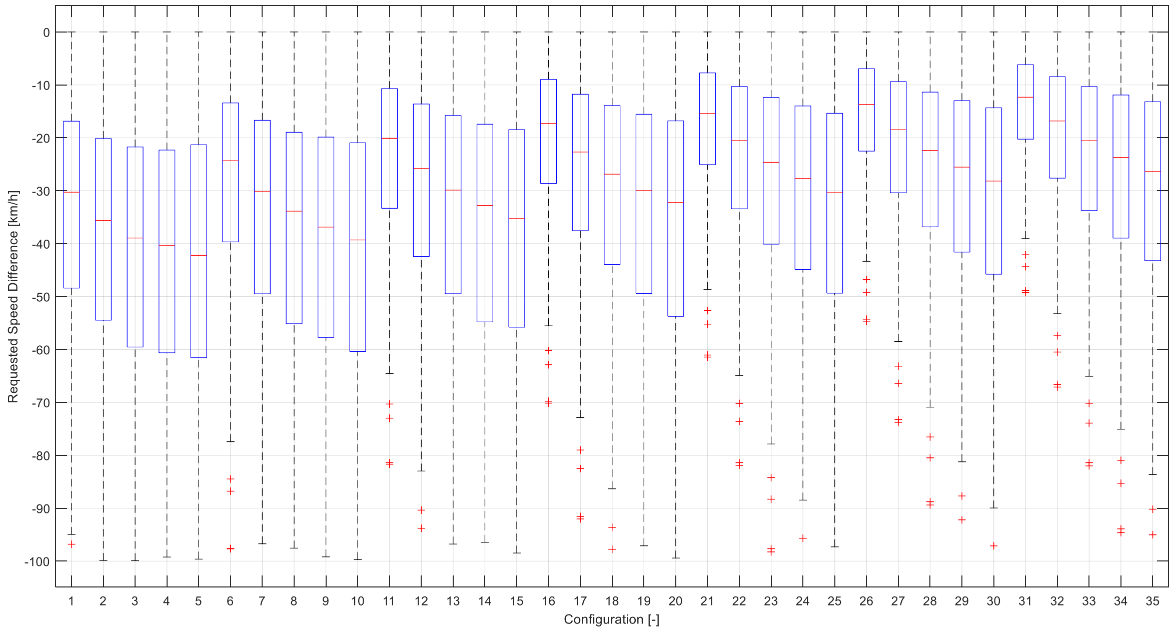


Figure 50 Results of the study to investigate the required speed reduction in order to achieve a certain PET.

7.5.4 Study D: Effectiveness of different thresholds for activation of the dynamic hazard model

The results of the study on the effectiveness of different thresholds for activation of the nudge is given in the Figure 51 (low likelihood of reaction on nudge) and Figure 52 (Medium likelihood of reaction on nudge). The detailed results for each analysed threshold are presented in the Annex B.

The results in Figure 22 show that the TTB thresholds are more effective in terms of accident prevention than the TTC threshold. Considering the characteristics of the threshold this is not surprising, since the nudge is given earlier. Furthermore, in Figure 51 the TTB threshold calculated with different presumed acceleration show only minor differences. In this case larger effectiveness in terms of accident avoidance can be achieved rather by an earlier activations of the nudge.

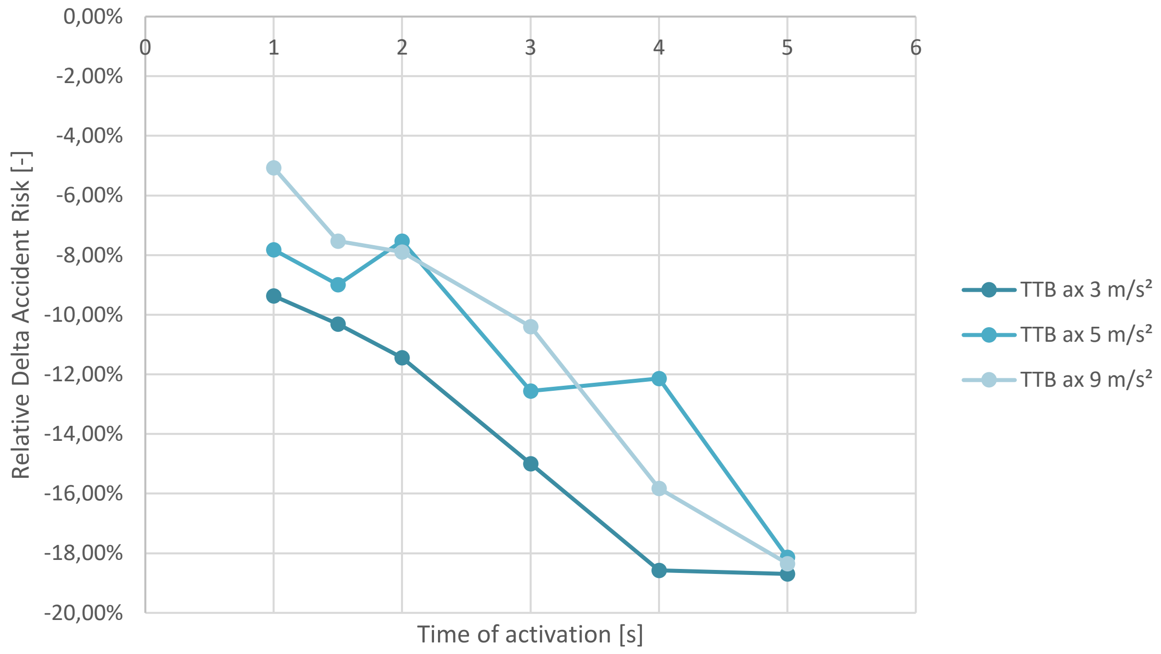


Figure 51 Results of the study to investigate effectiveness of different thresholds for activation of the dynamic hazard model with a low likelihood of reaction.

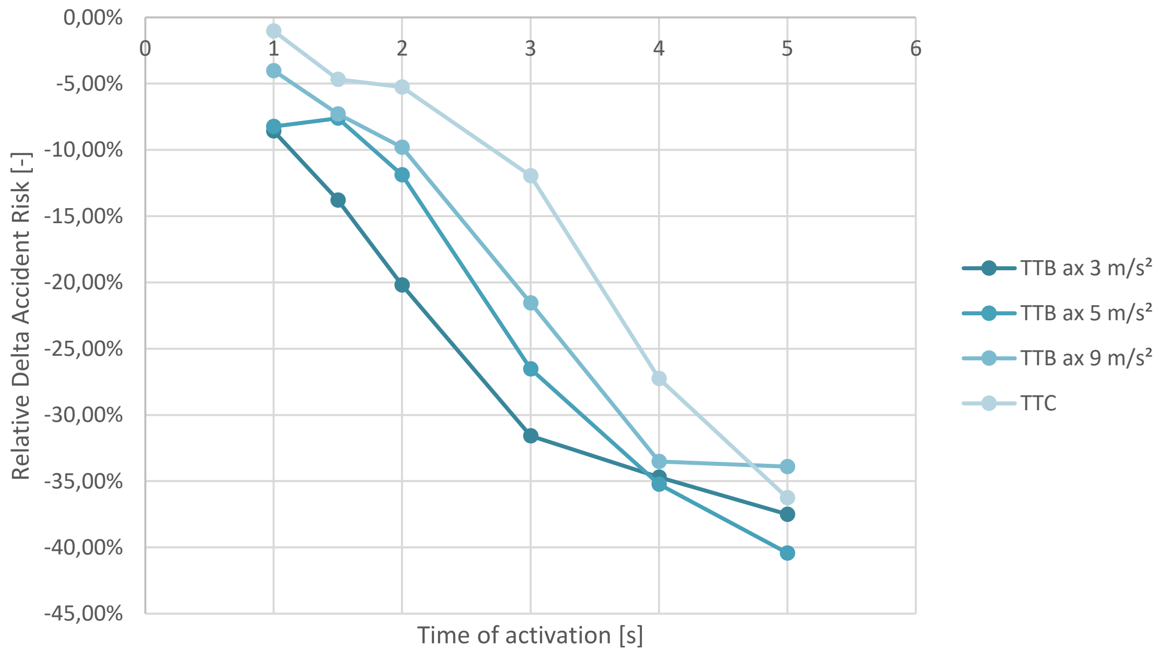


Figure 52 Results of the study to investigate effectiveness of different thresholds for activation of the dynamic hazard model with a medium likelihood of reaction.

Within the results it focused on the TTB and TTC threshold, since the required acceleration threshold shows only significant reductions of accidents for acceleration within the range of normal driving (see Annex B). If such a threshold would be applied, it is likely that this would result in a high number of issued nudges. This can – depending on the design of the nudge – limit the effect of the nudge in the more critical cases, since the driver might get used to it or learns that the nudge is not appropriated.

The result of this study are going to define the final parameter set. For this reason a final conclusion is not available yet and will be provided in the upcoming deliverable.

7.6 Conclusion

Overall, four different computer simulation studies have been conducted in order to support the development of the dynamic hazard model. The results have been reported for each study in the previous subchapters. In general, the studies show that there are limitations in terms of how early a nudge by the dynamic hazard model can be issued. These limitation are set by the environment as well as the difficulties to predict the movement of the involved traffic participants.

Regarding the chosen metric and thresholds for the dynamic hazard model different options have been analysed. The time-related metrics showed a clear advantage compared to the analysed acceleration related metric. Furthermore, the results show that there are two boundaries within the threshold(s) that should be chosen. The first boundary is that the closer the threshold is to an imminent collision the less effective it is. The second boundary is described by the fact that from certain values onwards no major improvement in the crash avoidance can be expected. Discussion about identifying the right threshold(s) of the dynamic hazard model within these boundaries will continue within the work package in the upcoming weeks. The final decisions will be reported in the deliverable D2.3.

8 Conclusion

This document describes the way of selecting the most promising nudging solution to direct the attention of drivers of passenger cars towards potentially hazardous situations. This solution is planned to be implemented in the FIAT 500X for evaluation in the field trial of WP5. The selection process is based on a combination of driving simulator and computer based simulation studies. Where driving simulator studies are indispensable to determine the response of drivers to different HMI options, the computer simulations are used to make a selection of the values for the parameters in the underlying models that provide input to the HMI. In this deliverable, the selection and calibration process is explained and the setup of the different simulator and simulation studies is described. Initial results are given, however, the completed results will be combined in D2.3, the final deliverable in WP2, in which the configuration and implementation of the nudging solution is given and is related to the results of the different studies.

8.1 First solution selection – Questionnaire study (OFFIS)

In the questionnaire study realised by OFFIS, the favorite designs chosen (c.f. Figure 3) by the participants were D2 and D3 which are nearly the same:

Figure 53 Favorite designs chosen.

Reason for that is the low complexity and easy understandability of the concept. Nevertheless also D5 had also a high preference (13%) even though it was quite complex. Another interesting aspect was that after explaining the design all designs lead to the correct adjustment of speed behavior despite of D4. All other designs were significantly better than D4. Based on some comments of the participants, it can be assumed, that this is based on the "warning symbol". The participants underestimated the warning sign. They are used to see this warning signs quite often at roadside and "learned" that in most cases no accident and problem occurs. Thus they are less willing to adapt their speed. Based on the results, further testing is done in the diver simulator study of CRF and the design concept will be adapted accordingly.

8.2 Driving simulator study (CRF)

Three main categories of dependent variables are collected during the driving simulator study for the analysis of the driver response to different HMI options: driving performance measures, driver direction of attention and subjective evaluations. The initial test using the FOVIO eye tracking system was useful to verify the instrumental integration of the eye tracking system and the possibility to determine the direction of attention by the driver; moreover this experiment was useful to implement indicators suggested by "ISO 15007-1:2014 Road vehicles - Measurement of driver visual behavior with respect to transport information and control systems" and evaluate the differences in the indicator results due to different situations: different types of scenarios and presence/absence of cyclist.

Similar indicators will be used to test the impact of the presence/absence and type of proposed HMI solution in the final test.

A test plan has been set up and is currently being executed. The results of the simulator study are being processed and the data will be evaluated to provide input to the implementation of the HMI in the test vehicle that is evaluated in the field trial of WP5. The results will be reported in deliverable D2.3 .

8.3 Simulation study on the static hazard model (Virtual Vehicle)

A simulation study has been performed by Virtual Vehicle to evaluate and calibrate the static hazard model in relevant scenarios, including view-blocking obstructions. During the simulation study the static hazard level in critical situations did not reach the maximum value of 1 but stayed below a maximum value of 0.6. This is the result of the fact that the simulated car drivers show “safe driving” behaviour and considerably slow down before the “right before left rule” intersection, thus reducing the possible static hazard level. So far only safe driving of the car drivers has been considered. As a next step, also unsafe driving will be studied to study the effect of speed on the static hazard level. With both safe and unsafe driving behaviour available, the static hazard model parameters will be further adapted and results will be provided in the upcoming deliverable.

8.4 Simulation study on the dynamic hazard model (BMW)

The additional simulation studies have been conducted in order to support the development of the dynamic hazard model. Overall, four different simulation studies have been conducted. The results of this study are going to be further used in order to define the final parameter set. For this reason a final conclusion is not available yet and will be provided in the upcoming deliverable.

As all the studies have been finalised “just in time”, results are not finalised and validated yet. They will be described in the upcoming deliverable D2.3.

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10 Annexes

10.1 Annex A: Detailed results of study C “required speed reduction in order to achive a certain PET”

Config. No.	TTC [s]	PET [s]	Mean required reduction of velocity [km/h]	STD of required reduction of velocity [km/h]
1	1	1	-34,14	20,85
2	1	1.5	-40,03	23,92
3	1	2	-43,64	25,78
4	1	2.5	-44,53	25,76
5	1	3	-44,33	24,95
6	1.5	1	-27,93	17,93
7	1.5	1.5	-34,30	21,39
8	1.5	2	-38,54	23,64
9	1.5	2.5	-41,32	25,00
10	1.5	3	-43,61	26,26
11	2	1	-23,30	15,18
12	2	1.5	-29,66	19,00
13	2	2	-34,33	21,75
14	2	2.5	-37,50	23,38
15	2	3	-39,80	24,52
16	2.5	1	-19,96	13,15
17	2.5	1.5	-26,19	17,25
18	2.5	2	-30,74	19,92
19	2.5	2.5	-34,31	22,00
20	2.5	3	-36,92	23,36
21	3	1	-17,45	11,60
22	3	1.5	-23,26	15,46
23	3	2	-27,91	18,54
24	3	2.5	-31,29	20,35
25	3	3	-34,28	22,19
26	3.5	1	-15,50	10,37
27	3.5	1.5	-20,93	14,00
28	3.5	2	-25,36	16,96
29	3.5	2.5	-28,78	18,95
30	3.5	3	-31,75	20,79
31	4	1	-13,95	9,38
32	4	1.5	-19,02	12,79
33	4	2	-23,24	15,62
34	4	2.5	-26,81	18,03
35	4	3	-29,59	19,59

Table 14 Detailed results of study C.

10.2 Annex B: Detailed results of study D "effectiveness of different activation thresholds of the dynamic hazard model"

1. Effect of TTB without obstruction (ax = 3 m/s²)

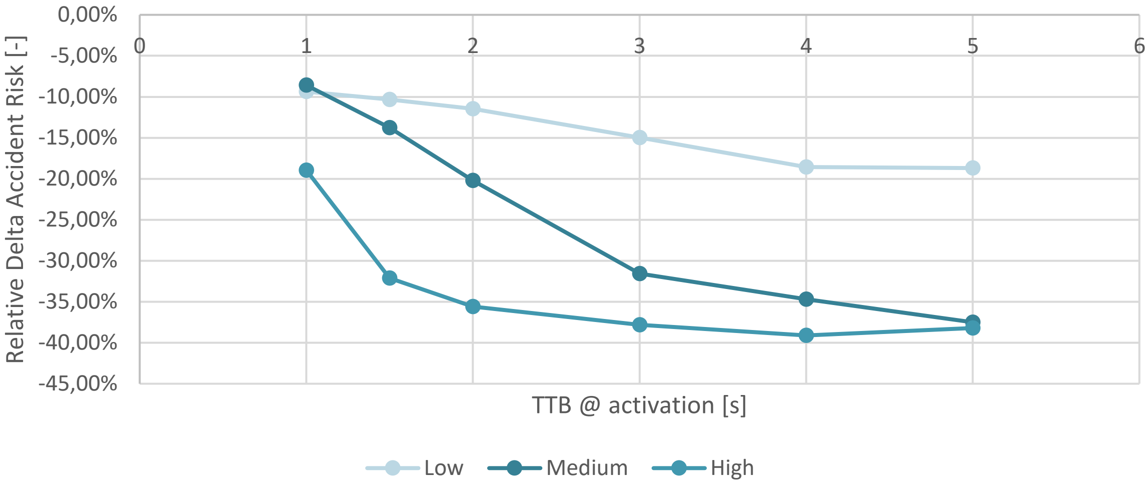


Figure 54 Results of the effectiveness of a TTB based dynamic hazard model (ax = 3 m/s²) without obstruction.

ID	Number of runs	TTB Thres-hold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
1	1000	1	Medium	-8.58%	B	57.10%	2.8%
					T	52.20%	3.5%
2	1000	1.5	Medium	-13.78%	B	59.50%	3.1%
					T	51.30%	2.9%
3	1000	2	Medium	-20.21%	B	57.40%	2.6%
					T	45.80%	2.7%
4	1000	3	Medium	-31.58%	B	57.00%	3.0%
					T	39.00%	2.8%
5	1000	4	Medium	-34.70%	B	55.90%	0.7%
					T	36.50%	1.5%
6	1000	5	Medium	-37.50%	B	55.20%	3.3%
					T	34.50%	1.5%
7	1000	1	High	-18.95%	B	57.00%	2.9%
					T	46.20%	3.9%
8	1000	1.5	High	-32.11%	B	57.00%	2.6%
					T	38.70%	2.8%
9	1000	2	High	-35.58%	B	56.50%	3.8%
					T	36.40%	3.0%
10	1000	3	High	-37.81%	B	56%	1.0%
					T	34.70%	1.4%
11	1000	4	High	-39.11%	B	56.00%	2.3%
					T	34.10%	5.0%
12	1000	5	High	-38.20%	B	55.50%	1.2%
					T	34.30%	1.9%
13	1000	1	Low	-9.37%	B	58.70%	2.1%
					T	53.20%	2.2%
14	1000	1.5	Low	-10.31%	B	57.20%	3.1%
					T	51.30%	3.3%
15	1000	2	Low	-11.44%	B	56.80%	2.6%
					T	50.30%	2.0%
16	1000	3	Low	-14.99%	B	59%	4.5%
					T	49.90%	4.5%
17	1000	4	Low	-18.57%	B	56.00%	1.4%
					T	45.60%	1.8%
18	1000	5	Low	-18.69%	B	56.70%	3.3%
					T	46.10%	3.8%

Table 15 Detailed results of the effectiveness of a TTB based dynamic hazard model ($ax = 3\ m/s^2$) without obstruction.

2. Effect of TTB with obstruction (ax = 5 m/s²)

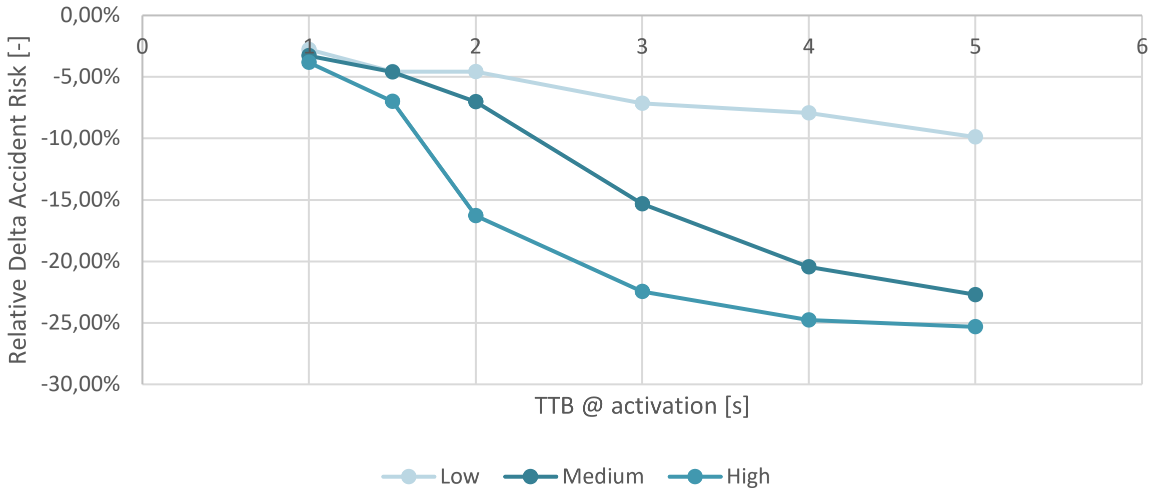


Figure 55 Results of the effectiveness of a TTB based dynamic hazard model ($ax = 5\ m/s^2$) with obstruction.

ID	Number of runs	TTB Thres-hold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
19	1000	1	Medium	-3.29%	B	57.80%	2.0%
					T	55.90%	1.5%
20	1000	1.5	Medium	-4.59%	B	56.60%	2.6%
					T	54.00%	2.6%
21	1000	2	Medium	-7.02%	B	57.00%	3.3%
					T	53.00%	4.5%
22	1000	3	Medium	-15.33%	B	56.10%	3.7%
					T	47.50%	4.2%
23	1000	4	Medium	-20.46%	B	56.20%	5.4%
					T	44.70%	5.2%
24	1000	5	Medium	-22.71%	B	56.80%	4.4%
					T	43.90%	3.1%
25	1000	1	High	-3.83%	B	57.40%	1.5%
					T	55.20%	1.0%
26	1000	1.5	High	-7.01%	B	58.50%	2.2%
					T	54.40%	1.6%
27	1000	2	High	-16.28%	B	60.20%	3.2%
					T	50.40%	3.0%
28	1000	3	High	-22.46%	B	57%	3.7%
					T	44.20%	4.6%
29	1000	4	High	-24.78%	B	57.30%	2.7%
					T	43.10%	1.9%
30	1000	5	High	-25.33%	B	53.30%	5.3%
					T	39.80%	5.7%
31	1000	1	Low	-2.77%	B	57.80%	6.2%
					T	56.20%	6.2%
32	1000	1.5	Low	-4.58%	B	56.80%	4.9%
					T	54.20%	5.0%
33	1000	2	Low	-4.58%	B	56.80%	4.2%
					T	54.20%	3.0%
34	1000	3	Low	-7.16%	B	56%	4.1%
					T	51.90%	3.0%
35	1000	4	Low	-7.93%	B	55.50%	2.7%
					T	51.10%	2.9%
36	1000	5	Low	-9.89%	B	56.60%	4.0%
					T	51.00%	4.5%

Table 16 Detailed results of the effectiveness of a TTB based dynamic hazard model ($ax = 5\ m/s^2$) with obstruction.

3. Effect of TTB with obstruction (ax = 5 m/s²)

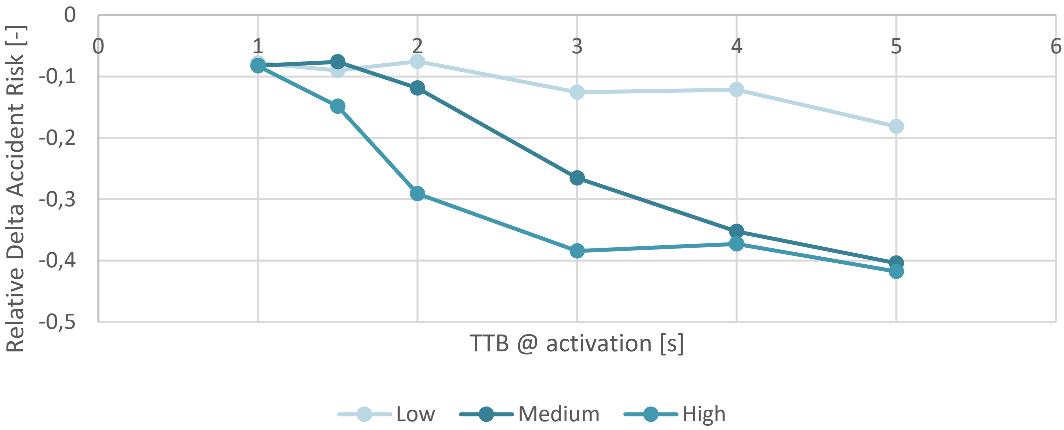


Figure 56 Results of the effectiveness of a TTB based dynamic hazard model (ax = 5 m/s²) without obstruction.

ID	Number of runs	TTB Thres-hold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
21	1000	1	Medium	-0.08244	B	55.8%	2.7%
					T	51.2%	2.7%
22	1000	1.5	Medium	-0.07614	B	59.1%	5.2%
					T	54.6%	4.9%
23	1000	2	Medium	-0.11876	B	58.1%	3.4%
					T	51.2%	2.3%
24	1000	3	Medium	-0.26541	B	58.4%	3.4%
					T	42.9%	3.4%
25	1000	4	Medium	-0.35229	B	54.5%	4.3%
					T	35.3%	3.0%
26	1000	5	Medium	-0.40422	B	56.9%	2.2%
					T	33.9%	2.1%
27	1000	1	High	-0.08288	B	55.5%	6.3%
					T	50.9%	5.9%
28	1000	1.5	High	-0.14851	B	60.6%	4.2%
					T	51.6%	3.8%
29	1000	2	High	-0.29082	B	58.8%	3.0%
					T	41.7%	3.0%
30	1000	3	High	-0.38424	B	60.9%	4.9%
					T	37.5%	4.9%
31	1000	4	High	-0.37279	B	56.6%	4.2%
					T	35.5%	5.8%
32	1000	5	High	-0.41788	B	54.8%	4.4%
					T	31.9%	3.7%
33	1000	1	Low	-0.07815	B	56.3%	5.4%
					T	51.9%	3.9%
34	1000	1.5	Low	-0.08993	B	55.6%	2.0%
					T	50.6%	2.9%
35	1000	2	Low	-0.07531	B	57.1%	3.5%
					T	52.8%	4.4%
36	1000	3	Low	-0.12563	B	59.7%	2.5%
					T	52.2%	2.7%
37	1000	4	Low	-0.12143	B	56.0%	2.6%
					T	49.2%	2.3%
38	1000	5	Low	-0.18134	B	56.8%	4.3%
					T	46.5%	4.1%

Table 17 Detailed results of the effectiveness of a TTB based dynamic hazard model (ax = 5 m/s²) without obstruction.

4. Effect of TTB with obstruction (ax = 9 m/s^2)

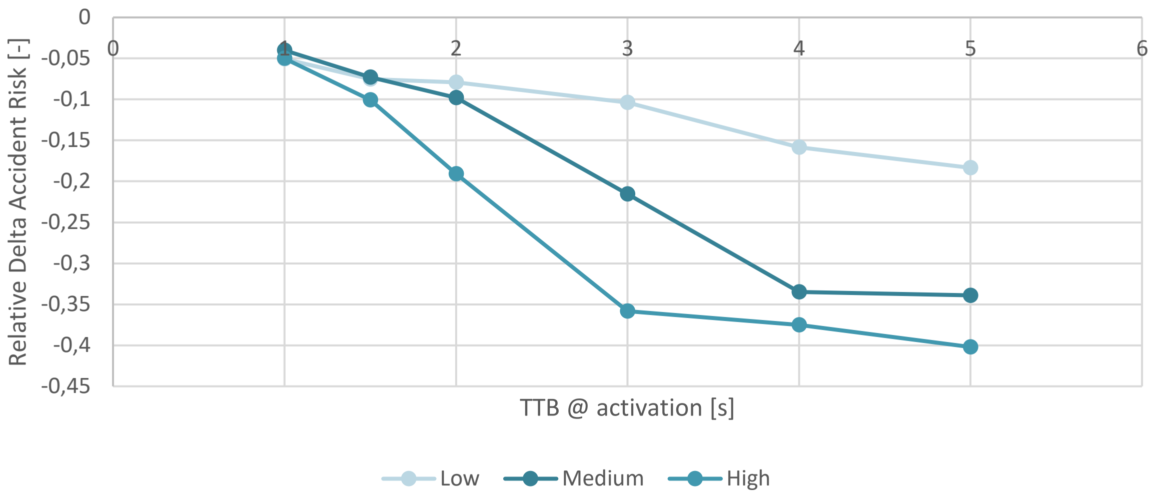


Figure 57 Results of the effectiveness of a TTB based dynamic hazard model (ax = 9 m/s^2) without obstruction.

ID	Number of runs	TTB Threshold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
39	1000	1	Medium	-0.04014	B	57.3%	1.7%
					T	55.0%	2.2%
40	1000	1.5	Medium	-0.07295	B	56.2%	3.3%
					T	52.1%	2.3%
41	1000	2	Medium	-0.09811	B	58.1%	2.2%
					T	52.4%	3.7%
42	1000	3	Medium	-0.21555	B	56.6%	2.5%
					T	44.4%	2.8%
43	1000	4	Medium	-0.33507	B	57.6%	3.1%
					T	38.3%	3.2%
44	1000	5	Medium	-0.33901	B	58.7%	3.8%
					T	38.8%	3.9%
45	1000	1	High	-0.05009	B	55.9%	3.5%
					T	53.1%	3.7%
46	1000	1.5	High	-0.10053	B	56.7%	1.4%
					T	51.0%	1.2%
47	1000	2	High	-0.19089	B	57.1%	4.0%
					T	46.2%	3.6%
48	1000	3	High	-0.35842	B	55.8%	3.3%
					T	35.8%	2.5%
49	1000	4	High	-0.37521	B	58.9%	2.7%
					T	36.8%	3.6%
50	1000	5	High	-0.40203	B	59.2%	2.4%
					T	35.4%	1.7%
51	1000	1	Low	-0.0507	B	57.2%	3.8%
					T	54.3%	3.7%
52	1000	1.5	Low	-0.07525	B	59.8%	2.8%
					T	55.3%	3.7%
53	1000	2	Low	-0.07899	B	59.5%	3.0%
					T	54.8%	4.1%
54	1000	3	Low	-0.10394	B	55.8%	1.8%
					T	50.0%	3.2%
55	1000	4	Low	-0.15825	B	59.4%	2.7%
					T	50.0%	2.7%
56	1000	5	Low	-0.18345	B	55.6%	3.9%
					T	45.4%	3.5%

Table 18 Detailed results of of the effectiveness of a TTB based dynamic hazard model ($ax = 9\ m/s^2$) without obstruction.

5. Effect of TTC with obstruction

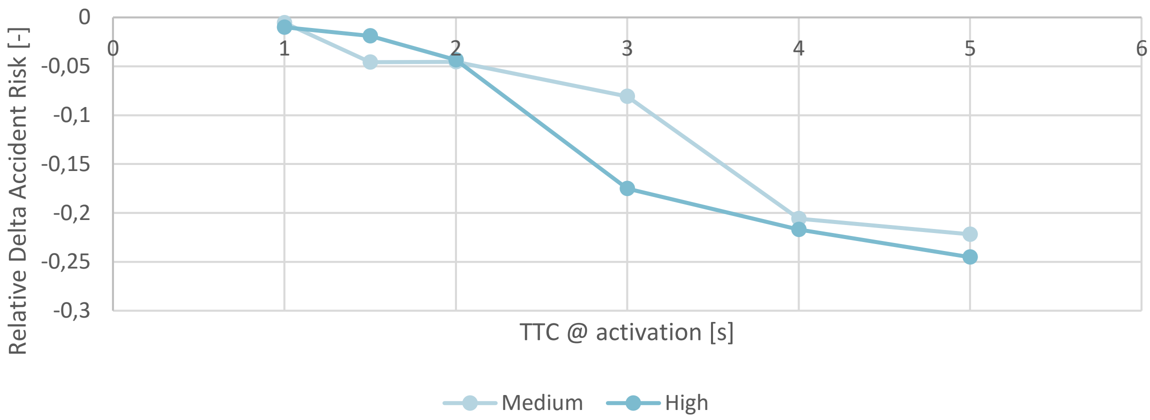


Figure 58 Results of the effectiveness of a TTC based dynamic hazard model with obstruction.

ID	Number of runs	TTB Thres-hold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
75	1000	1	Medium	-0.0055	B	55.0%	4.8%
					T	54.7%	4.7%
76	1000	1.5	Medium	-0.0459	B	56.6%	2.6%
					T	54.0%	2.6%
77	1000	2	Medium	-0.0455	B	57.1%	2.6%
					T	54.5%	2.0%
78	1000	3	Medium	-0.0808	B	59.4%	4.1%
					T	54.6%	5.8%
79	1000	4	Medium	-0.2058	B	58.8%	7.2%
					T	46.7%	4.4%
80	1000	5	Medium	-0.2218	B	56.8%	2.1%
					T	44.2%	1.7%
81	1000	1	High	-0.0101	B	59.7%	2.6%
					T	59.1%	2.5%
82	1000	1.5	High	-0.0189	B	58.2%	1.6%
					T	57.1%	0.9%
83	1000	2	High	-0.0433	B	57.7%	4.0%
					T	55.2%	3.8%
84	1000	3	High	-0.1751	B	57.1%	2.9%
					T	47.1%	1.1%
85	1000	4	High	-0.2169	B	59.0%	5.4%
					T	46.2%	4.8%
86	1000	5	High	-0.2453	B	57.9%	1.8%
					T	43.7%	2.4%

Table 19 Detailed results of the effectiveness of a TTC based dynamic hazard model with obstruction.

6. Effect of TTC without obstruction

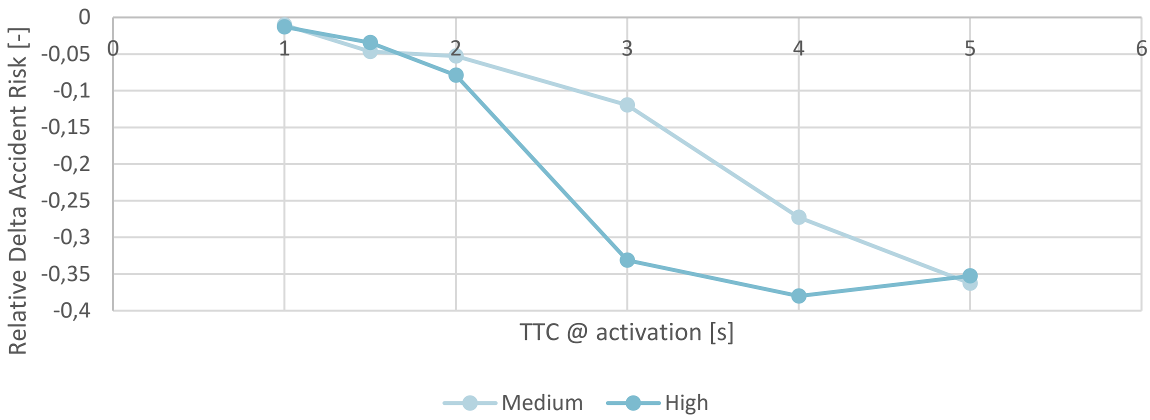


Figure 59 Results of the effectiveness of a TTC based dynamic hazard model without obstruction.

ID	Number of runs	TTB Thres-hold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
87	1000	1	Medium	-0.0103	B	58.4%	2.1%
					T	57.8%	2.1%
88	1000	1.5	Medium	-0.0468	B	57.7%	3.6%
					T	55.0%	2.6%
89	1000	2	Medium	-0.0526	B	58.9%	4.3%
					T	55.8%	4.1%
90	1000	3	Medium	-0.1194	B	56.1%	1.7%
					T	49.4%	2.3%
91	1000	4	Medium	-0.2726	B	53.2%	2.0%
					T	38.7%	3.0%
92	1000	5	Medium	-0.3626	B	60.4%	1.1%
					T	38.5%	3.1%
93	1000	1	High	-0.0129	B	54.1%	2.3%
					T	53.4%	2.2%
94	1000	1.5	High	-0.0344	B	58.1%	3.3%
					T	56.1%	4.3%
95	1000	2	High	-0.0791	B	59.4%	4.3%
					T	54.7%	3.6%
96	1000	3	High	-0.3311	B	59.8%	0.8%
					T	40.0%	3.2%
97	1000	4	High	-0.38	B	60.0%	4.1%
					T	37.2%	4.0%
98	1000	5	High	-0.3525	B	53.9%	2.3%
					T	34.9%	3.1%

Table 20 Detailed results of the effectiveness of a TTC based dynamic hazard model without obstruction.

7. Effect of $a_{x\ required}$ without obstruction

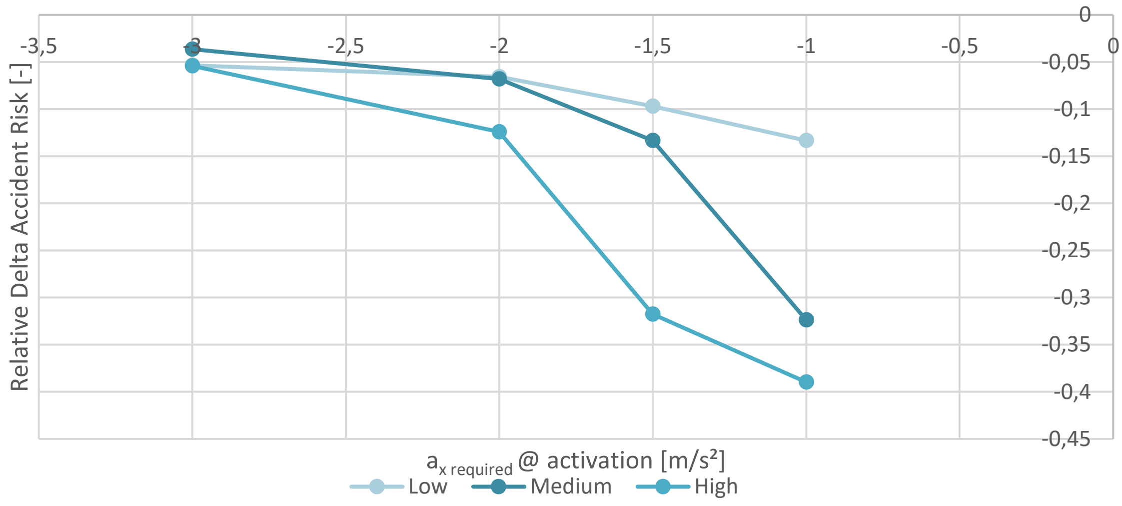


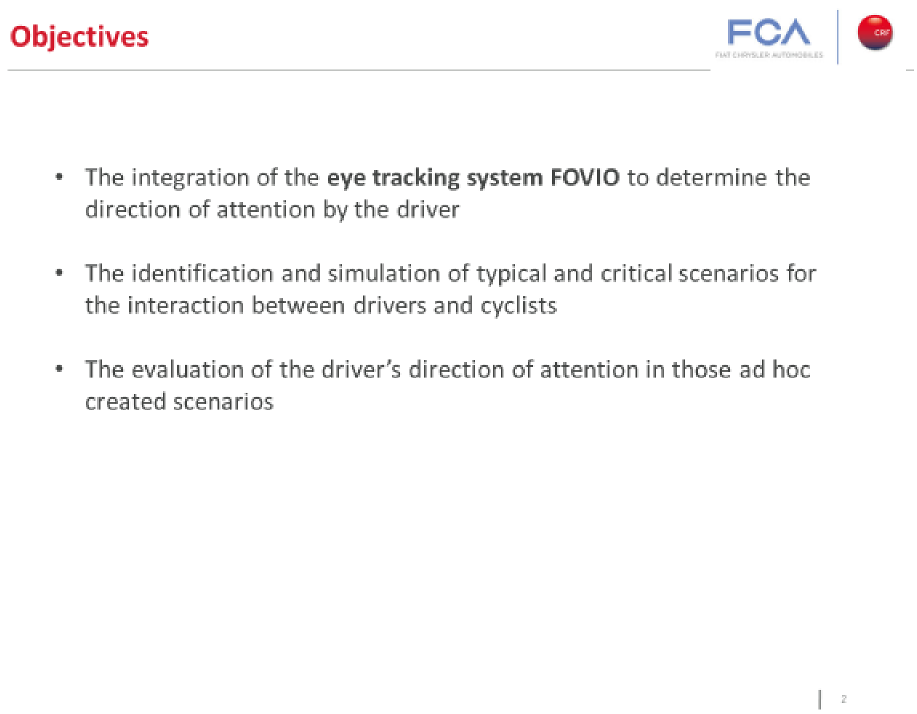
Figure 60 Results of the effectiveness of a $a_{x\ required}$ based dynamic hazard model without obstruction.

ID	Number of runs	TTB Thres-hold [s]	Intensity of Nudge [-]	Relative Delta Collision Rate [-]	Condition	Mean Collision Rate [-]	SD Collision Rate [-]
99	1000	-1	Medium	-0.3237	B	55.6%	4.5%
					T	37.6%	1.6%
100	1000	-1.5	Medium	-0.1333	B	58.5%	2.8%
					T	50.7%	0.9%
101	1000	-2	Medium	-0.0682	B	57.2%	1.5%
					T	53.3%	1.4%
102	1000	-3	Medium	-0.0364	B	57.7%	4.3%
					T	55.6%	4.2%
103	1000	-1	High	-0.3898	B	56.7%	2.7%
					T	34.6%	2.8%
104	1000	-1.5	High	-0.3175	B	57.0%	2.8%
					T	38.9%	2.3%
105	1000	-2	High	-0.1241	B	58.0%	3.0%
					T	50.8%	3.2%
106	1000	-3	High	-0.0541	B	57.3%	5.7%
					T	54.2%	4.2%
107	1000	-1	Low	-0.1334	B	59.2%	5.1%
					T	51.3%	4.4%
108	1000	-1.5	Low	-0.0969	B	57.8%	2.5%
					T	52.2%	3.0%
109	1000	-2	Low	-0.0658	B	59.3%	4.9%
					T	55.4%	4.3%
110	1000	-3	Low	-0.0536	B	56.0%	2.2%
					T	53.0%	3.0%

Table 21 Detailed results of effectiveness of a $a_{x\ required}$ based dynamic hazard model without obstruction.

10.3 Annex C: Sensing driver and vehicle state (CRF)

10.4 MeBeSafe: T2.1 – Sensing driver and vehicle state – CRF contribution



FOVIO eye tracker

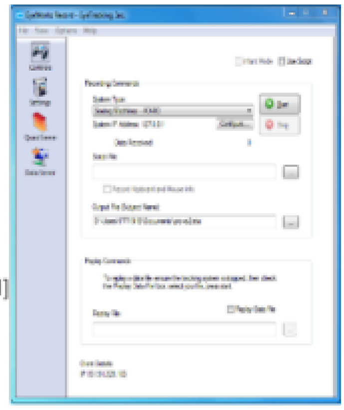
- The FOVIO eye tracker is a fully portable eye tracking device, with the cylinder gaze angular between -30° to 30° (Horizontal) and -15° to 30° (Vertical)
- The eye tracker is controlled by the EyeWorks software

EyeWorks Software

EyeWorks is a software suite designed to manage all aspects of eye tracking research. The suite consists of three modules: **Design**, **Record** and **Analyze**.

Eyeworks Record allows for example to:

- Record all data;
- View video during data collection



The output data provided are listed below:

- Data time [ms];
- Left/Right eye (X,Y) [in pixels];
- Left/Right eye pupil diameter;
- Left/Right eye intersected screen [0=no screen intersected]
- Left/Right gaze data quality [0=invalid, 3=most accurate];
- Left/Right eyeball rotation (X,Y,Z);
- Left/Right eyeball position (X,Y,Z);
- Distance from Left/Right eye to eye tracker.

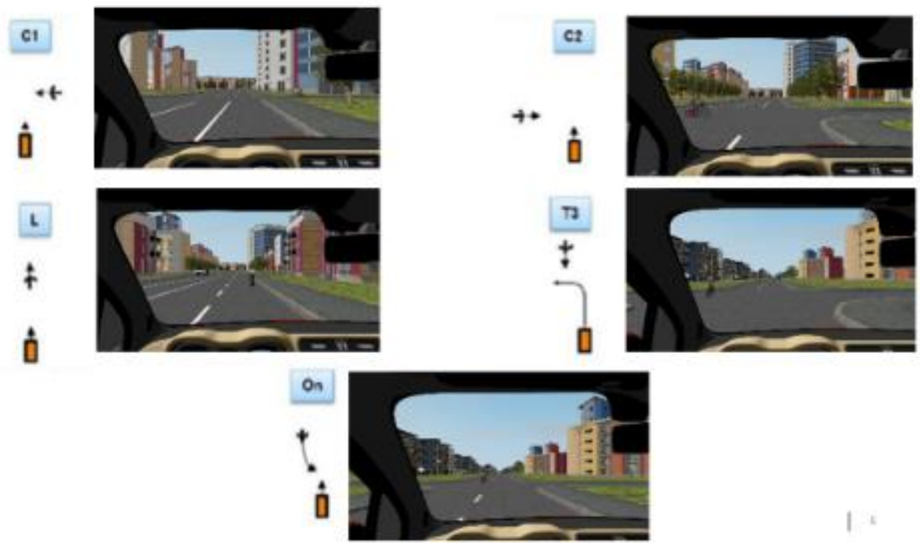
Experimental set up

Driving simulator:

- Driving mockup with LCD instrument cluster
- Force feedback on steering wheel
- Visual system: 75 " curved screen full HD
- Stereo audio system
- Software: Scaner Studio by OKTAL

Ad hoc simulated scenarios

Starting from the analysis done (see "MeBeSafe – WP2 – Task 2.1 Scenarios selection" presentation at the end), the following 5 scenarios were identified as typical and critical, agreed among partners and then simulated:



Method - Experimental tasks

PRIMARY TASK

- Participants had to drive in the randomized scenarios maintaining a speed of 50 km/h and reacting as during the everyday driving, accordingly to the type of scenario (e.g. incoming cyclist)

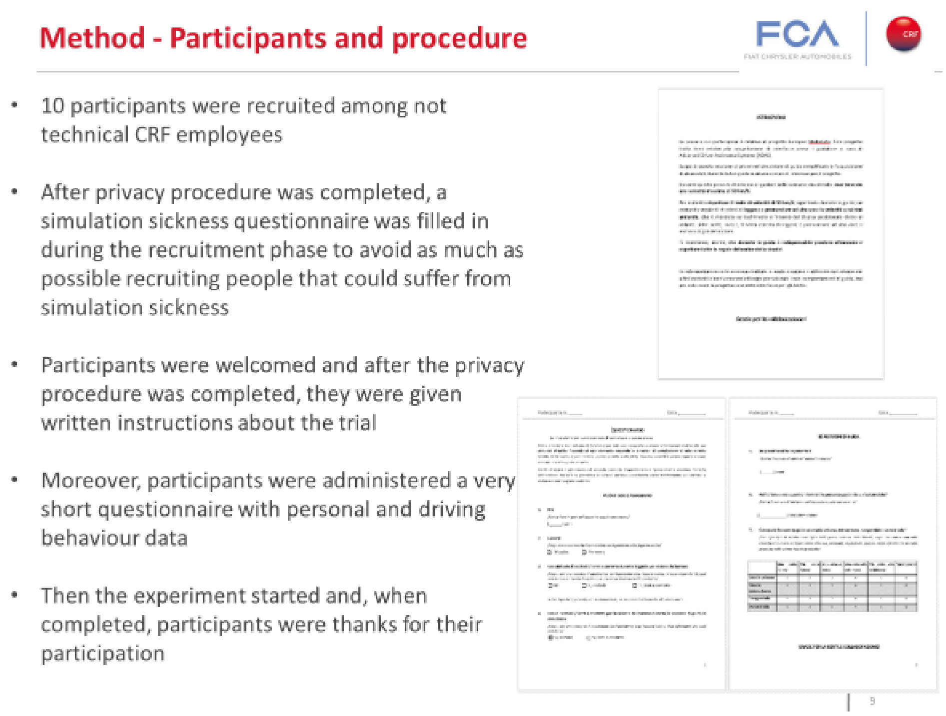
SECONDARY TASK

- Sometimes participants were requested by a synthetic voice to read their speed or rpm. The secondary task was inserted to avoid the driver was too much focalised on the incoming cyclist and to made the experiments a little bit less annoying.
- This voice was presented in a randomized order: sometimes between 5 to 8 seconds before the crossing. Other times between 8 to 13 seconds before the crossing.

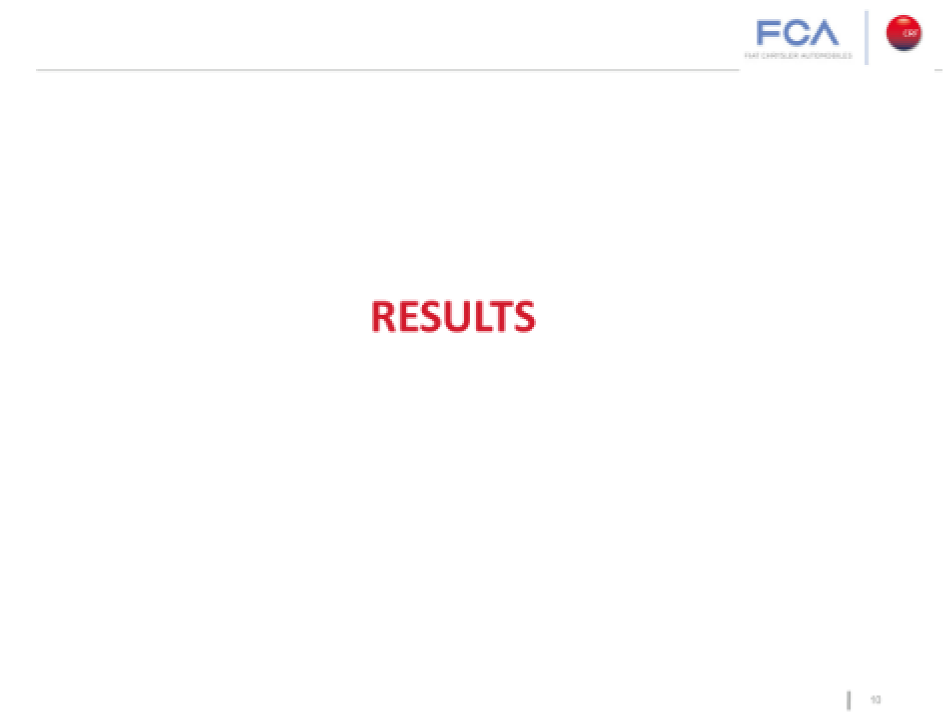
Method - Experimental design

- A within subject design was defined: all 10 participants drove in all the 5 conditions (scenarios)

- 3 conditions (C1,C2 and T3) were tested with and without cyclist
- 2 conditions (C1 and C2) were tested with cyclist that stop and doesn't stop at crossing
- Each condition was replicated 6 times
- The trials have been randomized both for the scenarios condition and for the incoming cyclist to avoid the order effects
- The experiment lasted about 40 m


Method - Participants and procedure
FCA
FIAT CHRYSLER AUTOMOBILES
CRF
• 10 participants were recruited among not technical CRF employees
• After privacy procedure was completed, a simulation sickness questionnaire was filled in during the recruitment phase to avoid as much as possible recruiting people that could suffer from simulation sickness
• Participants were welcomed and after the privacy procedure was completed, they were given written instructions about the trial
• Moreover, participants were administered a very short questionnaire with personal and driving behaviour data
• Then the experiment started and, when completed, participants were thanks for their participation
9

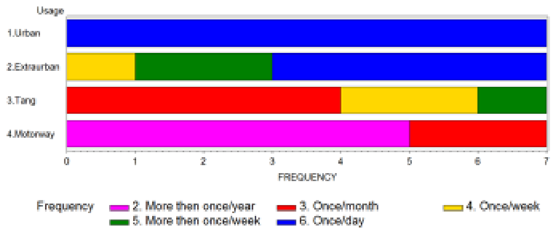
10.5 Results


FCA
FIAT CHRYSLER AUTOMOBILES
CRF
RESULTS
10

Participants sample characteristics

This slide reports description of the sub-sample that completed the test and has been used for data analysis.

- Age: Average 48 years (min 42, max 57)
- Gender: 30% Male, 70% Female
- Driven km/year: Average 12000km/year (min 8000, max 15000)
- Glasses / Contact lens: 43% nothing, 57% glasses
- Usage:



11

Collected data and their preliminary reduction

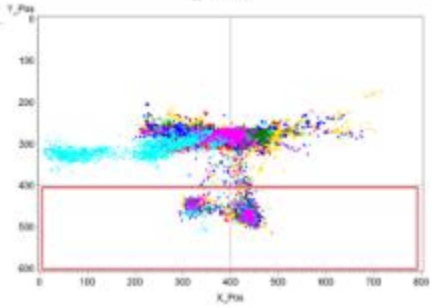
- Data were acquired by driving simulator (for scenario and vehicles data) and by camera (for driver visual behaviour) and aligned on time reference
- 7 drivers completed the test and have been considered for data analysis
- On original data acquired by FOVIO (frequency approximately 60Hz):
  - Separately for each eye, has been extended low quality to the first/last data with good quality
  - Separately for each eye, has been excluded X and Y positions with low quality or outside the expected ranges (0-800 for X position, 0-600 for Y position)
  - The average or available position for Left and Right eye has been considered, separately for X position and Y position
- On all data
  - Statistics has been calculated with a frequency of 20Hz
  - Only times with both set of data (simulator and camera) have been considered
  - For X position and Y position only average values calculated on at least 2 data have been considered (normally 3 data are available); after all these filters data quality can be considered good.
  - Additional variables have been calculated (example: distance and angle between cycle and car, total travelled distance during the test, direction of gaze in X ,...)

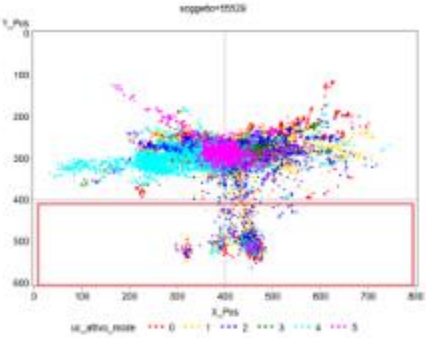
Subject	% of valid data for both direction
12333	90%
36510	70%
46982	97%
49221	86%
55529	85%
69248	94%
123846	86%

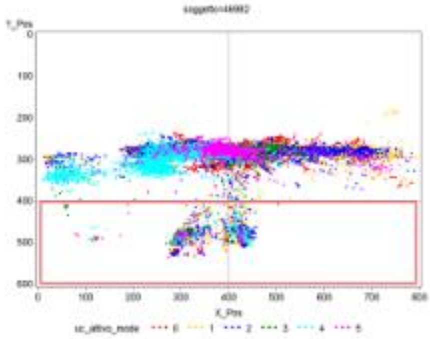
12

Main areas of interest

- This slide reports some example of **eyes direction during test**
  - Glance in the red area are glance to instrument panel (secondary task was to read speed/rpm)
  - Different colors represents different driving and cyclist tasks, for example in light blue driver has to turn left (with and without cyclist)





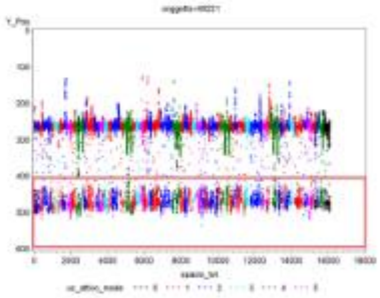


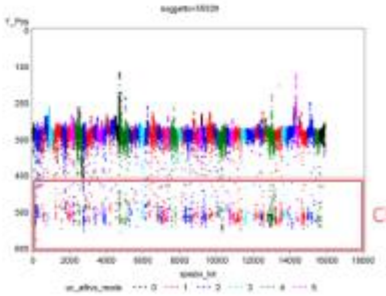
Focus on instrument panel

- Percentage of time on instrument panel and also type of glances to it are somehow **different among participants.**
  - Graphs reports space history of glances in Y direction
  - Data related to time with Y value higher then 400, probably referred to cluster glances, have not been considered during comparison between angle between cycle and car respect direction of gaze (in X).

Subject	% of estimated time to cluster
12333	10%
36510	2%
46982	7%
49221	30%
55529	7%
69248	35%
123846	21%

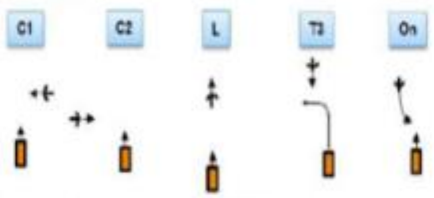
Glances to cluster not completely acquired could be reason for lower % of valid data (← 36510)





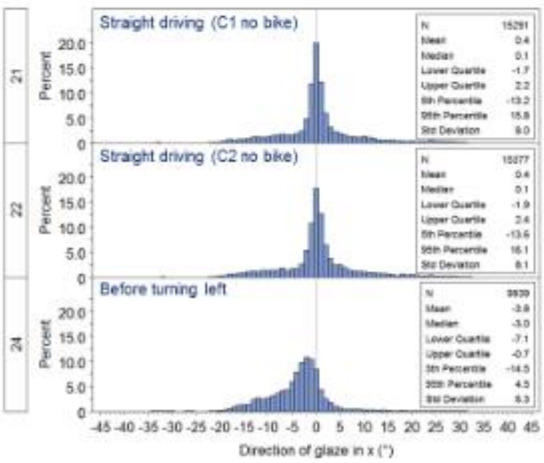
Focus during maneuvers

- Only a **part of the maneuvers was considered** in order to avoid to concentrate interest in some areas too later respect to cyclist needs or not in the desired configuration
  - Maneuver L starts when the bike has approximately the same direction of the car (it arrives from a lateral street)
  - Maneuver L ends when distance of car from bike is lower then 15m
  - Other maneuvers end when distance of car from intersection is lower then 15m
  - Angles between car and bike bigger then 45° were not considered



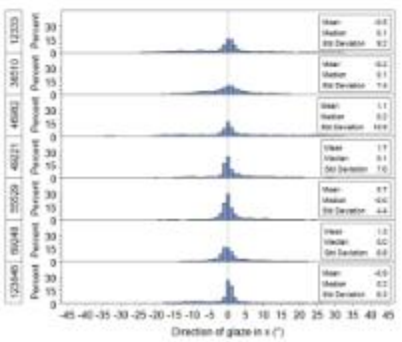
Average direction of glaze (in X)

- This slide reports glaze direction in X during **intersection approaching without cyclists,** excluding last 15m
- During straight driving main focus is on the central part of the screen, more glances on the left before turning left



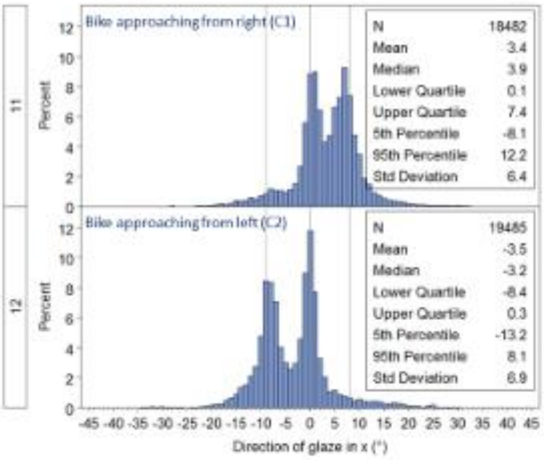
Some differences in data distribution and dispersion can be observed among drivers (in small graph glances during straight driving)

NOTE: X direction angles referred to cluster

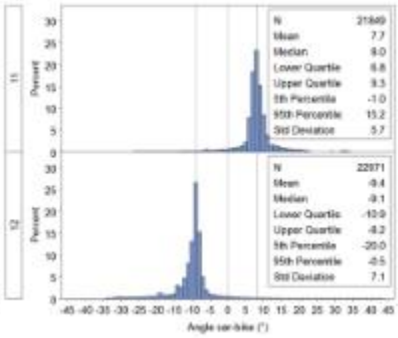


Direction of glaze in presence of bike (1/2)

- This slide report glaze direction in X during **intersection approaching in presence of a cyclist approaching the intersection**, excluding last 15m
- A multimodal distribution of glazes can be observed and, in addition to glances in central area, a second peak can be observed at approximately the peak of angles between car and bike during the maneuver (-9° and 8°)

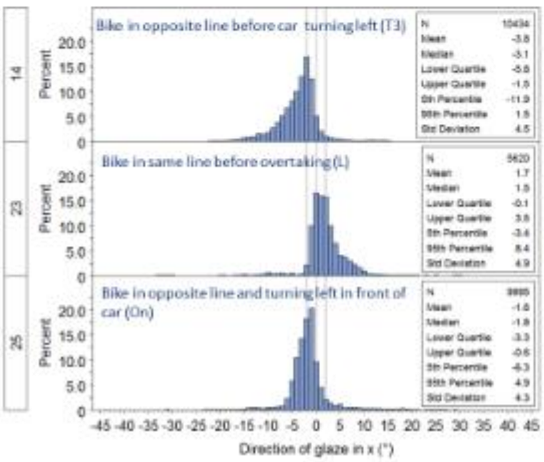


NOTE: X direction angles referred to cluster are not considered in this graphs

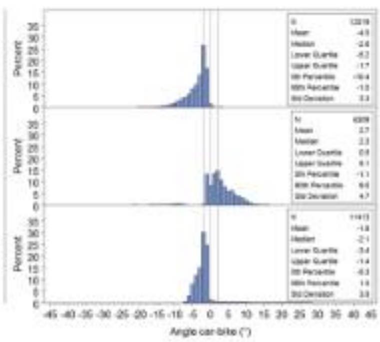


Direction of glaze in presence of bike (2/2)

- This slide report glaze direction in X **presence of a cyclist in front of car** (both in the same or opposite lane) excluding last 15m (before intersection or overtaking)
- The distribution of glazes is among central area and the peak of angles between car and bike during the maneuver (-2° and 2°)



NOTE: X direction angles referred to cluster are not considered in this graphs.



Identification of cyclist by driver

- During maneuvers, **direction of glaze in X and calculated angle between car and bike have been compared and used to define time when bike has been probably identified.**
- Bike is assumed identified by driver if for at least 7 data on 9 successive data (450ms) difference among angles (car versus bike and direction of glaze) is lower then 1.5° and y direction not referred to instrument panel.
  - With the assumed definition, almost all bike have been identified, according to observation done by experimenters conducting the test
  - Moreover, in absence of car, have been calculated hypothetical identification with reference angles, obtaining lower percentages.

Maneuver	Percentage of bike identifications
Bike from right (C1)	83%
Bike from left (C2)	91%
Bike in front opposite line (T3)	97%
Bike in front same line (L)	95%
Bike in front and turning (On)	100%

Reference angle in absence of bike (straight driving)	Percentage of bike identifications
+8°	19%
+15°	10%

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Direction of glaze before and after cyclist identification

- Tables reported in this slides show **percentage of time in different ranges of x angle for glances not referred to cluster**, respectively:
  - In absence of bike or bike not identified
  - After bike identification
- In **straight driving condition and absence of bike identification focus in on central area for 40-50% of time**, slightly low before turning left
- **After bike identification and with bike not in front the driver**, (in test condition, few traffic**) around 50% of time driver monitor the bike and around 20% of time continue to monitor the central area**.

Direction of gaze – bike not present or not identified

	C1 no bike	C2 no bike	T3 no bike	C1 bike not id	C2 bike not id	T3 bike not id
00. Byke	.	.	.	4.4	4.9	18.7
01. Angle<-14°	4.0	4.4	5.8	2.4	1.6	5.4
02. [-14,-10)°	4.6	4.7	9.6	3.6	2.9	12.6
03. [-10,-6)°	6.3	6.2	14.2	5.6	9.9	8.4
04. [-6,-2)°	8.9	9.2	31.2	6.9	9.5	13.0
05. [-2,+2]°	50.9	49.2	30.6	37.6	49.5	24.1
06. (+2,+6]°	11.3	12.4	4.7	19.5	8.2	9.3
07. (+6,+10]°	5.1	5.5	1.7	11.5	4.6	2.2
08. (+10,+14]°	3.7	3.3	0.9	6.0	3.8	4.0
09. Angle>+14°	5.2	5.2	1.3	2.6	5.0	2.4

Direction of glaze - bike identified

	C1	C2	T3	L	On
00. Byke	51.0	47.7	70.3	64.4	73.7
01. Angle<-14°	0.8	2.2	2.2	0.9	0.7
02. [-14,-10)°	0.8	2.9	3.2	0.6	1.3
03. [-10,-6)°	2.5	7.0	7.4	1.2	2.0
04. [-6,-2)°	3.4	8.8	7.8	1.4	5.0
05. [-2,+2]°	19.1	23.4	5.6	18.6	11.0
06. (+2,+6]°	10.8	4.5	2.1	7.9	3.4
07. (+6,+10]°	6.0	1.5	0.5	3.4	1.3
08. (+10,+14]°	2.8	0.9	0.4	0.9	0.6
09. Angle>+14°	2.9	1.1	0.4	0.8	0.9

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Differences among drivers on direction of glaze

- Tables reported in this slides show percentage of time in different ranges of x angle for glances not referred to cluster, for different drivers and in different condition related to lateral bike approaching in straight driving.
- We can observe significant differences among drivers, due to different habits of people, but all of them monitor partially lateral situations and continue to monitor central direction after bike identification, also in the simulated driving situation, with few traffic.

Left direction of gaze [-10,-6]° bike not present

Subject	C1	C2
12333	6.3	7.8
36510	12.2	9.8
46982	6.0	5.5
49221	2.7	3.4
55529	1.8	2.4
69248	3.7	4.6
123846	7.9	8.7

Right direction of gaze [+6,+10]° bike not present

Subject	C1	C2
12333	4.8	3.2
36510	7.6	7.3
46982	5.6	6.9
49221	4.8	7.7
55529	2.8	5.2
69248	6.6	6.4
123846	3.4	1.6

Central direction of gaze [-2,+2]° bike identified

Subject	C1	C2
12333	17.7	18.4
36510	12.8	20.9
46982	25.1	27.5
49221	16.0	21.1
55529	15.4	23.5
69248	17.5	20.3
123846	23.1	30.1

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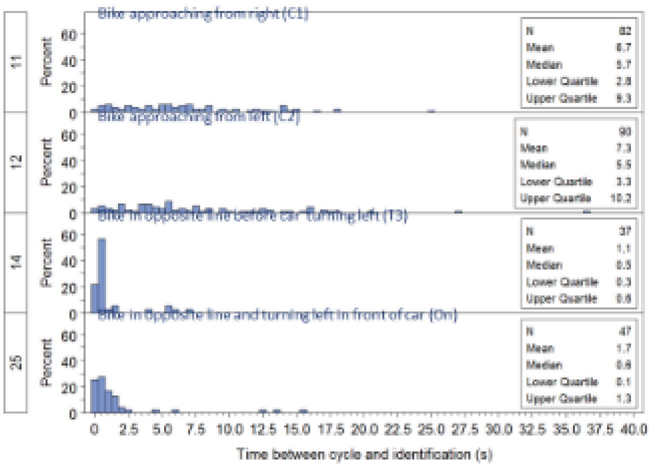
Time necessary to identify cyclist

- This slides reports distribution and statistics on time between bike appearing and it is identified by the driver
- Obviously this time is lower when cyclist is approaching in front of the car whereas is higher and more dispersed when bike is approaching laterally



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Glances analysis methodology (1/2)

- An analysis of glances has been done respect to the following AOIs (Areas of Interest):
  - Dashboard (y >400)
  - Central direction (y<400 & direction of glaze∈ (-2,+2)°)
  - Left direction (y<400 & direction of glaze∈ (-10,-6)°)
  - Right direction (y<400 & direction of glaze∈ (+6,+10)°)
  - Bike direction (y<400 & difference among angles (car versus bike and direction of glaze) is lower then 1.5°)
- A glaze has been defined if at least 4 successive data (150ms) belong to the analysed condition; moreover we assumed that:
  - Glaze is not interrupted if 1 data (50ms) is missing or outside AOI
  - Same time can be considered belonging to glances to different AOI (for example to central direction and bike direction) if more than one condition is verified
  - If more than one data is missing, when data become available a new glaze is counted, even if in the same direction of previous data; time when data are not available are not used to individuate glace rate and percent time on AOI.
- Metrics calculated on glances are:
  - Mean glance duration (s)
  - Glance rate (n/s)
  - Percent Time on AOI (% of total time)

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Glances analysis methodology (2/2)

- The metrics have been calculated for each repetition of each subject considering 4 conditions:
  i. Bike approaching from right (C1) and bike identified
  ii. Bike approaching from left (C2) and bike identified
  iii. No bike approaching

- For AOI, the metrics have been calculated for each repetition longer then 1.5s (to have enough data to calculate significant rates and percentages) and results have been analyzed using ANOVA:
  - Considering as main effect both subject and use case (i-iv)
  - Considering as effect only the use case

- Even if generally the impact of subject is significant in the ANOVA, the comparison among use cases are very similar both considering and not considering the impact of subject, so for simplicity in next slides are reported results related to multiple comparison test (with Tukey method) considering only use-case impact

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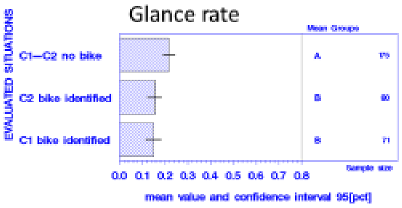
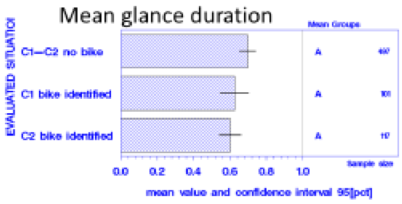
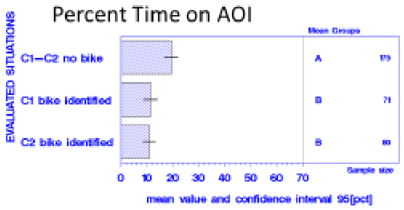
Glances analysis on dashboard

- **Percent Time on dashboard and Glace Rate on dashboard are significantly lower when a bike has been identified,** without difference due to the bike direction.

- **Difference on Mean Glance Duration on dashboard doesn't highlight significant difference** with 95% of statistical confidence.





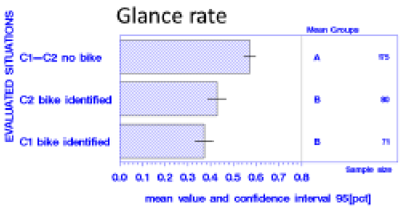


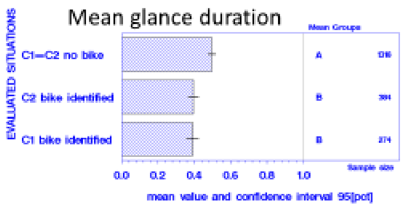
NOTE FOR GRAPHS

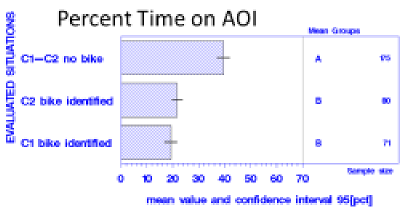
- "Mean groups": the groups of configuration not different in terms of mean rate from statistical point of view obtained using the Tukey test with 95% of confidence
- "Sample size": the number of measures available
- "Black interval": the confidence interval for mean at 95% of confidence

Glances analysis on central direction

- **All the indicators related to glances on central direction** (Percent Time on, Glace Rate and Mean Glance Duration) **are significantly lower when a bike has been identified**, without difference due to the bike direction.





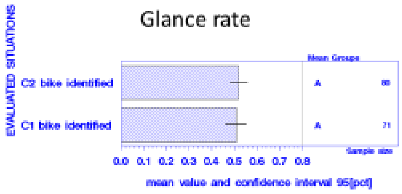


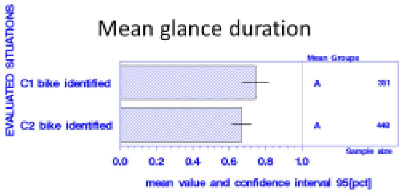
NOTE FOR GRAPHS

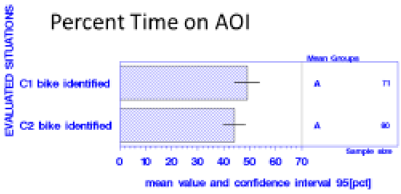
- "Mean groups": the groups of configuration not different in terms of mean rate from statistical point of view obtained using the Tukey test with 95% of confidence
- "Sample size": the number of measures available
- "Black interval": the confidence interval for mean at 95% of confidence

Glances analysis on bike direction

- **All the indicators related to glances on bike direction** (Percent Time on, Glace Rate and Mean Glance Duration) after bike identification, **are similar for the two direction of bike approaching** (C1 and C2).







NOTE FOR GRAPHS

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- "Sample size": the number of measures available
- "Black interval": the confidence interval for mean at 95% of confidence

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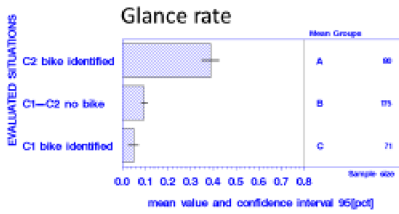
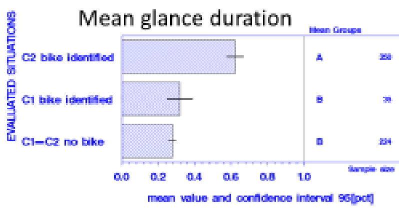
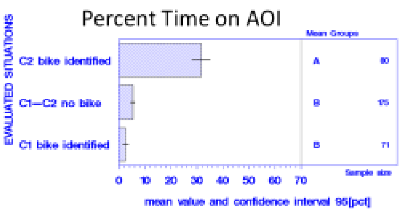
Glances analysis on left direction

- **All the indicators related to glances on left direction** (Percent Time on, Glace Rate and Mean Glance Duration) **are significantly higher when a bike approaching from the left (C2) has been identified.**
- In presence of a bike approaching from the right, the glance rate to left decrease also respect to absence of cyclists.







NOTE FOR GRAPHS

- "Mean groups": the groups of configuration not different in terms of mean rate from statistical point of view obtained using the Tukey test with 95% of confidence
- "Sample size": the number of measures available
- "Black interval": the confidence interval for mean at 95% of confidence

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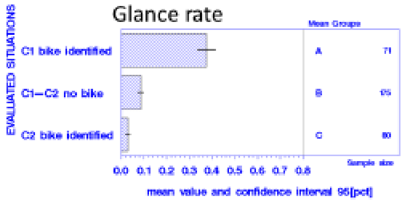
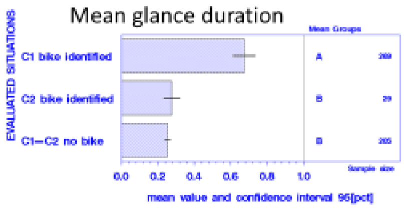
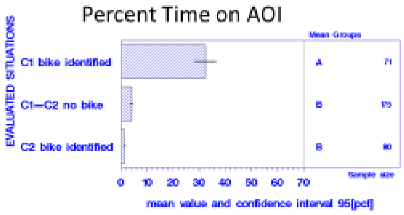
Glances analysis on right direction

- **All the indicators related to glances on right direction** (Percent Time on, Glace Rate and Mean Glance Duration) **are significantly higher when a bike approaching from the right (C1) has been identified.**
- In presence of a bike approaching from the left, the glance rate to right decrease also respect to absence of cyclists.







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- "Sample size": the number of measures available
- "Black interval": the confidence interval for mean at 95% of confidence

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Conclusions

- The executed test permitted to verify integration of instrumentation, feasibility of test procedure and correct data acquisition.
- An analysis of available data was done using as reference "ISO 15007-1:2014 Road vehicles -- Measurement of driver visual behavior with respect to transport information and control systems"
- The data analysis done on this test allowed some preliminary conclusion related to drivers habit in presence/absence of cyclist, without support of specific HMI:
  - During test a secondary task required driver glances to cluster. All participants followed this task even if with differences among them. Percent Time on dashboard and Glace Rate on dashboard are significantly lower when a bike has been identified.
  - During straight driving main focus is on the central part of the screen (40-50% of total time). We can observe significant differences among drivers, due to different habits of people, but all of them monitor partially lateral situations and continue to monitor central direction after bike identification, also in the simulated driving situation, with few traffic.
  - All the indicators related to glances on central direction (Percent Time on, Glace Rate and Mean Glance Duration) are significantly lower when a lateral bike has been identified.
  - All the indicators related to glances on bike direction after bike identification, are similar for the two direction of bike approaching (C1 and C2).

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10.6 Scenario selection

Overview

We analyzed previous research to understand the car-cyclist accident scenarios, describing their dynamics and their characteristics.

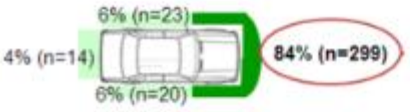
The goal of this phase is to enucleate critical scenarios starting from accidents databases, selecting them starting from their frequency and severity and analysing the main aspects that characterize them.
We started from a literature review to understand previous efforts in defining prototypical accident scenarios based of specific criteria, as recurrent aspects or typical dynamics.

For our purpose we selected several research papers and EU projects that addressed the theme analysed. We selected them to have a sufficient set of databases capable to cover different years and different countries.

Kuehn and colleagues (2015)

German Insurers Accident Research (GIAR)

Period analysed: 2002-2010
Database: German
Selection criteria: accidents with serious personal injury
Selected sample: 407 cases



Analysed this accidents set the authors found three specific configurations that seems to describe the highest proportion of frequency.
The analysis of these cases shows that the majority of the accidents in the dataset selected happened in a **junction**, in **daylight** condition, with a **dry road** surface and with the car's average **speed** that doesn't exceed the **30 km/h**, with the car braking only in half of the cases.

In the 84% of the cases, the impact between the bicycle and the car occurred at the front part of the vehicle.

The 76% of the "frontal impact" cases described a perpendicular impact with the bicycle coming from the right (42%) or from the left (34%) of the car.

MacAlister & Zuby (2015) - 1/2

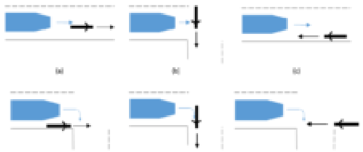
Insurance Institute for Highway Safety

Period analysed: 2008-2012

Database: the National Highway Traffic Safety Administration (NHTSA) and the National Automotive Sampling System General Estimates System (NASS GES)

Selection criteria: accidents involving one motor vehicle and one cyclist

Selected sample: 7835 cases



[illegible]
Vehicle, environment, and cyclist characteristics, 2008-2012

	All cyclists N=[illegible]	Injured cyclists N=[illegible]	Fatally injured cyclists N=[illegible]
Vehicle type			
Passenger vehicle	97.6	97.3	83.8
Heavy truck or bus	[illegible]	2.1	11.1
Motorcycle	0.7	0.6	0.9
Other or unknown	0.0	0.6	5.1
Point of initial impact on vehicle			
Front	63.8	64.3	83.6
Right	22.9	23.0	7.0
Left	[illegible]	9.2	2.8
Rear	4.1	3.4	2.1
Other or unknown	0.3	0.1	4.5
Speed limit			
No limit	[illegible]	2.1	0.0
<30	30.3	30.6	18.6
30-39	32.9	34.1	27.1
40-49	11.8	13.2	38.6
>49	[illegible]	3.1	26.6
Unknown	14.6	15.0	5.0
Light condition			
Daylight or unknown	77.9	79.0	53.2
Dark	[illegible]	4.1	20.0
Dark but lighted	13.6	13.2	21.3
Dawn/dusk	4.8	3.8	5.5
Inclement weather	11.4	11.3	13.1
Cyclist age			
<6	0.7	0.8	0.9
6-12	10.5	11.5	5.6
13-17	16.0	15.1	7.0
18-64	68.4	68.5	74.4
>64	4.4	4.2	12.1
Unknown	0.0	0.0	0.0
Male cyclists	79.1	79.0	86.8
Cyclist location			
Intersection	35.3	33.5	22.1
Roadway, non-intersection	31.7	31.6	68.9
Dedicated bike lane*	[illegible]	1.7	1.4
Unknown	31.6	33.2	5.6
Cyclist wearing helmet	16.3	18.4	12.8

*Prior to 2010, information on dedicated bike lanes was not available in the NASS GES and FARS databases.

- 97,6% of the accidents involved cars or vehicles with passengers
- The 63,8% of the impacts started on the front side of the vehicle
- In most of the cases the speed of the car does not exceed 40 mph
- The 77,9% happened in daylight
- The 35,3% of the accident happened in junctions, while the 31,7% in the roadways (non-intersection)

4

MacAlister & Zuby (2015) - 2/2

Insurance Institute for Highway Safety

Period analysed: 2008-2012

Database: the National Highway Traffic Safety Administration (NHTSA) and the National Automotive Sampling System General Estimates System (NASS GES)

Selection criteria: accidents involving one motor vehicle and one cyclist

Selected sample: 7835 cases

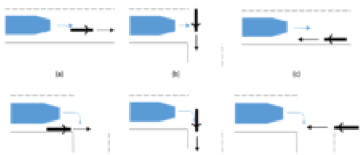


TABLE 3
Percent distribution of cyclists in single-vehicle crashes involving fronts of passenger vehicles by vehicle, environment, and cyclist characteristics, 2008-2012

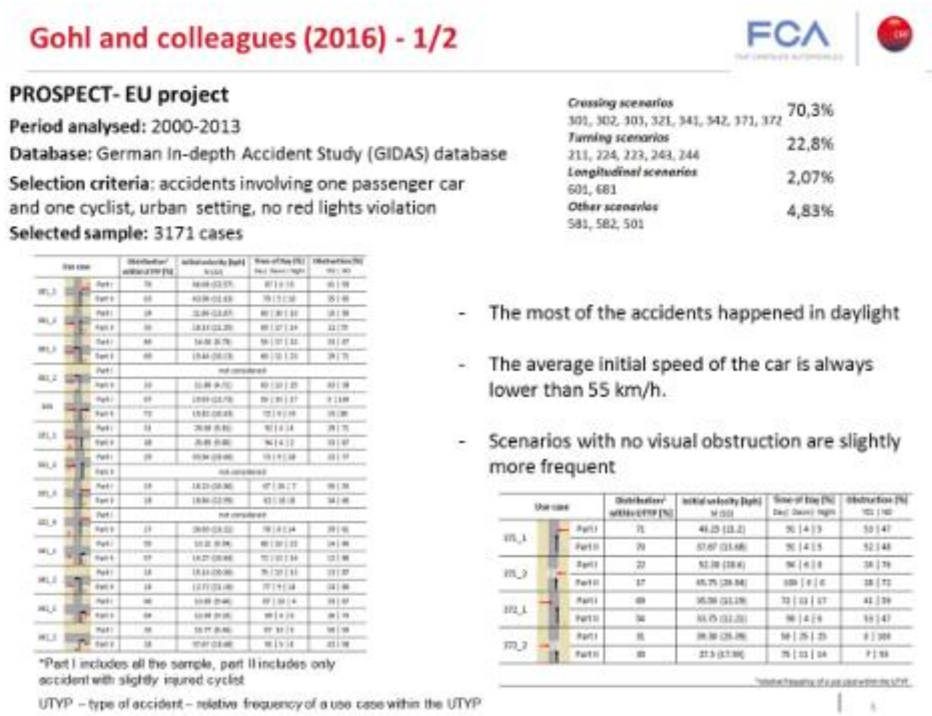
	All cyclists N=172,000	Injured cyclists N=93,000	Fatally injured cyclists N=2163
Speed limit (mi/h)			
No limit	[illegible]	0.1	0.0
<30	30.4	31.7	9.4
30-39	33.1	32.7	25.1
40-49	[illegible]	18.8	32.8
>49	3.3	2.6	29.1
Unknown	13.8	11.2	3.6
Light condition			
Daylight or unknown	76.5	76.7	40.9
Dark	[illegible]	4.7	22.4
Dark but lighted	14.7	14.7	22.6
Dawn/dusk	4.8	3.9	5.2
Inclement weather	11.4	11.6	15.2
Cyclist age			
<6	0.9	1.0	0.6
6-12	11.3	12.2	5.9
13-17	17.2	15.9	7.5
18-64	65.6	66.4	74.8
>64	4.5	4.5	11.9
Unknown	0.0	0.0	0.0
Male cyclists	78.2	78.2	87.5
Cyclist location			
Intersection	35.1	35.4	30.3
Roadway, non-intersection	27.8	25.9	63.1
Dedicated bike lane*	[illegible]	1.0	1.5
Unknown	36.3	38.6	5.2
Cyclist wearing helmet	11.6	14.8	12.8
Vehicle movement			
Traveling straight	50.1	50.6	93.3
Turning	44.0	44.9	6.1
Other or Unknown	[illegible]	4.4	0.6
Cyclist movement			
Crossing traffic	54.2	54.1	24.1
Moving in-line with traffic	20.8	23.2	47.8
Moving against traffic	[illegible]	5.5	6.7
Other or unknown	18.5	17.2	22.3
Driver view obstruction reported	9.1	10.2	6.8
Vehicle braking reported	6.3	7.8	10.4

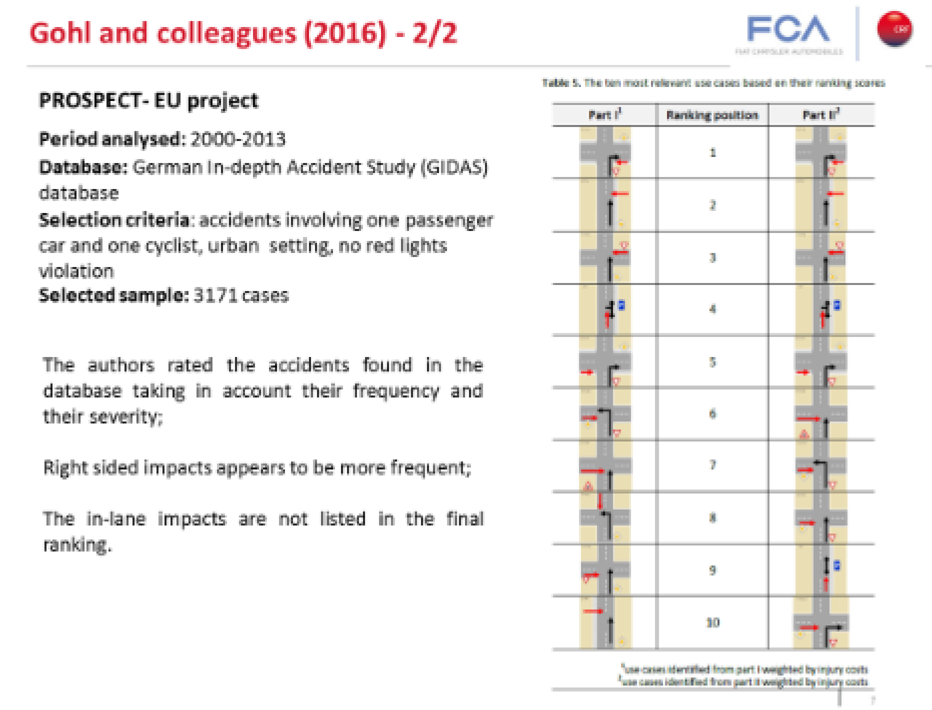
*Prior to 2010, information on dedicated bike lanes was not available in the NASS GES and FARS databases.

From the analysis of the 63,8% of the impacts started on the front side of the vehicle:

- In most of the cases the speed of the car does not exceed 40 mph
- The 76,5% happened in daylight
- The 35,1% of the accident happened in junctions, while the 27,8% in the roadways (non-intersection)
- In the 50,1% of the cases the car involved was travelling straight, while in the 44% was turning left or right
- In the 54,2% the cyclist was moving crossing traffic, in the 20,8% the cyclist was moving in-line with the traffic flow

5


Gohl and colleagues (2016) - 1/2
FCA
PROSPECT- EU project
Period analysed: 2000-2013
Database: German In-depth Accident Study (GIDAS) database
Selection criteria: accidents involving one passenger car and one cyclist, urban setting, no red lights violation
Selected sample: 3171 cases
Crossing scenarios
301, 302, 303, 321, 341, 342, 371, 372
70,3%
Turning scenarios
211, 224, 223, 243, 244
22,8%
Longitudinal scenarios
601, 681
2,07%
Other scenarios
581, 582, 501
4,83%
- The most of the accidents happened in daylight
- The average initial speed of the car is always lower than 55 km/h.
- Scenarios with no visual obstruction are slightly more frequent
*Part I includes all the sample, part II includes only accident with slightly injured cyclist
UTYP – type of accident – relative frequency of a use case within the UTYP


Gohl and colleagues (2016) - 2/2
FCA
PROSPECT- EU project
Period analysed: 2000-2013
Database: German In-depth Accident Study (GIDAS) database
Selection criteria: accidents involving one passenger car and one cyclist, urban setting, no red lights violation
Selected sample: 3171 cases
The authors rated the accidents found in the database taking in account their frequency and their severity;
Right sided impacts appears to be more frequent;
The in-lane impacts are not listed in the final ranking.
Table 5. The ten most relevant use cases based on their ranking scores
Part I
Ranking position
Part II
1
2
3
4
5
6
7
8
9
10

Prati and colleagues (2017) - 1/7

Università di Bologna

Period analysed: 2011-2013

Database: ISTAT – Italian National Institute of Statistics

Selection criteria: all the bicycle crashes

Selected sample: 49621 cases

Using a latent class analysis, they segmented 19 classes which represents 19 bicycle crash types

Of the total number of accidents, the 71% involved a car as opponent vehicle (n=35246).

They described both the manoeuvres of the opponent vehicles and of the cyclists in terms of both possible prescribed behaviour and violations.

While the cyclist seems to be involved in the accident for the 42% of times when driving in straight forward direction, the opponent vehicles seem to be violating more the prescribed behavior in the accident scenarios.

Table 1. Sample Characteristics.

Variable	N	%
Opponent vehicle		
Car	35246	71.0
Bus	365	0.7
Truck	3050	6.1
PTW	2952	5.9
Other vehicles	945	1.9
Multiple vehicles	910	1.8
No opponent vehicle	6153	12.4
Opponent vehicle manouver		
Straight forward or normal driving	11030	22.2
Not keeping a safe distance	2786	5.6
Ignoring stop signs or red traffic light	2857	5.8
Not respecting the right of way	7038	14.2
Driving in a forbidden direction or on opposite side of road	540	1.1
Traveling too fast	1626	3.3
Turning right	1661	3.3
Turning left	2387	4.8
Overtaking	747	1.5
Unknown or others	18980	38.2
Road type		
Urban municipal	39327	79.3
Urban provincial, regional and national	4540	9.15
Rural	5754	11.6
Pavement condition		
Dry	45079	90.8
Wet	4178	8.4
Slippery, frozen, or snowy	364	0.7
Cyclist's age		
0–14	3142	6.3
15–24	5919	11.9
25–44	14550	29.3
45–54	7974	16.1
55–64	6236	12.6
65 and older	11504	23.2
Not specified	296	0.6
Cyclist's gender		
Male	33912	68.3
Female	15709	31.7
Cyclist's maneuver		
Straight forward or normal driving	21247	42.8
Not keeping a safe distance	1439	2.9
Ignoring stop signs or red traffic light	1628	3.3
Not respecting the right of way	2112	4.3
Driving in a forbidden direction or on opposite sides of road	3599	7.3
Traveling too fast	858	1.7
Turning right	364	0.7
Turning left	1626	3.3

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Prati and colleagues (2017) - 2/7

Università di Bologna

Period analysed: 2011-2013

Database: ISTAT – Italian National Institute of Statistics

Selection criteria: all the bicycle crashes

Selected sample: 49621 cases

Almost the 70% other impacts is located on the side (of the cyclist);

The 82% of the cases has situated in daytime and more frequently in in weekdays;

Bad weather conditions don't seem to have an impact on the accidents data;

There's no difference in terms of location typology (crossroads vs not at junction).

Table 1. (Continued)

Variable	N	%
Overtaking	317	0.6
Unknown or others	16431	33.1
Type of collision		
Head-on collision	3232	6.5
Side-impact	34693	69.9
Rear-end collision	3925	7.9
Hit pedestrian	237	0.5
Hit stopped vehicle	2721	5.5
Hit parked vehicle or object	1122	2.3
Run-off the road	1912	3.9
Other (no vehicle was involved)	1736	3.6
Time of the day		
Daytime (6.00 am to 6.00 pm)	40876	82.0
Evening (6.00 pm to midnight)	7881	15.9
Late night (midnight to 6.00 am)	898	1.8
Not specified	166	0.3
Day of the week		
Weekdays	39027	78.7
Weekend	10549	21.3
Season		
Winter	8036	16.2
Spring	14783	29.8
Summer	15738	31.7
Autumn	11068	22.3
Weather		
Clear	44072	88.8
Foggy	267	0.5
Rainy	2381	4.8
Hail, Snow, Strong wind, other	2901	5.8
Road signage		
Absent	4171	8.4
Vertical	3266	6.6
Horizontal	3988	8.0
Vertical and horizontal	38197	77.0
Location type		
Crossroads	22094	44.6
Not at junction	22903	46.2
Roundabouts	4424	8.9
Severity of bicycle crash		
Injury	48798	98.3
Fatality	823	1.7

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Prati and colleagues (2017) - 3/7

Università di Bologna

Period analysed: 2011-2013

Database: ISTAT – Italian National Institute of Statistics

Selection criteria: all the bicycle crashes

Selected sample: 49621 cases

Fig 2. Representation of the 19 types of bicycle crashes.

Prati and colleagues (2017) - 4/7

Università di Bologna

Period analysed: 2011-2013

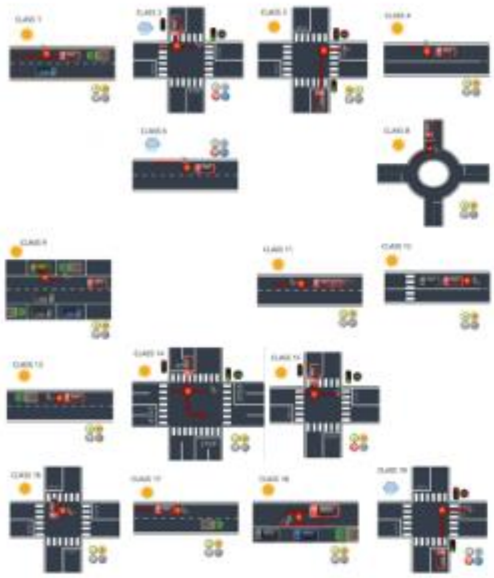
Database: ISTAT – Italian National Institute of Statistics

Selection criteria: all the bicycle crashes

Selected sample: 49621 cases

Eliminating from their list:

- The scenarios where there's no car involved



Prati and colleagues (2017) - 5/7

Università di Bologna

Period analysed: 2011-2013

Database: ISTAT – Italian National Institute of Statistics

Selection criteria: all the bicycle crashes

Selected sample: 49621 cases

Eliminating from their list:

- The scenarios where there's no car involved (not in scope for MeBeSafe)
- Red lights violations (not in scope for MeBeSafe)

Prati and colleagues (2017) - 6/7

Università di Bologna

Period analysed: 2011-2013

Database: ISTAT – Italian National Institute of Statistics

Selection criteria: all the bicycle crashes

Selected sample: 49621 cases

Eliminating from their list:

- The scenarios where there's no car involved (not in scope for MeBeSafe)
- Red lights violations (not in scope for MeBeSafe)
- The scenarios where the car is not actively moving

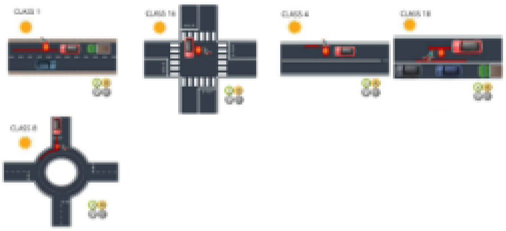
Prati and colleagues (2017) - 7/7

Università di Bologna

Period analysed: 2011-2013
Database: ISTAT – Italian National Institute of Statistics
Selection criteria: all the bicycle crashes
Selected sample: 49621 cases

Eliminating from their list:

- The scenarios where there's no car involved (not in scope for MeBeSafe)
- Red lights violations (not in scope for MeBeSafe)
- The scenarios where the car is not actively moving
- The duplicated scenarios in different weather conditions and the scenarios involving third parties



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EU project CATS (2014) - 1/4

CATS

Period analysed: 1999 - 2014

Database: LAB (France), GIDAS based PCM (Germany), Fiat Internal (Italy), BRON (Netherlands), STA/STRADA (Sweden), STATS19 (UK)

Selection criteria: all the car to bicycles accident scenarios that happened in the European Union and led to death or serious injuries that could be prevented by the adoption of AEB systems on cars.

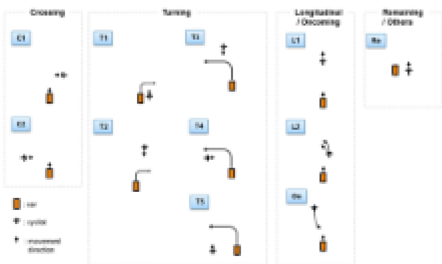
Selected sample: 16211 cases

Methods: Results were weighted on national incidence and divided in Fatal (K) and Seriously Injured (SI) incidents. Percentages based on K and SI have been then calculated.

Through the method they described 10 different scenarios, describing also their frequencies, probabilities and direction of impact.

#	Country	Source	Killed		Seriously injured		Period
			Definition	n	Definition	n	
1	France	LAB [7]	Fatal	72	Severely injured	620	2011
2	Germany	GIDAS based PCM [9]	Fatal	11	AIS2+	360	1999-2012
3	Italy	Fiat internal [10]	Fatal	23	AIS2+	17	2003-2014
4	Netherlands	BRON [11]	Fatal	902	Seriously injured	10854	2000-2013
5	Sweden	STA/STRADA [12]	Fatal	104	AIS2+	435	2005-2014 K 2010-2014 SI
6	UK	STATS19 [14]	Fatal	116	Seriously injured	2699	2008-2010

Table 3 Overview of CATS accident scenarios between M1 vehicle and cyclist



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EU project CATS (2014) - 2/4

Scenario	Description
C1	• Car driving straight • Cyclist crossing the vehicle path from the near side
C2	• Car driving straight • Cyclist crossing the vehicle path from the far side
T1	• Car turning right • Cyclist is riding straight in the same direction as the heading of the car before turning • Blind spot scenario
T2	• Car turning right • Cyclist is riding straight in the opposite direction as the heading of the car before turning
T3	• Car turning to the left, crossing the (straight) bicycle path • Cyclist coming from the opposite direction, riding straight
T4	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight, coming from the far side of the car. • Some similarity with C2
T5	• Car turning to the left, crossing the (straight) bicycle path • Cyclist is riding straight in the same direction as the heading of the car before turning

L
L1
L2
	• Car and cyclist driving in the same direction
	  • Cyclist is riding straight and hit by the car from the rear
	  • Cyclist is swerving to the left in front of the car and hit by the car from the rear

On	• Car driving straight, possibly driving towards the far road side in a passing manoeuvre • Cyclist coming in the opposite (on-coming) direction riding straight
Re	• All other scenarios that are not covered by any of the previously described scenarios

They analyzed the distribution of the accidents in the different databases, analyzing also the consistency of each scenarios with the implementation of possible driving aids

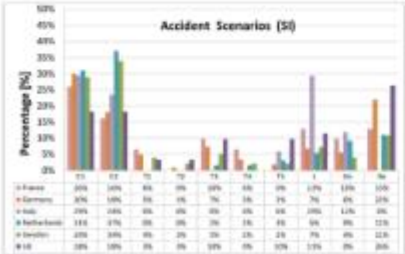


Figure 3-3. Distribution of seriously injured over the 9 main accident scenarios that are distinguished for 6 EU countries.

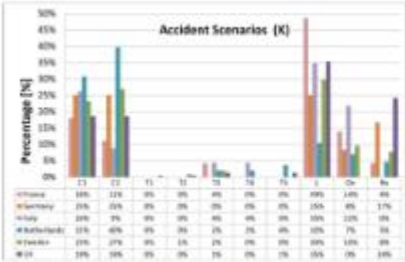
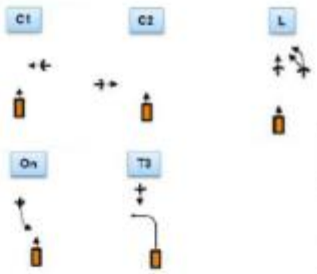


Figure 3-4. Distribution of fatally injured over the 9 main accident scenarios that are distinguished for 6 EU countries.

EU project CATS (2014) - 3/4

The results of the analysis generated a scenario list for a deeper understanding.

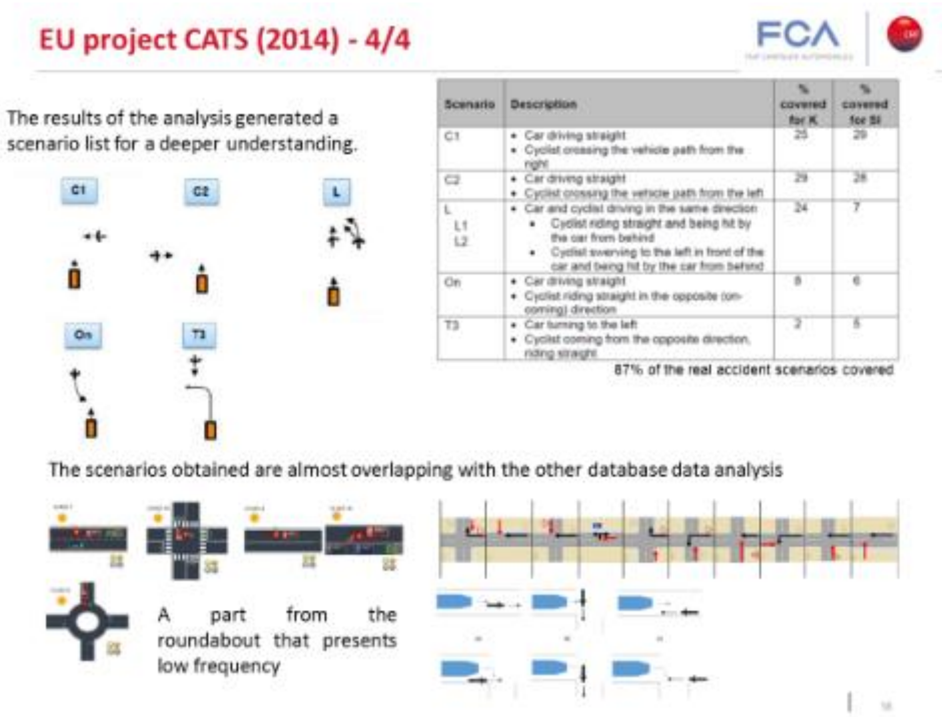


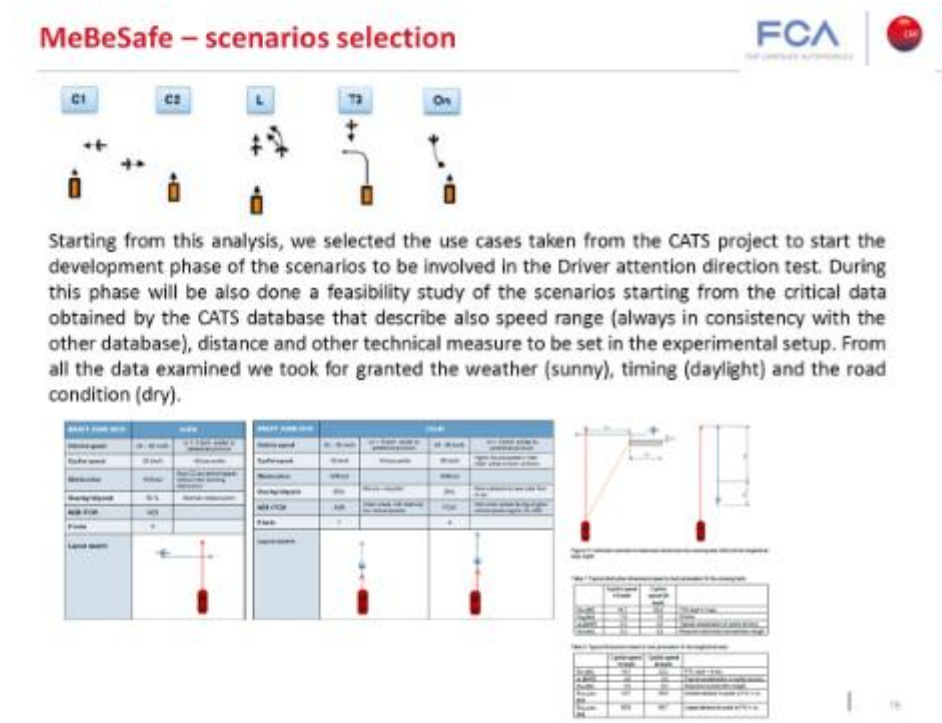
Scenario	Description	% covered for K	% covered for SI
C1	• Car driving straight • Cyclist crossing the vehicle path from the right	25	29
C2	• Car driving straight • Cyclist crossing the vehicle path from the left	29	28

L
L1
L2
	• Car and cyclist driving in the same direction
	  • Cyclist riding straight and being hit by the car from behind
	  • Cyclist swerving to the left in front of the car and being hit by the car from behind
		24	7

On	• Car driving straight • Cyclist riding straight in the opposite (on-coming) direction	8	6
T3	• Car turning to the left • Cyclist coming from the opposite direction, riding straight	2	5

87% of the real accident scenarios covered


EU project CATS (2014) - 4/4
FCA
The results of the analysis generated a scenario list for a deeper understanding.
C1
C2
L
On
T3
Scenario | Description | % covered for K | % covered for SI
C1 | • Car driving straight • Cyclist crossing the vehicle path from the right | 25 | 29
C2 | • Car driving straight • Cyclist crossing the vehicle path from the left | 29 | 28
L L1 L2 | • Car and cyclist driving in the same direction • Cyclist riding straight and being hit by the car from behind • Cyclist swerving to the left in front of the car and being hit by the car from behind | 24 | 7
On | • Car driving straight • Cyclist riding straight in the opposite (on-coming) direction | 8 | 6
T3 | • Car turning to the left • Cyclist coming from the opposite direction, riding straight | 2 | 5
87% of the real accident scenarios covered
The scenarios obtained are almost overlapping with the other database data analysis
A part from the roundabout that presents low frequency


MeBeSafe – scenarios selection
FCA
C1
C2
L
T3
On
Starting from this analysis, we selected the use cases taken from the CATS project to start the development phase of the scenarios to be involved in the Driver attention direction test. During this phase will be also done a feasibility study of the scenarios starting from the critical data obtained by the CATS database that describe also speed range (always in consistency with the other database), distance and other technical measure to be set in the experimental setup. From all the data examined we took for granted the weather (sunny), timing (daylight) and the road condition (dry).

10.7 References

References

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