Ref. Ares(2020)5482570 - 14/10/2020

Delivery Report for

# MeBeSafe

## Measures for behaving safely in traffic

| | |
|---|---|
| Deliverable Title | Report test vehicles |
| Deliverable | D2.3 |
| WP | WP2<br>In-vehicle nudging solutions |
| Task | Task 2.6<br>Implementation of the nudge solution in the test vehicles |

This project (MeBeSafe) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723430.

## Disclaimer



## Copyright

| | |
|---|---|
| Grant Agreement No. | 723430 |
| Project Start Date | 01/05/2017 |
| Project End Date | 31/10/2020 |
| Duration of the Project | 42 months |
| Deliverable Number | D2.3 |
| Deliverable Leader (according to GA) | TNO |
| WP Leader | Olaf **Op den Camp**, TNO |
| Deliverable Leader(s)/ (Editor(s)) | Olaf **Op den Camp**, TNO |
| Dissemination Level (Confidentiality) | Public |
| Nature | Report |
| Status | Final |
| Due Date | M28 (August 2019) |
| Main Author(s) | Olaf **Op den Camp**, TNO |
| Other Contributing Author(s) *alphabetical order by last name | Bram **Bakker**, Cygnify<br>Elena **Bianco**, CRF<br>Laura **Borgarello**, CRF<br>Frank **Evers**, TNO<br>Dario **Niermann**, OFFIS<br>Alexis **Siagkris Lekkos**, TNO<br>Antonella **Toffetti**, CRF |
| Reviewer(s) | Mikael **Ljung Aust**, Volvo Cars (VCC) |
| Formal review and upload by Coordinator | Institute for Automotive Engineering (ika) – RWTH Aachen University |

Please refer to this deliverable as follows:

Op den Camp, O., et al. (2019). Report test vehicles (Deliverable 2.3). Retrieved from MeBeSafe website: https://www.mebesafe.eu/results/.

Abstract

This deliverable describes the results of the driver simulator tests performed by CRF to determine the potential effectiveness of the three main promising HMI options as proposed by OFFIS. The HMI provides in-vehicle nudging information to the driver of a passenger car to direct the attention of the driver towards potentially hazardous areas on the road. Hazards are related to cyclists that possibly cross the trajectory of the ego-vehicle.

The study has been performed with 30 test subjects (15 female), and different type of results were analysed to evaluate HMI performance in comparison to a situation without nudging:

1. Subjective evaluations, by analysis of questionnaires that are completed by the test subjects;
2. The analysis of eye movements and gaze direction, as strong indicators for the direction of attention of the drivers;
3. Analysis of the objective driving performance, such as the braking and steering response upon encounter of a cyclists possible crossing the vehicle's path.

It appears that the nudging option with augmented reality projected in a Head-UP Display on the windscreen is the most favourable option, increasing the attention on the road with 40% compared to the situation without nudging. All three nudging options lead to better performance compared to the situation without nudges. Moreover, most test subjects were very positive regarding the in-vehicle nudging solutions.

For practical reasons, an abstract nudging cross has been implemented on a tablet to be integrated with a test vehicle, either as a Head-Up Display option (reflecting the image in the windscreen) or as an image on the instrument cluster. The report describes the addition of sensors and cameras to the test vehicle, the integration of the computer system for world modelling & hazard prediction and the computer

system for cyclist behaviour prediction (based on machine learning), the interfaces between the computer systems and the sensor systems at one hand and the HMI tablet on the other hand.

Though fine-tuning of the system currently continues, the vehicle is ready for performing the first tests on the public road in September. These tests are part of MeBeSafe WP5: Field Operational Tests.

Regarding the concept where drivers are to be nudged towards increased ACC usage, this deliverable describes the background for the nudge, a wider palette of candidate concepts that were generated and evaluated, and then the iterative implementation and evaluation of one of those concepts into a working in-vehicle application. The final usability tests showed that usability is good and ACC usage was influenced in a positive way in the pilot tests.

As for the concept where drivers are to be incentivized towards taking a break when the in-vehicle drowsiness monitoring system (Driver Alert) indicates that they are very drowsy, the necessary backend for this nudge has been defined. Various incentives, as well as means for distributing them, have been evaluated. For the field trials, given the relative infrequency of these alerts, it was decided not to spend effort on setting up a distribution scheme involving companies outside of the MeBeSafe consortium (e.g. gas stations). Instead, personnel from the Volvo 24/7 response ready accident investigation team will take on monitoring of Driver Alerts form the test fleet, so that when a Driver Alert is triggered and other qualifying conditions are met, that test person will receive their incentive via their preferred means (call, e-mail, text message) within 1-2 minutes of actually stopping the car to take a break.

| Version | Date | Comment |
|---|---|---|
| 1 | 31.05.2019 | Driver simulator study described incl. results and discussion (CRF) |
| 2 | 29.07.2019 | In-vehicle nudging implementation added (TNO) |
| 3 | 29.07.2019 | CRF review included. |
| 4 | 30.07.2019 | Reference list completed, Executive summary added |
| 5 | 23.08.2019 | Sections on ACC and Driver Alert added |
| 6 | 26.08.2019 | Comments bij reviewer included |
| 7 | 27.08.2019 | Version ready to be send to coordinator |
| 8 | 29.08.2019 | 1st formal review ika |
| 9 | 30.08.2019 | 2nd formal review ika |
| 10 | 28.07.2020 | Deliverable released for revision by the EC |
| 11 | 28.09.2020 | Final version after release for revision by the EC |

table of document history

## Table of Contents

## List of Figures

## List of Tables

## Acronyms

**ACC** Adaptive Cruise Control

**AEB** Autonomous Emergency Braking

**ANOVA** Analysis of Variance

**AOI** Area of interest

**AR** Augmented Reality

**GNNS** Global Navigation Satelite System

**GPS** Global Positioning System

**HMI** Human Machine Interface

**HUD** Head-up Display

**IC** Instrument Cluster

**IMU** Inertia Measurement Unit

**km/y** driving experience expressed in driven kilometres per year

**NHTSA** National Highway Traffic Safety Administration

**OSM** Open Street Map

**ROS** Robot Operating System

**SD** Standard Deviation

# 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. In this context, 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.

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

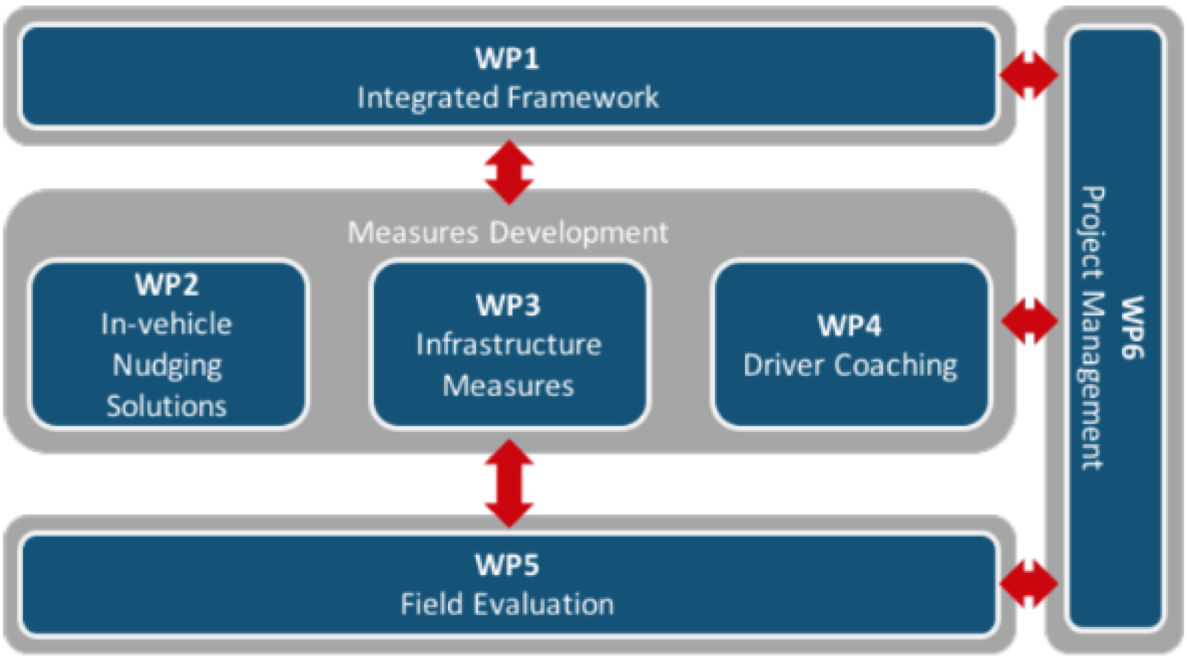



*Figure 1 - Work packages in MeBeSafe*

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.

The in-vehicle solutions mainly target drivers of passenger cars, with a focus on stimulating the use of safety functions, particularly Adaptive Cruise Control and Driver Alert (drowsiness monitoring), as well asdirecting the driver's attention to potential hazards. In a previous report (D2.1), different possible solution concepts were 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:

- **O1: Nudge drowsy drivers to take a break** when a drowiness monitoring system indicates a high level of driver drowsiness. Drowiness related crashes, though hard to estimate, is a contributing factor in up to 20 % of road accidents.
- **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 get information regarding the vehicle state such as current speed, heading, and acceleration, and whether ACC is switched on or not.

- 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.

## Task 2.2 – Sensing and predicting cyclist intent

To be able to provide nudging information to the driver in an earlier stage than when a critical situation is imminent, information on the intent of cyclists that might interfere with the host vehicle path needs to be available some seconds before a potentially critical situation occurs. This information comes from an interpretation of the vehicle's sensor data. Based on analysis of the bicycle's trajectory over the last few seconds, a prediction of its intended trajectory for the coming seconds is generated.

Developing a sensing and prediction system of this type requires the following tasks to be completed:

- 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 the 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 cyclist 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 on the other hand 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 simulations of a large number of situation variations in order to support the development.

### 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 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 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.

To increase drivers' willingness to take a break when drowsy, a nudge in the form of a a timely incentive to do so will be provided when the drowiness monitoring system (Driver Alert) indicates a high level of driver drowsiness.

For increased ACC usage, the main nudging 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[1].

The actions to be undertaken within this task are:

- Decision logic and control law development and implementation;
- HMI development for Directing the Driver Attention towards possibly hazardous situations involving crossing bicycles;
- HMI implementation for evaluation in a virtual test environment and for testing in the driving simulators at FIAT Chrysler Automobiles (FCA Italy);
- HMI development for providing Driver Alert based incentive;
- HMI development for presenting current ACC usage levels.

### Task 2.5 – Solution selection

The objective of task T2.5 is to evaluate what has been developed in tasks T2.2-T2.4 and select the most promising and feasible options for implementation for testing in the field trials in WP5.

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

Based on the selections made in task T2.5, the nudging systems and corresponding HMIs are 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.

[1] The development of a coaching app to encourage ACC usage in drivers who do not trust this type of technology and therefore has no usage level that can be nudged is dealt with in WP4 (De Craen, S. et al., 2019).

For the intersection nudge, the first implementation will be done in a TNO laboratory vehicle, a VW Jetta. This provides for maximum flexibility in starting the first field trial tests in WP5 and updating the system before a final implementation is done in a FIAT 500X provided by FCA Italy. The ACC and Driver Alert based nudges will be implemented in company cars at Volvo Cars.

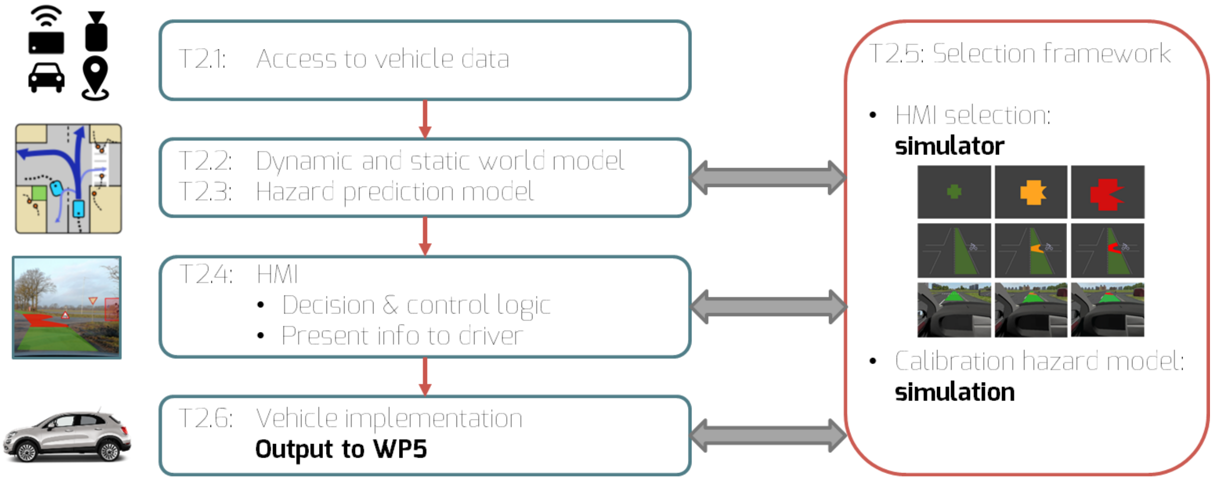



*Figure 2 - Schematic overview of tasks and their relations in WP2*

## 1.3 Structure of deliverable

This deliverable provides:

- Results of a CRF driving simulator study into the effectiveness of different HMI options to direct the attention of a driver towards a potential hazard of a cyclist crossing the path of the vehicle.
- A description of the implementation of the nudging solution in the TNO test vehicle.
- A discussion on the use of the FIAT 500X vehicle in MeBeSafe once the implementation in the TNO test vehicle has proven to be successful.
- Results from piloting of a number of ACC usage level HMI concepts with current company car owners at Volvo Car Corporation (VCC).
- Decision logic and HMI implementation for making drivers take a break when they are really drowsy.

# 2 Executive Summary

First, this report describes the results of a driving simulator study performed at the CRF Virtual Reality Driving Simulator to determine the effectiveness of different in-vehicle HMI options (proposed by OFFIS) on directing the attention of drivers towards potentially hazardous situations in the interaction between passenger cars and cyclists. 30 participants (15 female) evaluated three HMI options, labelled D5 (nudging cross on instrument cluster), D2 (street view on instrument cluster) and D3 (augmented reality as Head-Up Display in the windscreen), using a within subjects design:

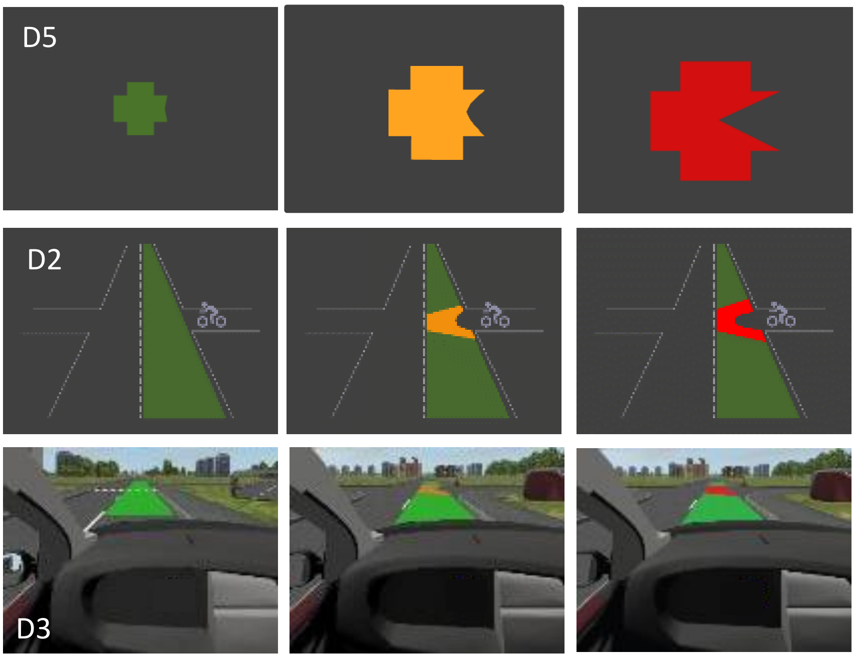



*Figure 3 - MeBeSafe nudging HMI (D5, D2, D3 versions) with different warning levels*

Three types of evaluations have been performed:

1. Subjective evaluations, by analysis of questionnaires that are completed by the test subjects;
2. The analysis of eye movements and gaze direction, as strong indicators for the direction of attention of the drivers;
3. Analysis of the objective driving performance, such as the braking and steering response upon encounter of a cyclists possible crossing the vehicle's path.

In all cases, the nudging solution provides favourable conditions compared to no-nudging. The study shows that option D3 (the "Street" on Augmented Reality HUD) was most easily understood by the test subjects. It also had the highest effectiveness; the glance rate and the total time to the center of road was more than 40% higher with Augmented Reality than without nudging. However, for the field trial, it was decided to implement the more abstract intersection "Cross" on the instrument cluster (D5) on a tablet in the TNO test vehicle, since implementing "Street" would have been too time consuming and costly.

The report describes the complete implementation into the vehicle. Also the process of continuous improvement of the software implementation and hard- and software testing is described. With the realization of the HMI on a tablet that is controlled through a TNO Axiomtek computer that continuously computes the hazard level and the potential direction of approach of the hazard in realtime, the TNO vehicle is ready for use in WP5: Field Operational Test.

Once the performance of the nudging solution has been quantified successfully in WP5, the system will be integrated in one production type vehicle FIAT 500X. The nudging system will be interfaced with the standard FIAT 500X sensor suite (a fused radar and camera sensor set). Only the GPS-based GNSS-IMU and one ELP industrial machine vision camera will be added to the FIAT's sensor suite. The nudging system only reads the sensor signals and it is in no way connected to the vehicle's actuators. Consequently, it is possible to demonstrate the added value of nudging to any driver having a valid driving license in the FIAT 500X.

Both the quantification of the nudging performance as the demonstration of the system is part of MeBeSafe WP5.

This deliverable describes the results of the driver simulator tests performed by CRF to determine the potential effectiveness of the three main promising HMI options as proposed by OFFIS. The HMI provides in-vehicle nudging information to the driver of a passenger car to direct the attention of the driver towards potentially hazardous areas on the road. Hazards are related to cyclists that possibly cross the trajectory of the ego-vehicle.

The study has been performed with 30 test subjects (15 female), and different type of results were analysed to evaluate HMI performance in comparison to a situation without nudging:

1. Subjective evaluations, by analysis of questionnaires that are completed by the test subjects;
2. The analysis of eye movements and gaze direction, as strong indicators for the direction of attention of the drivers;
3. Analysis of the objective driving performance, such as the braking and steering response upon encounter of a cyclists possible crossing the vehicle's path.

It appears that the nudging option with augmented reality projected in a Head-UP Display on the windscreen is the most favourable option, increasing the attention on the road with 40% compared to the situation without nudging. All three nudging options lead to better performance compared to the situation without nudges. Moreover, most test subjects were very positive regarding the in-vehicle nudging solutions.

For practical reasons, an abstract nudging cross has been implemented on a tablet to be integrated with a test vehicle, either as a Head-Up Display option (reflecting the image in the windscreen) or as an image on the instrument cluster. The report describes the addition of sensors and cameras to the test vehicle, the integration of the computer system for world modelling & hazard prediction and the computer system for cyclist behaviour prediction (based on machine learning), the interfaces between the computer systems and the sensor systems at one hand and the HMI tablet on the other hand.

Though fine-tuning of the system currently continues, the vehicle is ready for performing the first tests on the public road in September. These tests are part of MeBeSafe WP5: Field Operational Tests.

Regarding the concept where drivers are to be nudged towards increased ACC usage, this deliverable describes the background for the nudge, a wider palette of candidate concepts that were generated and evaluated, and then the iterative implementation and evaluation of one of those concepts into a working in-vehicle application.

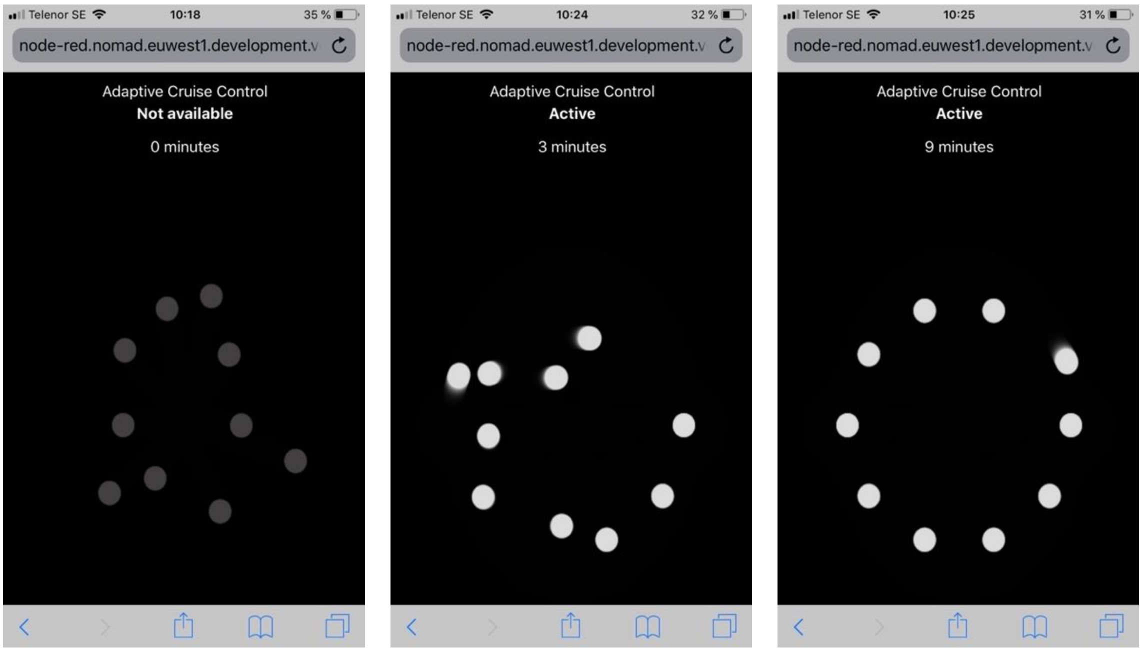



*Figure 4 - MeBeSafe nudging HMI to increase ACC use*

The final usability tests showed that usability is good and ACC usage was influenced in a positive way in the pilot tests.

As for the concept where drivers are to be incentivized towards taking a break when the in-vehicle drowsiness monitoring system (Driver Alert) indicates that they are very drowsy, the necessary backend for this nudge has been defined. Various incentives, as well as means for distributing them, have been evaluated. For the field trials, given the relative infrequency of these alerts, it was decided not to spend effort on setting up a distribution scheme involving companies outside of the MeBeSafe consortium (e.g. gas stations). Instead, personnel from the Volvo 24/7 response ready accident investigation team will take on monitoring of Driver Alerts form the test fleet, so that when a Driver Alert is triggered and other qualifying conditions are met, that test person will receive their incentive via their preferred means (call, e-mail, text message) within 1-2 minutes of actually stopping the car to take a break.

# 3 Simulator study on HMI effectiveness (CRF)

## 3.1 Introduction and aim

The CRF Virtual Reality Driving Simulator was chosen as test facility for evaluating the different MeBeSafe in-vehicle HMI solutions. It allows for the possibility to manipulate both the presentation of different visual nudging stimuli and critical road scenarios, in a controlled, repeatable and safe environment.

The research questions for the study were:

- Are there differences in driving performance with and without the visual nudging HMI presentation?
- When the nudging HMI is displayed, is driving performance more correct (i.e. improves road safety) compared to situations when it is not displayed?
- Which of the HMI proposals is most successful in inducing a more correct driving performance near intersections?

## 3.2 Method

### 3.2.1 Participants

Participants were recruited by an external agency according to participants sample characteristics decided in the MeBeSafe consortium. 30 participants (15 female) with an average age of 44.7 years (*SD*=13.6, range 25 - 67 years) took part in the study. 77% of the participants had a high school diploma, while 23% of them had a university degree.

All participants hold a driving license since since on average 25,4 years (*SD*=13,62, range: 6-48 years). 23% of participants owned small segment cars, 23% owned medium segment cars, 23% owned small Sport Utility Vehicle (SUV) and 30% owned medium SUV. Participants drove an average of 16000 kilometers per year (*SD* = 7331.9, range 5000 - 40000 km/y) on mixed types of roads.

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 indicated to have experience with in-vehicle technologies, according to a CRF questionnaire based on the use of technology devices.

### 3.2.2 Apparatus: CRF Virtual Driving Simulator

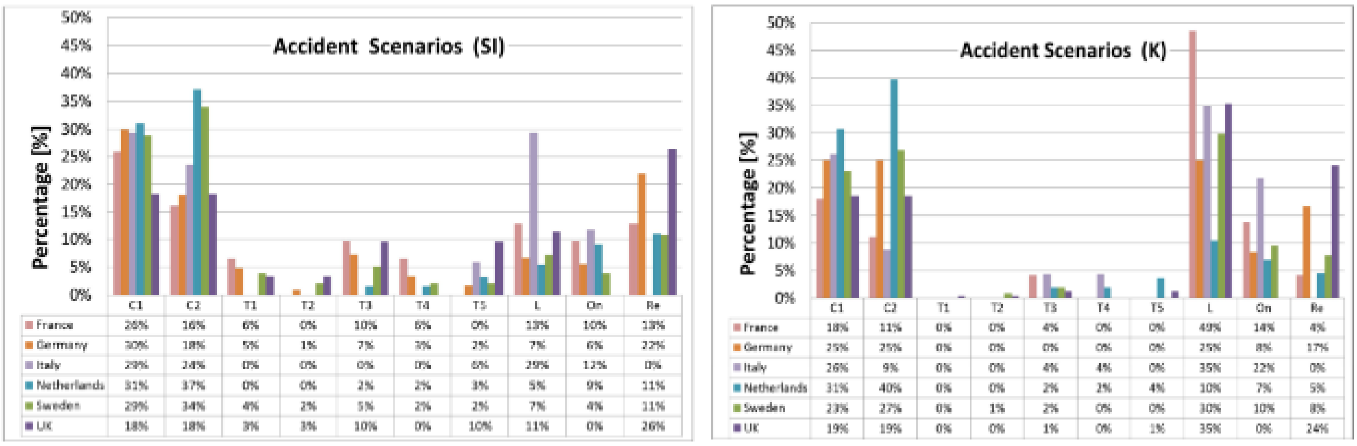
The CRF Virtual Driving Simulator is based on six degrees of freedom (surge, sway, heave, roll, pitch, and yaw) dynamic platform. Other characteristics of the CRF driving simulator are the highly realistic vehicle dynamic models and a flexible and configurable vehicular traffic model, allowing for the implementation of even critical traffic situations. The simulator also is equipped with an eye-tracker for analysis of gaze behaviours. For a complete list of parameters, see Appendix A.

### 3.2.3 Scenarios definition

The goal of this phase was to identify critical scenarios from accident databases, selecting them on their frequency and severity and analyzing the main aspects that characterize them. A literature review was done to understand previous efforts in defining accident scenarios based of specific criteria, like recurrent aspects or typical dynamics.

Many research works and projects addressed the analysis of accident scenarios in the last years (see Appendix A). For this study, the project CATS (Op den Camp, van Montfort, Uittenbogaard, & Welten, 2017), was used as starting point. In CATS, 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 those car to bicycles accident scenarios that happened in the European Union and led to death or serious injuries that could be prevented or mitigated 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.

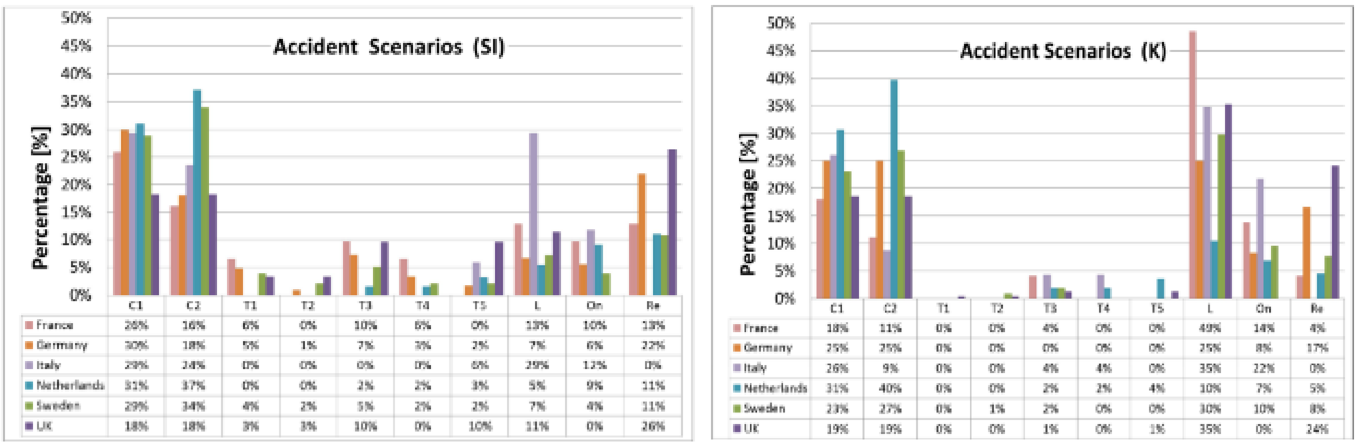
Through this method, they analyzed 10 different scenarios, describing also their frequencies, probabilities and direction of impact (




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 5).

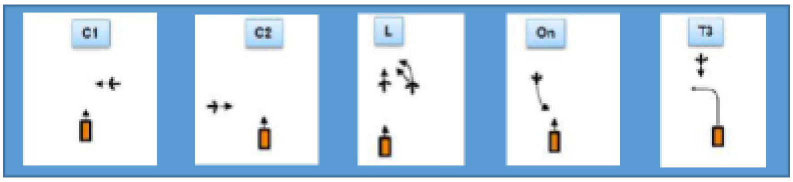



Distribution of seriously injured over the 9 main accident scenarios that are distinguished for 6 EU countries.

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

*Figure 5 - 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 scenario with the implementation of possible driving aids. The results of the analysis generated a scenario list for a deeper understanding (Figure 6).




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

*Figure 6 - Scenarios selected for MeBeSafe(K: number of killed traffic participants, SI: number of seriously injured)*

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. It should be noted that these scenarios are substantially overlapping with all previous research in the same area. They involve predominantly frontal scenarios as found in (Kuehn, Hummel, & Lang, 2015), with very similar crossing situations. Also, analyzing the classes selected by (Prati, De Angelis, Puchades, Fraboni, & Pietrantoni, 2017) and limiting the analysis to scenarios involving one car and one cyclist, only scenarios with the same dynamics of those selected by CATS remain. In accordance with all the carried out analyses, the scenarios that had greater impact are those considered as the basis for the MeBeSafe project.

In the "Driver attention direction" test done in June 2018 in the CRF Driving Simulator (Appendix B) all the scenarios described in Figure 6 (C1, C2, L, On and T3) were tested while logging drivers' eye movement through the FOVIO$^{TM}$ eye tracking system. This study was done to evaluate drivers' attention direction in presence and absence of cyclists, and with cyclist that sometimes gave and sometimes did not give priority at intersections.

In this experiment, a *within-subjects-design* was used in which all 10 participants drove in all the 5 previous mentioned scenarios (Figure 7).

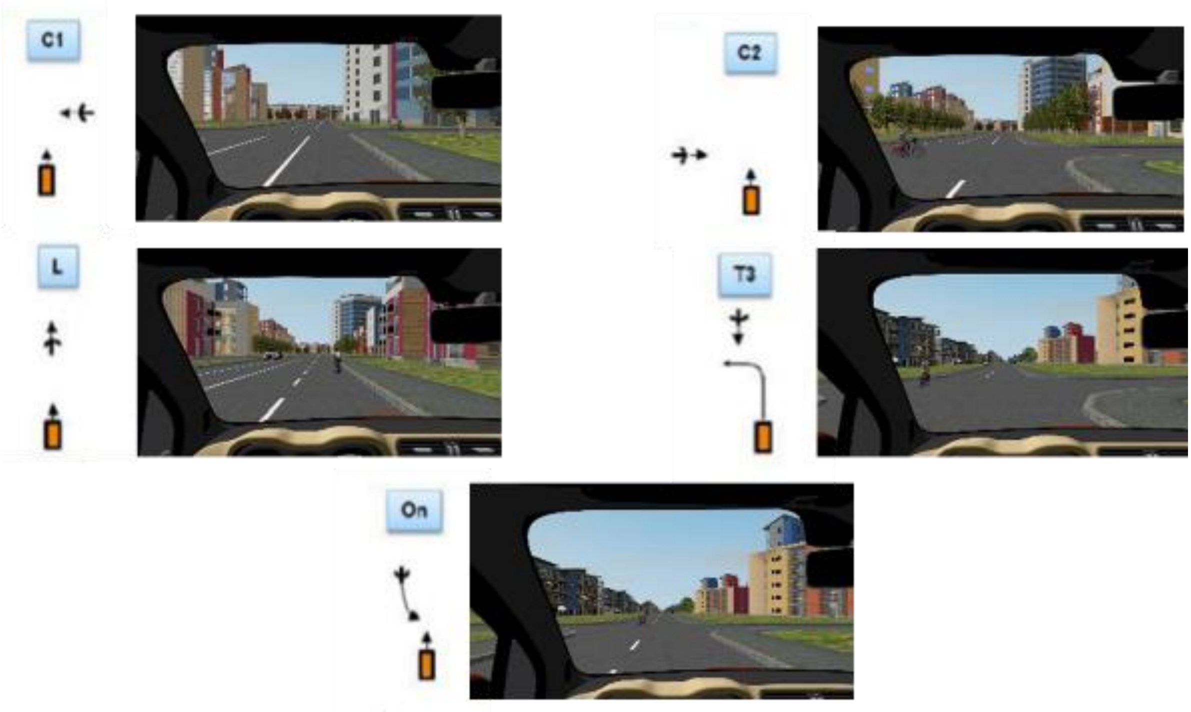



*Figure 7 - June 2018 CRF "Driver attention direction" test scenarios*

Gaze and glance related indicators were analysed using "ISO 15007-1:2014 Road vehicles - Measurement of driver visual behavior with respect to transport information and control systems" as reference. The analysis showed that presence of cyclists in scenarios C1 and C2 had a higher impact on drivers' attention direction compared to the other three scenarios. This is due to the fact that in scenarios L, On and T3 the cyclist is inside or very near to the main direction of the driver's attention focus, that is on the forward roadway (and partially on the left in T3 scenarios, where the driver has to turn left).

In the next three figures gaze direction during the approach of an intersection in absence and in presence of a cyclist is shown.

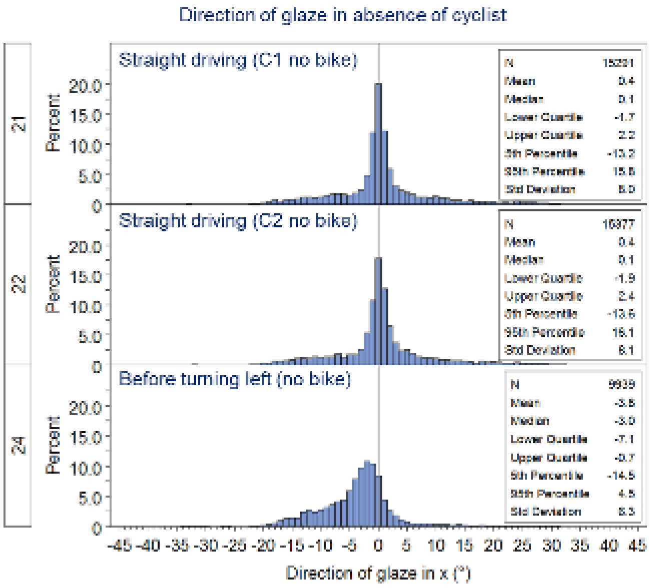



*Figure 8 - June 2018 CRF "Driver attention direction" test: Direction of glaze in absence of cyclist*

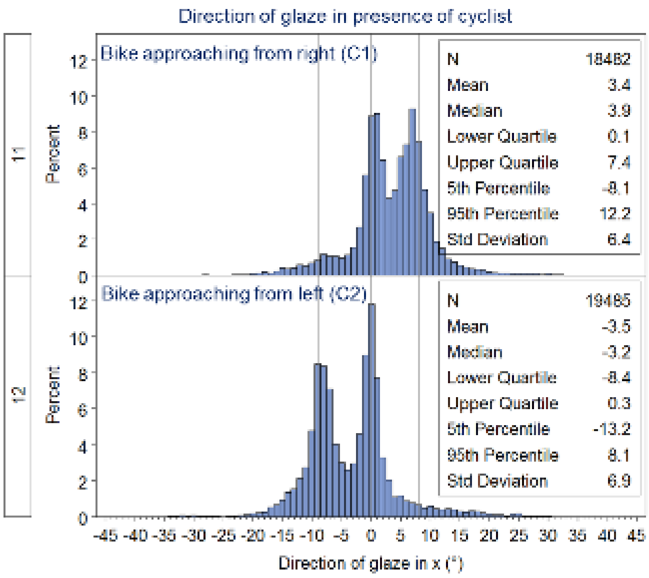



*Figure 9 - June 2018 CRF "Driver attention direction" test: Direction of glaze in presence of cyclist: scenarios C1 and C2*

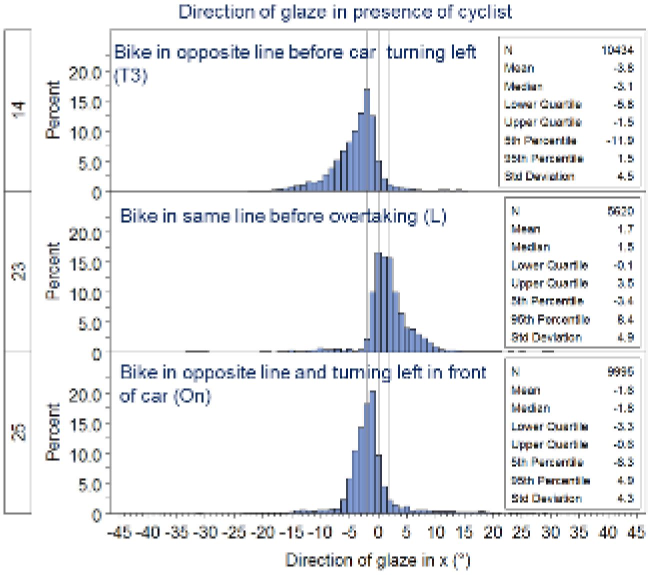
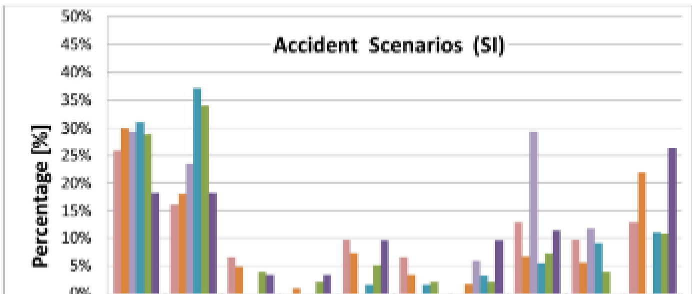



*Figure 10 - June 2018 CRF "Driver attention direction" test: Direction of glaze in presence of cyclist: scenarios L, On and T3*

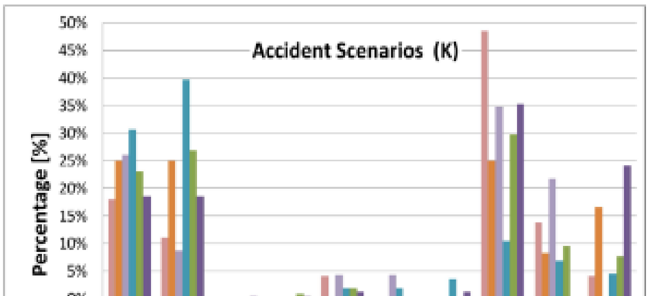
### 3.2.4 Experimental scenarios

The above analysis, and considerations on percentage of covered Fatal (K) and Seriously Injured (SI) incidents in (




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

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




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

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

Figure 5), led to a focus in the CRF driving simulator experiment on the following two urban scenarios:

- C1 (car driving straight and cyclist crossing the vehicle path from the right). In this case the cyclist always has priority, because the road in which the participant had to drive is a road without right of way

- C2 (car driving straight and cyclist crossing the vehicle path from the left). In the simulator implentation, the cyclist would sometimes give priority to the ego-vehicle (as obliged by law) and sometimes not, to create a more realistic scenario.

The cyclist speed was around 15 km/h, which is considered the nominal speed of cyclists. In both C1 and C2 scenarios there was surrounding traffic constituted by other cars present to make the driving experience more realistic. Moreover, both in C1 and C2 some intersections could be obstructed by buildings or not (**Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.**) to evaluate the impact of the nudging HMI.

*Figure 11 - CRF driving simulator C1 scenario with and without obstruction*

*Figure 12 - CRF driving simulator C2 scenario with and without obstruction*

### 3.2.5 Stimuli and test conditions

The nudging visual stimuli 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 OFFIS. From several options, D2, D3 and D5 (see Figure 13 were selected as most promising according to a study performed by OFFIS (Kirchbichler, Stefan, et al., 2019).

To optimize the D2, D3, D5 nudging HMI graphics 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. 10 participants (CRF employees not involved in HMI and Advanced Driver Assistance Systems activities) were involved in this first study and recruited with the same characteristics as presented in Section 0. This experiment was within-subjects, in which all participants experienced all test conditions in the different driving scenarios. After these trials, participants were interviewed on the nudging HMIs experienced during their driving and verbalized comments were used to slightly modify graphics. Then, HMI solutions were harmonized (e.g. same colors among same levels of nudging in D2, D3 and D5) and better adapted to the visualization in augmented reality in the driving simulator (e.g. amber and red indent made larger, green path made longer), because the view perspective was different from that on the instrument cluster.

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 13).

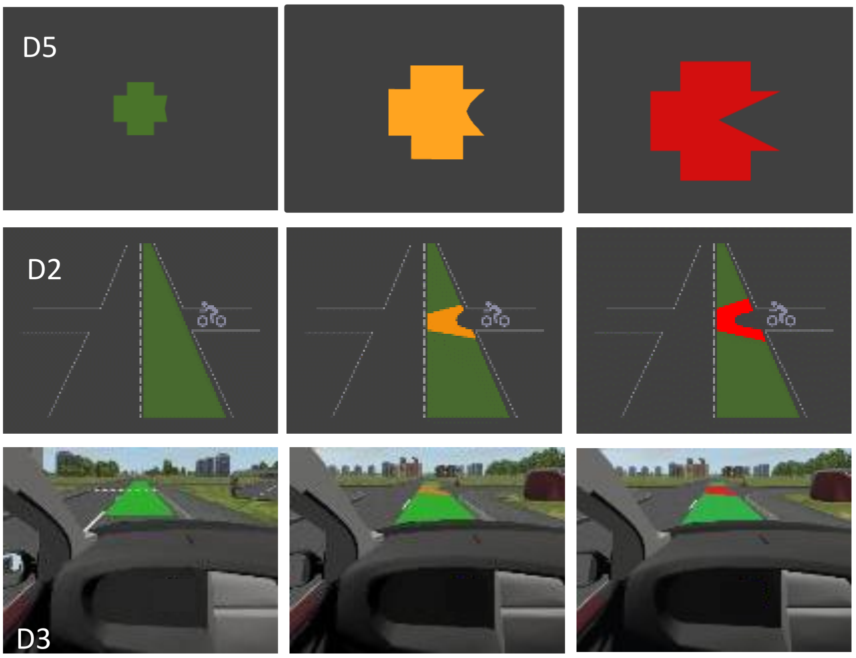



*Figure 13 - MeBeSafe nudging HMI (D5, D2, D3 versions) with different warning levels*

Four different conditions were evaluated:

- Absence of nudging visual HMI

- D5 visual nudging HMI (abstract cross) on the instrument panel (with a 16:9 7-inches display with a 1024x600 resolution at 150 pixels per inch, a width of 15.50 cm and a height of 8.72 cm)
- D2 visual nudging HMI (road view) shown on the instrument panel
- One visual nudging HMI (D3) displayed as Augmented Reality on the scenario (e.g. Head-Up display in the windscreen), 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".These test results, in fact, showed that the focus of the driver attention is the central area in front of the driver. This area is the focus in absence of cyclists and remains the second largest driver attention direction, with around 20% of time on this AOI (Area of Interest) in presence of an identified cyclist. Figure 14 reports main indicators of glances in this area in presence and absence of cyclist during approaching a C1 or C2 intersection.

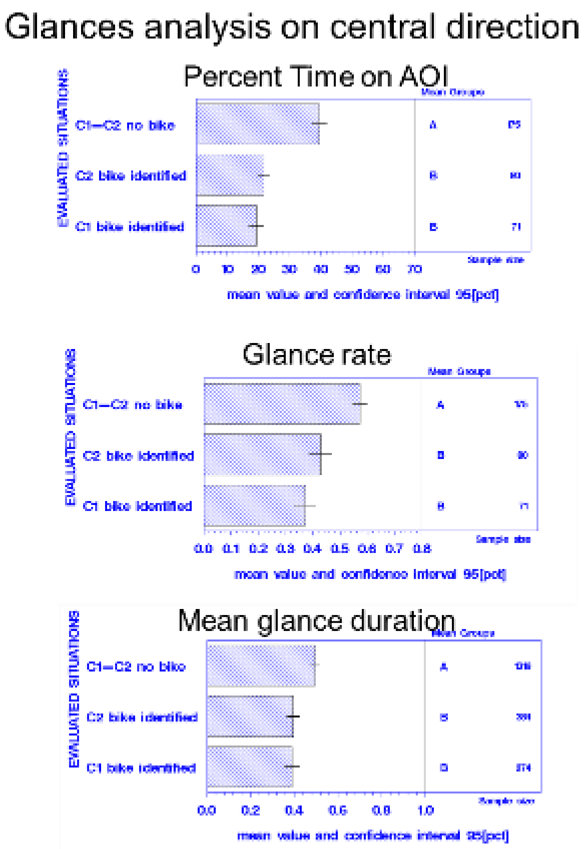



*Figure 14 - June 2018 CRF "Driver attention direction" test: Glances on central area in front of the driver*

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 it is always present even if the Head-Up Display is not present in a car.

### 3.2.6 Experimental Design

The CRF study on nudging HMI used a *within-subjects-design*, in which each of the 30 participants were exposed to all test conditions in the different driving scenarios. The experiment consisted of five driving sessions in both C1 and C2 scenarios.

All participants drove a baseline condition (no nudging, no approaching cyclist at intersections) always as a first session of the test, in order to identify the individual driving performance and direction of attention near intersections.

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 order effects. In these four sessions the approaching cyclist and the intersection view obstruction (building) were sometimes present and sometimes not. Moreover, in the C2 scenario the approaching cyclist could give priority to the ego-vehicle or not, to create a more challenging, not repetitive and realistic situation. Each session included 18 intersections 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 not to exceed 50 km/h and respect all traffic rules.

### 3.2.7 Procedure

As a first step, participants were received at the CRF Virtual Reality Driving Simulator by an experimenter and they were welcomed, thanked for taking part to the study and introduced to the test they were about to start, through written instructions, that informed also about privacy aspects according to the EU General Data Protection Regulation.

After a five minutes practice drive with the driving simulator to be 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 a questionnaire rating 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 intersections 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.

### 3.2.8 Questionnaires

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

After the driving in the different conditions, participants had to explain the meaning of the displayed nudging solutions to understand their comprehensibility through an open question and to evaluate, using a 7 points differential semantic scale:
(very ..., slightly..., little..., neither/nor ..., little ..., slightly ..., very ...):

- The driving task on the values *Easy*, *Relaxing* and *Pleasant* and their opposite meanings
- The feeling participants had during the driving, evaluating the aspects *Safe*; *Annoyed* and *Quiet* and corresponding opposite meanings
- The displayed HMI nudging solutions (if present) on the following aspects: *Easy to understand*, *Effective*, *Necessary*, *Distracting*, *Pleasant*, *Rising attention*, *Useful* and *Visible* and corresponding opposite meanings

Moreover, usage intention was investigated through open questions. In the final questionnaire, subjects were asked to sort the preferred HMI in order. In the last phase, participants filled in a demographic questionnaire as well as a driving habits one.

### 3.2.9 Variables

In the experimental design, the following *independent variables* were considered:

- Nudging HMI: three different visual nudging HMI (O) 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 maneuvers performed by cyclists in C2 scenario (O)

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 measures describing driver behavior and reactions to the different stimuli such as distance between cyclist and car, car speed, pedals and steering-wheel usage behavior, etc. were calculated. Also, articipants' eye movements during the various tests, including the baseline, collected by FOVIO$^{TM}$ were analysed.

## 3.3 Results

The results are presented in subsequent paragraphs dedicated to subjective evaluation, eye movement (driver attention direction) and objective driving performance data.

### 3.3.1 Subjective evaluations

A preliminary analysis was done to evaluate the participants ability in answering through questionnaire scales. In particular, aspects taken into account for this evaluation were scale usage (all anchors or polarization on extremes/medium anchors), discriminant capacity among different nudging solutions and coherence in evaluation between each participant and the average of the other ones. One participant had a lower capacity to discriminate among different solutions (always extreme anchors were chosen) and another one did not finish the test because of the simulator sickness effect. These two participants' subjective data was excluded. Then the final sample were composed from 28 participants. The evaluations were standardized at the same mean for each variable without modifying individual standard deviation and results with a 95% of confidence level are reported.

The subjective evaluations were analysed to understand:

- *Nudging HMIs participants' comprehension*
- *Participants' driving task and their feeling with and without the nudging support during driving*
- *MeBeSafe HMI nudging solutions participants' judgment and preferred solution among the tested ones*
- *Participants' nudging judgment when the view at the intersection is obstructed by a building*
- *Participants' suggestions to modify the MeBeSafe nudging HMI solutions*

*Nudging HMIs participants' comprehension*

After driving in the different conditions, users explained the meaning of the nudging solutions they tested. Answers were categorized in:

- correct answer: when participants expressed specifically the presence of the bike and the levels of warning
- partially correct answer: when participants expressed a general idea of warning without specific reference to the bike
- incorrect answer: when participants provided a completely wrong response

As shown in Figure 15, participants provided significantly more correct or partially correct answers than wrong answers, while difference between correct and partially correct answers emerged between D5 nudging solution ("Cross") on Instrument Cluster (IC) condition and the other D2 and D3 conditions ($\chi^2(4, N=168) = 14.5, p<.01$).

In fact, participants provided more correct responses with conditions in D3 ("Augmented reality") displayed on the scenario and D2 ("Street") on the Instrument Cluster.

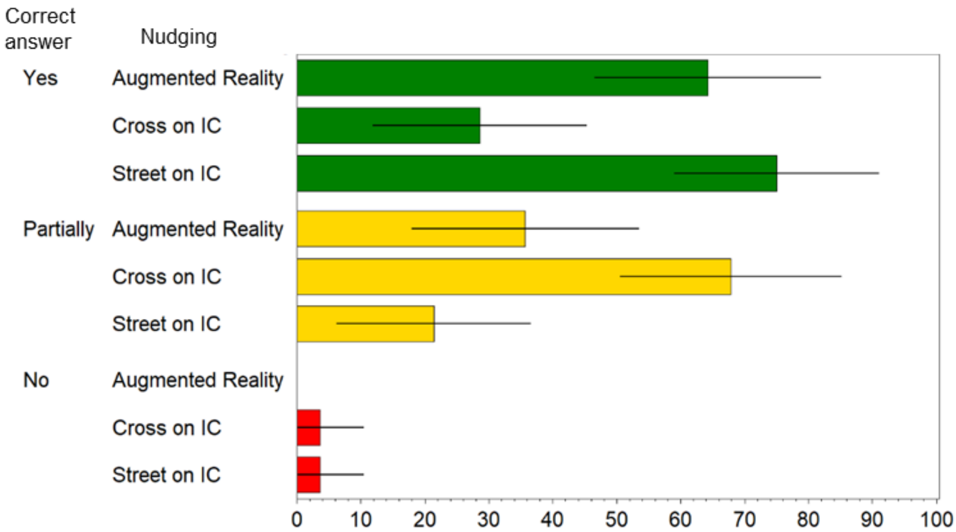



*Figure 15 - Percentage of correct, partially correct and wrong answers. Green bars represent the correct answer, yellow bars represent the partially correct answers and red bars represent the wrong answers, among the different conditions*

*Participants' driving task, their feeling with/without the nudging support during driving*

After the driving in the different conditions, participants evaluated (7 points scale) how the driving was experienced, referring to the adjectives *Easy*, *Relaxing* and *Pleasant* or the opposite meaning.

Participants evaluated all the different driving sessions in a positive way. In fact, all average values are included within the range from 1 (slightly positive) to 3 (very positive). Figure 16 shows the evaluations for the different conditions. Red values are statistically lower than the average evaluation; green values are higher than the average evaluation.

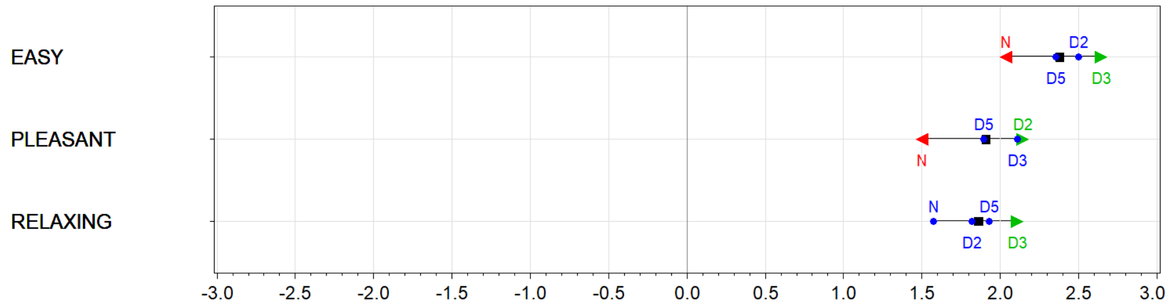



*Figure 16 - Driving evaluation. Black squares indicate the average of the evaluation; red arrows mean statistically lower than average evaluation; green arrows mean statistically higher than average evaluation; blue circles mean not statistically different from average evaluation. D2 is the nudging of the "Street" on the Instrument Cluster, D3 is the nudging of the "Street on the Augmented Reality", D5 is the nudging of the "Cross" on the Instrument Cluster and N is the condition without nudging*

Pairwise comparisons are reported in Figure 17 and reveal that driving without nudging is considered statistically different compared to the driving with "Augmented Reality" nudging and with the "Street" on Instrument Cluster for the adjective *Easy* ($F(3,108) = 4.43$, $p<.01$), indeed driving without nudging obtained lower values. Driving without nudging is also considered less *Pleasant* than driving with nudging ($F(3,108) = 5.36$, $p<.01$). Moreover, with 90% of confidence level, driving without nudging is evaluated less *Relaxing* than driving with "Augmented Reality" nudging ($F(3,108) = 2.44$, $p=.07$).

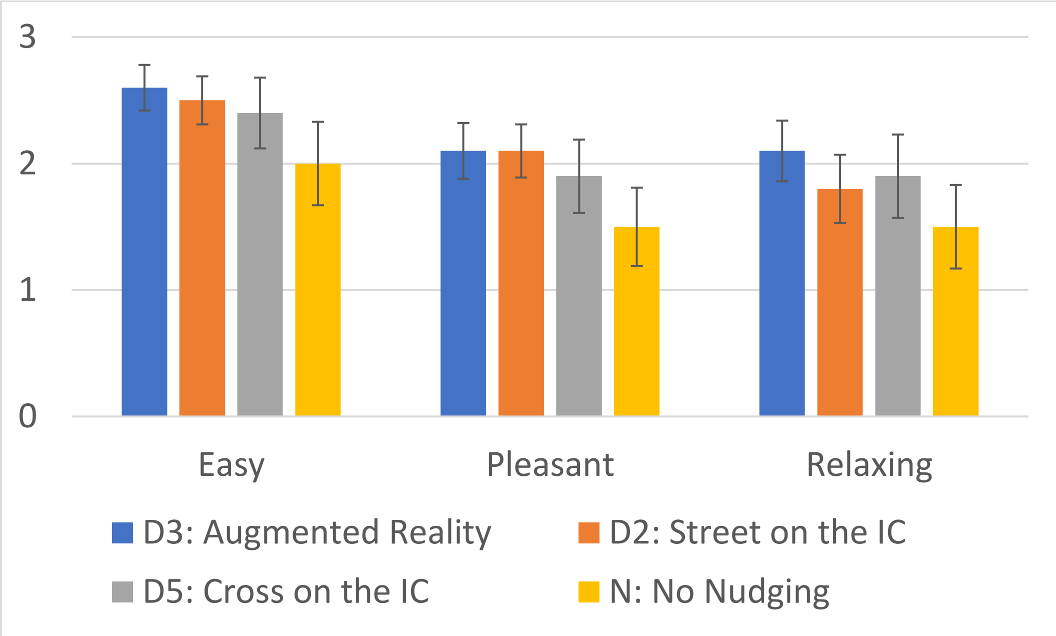



*Figure 17 - Driving judgment. Mean evaluation and confidence intervals (with 95% confidence) in the different conditions*

Then, results indicate that participants appreciated driving with nudging and judged this condition more *Easy*, *Pleasant* and *Relaxing* than the other conditions.

With respect to participants' feeling during driving, participants were asked to evaluate how much they felt *Annoyed*, *Quiet* and *Safe* or the opposite (7 points scale). Again, the values are positive for all the conditions. Figure 18 shows the evaluation for the different conditions.

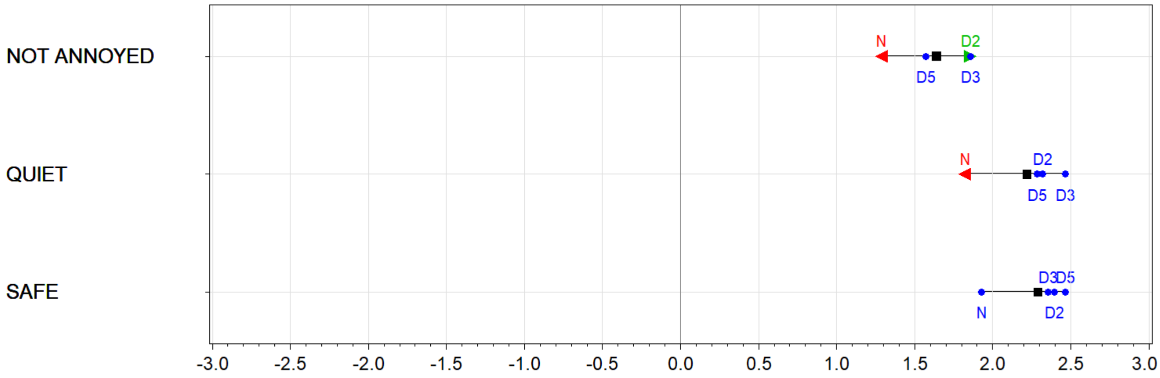



*Figure 18 - Driver feeling evaluation. Black squares indicate the average of the evaluation; red arrows mean statistically lower than average evaluation; green arrows mean statistically higher than average evaluation; blue circles mean not statistically different from average evaluation.D2 is the nudging of the "Street" on the Instrument Cluster, D3 is the nudging of the "Street on the Augmented Reality", D5 is the nudging of the "Cross on the Instrument Cluster and N is the condition without nudging*

Pairwise comparisons are shown in Figure 19. Participants felt less *Annoyed* while driving with the "Augmented Reality" nudging and with the "Street" on Instrument Cluster nudging ($F(3,108)=4.95$, $p<.01$) than during the no nudging driving, and less *Quiet* in the no nudging condition than all the other conditions with nudging ($F(3,108) = 4.68$, $p<.01$). Moreover, with 90% of confidence level, driving without nudging is evaluated less *Safe* than the driving with nudging ($F(3,108) = 2.04$, $p=.1$).

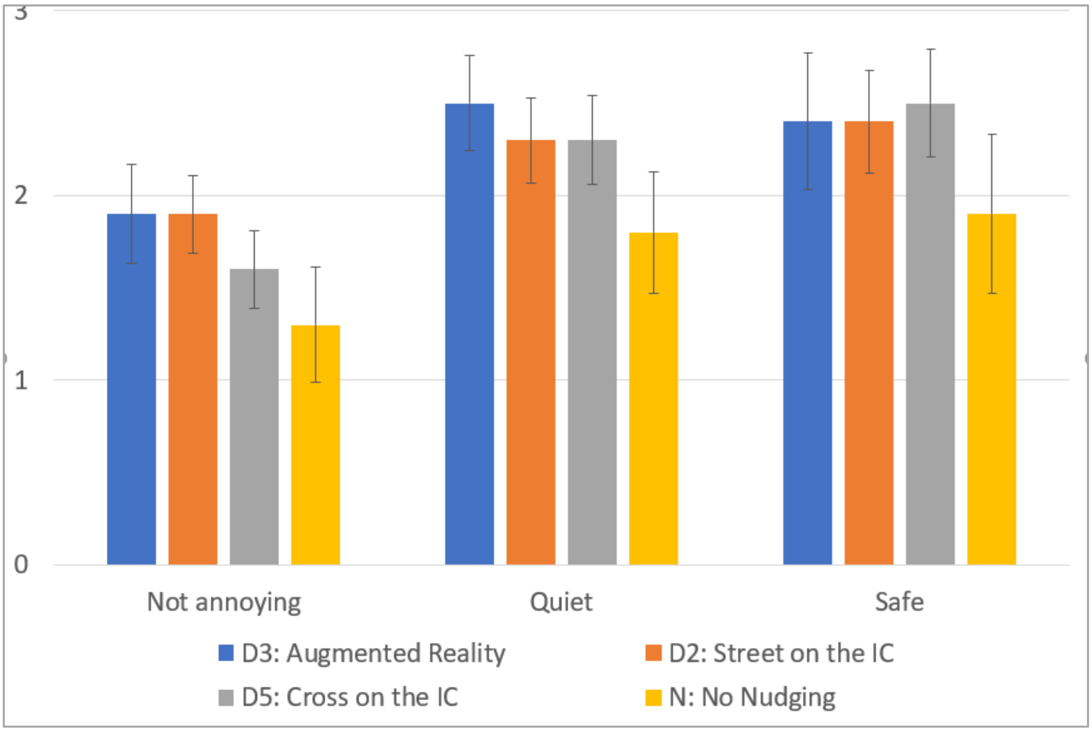



*Figure 19 - Driver feeling. Mean evaluations and confidence intervals (with 95% confidence) in the different conditions*

*MeBeSafe HMI nudging solutions participants' judgment and preferred solution among the tested ones*

At the end of the test with each HMI condition, participants evaluated the different nudging HMIs. All averages show positive response (range from 1=slightly positive to 3=very positive). "Augmented Reality" was rated the highest, while "Cross" on Instrument Cluster graphics had less good scores, in almost all aspects (Figure 20).

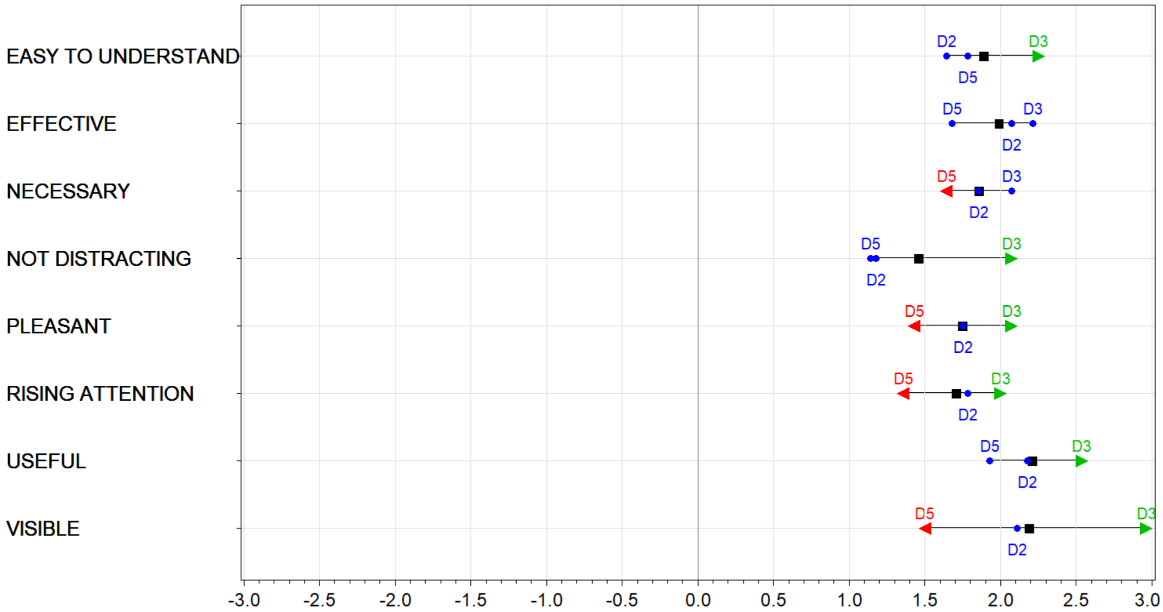



*Figure 20 - Graphics evaluation. Black squares indicate the average of the evaluation; red arrows mean statistically lower than average evaluation; green arrows mean statistically higher than average evaluation; blue circles mean not statistically different from average evaluation. D2 is the nudging of the "Street" on the Instrument Cluster, D3 is the nudging of the "Street on the Augmented Reality" and D5 is the nudging of the "Cross" on the Instrument Cluster*

Then, participants preferred the "Augmented Reality" nudging, because they considered this graphic easier to understand, less distracting, more visible and useful. Previous results are confirmed in the participants' ranking of the four conditions. Figure 21 shows that most participants preferred the "Augmented Reality" condition. The second preferred solution is the "Street" on the Instrument Cluster.

More than 80% ranked the solution without nudging as least preferred.

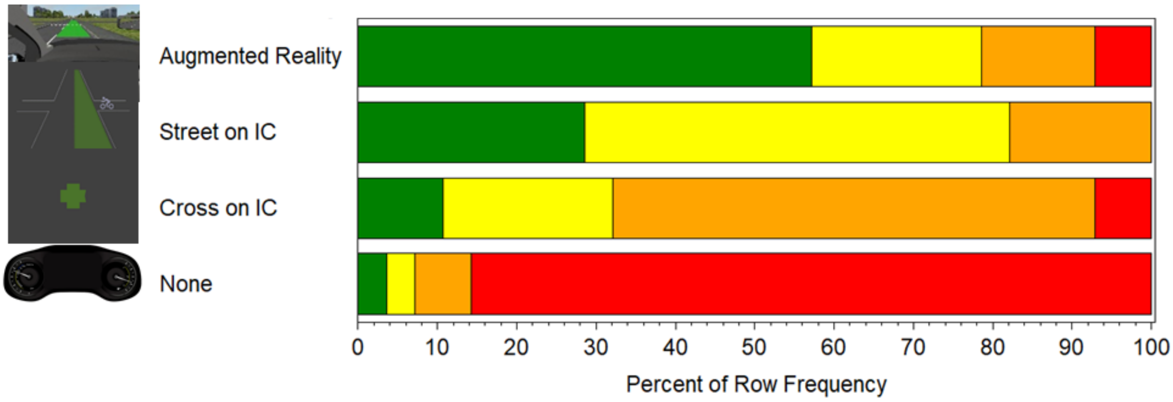



*Figure 21 - Ranking of the four conditions tested. In green the percentage of the conditions ranked as first, in yellow the percentage of the conditions ranked as second, in orange the percentage of the conditions ranked as third, in red the percentage of the conditions ranked as forth*

Participants ranking have different reasons:

- participants who preferred the "Augmented Reality" nudging ranked it as first because of the frontal position and its higher visibility, because it is less distracting and for the higher comprehensibility
- participants who preferred the "Street" on Instrument Cluster nudging ranked it as first because of the high visibility of the cyclist and of the street and because they consider this graphic easy to understand
- participants who preferred the nudging of the "Cross" on Instrument Cluster appreciated the cross icon which is identified with the concept of warning
- one participant only preferred the no nudging solution because he judged the system as not useful

As shown in Figure 22, more than 60% of participants preferred the Frontal Windshield (FW) Augmented Reality compared to the Instrument Cluster nudging location.

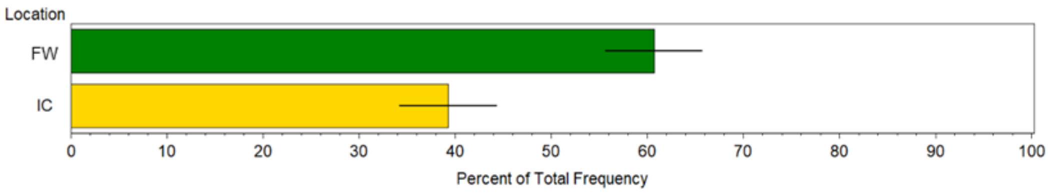



*Figure 22 - Percentage of the preferred location*

Frontal Windshield location is preferred because it allows the driver to maintain the view on the street, and avoids the driver to look down to the Instrument Cluster. At the opposite, other participants prefer the Instrument Cluster because important indications are usually located on the Instrument Cluster. Moreover, the view of the street could be occluded by the nudging image, if not well designed.

*Participants' nudging judgement when the view is obstructed by a building*

This aspect was investigated because, in presence of a view-blocking obstruction, the displayed nudging HMI might show a possible hazard of an approaching cyclist (static hazard model), while actually no cyclist appears to be approaching the intersection, rising to a sort of false warning. Notwithstanding this, participants evaluated in a positive way the nudging shown when there was a view-blocking obstruction at an intersection (e.g. building). No difference in the subjective evaluation between the conditions with and without obstruction emerged, and more than 65% of participants said they would leave the feature turned on also in the condition of a view-blocking obstruction.

*Participants' suggestions to modify the MeBeSafe nudging HMI solutions*

Participants were particularly interested in the possibility to have the nudging HMI solutions on vehicles. They suggested this nudging system could advise also in case of other Vulnerable Road Users and vehicles.

Participants argued about the possibility to associate a sound to the more critical nudging level (e.g. red areas).

Moreover, they gave some points of attention for each MeBeSafe tested solution:

- for the D5 nudging ("Cross" on Instrument Cluster), participants blamed the head down solution that could create potential distraction caused by the eyes off the road needed, the comprehensibility of the graphical solution, and reported as the indent (representing the deviations from the symmetry at the side where the cyclist were arriving) was not clear
- for the D2 nudging ("Street" on Instrument Cluster), participants highlighted the potential distraction effect due to the head down position to acquire the information and the high number of small elements in the displayed graphics that decrease the comprehension
- for the D3 nudging ("Street in the Augmented Reality), participants had some worries about a possible interaction between the displayed nudging and the outside street visibility, in case of not careful design

### 3.3.2 Eye movement (driver direction of attention)

Data acquired by FOVIO™ were used to quantify and evaluate the driver direction of attention during the driving sessions. A preliminary analysis highlighted some interesting differences compared to the preliminary test in June 2018. In June 2018, participants were asked to always give priority. In the current study, drivers give priority only to cyclists approaching the intersection from the right side. Vice versa, when cyclists appear on the left side of the vehicle, even if cyclists should give priority (accordingly to traffic rules), sometimes they did not. This was done to create also a more difficult and realistic use case for the ego vehicle driver.

Figure 23 shows gaze direction in X horizontal axis, during the approach of an intersection in absence and in presence of a cyclist, when eyes are on the road (excluded time when drivers are looking at the cluster).

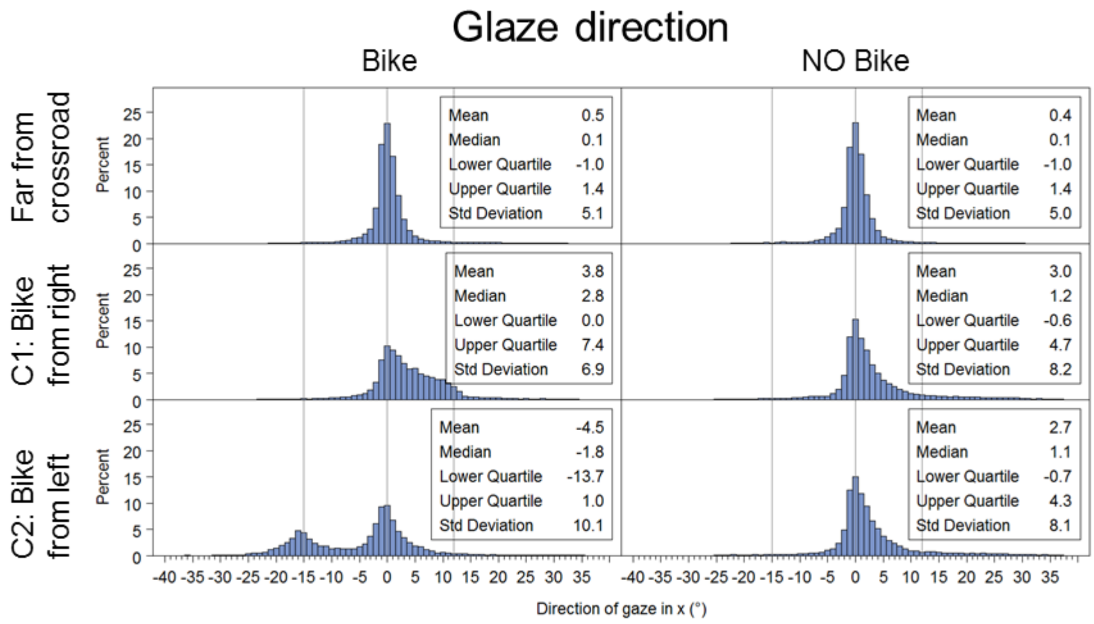



*Figure 23 - Horizontal gaze direction in road proximity with and without bike presence*

Looking at the distribution in second and third row, a higher level of attention to the right in intersection proximity is visible, due to the instruction given to participants to always give priority to any vehicle approaching from right. Looking to the left graph in the third row, when a bike is approaching from the left, an increased gaze direction to the left side of the road emerges, even if the ego vehicle had always priority, because cyclists do not always give priority to the incoming ego vehicle. Participants were not told about the possibility that the biker, approaching the intersection from the left, could have ignored the rule of giving priority to right incoming vehicles. However, once they understood this could happen, participants were very careful in looking at the cyclist to verify whether s/he was yielding or not.

To summarize, approaching an intersection drivers look more at road users approaching from the right side in order to be able to yield if necessary, but if drivers see a cyclist arriving from the left, they look at the cyclist and follow their behaviour to avoid incidents. Similar trends were observed both with and without nudging.

In addition to this analysis, the lateral gaze direction and the calculated angle between ego vehicle and bike from simulator data were used to define the time when the bike was probably identified by the driver. The bike is assumed to be identified by the driver if for 450ms, gaze was on the road (i.e. not on the cluster) and the difference in angle between bike direction and gaze direction was less than 2°.

The percentage of identified cyclists and the distance from the intersection when the identification was completed were compared. Table 1 reports the percentage of identified bikes in different use cases and HMIs: D5 "Cross" on Instrument Cluster (IC), D2: "Street" on IC and D3: "Street on Augmented Reality"). Difference among use cases are significant ($\chi^2(3, N=546) = 58.9$, $p<.01$), while differences among HMIs are not.

As can be seen, cyclists were identified with higher frequency when there was no obstruction. No significant difference is noted between the direction of approach of the bike or for the different HMIs.

| Bike identified | C1 no obstruction | C1 obstruction | C2 no obstruction | C2 obstruction |
|---|---|---|---|---|
| D2: Street on IC | 82% | 68% | 93% | 50% |
| D5: Cross on IC | 70% | 63% | 92% | 67% |
| D3: Augmented reality | 71% | 54% | 93% | 57% |
| N: None | 81% | 69% | 89% | 54% |

*Table 1 - Percentage of identified bikes in different use cases and HMIs*

Figure 24 reports the comparison of the distance from the intersection at which the cyclist is identified in presence or absence of a view-blocking obstruction (for both cyclist incoming directions) with the different HMIs (C="Cross" on IC, S="Street" on IC, AR="Street on Augmented reality"). As could be expected, the presence of obstruction has a significant effect ($F(7,387)=15.9$, $p<.01$) while the distance from the intersection at which the cyclist is identified is not significantly different among the HMIs.

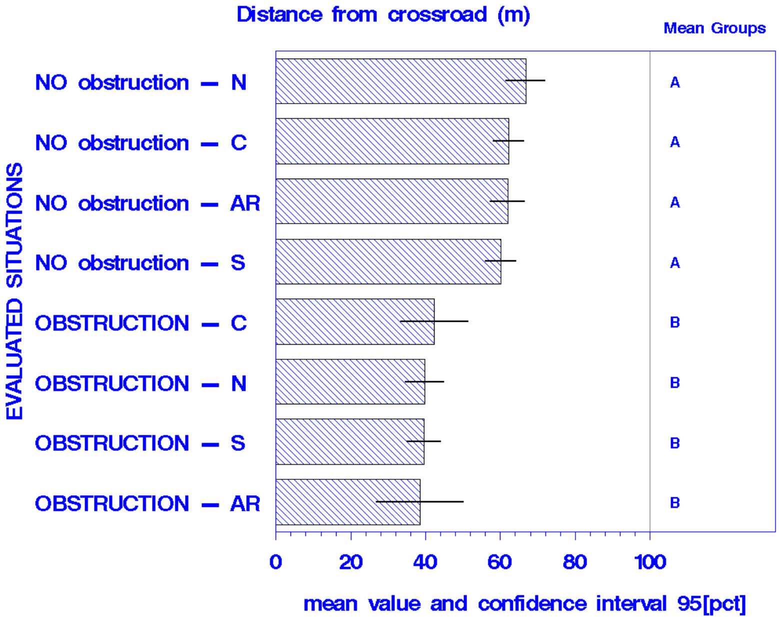



*Figure 24 - Distance from intersection (m) when the cyclist is identified. To enhance graph legibility, both cyclist directions are considered together.*

Similar results are obtained considering the time of cyclist identification (Figure 25). The time is counted starting from the cyclist appearance in lateral field of view in the scenario, when the ego-vehicle is estimated to be 6s from the intersection. The presence of an obstruction is significant ($F(7,387) = 25.1$, $p<.01$), but differences between HMIs are not significant. In case of the time, the cyclist direction of approach is statistically significant; cyclists from the left are identified half a second before the cyclists incoming from the right on average.

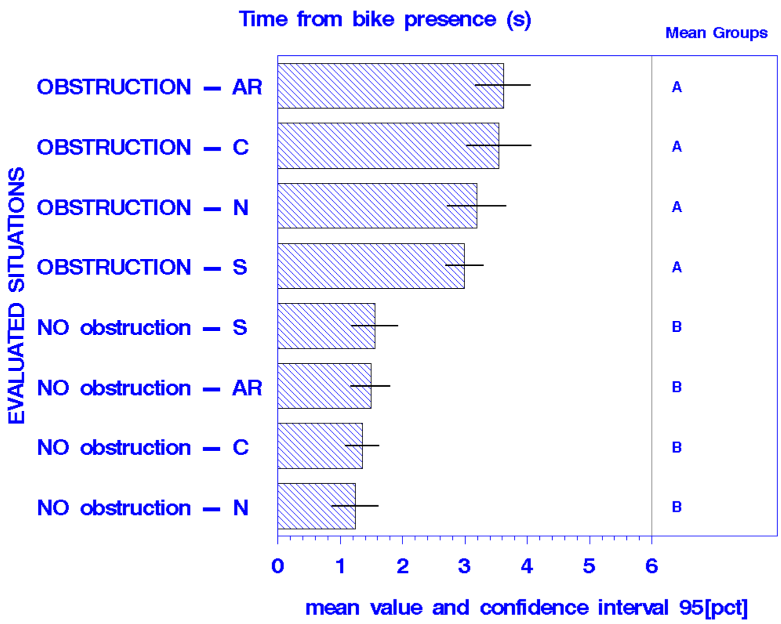



*Figure 25 - Time from intersection (m) when the cyclist is identified. To enhance graph legibility, both cyclist directions are considered together.*

Finally, standard metrics suggested by ISO 15007 were calculated with respect to the main Area of Interests (AOIs) in different situations considering different HMIs, presence/absence of cyclist and obstruction, bike direction and priority and time before/after bike identification.

Figure 26 compares glance rate to instrument cluster among different HMIs in different conditions (cyclist identified, not identified and not present). Differences among conditions are significant ($F(11,1133)=52.65$, $p<.01$). HMIs on Instrument Cluster increase the glance rate on instrument cluster, especially before cyclist identification. If we consider an ANOVA with the separate effect of HMIs and conditions (bike presence and identification), the ANOVA is significant ($F(5,1139) = 109$, $p<0.01$) and the Type III Sum of Square highlights a significant contribution of HMI ($F(3,1139)=167.4$, $p<.01$) and condition ($F(2,1139)=25.4$, $p<.01$).

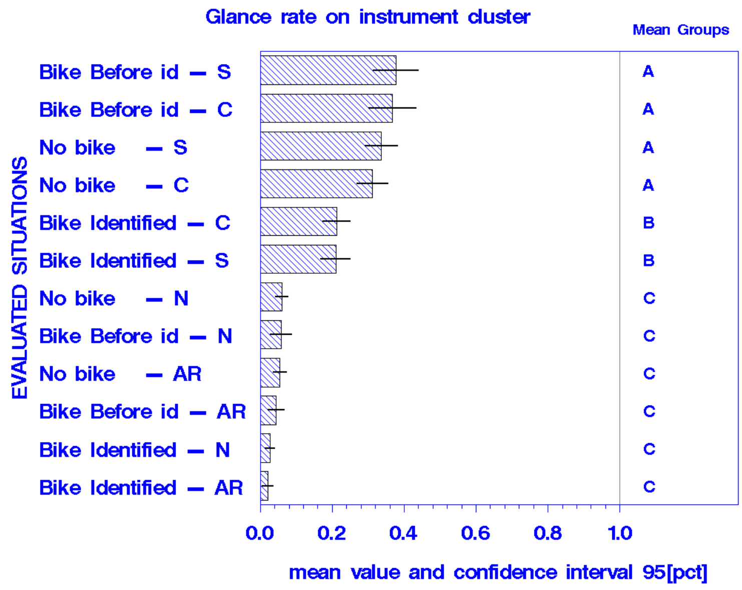



*Figure 26 - Glance rate (glances/s) on Instrument cluster*

This indicates that the "Augmented Reality" nudging option leads to fewer off road glances, compared to having the nudging on the Instrument Cluster.

Figure 27 compares the duration of glances to the instrument cluster for different HMIs in different conditions (cyclist identified, not identified and not present). Here, there were no significant differences.

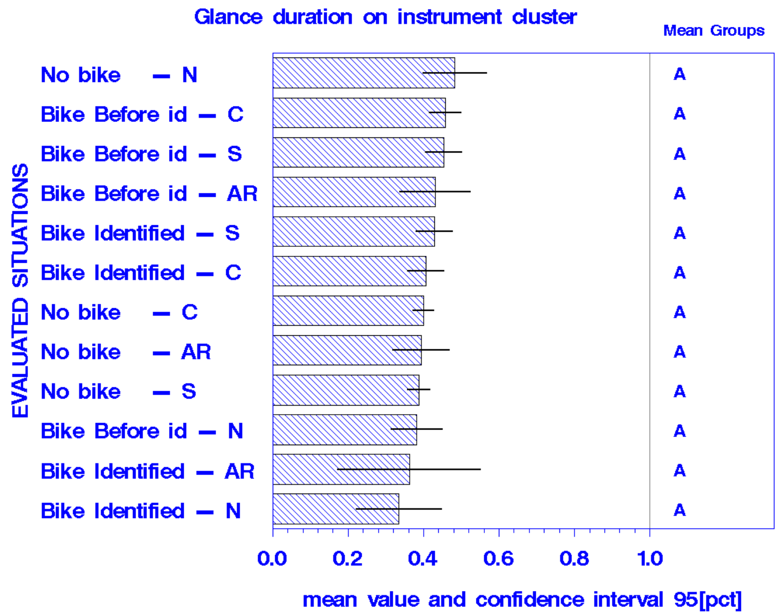



*Figure 27 - Glance duration (s) on Instrument cluster*

The indicates that glance durations towards the Instrument Cluster do not appear to be significantly longer because there is a nudging HMI present in the IC. Nudging on the IC does not lead to longer off the road gazes compared to the case without nudging. This is explained by the fact that the cluster is always regularly monitored by the driver to acquire other information such as speed.

Figure 28 reports the comparison between different HMIs in different conditions (cyclist identified, not identified and not present) regarding the total percentage of time looking at the instrument cluster. Differences between conditions are significant ($F(11,1130)=56.4$, $p<.01$). Considering an ANOVA with the separate effect of HMIs and conditions (bike presence and identification), the ANOVA is significant ($F(5,1136)=113.4$, $p<.01$) and the Type III Sum of Square highlights a significant contribution of HMI ($F(3,1136)=163.3$, $p<.01$) and condition ($F(2,1136)=41.6$, $p<.01$).

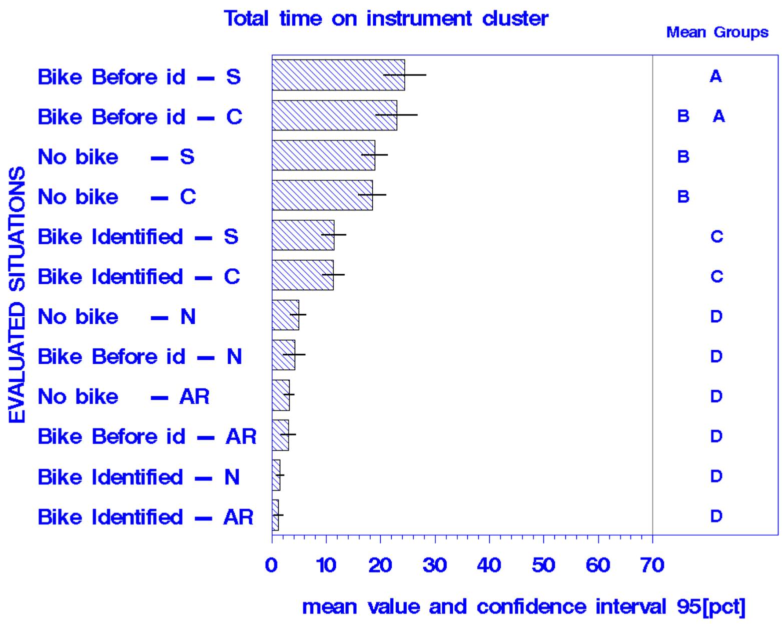



*Figure 28 - Percent time (%) on Instrument cluster*

The "Augmented reality" HMI minimizes the drivers' off the road time to acquirenudging information.

Moreover, the criteria suggested by the NHTSA document "Visual-Manual NHTSA Driver Distraction Guidelines for in-Vehicle Electronics Devices" Docket No.NHTSA-2010-0053" have been used with respect to Instrument Cluster glances for the HMIs on cluster (D5 and D2). All three criteria are fully satisfied by both HMIs for all participants, also considering the use cases where cyclist is not present or cyclist has not yet been identified:

- for all participants, the mean duration of off-road eye glances <0.7s
- for all participants less than 15% of off-road glances were longer than 2s
- for all participants, the sum of off-road glance durations during the approach of an intersection <4s.

All indicators show that Augmented Reality has an advantage in terms of more visual attention on the forward roadway. The "Augmented reality" HMI increases the driver percentage of total time on the frontal area, having a positive impact on driving safety.

Moreover, Table 2 summarizes the percentage difference in glances to frontal road area with AR HMI with respect to no nudging, both on glance rate and on total time, in the three situations: no bike, before bike identification and bike identified.

| Situations | Glance Rate | Total time |
|---|---|---|
| No bike | +40% | +55% |
| Before identification | +43% | +73% |
| When bike has been identified | +68% | +60% |

*Table 2 - Increase in the percentage in glances at the frontal road area and the time of gaze at the frontal road area when nudging is applied through Augmented Reality with respect to the situation in which no nudging is applied*

Figure 29 shows the comparison between different HMIs with respect to the glance rate towards the cyclist, after the cyclist has been identified. Difference between HMIs are significant with 95% of confidence ($F(3,368) = 3.02$, $p=0.03$).

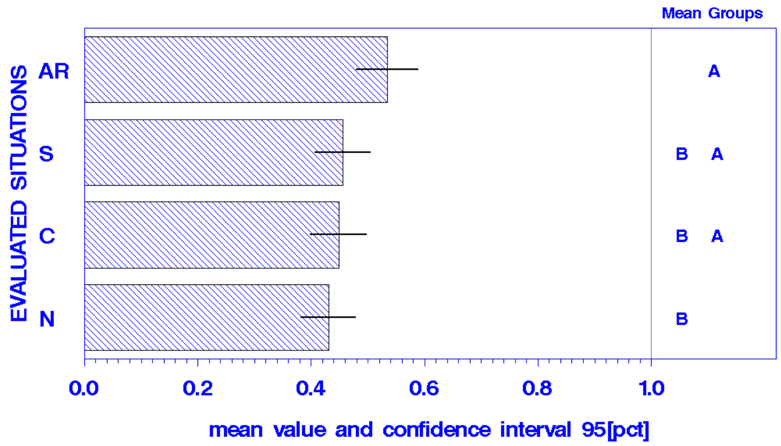



*Figure 29 - Glance rate (glances/s) to cyclist*

It is interesting to underline that with the "Augmented Reality" HMI, the glance rate at the cyclist is significantly higher than in absence of nudging.

Figure 30 reports the comparison between different HMIs towards duration of glance to cyclist, when the cyclist has been identified.

Differences between HMIs are significant ($F(3,825) = 5.9$, $p<.01$).

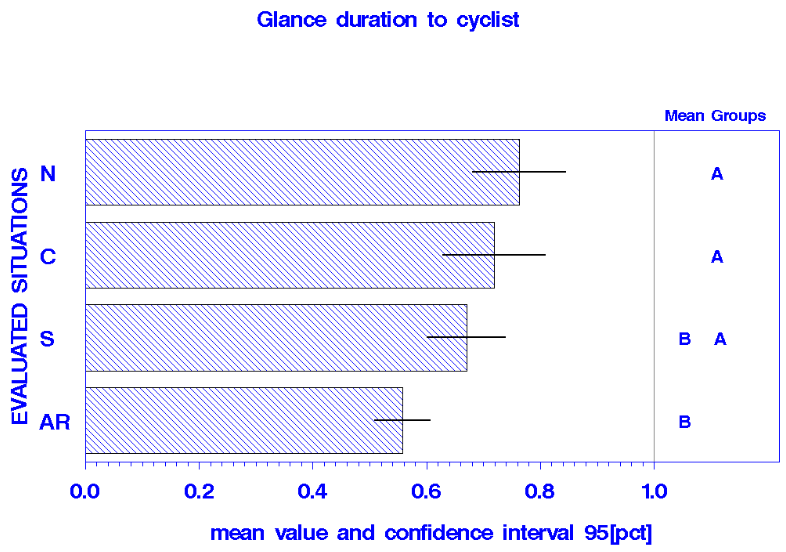



*Figure 30 - Glance duration (s) to cyclist*

It is important to note that with the "Augmented Reality" HMI, the glance duration at the cyclist is significantly lower than in absence of nudging and with "Cross" on Instrument Cluster HMI. The "Augmented Reality" nudging solution is believed to make it easier and quicker to monitor the cyclist path.

Figure 31 compares the percentage of time that the driver gazes at the cyclist between different HMIs, after the cyclist has been identified. Difference between HMIs is not significant ($F(3,368) = 0.93$, $p=0.43$).

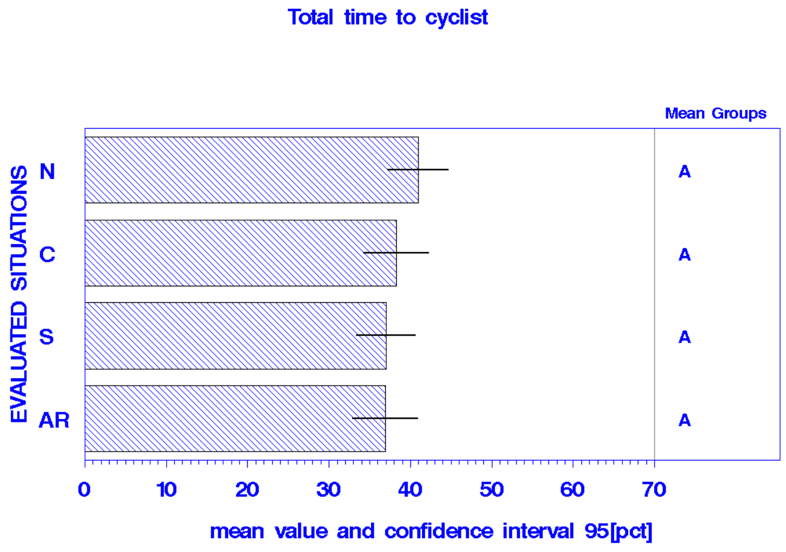



*Figure 31 - Percent time (%) to cyclist*

Summarizing, the Augmented Reality HMI increases the glance rate to the cyclist, but glances are shorter. Table 3 reports the difference in glances to the cyclist between the AR HMI and no nudging.

| Glance Rate | Total time |
|---|---|
| +24% | -10% |

*Table 3 - Difference in percentage of glance rate and total time glancing at the cyclist between AR and no nudging*

Figure 32 reports the comparison between different HMIs and absence of nudging regarding the glance rate on lateral road areas, where cyclist could appear: X-direction in (-17°,-7°) or (7°,17°) and y direction on the road. The statistics are calculated during all of the intersection approaching phase, when the cyclist is not visible. These glances are believed to be done to look for a possible approaching cyclist. Differences between HMIs are significant ($F(3,421) = 3.6$, $p=0.01$).

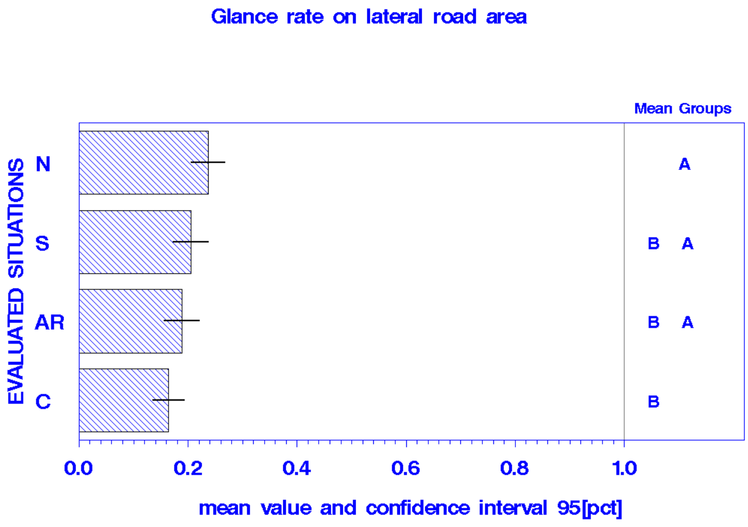



*Figure 32 - Glance rate (glances/s) to lateral area looking for an absent cyclist*

It is interesting to see that in absence of an HMI, the glance rate to lateral areas is significantly higher than in the presence of nudging, in particular regarding the Cross on the IC, which may be perceived as a more generic warning that is not only warning for cyclists.

Figure 33 reports the comparison between different HMIs regarding the duration of glances to the lateral area, looking for a cyclist, when the cyclist is not present. Differences between HMIs are not significant ($F(3,637) = 0.95$, $p=0.42$).

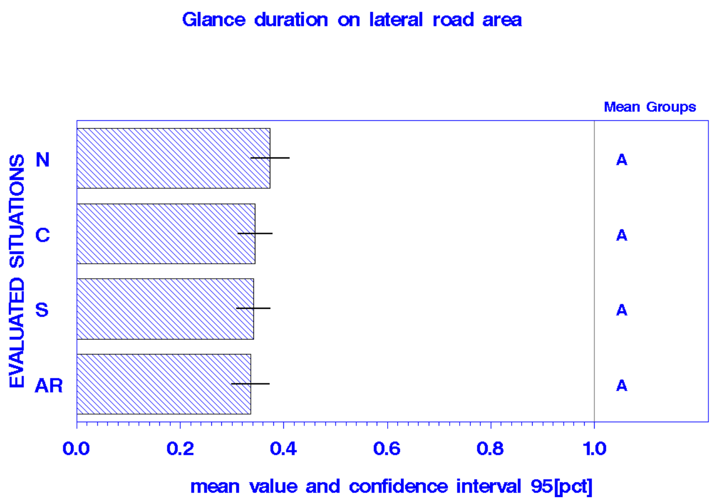



*Figure 33 - Glance duration (s) to lateral area looking for a cyclist that is not yet visible*

Figure 34 compares the percentage of time that the driver gazes into the lateral area looking for a cyclist between different HMIs, for the time that the cyclist is not visible. The differences between HMIs are significant ($F(3,421) = 10.5$, $p<0.01$).

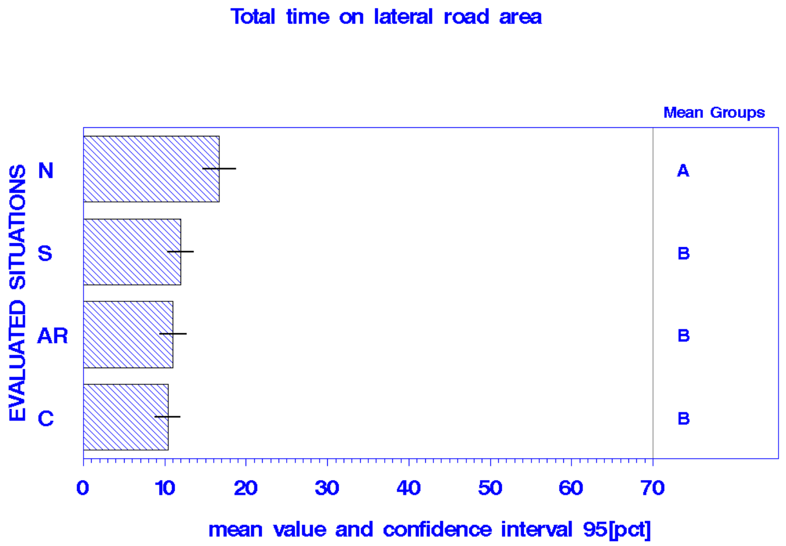



*Figure 34 - Percent time (%) to cyclist*

The presence of nudging allows users to significantly reduce the time spent in scanning lateral areas looking for a possible incoming cyclist, even if the task is in any case present.

Summarizing, the eye movements behaviour analysis shows interesting impact towards safer driving behaviour with the MeBeSafe nudging options, especially with the "Augmented Reality" HMI:

- HMIs on the Instrument Cluster increase the glance rate and the percentage of time focused on the instrument cluster, especially before a cyclist has been identified. However, the glances to the cluster are not distracting considering the criteria suggested by NHTSA.
- "Augmented Reality" nudging increases the glance rate and the percentage of time focused on the front area on the road. In absence of cyclists and before cyclist identification, also glance duration versus this important area for safety is increased.

- There is a shorter glance duration and a higher glance rate at the cyclist in Augmented Reality nudging in comparison to no nudging; with other HMIs, glance duration and glance rate are in between those for AR and no nudging.
- In absence of cyclists, the presence of nudging allows a reduction in glance rate and in the total time used for scanning the lateral area to look for possibly approaching cyclists.

### 3.3.3 Objective driving performance

Some indicators related to driving performance measures were considered in order to highlight possible differences while driving with different MeBeSafe HMIs nudging solutions and without nudging.

Figure 35 compares the average deceleration in intersection proximity among HMIs in the different conditions with cyclists possibly approaching from the right (cyclist present or not, view-blocking obstruction present or not). As can be seen, participants decelerate more in the presence of an incoming cyclist from the right or a view-blocking obstruction than without them.

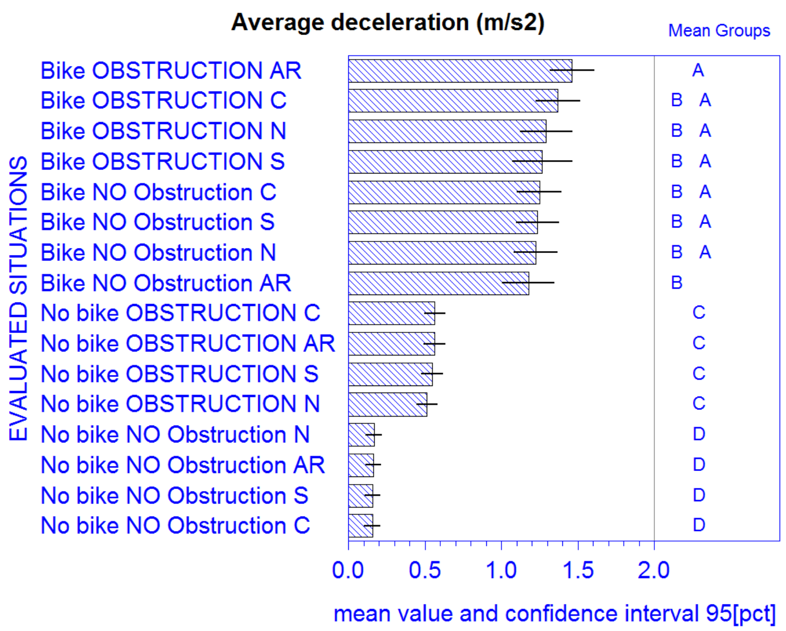



*Figure 35 - Average deceleration in approach of an intersection at a C1 scenario*

Figure 36 compares the 95° percentile of deceleration in approaching an intersection between HMIs in the different conditions with cyclist from the right without obstruction (cyclist present or not, gives priority or not). As can be seen, participants' deceleration is higher in the presence of a cyclist from the right appearing from behind a view-blocking obstruction than without them.

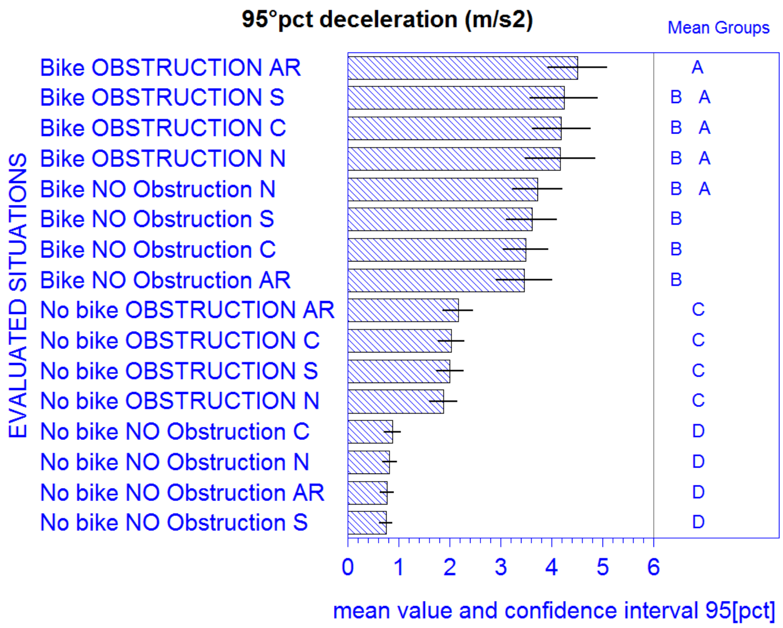



*Figure 36 - 95°percentile of deceleration in intersection approximation C1 condition*

Figure 37 compares average deceleration in the approach of an intersection between HMIs in the different conditions with cyclist from the left without view-blocking obstruction (cyclist present or not, givingpriority or not). As expected, participants decelerate more in the presence of incoming cyclists from the left, especially if the cyclist does not give priority.

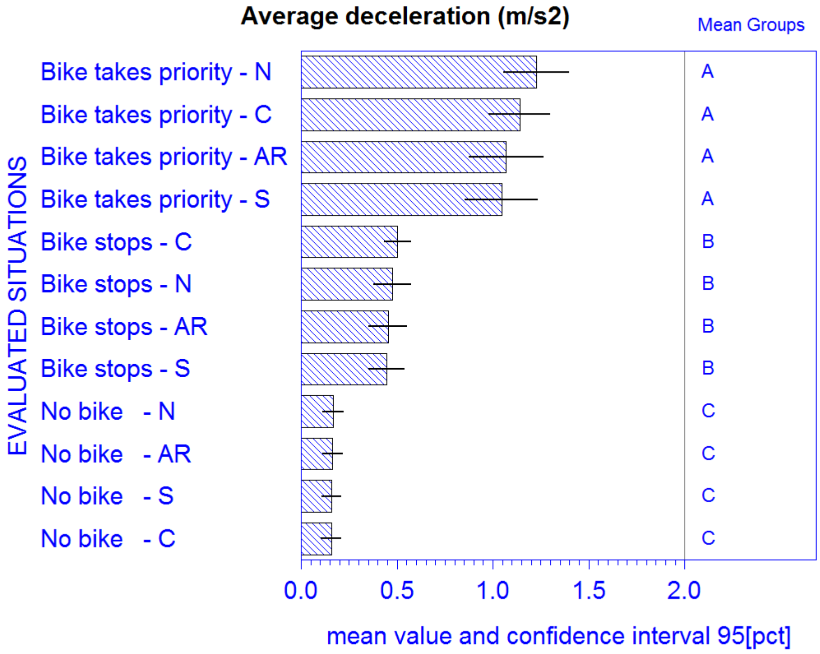



*Figure 37 - Average deceleration in intersection approximation C2 condition without obstruction*

Figure 38 compares the 95° percentile of deceleration in approach of an intersection between HMIs in the different conditions with cyclist from left without obstruction (cyclist present or not, giving priority or not). As can be seen, participants' deceleration is higher in the presence of an incoming cyclist from the left, especially when the cyclist does not give priority.

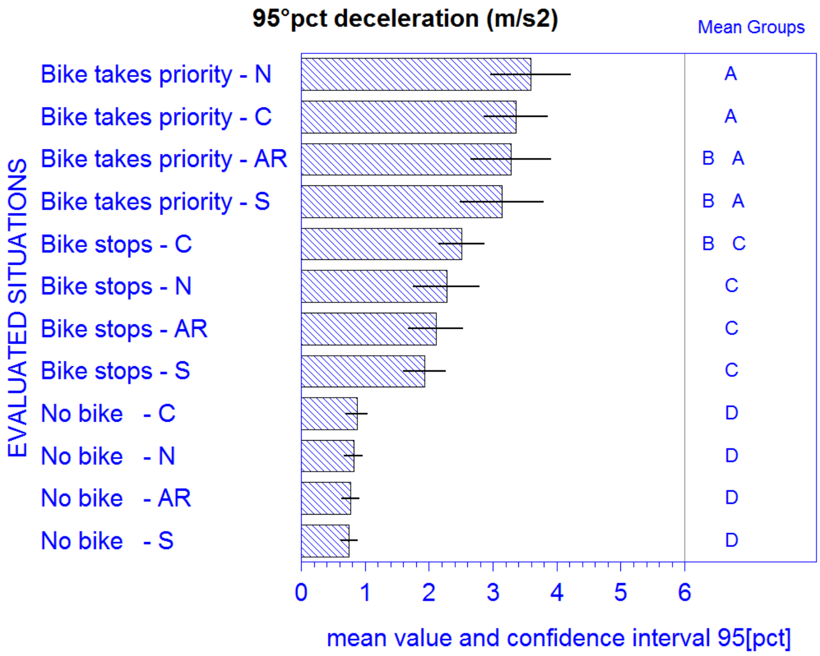



*Figure 38 - 95°percentile of deceleration in approaching an intersection with a C2 without obstruction*

## 3.4 Discussion

The aim of the study was to understand the driver behavior without a nudging HMI and the behavior when different nudging HMIs are displayed in different use cases, to highlight the possible benefit of a nudging stimulus without influencing the driver behavior negatively.

Results show that almost all participants correctly understand all the proposed MeBeSafe nudging visual HMIs, and subjective evaluations of the HMI solutions were very positive. Participants judged driving with MeBeSafe nudging HMIs easier, more pleasant and more relaxing than without nudging, and the feeling participants experienced while using the system was quieter and more safe than without the nudging system. Participants appreciated the nudging HMI feature and would leave it turned on, even if they could decide to switch it off. This confirms that MeBeSafe nudging HMI is not annoying and well perceived. The timing of the nudging presentation is very ecological, not creating annoying effects, and coherent with human cyclist identification possibilities (in good visibility conditions).

Between Instrument Cluster and Augmented Reality positions, participants prefer the Augmented Reality display. This location was considered optimal, because it allows to avoid looking down and to maintain the eyes on the road. This was confimed in the gaze analysis; glance rate and total time spend looking at the forward roadway was more than 40% higher with the Augmented Reality than without nudging. Still, the Instrument Cluster is acceptable and not critical for distraction according to NHTSA standards, even if it significantly increases the time spent looking down at the cluster.

Participants appreciate the nudging appearing also in case of intersection visual obstructions like buildings. Also in this condition, participants would leave the feature turned on even if false warnings could arise (e.g. no cyclist approaching from behind the view-blocking obstruction).

Considering the driver direction of attention aspect, presence of nudging (for all HMI options) allows to reduce the glance rate and the total time used to scan lateral road areas looking for a possible incoming cyclist when the cyclist is not present. This is due to the drivers' trust in the MeBeSafe nudging system that allows a safe and more relaxed driving, while scanning stays to be present.

In conclusion, the MeBeSafe HMI options seem capable of promoting driver behavior that makes traffic safer. The Objective from the project proposal to enhance attention to the forward roadway when potential hazards may occur with 20% is overachieved with the Augmented Reality nudging solution reaching more than a 40% increase in attention to the forward roadway (Table 2).

# 4 Implementation of the nudging solution in the TNO vehicle

## 4.1 Introduction

In deliverables D2.1 (Op den Camp, Olaf et al., 2018) and D2.2 (Kirchbichler, Stefan, et al., 2019), detailed descriptions of the nudging system for directing driver attention towards potentially hazardous cyclists in intersections can be found. The system consists of a sensor set onboard the vehicle, to build a realtime model of the world through which the vehicle is driving. Sensors provide inputs regarding the location of the vehicle on the road in the infrastructure, but also on the presence of other road users that possibly interact with the vehicle. A static and dynamic hazard model has been developed to determine the potential hazard that the vehicle faces based on its location and direction, the presence of view-blocking obstructions, the probability that cyclists cross the path of the vehicle, e.g. based on historic data of cyclist flows at intersections, and the actual road users in direct view of the vehicle. Finally, the information regarding potential hazards needs to be used to nudge the driver. To do so, different HMI options have been developed and evaluated (Chapter 3 above).

From the HMI effectiveness evaluation, it appears that all nudging HMI options are able to nudge the driver and direct the driver's attention to areas of possible hazards. To confirm that these results also hold true in real traffic and not just in the driving simulator, one HMI solution is integrated in a vehicle for performing tests on public roads. This chapter describes the implementation of the system in one laboratory vehicle at TNO (a VW Jetta) that will be used for field testing in MeBeSafe WP5. Once the implementation in the laboratory vehicle has been finalized and the effectiveness of the HMI has been verified in real traffic, the system will be integrated in a FIAT 500X production car, to complete the tests.

## 4.2 Incremental development process

An incremental way of development and testing has been used. First, the interfaces between TNO and Cygnify software modules have been carefully designed and corresponding ROS messaging has been developed. Next, based on sensor data collected during early test data collection runs, stored in so-called ROS “bags” (collections of stored sensor and processed module data), TNO and Cygnify independently worked with those ROS bags. The ROS bags were played back as though they happened ‘live’, allowing the respective systems on each end to pretend the corresponding sensor data was coming in from sensors, and to produce the agreed-upon ROS messages. Each partner collected the ROS messages thus produced and stored those in new ROS bags.

Those new ROS bags, containing outputs from specific newly developed modules from a specific partner, were subsequently exchanged with the other partner, again allowing the other partner to test with those outputs from the other messages as though (i.e. simulated) they happened in real time; without actually requiring the teams to sit together yet and without the need for real hook-up of the various computers from the different partners.

When the results from those simulation tests were passed successfully, a “virtual integration” test day was organised. On that day, the two teams (TNO and Cygnify) connected the different modules and computers to the same (ethernet) network for real-time integration and testing. That ethernet network was not yet the actual vehicle ethernet network, but sufficiently similar in set-up for such virtual, real-time integration. This virtual integration test day allowed to test the complete set-up, in real time, mimicking the vehicle set-up, but without having to use the (more difficult to work with) actual vehicle and its ethernet network, and without using the actual sensors but still using the simulated sensor outputs using the ROS bags.

Finally, given the good results from that virtual integration test day, the actual vehicle integration process was performed. From the originally three allotted days for vehicle integration, only two were needed; some small issues were solved either on the spot or quickly thereafter.

The following figures show the actual integration of computers, power supply, and networking equipment in the trunk of the TNO vehicle. Additional computing and testing equipment has been integrated in the passenger cabin.

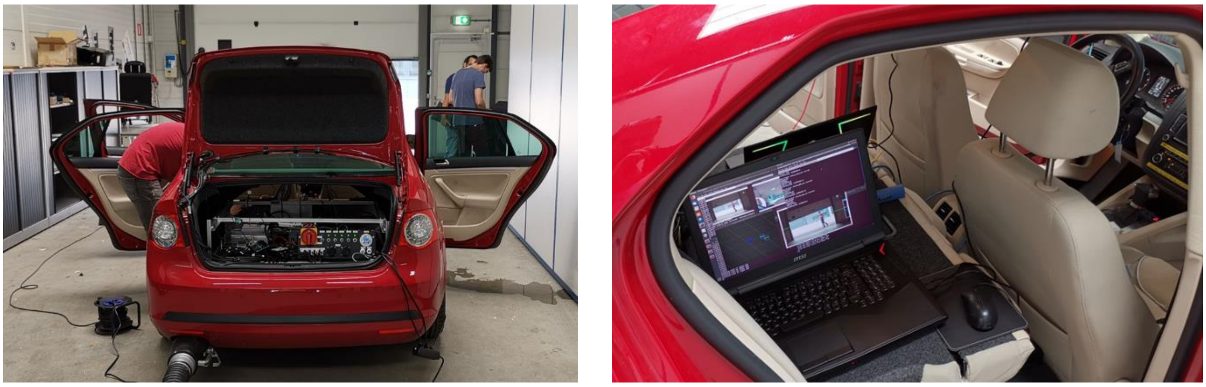


*Figure 39 - Integration of equipment in the TNO vehicle*

## 4.3 Vehicle description, sensor system and interfaces

Hazard prediction is based on two parts. The first part, referring to a static world model, provides a hazard based on potentially appearing cyclists that cannot be observed due to a view-blocking obstruction. The static model makes use of 1. the lay-out of the intersection that is being approached, based on map information, 2. a typical speed distribution of cyclists, and 3. the probability that a cyclist appears from behind a view-blocking obstruction, based on cyclist flow statistics from an observation study conducted in Eindhoven on a busy uncontrolled four-armed intersection with severe view-blocking obstructions.

The second part refers to a dynamic world model and provides a hazard analysis on cyclists that are actually observed from the perspective of the vehicle. The dynamic hazard algorithm uses the trajectories (and their probabilities) of the vehicle and cyclist(s) that are observed with the sensor system onboard the vehicle. From the possible (predicted) trajectories the minimum distance between vehicle and cyclist can be computed at any point in time, and based on that distance, a hazard level can be attributed.

The in-vehicle nudging solution gets input from the vehicle's sensor set, feeding the dynamic and static world models, as well as the cyclist trajectory prediction (Op den Camp, Olaf et al., 2018). The output of these three models is combined in the hazard prediction model to provide an overall estimate of the potential hazard in the approach of an urban intersection at which cyclists possibly cross the path of the ego vehicle. The level of the hazard and the direction of the hazard is communicated to the ego-vehicle driver by an HMI.

Figure 40 shows the integration diagram of the different models in the hardware that Cygnify and TNO implemented in the TNO laboratory vehicle, a Volkswagen Jetta.

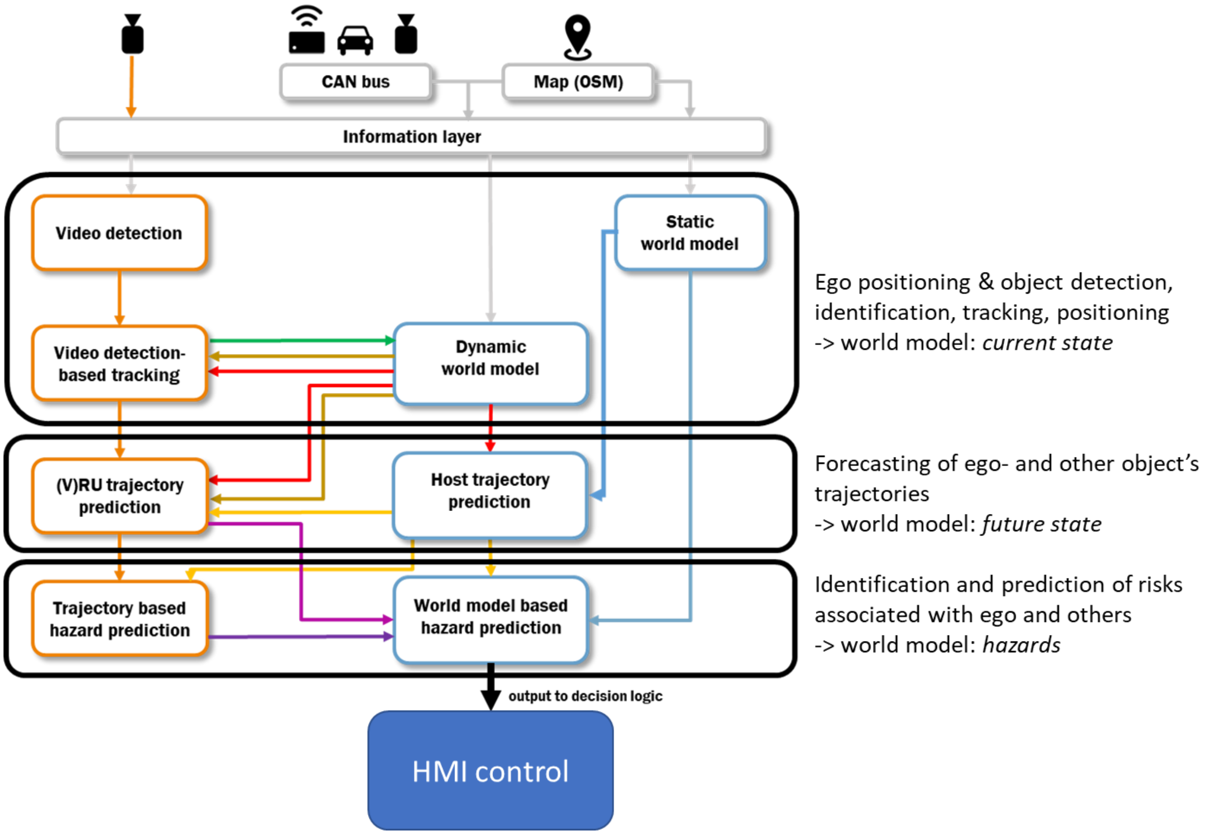



*Figure 40 - Schematic overview of the information collection, analysis and use to provide the HMI in the vehicle with the required inputs.*

The following sensors are mounted on the TNO vehicle:

a. Automotive grade front radar, for object detection and tracking (especially vehicles, bicycles en pedestrians)

b. GPS sensor combined with a Global Navigation Satellite System - Inertial Measurement Unit (OxTS GNSS-IMU) for accurate ego-vehicle positioning/localization
c. ELP industrial machine vision cameras, forward-looking for cyclist tracking and inward-looking to track the gaze of the driver
d. Pointgrey front right and left context cameras for analysis purposes

*Figure 41 - Mounting of GPS antenna and Velodyne LIDAR on the roof of the TNO vehicle*

The figure above shows the antenna for the high-accuracy GPS positioning GNSS-IMU OxTS system (top left). Also a Velodyne 360 degrees lidar (top right), mounted to the vehicle roof is shown, however this sensor is not used in MeBeSafe for providing input to the static and dynamic hazard model. The sensor is not yet considered state-of-the-art in production vehicles and in MeBeSafe, we expect to be able to acquire an accurate view on the surrounding traffic as input to the nudging system without the use of expensive lidar sensors.

<u>Automotive grade radar</u>

Such radar sensor, often used in combination with a MobilEye camera, represents a state-of-the-art sensor set that is currently found in production vehicles to provide input to active safety systems, such as Advanced Cruise Control, Autonomous Emergency Braking, Lane Keep Assist, etc. One forward looking radar in combination with a forward looking camera (MobilEye) is considered a minimum set. Premium passenger cars currently have several radars to the front and the rear in combination with a forward looking (stereo) camera mounted at the windscreen to provide a reliable view on the other traffic participants in the close neighbourhood of the ego-vehicle (and some of the infrastructure elements such as lane markers) and activate the safety systems appropriately.

In case of the use of multiple sensors, a fusion algorithm is applied to combine the 'images' of the different sensors into one world model for the decision and control logic of the car, on which decisions and control actions of the different functions are based. In this world model, each traffic participant, although possibly detected by more than one sensor, is represented once in this world model. In the world model, information regarding the 'objects' on the road is presented as the type of object (car, truck, bus, pedestrian, cyclist, etc.), its position and orientation with respect to the ego vehicle, and an estimate of the object's speed and heading.

In MeBeSafe, we assume that a state-of-the-art sensor set is present and that it is possible to get access to the object level output of the vehicle's world model. Such object level data regarding the road users in the neighbourhood of the ego-vehicle (especially cyclists) is essential input for the dynamic hazard model.

<u>GPS sensor combined with a GNSS-IMU</u>

It can be reasonably assumed that state-of-the-art vehicles also have a GPS sensor on-board and a digital navigation map. The GPS signal is required for our nudging solution, as we need to know the position and orientation of our ego-vehicle in the map with respect to the infrastructure, specifically regarding the approaches of intersections. We identified urban intersections as the locations at which potential hazards with crossing cyclists occur. For analysis purposes, TNO has added an OxTS GNSS-IMU measurement unit to the GPS sensor, to increase the accuracy of positioning from 10 m (GPS only) to less than 0.25 m (GPS with GNSS-IMU).

The implementation in the TNO lab vehicle makes use of a publicly available map OSM (Open Street Map: www.openstreetmap.org ) which includes all public roads in the EU. The detail of OSM is more than sufficient to determine the location of intersections on the routes that the TNO vehicle will drive on. Continuous projection of the location and heading of the TNO vehicle as provided by the GPS sensor onto the map, provides an estimate of the time until the vehicle crosses the next intersection on the route. It is this time scale that is used in the HMI to nudge the driver. The static hazard model is directly coupled to this time scale, as the static hazard only depends on the infrastructure layout that is reflected in the map. For the dyna

<u>ELP industrial machine vision cameras for cyclist intent detection</u>

Cygnify installed two ELP industrial machine vision cameras into the vehicle. These cameras have a separate power supply and data connection through USB. For reasons of latency and speed of data transfer as well as convenience, these cameras are directly linked to the installed Cygnify GPU-computers in the vehicle.

One of the cameras is mounted to the windshield next to the rearview mirror, with a forward-looking field of view. This is the camera that provides the main input to Cygnify's video-based detection, tracking, and forecasting modules for road-users possibly interacting with the ego-vehicle, especially bicycles. This camera is used as input to the cyclist prediction model. The images of this specific camera are analysed by a machine learning algorithm, in order to add attributes (such as hand gestures, head turning, pedelling behaviour) to the objects that are identified as cyclist and tracked by the 'standard' automotive grade sensor set. Even if the standard automotive grade sensor set contains a (MobilEye) camera, such a camera needs to be added, as the supplier of the automotive camera in production vehicles, does not allow access to the camera images, also not for research purposes. Consequently, an additional ELP industrial machine vision camera is added as to have access to this type of data. Such cameras have a comparable framerate and resolution as automotive grade cameras.

The other ELP camera is also mounted to the windshield, but closer to the driver, next to the steering wheel, and is looking at the driver's face. The information from this camera will be used in the field trials (possibly in addition to other data and information) to assess driver gaze direction and direction of attention. This camera driver facing camera is only used to evaluate the effectiveness of the HMI on nudging the driver attention, and is consequently no part of the in-vehicle nudging system itself.

*Figure 42 - Mounting of the two ELP machine vision cameras at the windscreen, one facing forward to the traffic, the other facing inwards towards the driver.*

Neither camera obstructs the view of the driver looking towards the road and traffic situation in a significant way. Figure 42 shows the positioning of these two cameras: one close to the steering wheel facing inward, and the other close to the rearview mirror, facing forward.

Visual processing comes from the Cygnify cameras, which are particularly suitable for machine vision tasks and which have advantages in terms of quality, calibration and adjustment possibilities, convenience, and data throughput and latency. Figure 43 shows a screen snapshot of initial testing of the cameras, showing both the outside (forward) view and the inside (driver position view), together with initial testing of the visual object detection and tracking and cartesian real-world position estimation processes.

Pointgrey context cameras

Two pointgrey cameras are added to the vehicle equipment to have easy access to the context in which the vehicle is driving. These cameras do not feed into the nudging system, but provide a view on the direct environment in front of the TNO vehicle. In case the automated analysis of sensor data provides unexpected results, the context cameras are used to check the situation during the experiments and tests.

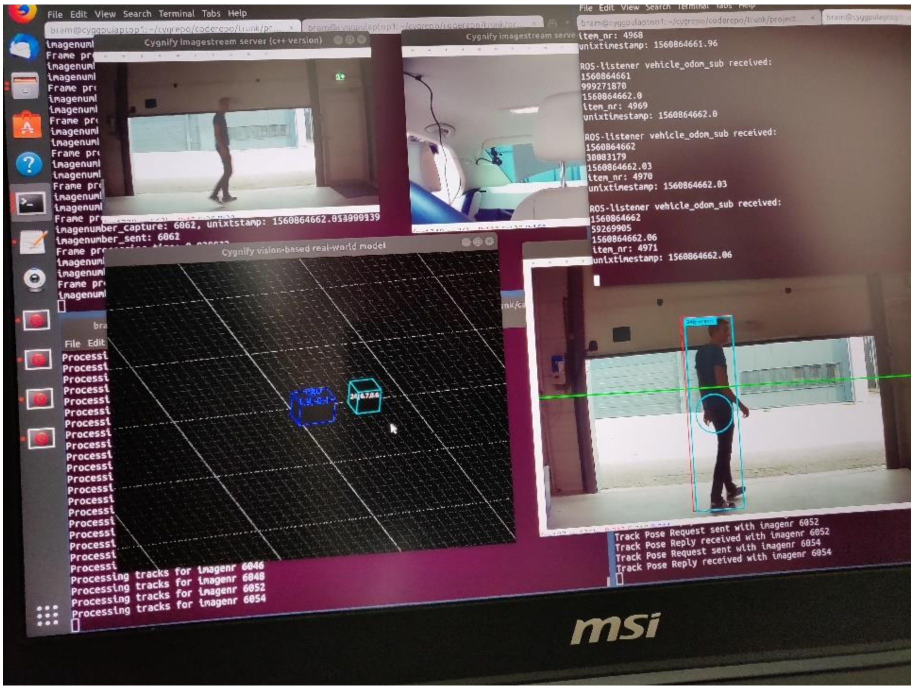



*Figure 43 - Testing of the Cygnify detection and tracking*

<u>Hardware and software interfacing set-up</u>

The schematic in Figure 44 shows the sensors in conjunction with the main computing devices installed in the vehicle and the ways of connecting the different components, i.e. the interfacing protocols. The radar, lidar, GPS-IMU and context cameras are connected to the TNO (Axiomtek) in-vehicle computers, using various appropriate protocols (CAN, ethernet, and ROS). ROS (Robotic Operating System) provides the main communication and logging framework in the vehicle, allowing communication both from sensors to computing devices, and between computing devices; including all the communication between the TNO computers and the Cygnify computers.

The Cygnify computers are MSI computers with powerful GPU (Graphical Processing Unit) processors, which are necessary for the computation-demanding computer vision and deep learning-based algorithms from Cygnify. They directly receive their main sensor inputs through USB from the ELP indiustrial machine vision cameras, other sensor information and TNO-processed information through ROS messages provided by the TNO sensors and computers. There are two such GPU machines, and between them they communicate over the same ethernet car network used for ROS using a Cygnify proprietary TCP protocol.

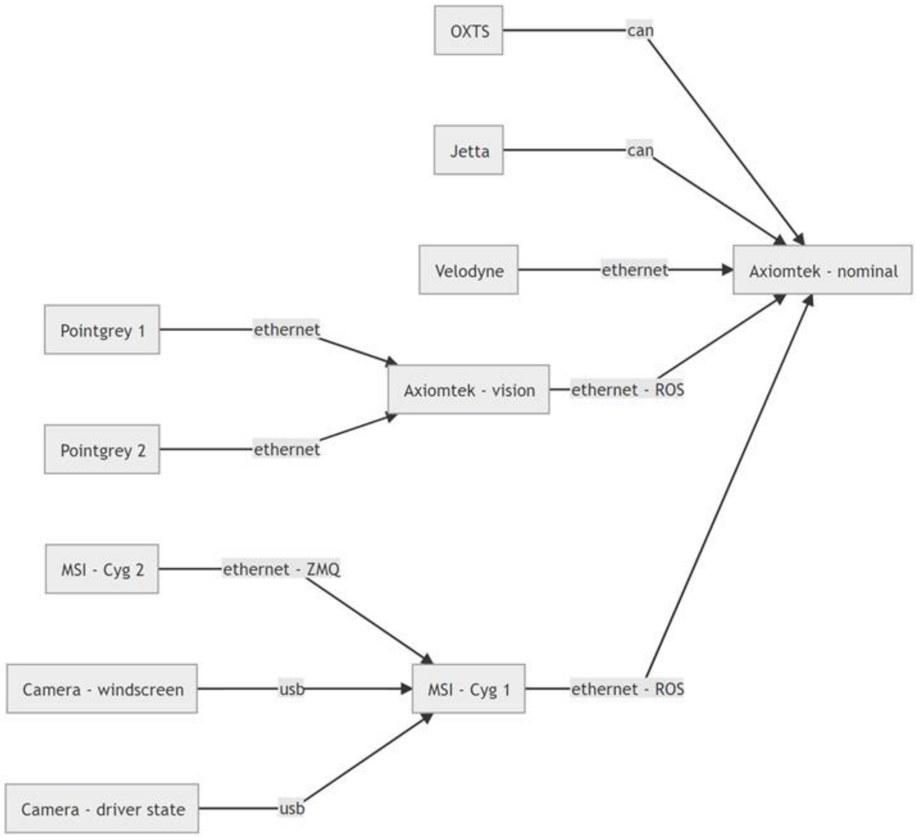



*Figure 44 - Interface scheme showing the sensor connections with the TNO Axiomtek and Cygnify MSI*

The TNO computers, in turn, next to their own sensor inputs, receive ROS messages from the Cygnify computers regarding the video-based detection, tracking, forecasting, and associated hazard assesment.

World model

The static world model takes the GPS data as input and outputs the near-side and far-side hazard levels according to the intersection traffic data and the distance to the intersection points. The dynamic world model receives the OxTS (GNSS-IMU) data as well as the lidar and radar detections, in order to detect targets around the vehicle, hence the dynamic hazards. It also receives the video detection-based targets from the Cygnify side and fuses these targets with the TNO world model targets to provide a more accurate output.

The ego-vehicle trajectory prediction receives the vehicle data (CAN bus) data and outputs a predicted trajectory with a time horizon of 5 sec. At the Cygnify side, a trajectory prediction for the vulnerable road users (VRU) is being done, using as input the output of the video detection-based tracking, the dynamic world model and the ego-vehicle trajectory prediction output.

The ego-vehicle predicted trajectory and the VRU predicted trajectories are used to predict trajectory based hazards. Finally the world model based hazard prediction block collects the output of the static world model, the ego-vehicle and VRU trajectory predictions, as well as the trajectory based hazard prediction in order to produce the output to the decision logic. This output is fed into the HMI, to produce semantic nudges to the road user, based on the current state and also the future state of the world around the host vehicle.

## 4.4 HMI integration

Despite the favourable performance of the HMI options "Street" on Augmented Reality (D3) and on Instrument Cluster (D2), it was decided for practical reasons to implement the more abstract intersection "Cross" on the instrument cluster (D5) on a tablet. Implementation of the augmented reality option in a vehicle that is allowed to drive on public roads in Europe was not feasible within the scope of the project; projecting the augmented reality image on the windscreen is extremely difficult, if only since the projection depends on the position and posture of the driver's head in the car. Similar, the projection of a realistic road area on the Instrument Cluster appeared not to be feasible. As the Nudging Cross still was favoured as a nudging-measure over no nudging at all, this feasible option was chosen for practical implementation in the vehicle.

The interface between the World model based hazard prediction block and the HMI is built together with OFFIS. The available hazards (resulting from the dynamic and static hazard model) are collected in one interface block; the largest hazard is outputted to an implementation of the HMI on a tablet computer. The tablet can be placed near the instrument cluster, at the console between driver and passenger, or even on the dashboard projecting the HMI image to the windscreen. During first tests, a position of the tablet will be selected; an inventory will be made of the preference of participants in tests.

An intersection cross is outputted in the HMI, whose size and colour changes based on the hazard level. The colour can be grey if there is no hazard, green if the hazard level is small, yellow if the hazard level is mediocre and red when the hazard level is high. The size of the cross increases with the hazard level as well. At the same time, this cross visualizes the direction of the hazard (left or right). In the following picture, a hazard of "medium severity" (yellow colour), originating from the right is depicted. Furthermore, a hazard description is outputted to the HMI ("Right possible hazard"), as well as a possible solution for the hazard ("Check your right").

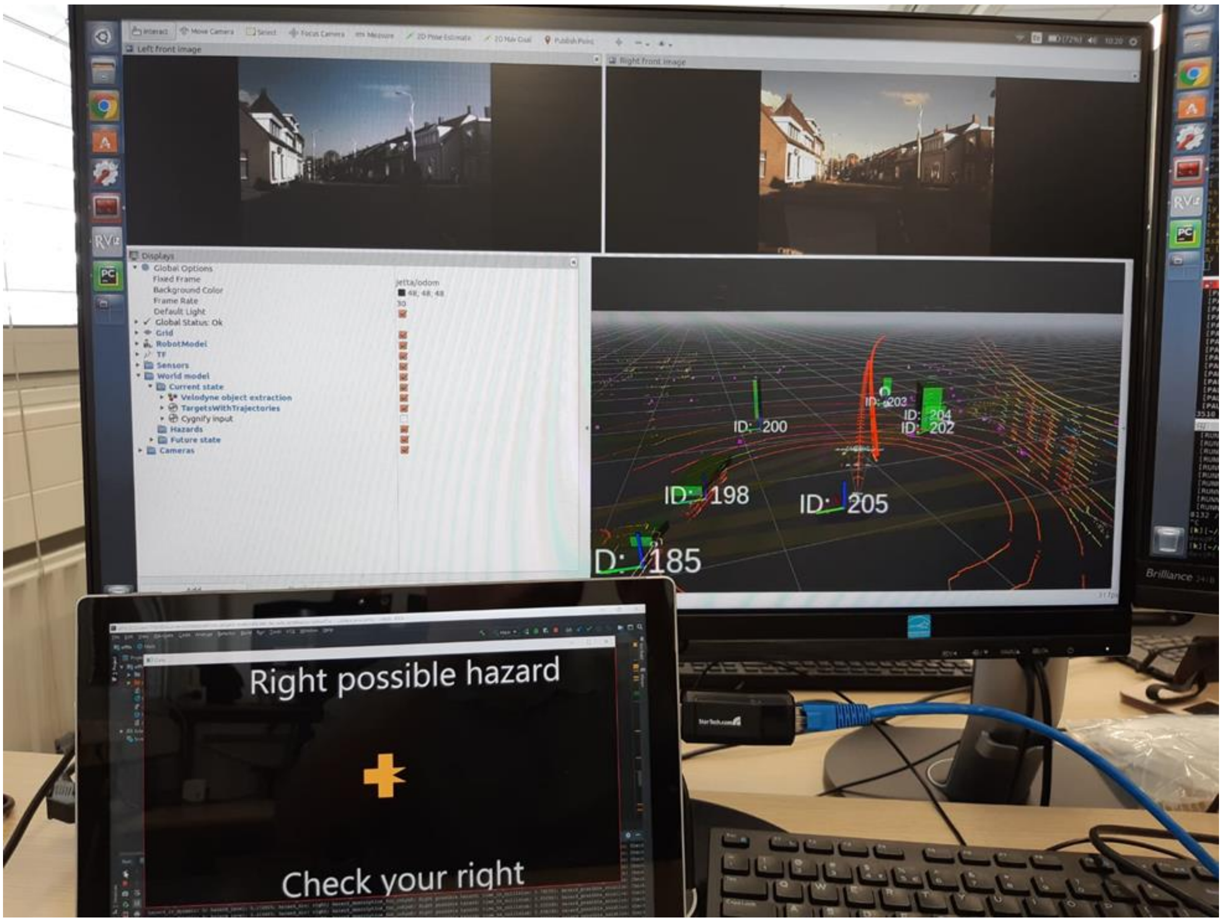



*Figure 45 - Testing the HMI on the tablet that receives messages from the hazard model in TNO's Axiomtek computer.*

shows the integration of the HMI on the tablet and the connection to TNO's Axiomtek computer.

## 4.5 Use of the prototype vehicle in the field tests of WP5

In the simulator study described in Chapter 3, it was shown that all nudging HMIs were effective in terms of directing driver attention towards potential hazards. The objective of the WP5 Field trial is therefore to check whether the results found in the simulator study are reproducible when driving in real traffic on public roads. The trial focuses on response to output from the static hazard model for which the driver attention is directed towards a possibly approaching cyclist that is not yet visible for the driver due to a view blocking obstruction.

It will be a within-subjects study, which means that we will test each subject with and without nudging HMI that intends to draw the attention of a subject into the direction of a potential hazard while driving. For the trial it does not matter whether a cyclist actually appears from behind a view-blocking obstruction corner or not, as the nudge should already have affected the driver's (visual) attention.

A fixed route through the inner city of Eindhoven will be generated, to expose each subject to busy, non-signalized, non-priority intersections. The route layout will be such that at least 30 intersection crossings are made by each subject per run. A route of 30 to 45 minutes will suffice, with one intersection for each 1 to 2 minutes.

The introduction of the nudging HMI is the independent variable in the study. We will provide 3 possible triggers: true positive (display nudge for an intersection with view-blocking obstruction), false positive (display nudge without the presence of an intersection), and false negative (no nudge is displayed, but an intersection with view-blocking obstruction is present). These will be considered baseline events. The trigger distribution will be randomised between over the route, thus preventing order effects.

Data collection is done in the vehicle in which the nudging HMI is integrated. The following time dependent signals will be recorded from the vehicle with a frequency of at least 10 Hz (if available at that frequency):

- Vehicle location (GPS)
- Vehicle speed and acceleration, brake and gas pedal position, angular steering position from the vehicle CAN-bus
- The time evolution of the HMI triggers
- The gaze direction of the driver analysed from a context camera directed at the driver's face
- The object level data of the road users detected by the vehicle's sensor system: type, position and speed of the most important objects relative to the ego-vehicle
- The video images of the various forward-looking context cameras.

All data will be synchronously recorded, to avoid the need for retrospective synchronisation.

The triggering of the HMI will be fully staged. As it is the objective to check the effectiveness in directing attention of the driver towards the direction indicated by the HMI under realistic real world conditions on the public road, and the HMI has no coupling to the control of the vehicle other than through the driver, it is best to fully stage the triggers of the HMI (based on GPS) for best reproducibility and accuracy. In this way, it is possible not only to provide true positives, but also false positives and even false negatives. Especially important is the possibility of providing false positive triggers towards the end of the route to check how well the HMI is capable to direct the attention of the driver, even in cases where it is not necessary from traffic perspective. In case the gaze direction distribution over the last 6 seconds before an intersection is wider, or shows convincing evidence in another way that the driver indeed pays attention to the direction indicated by the HMI, the HMI trigger is considered successful.

During the tests, the Cygnify cyclist prediction model will run in real-time in the vehicle and the output of the model will be stored as well for *a posteriori* analysis. The results of this study should show how the hazard prediction model can be enhanced with reliable and accurate predictions of the cyclist intent. The results of WP5 tests are used to complete the world model based hazard prediction that is enhanced with input from the trajectory based hazard prediction for cyclists.

## 4.6 Discussion on the use of the FIAT 500X in MeBeSafe

Once the full static and dynamic hazard prediction model (enhanced with trajectory based hazard predictions for cyclists) is completed in the TNO vehicle, and the WP5 tests have been completed successfully, the nudging system (computers, ELP industrial machine vision cameras, point grey context cameras and HMI tablet) will be integrated in the FIAT 500X that is provided in the project by FCA Italy. An interface is being defined and discussed with Continental that provide the FIAT 500X sensor system consisting of a fused forward looking radar and camera. The integration will be completed to demonstrate the in-vehicle nudging solution in a production vehicle on the public road.

Through the interface with Continental, the nudging system should be able to read the object level information of road users (position, velocity, heading, type of road user) detected by the Continental sensor system. The information is only read; the nudging system does not provide feedback to the Continental system. No actuation of the vehicle is done through input of the in-vehicle nudging system; Continental's sensor output is solely used to estimate a dynamic hazard as input to the MeBeSafe HMI tablet.

# 5 Design of the nudge towards increased ACC usage

Chapters 3 and 4 discussed the implementation of in-vehicle nudging measures to direct the attention of drivers to potentially hazardous situations. In this chapter, a concept is proposed regarding the in-vehicle nudging measures to increase the use of

ACC functionality when available. To understand the purpose of this nudge concept, this chapter will start with a short problem description and analysis. In order to crash into a lead vehicle (have a rear end collision), accident causation research shows that generally two things are required:

1. A distracted driver, and…
2. … a lead vehicle.

Many proposed solutions to the distracted driver problem only focus on the first issue (the distracted driver), but do not address the second one (close following). However, research on this conflict type clearly shows that the risk of crashing is highly influenced by how far behind you are when something unexpected happens in front (Dunn et al, 2014). if you are not following a lead vehicle very closely, you are much more able to resolve the conflict once it arises. Rear end crashes can therefore most likely be addressed just as well by avoiding close following as by avoiding distracted drivers.

That rear-end crashes remain a highly relevant problem to solve is clear from the following table, which shows the magnitude of the problem in an extrapolated European context.

*Table 4: Safety potential of the ACC measure and EU-27 extrapolation of casualties in 2025 and 2030 according to the accident location, kind of road user and injury severity.*

| ACC Usage GIDAS 1999 - 2019* - relative weighted - | | | CITY (URBAN) | | | | | | RURAL (w/o motorway) | | | | | | MOTORWAY | | | | | | TOTAL | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ALL (GIDAS) | | SAFTEY POTENTIAL | | $EU_{SP,2025}$ | $EU_{SP,2030}$ | ALL (GIDAS) | | SAFTEY POTENTIAL | | $EU_{SP,2025}$ | $EU_{SP,2030}$ | ALL (GIDAS) | | SAFTEY POTENTIAL | | $EU_{SP,2025}$ | $EU_{SP,2030}$ | ALL (GIDAS) | | SAFTEY POTENTIAL | | $EU_{SP,2025}$ | $EU_{SP,2030}$ |
| | | | n | % | n | % | n | n | n | % | n | % | n | n | n | % | n | % | n | n | n | % | n | % | n | n |
| CASUALTIES | Car Occupants | slightly | 12,470 | 52.2% | 1,351 | 10.8% | 32.529 | 29.336 | 8,332 | 34.9% | 854 | 10.3% | 20.580 | 19.108 | 3,105 | 13.0% | 712 | 22.9% | 23.367 | 27.762 | 23,907 | 100% | 2,918 | 12.2% | 76.476 | 76.206 |
| | | seriously | 1,180 | 29.0% | 76 | 6.5% | 1.252 | 929 | 2,302 | 56.5% | 72 | 3.1% | 1.593 | 1.539 | 593 | 14.5% | 124 | 20.9% | 2.273 | 2.211 | 4.075 | 100% | 272 | 6.7% | 5.118 | 4.679 |
| | | fatally | 38 | 16.4% | 3 | 7.9% | 126 | 100 | 154 | 66.5% | 1 | 0.6% | 33 | 27 | 39 | 17.1% | 4 | 11.0% | 116 | 110 | 231 | 100% | 8 | 3.6% | 275 | 238 |
| | Goods Vehicle Occupants | slightly | 97 | 20.0% | | | | | 140 | 29.0% | | | | | 247 | 51.0% | 12 | 4.8% | 966 | 1.527 | 485 | 100% | 12 | 2.5% | 966 | 1.527 |
| | | seriously | 16 | 12.2% | | | | | 32 | 24.5% | 1 | 3.7% | 110 | 100 | 84 | 63.3% | 1 | 0.9% | 41 | 61 | 132 | 100% | 2 | 1.5% | 151 | 161 |
| | | fatally | 2 | 15.6% | | | | | 2 | 15.0% | | | | | 7 | 69.4% | | | | | 10 | 100% | | | | |
| | Motorised Two-Wheelers | slightly | 3,110 | 77.6% | | | | | 836 | 20.9% | | | | | 60 | 1.5% | | | | | 4,006 | 100% | | | | |
| | | seriously | 783 | 56.5% | | | | | 567 | 40.9% | | | | | 35 | 2.6% | | | | | 1,385 | 100% | | | | |
| | | fatally | 22 | 28.2% | | | | | 52 | 66.5% | | | | | 4 | 5.3% | | | | | 79 | 100% | | | | |
| | Cyclists | slightly | 8,178 | 94.4% | 1 | 0.1% | 10 | 13 | 488 | 5.6% | 1 | 0.2% | 82 | 120 | 0 | 0% | | | | | 8,665 | 100% | 2 | 0.1% | 93 | 133 |
| | | seriously | 1,429 | 87.6% | | | | | 202 | 12.4% | 2 | 1.2% | 358 | 685 | 0 | 0% | | | | | 1,631 | 100% | 2 | 0.1% | 358 | 685 |
| | | fatally | 26 | 60.1% | | | | | 17 | 38.9% | | | | | 1 | 1.0% | | | | | 43 | 100% | | | | |
| | Pedestrians | slightly | 2,449 | 95.8% | 3 | 0.1% | 120 | 116 | 101 | 3.9% | | | | | 7 | 0.3% | | | | | 2,557 | 100% | 3 | 0.1% | 120 | 116 |
| | | seriously | 840 | 92.1% | 1 | 0.1% | 54 | 59 | 64 | 7.0% | | | | | 8 | 0.9% | | | | | 911 | 100% | 1 | 0.1% | 54 | 59 |
| | | fatally | 45 | 70.5% | | | | | 15 | 23.5% | | | | | 4 | 6.0% | | | | | 64 | 100% | | | | |
| | Other | slightly | 883 | 84.1% | | | | | 142 | 13.5% | 11 | 7.5% | 148 | 86 | 25 | 2.3% | 2 | 6.2% | 30 | 17 | 1,049 | 100% | 12 | 1.2% | 178 | 104 |
| | | seriously | 70 | 73.6% | | | | | 24 | 24.7% | | | | | 2 | 1.7% | | | | | 96 | 100% | | | | |
| | | fatally | 1 | 32.8% | | | | | 2 | 53.1% | | | | | 0 | 14.1% | | | | | 3 | 100% | | | | |
| | **TOTAL** | **slightly** | 27,187 | 66.8% | 1,355 | 5.0% | 32.659 | 29.465 | 10,039 | 24.7% | 866 | 8.6% | 20.811 | 19.314 | 3,444 | 8.5% | 726 | 21.1% | 24.363 | 29.306 | 40,670 | 100% | 2,946 | 7.2% | 77.833 | 78.086 |
| | | **seriously** | 4,318 | 52.5% | 77 | 1.8% | 1.306 | 988 | 3,191 | 38.8% | 76 | 2.4% | 2.061 | 2.323 | 722 | 8.8% | 125 | 17.3% | 2.314 | 2.272 | 8,230 | 100% | 278 | 3.4% | 5.681 | 5.583 |
| | | **fatally** | 133 | 31.0% | 3 | 2.2% | 126 | 100 | 241 | 56.1% | 1 | 0.4% | 33 | 27 | 55 | 12.9% | 4 | 7.8% | 116 | 110 | 430 | 100% | 8 | 1.9% | 275 | 238 |

*Due to the use of weighting factor rounding differences from ± 1 persons may occur.

So, how to make drivers avoid close following? Given that distance keeping is a largely automatized and habitual skill, changing how a particular individual is managing his/her headway keeping is challenging, to say the least. However, there is a simpler way, further illustrated in the figure below. This is a result that comes from euroFOT (Benmimoun et al, 2012), where driving with and without ACC activated in lead vehicle following situations was compared:

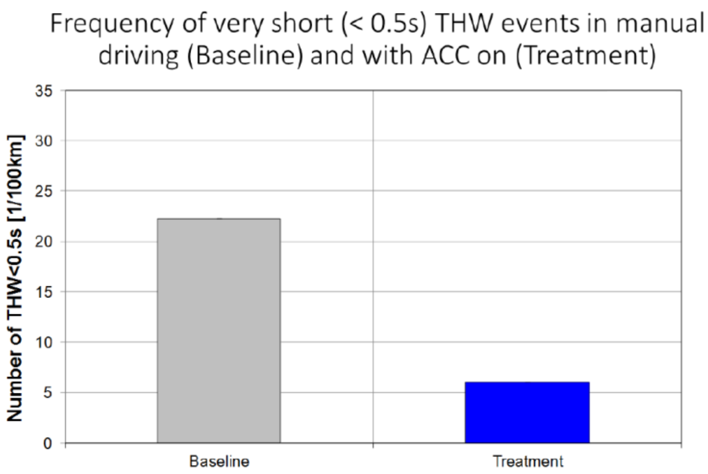



*Figure 46 – Frequency of short time headway events per 100 km of driving, where driving with ACC 'on' compared with situations without ACC in lead vehicle following situations (Brouwers et al., 2017).*

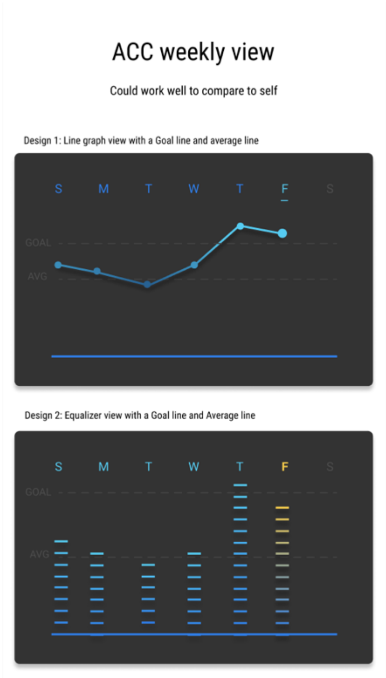



*Figure 49 – weekly view concept*

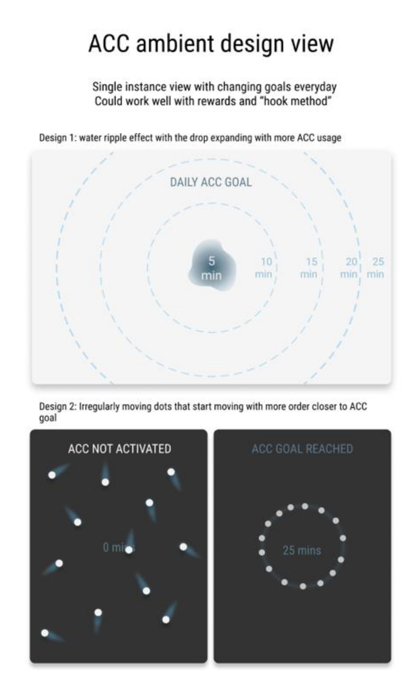



*Figure 49 – ambient design view concept*

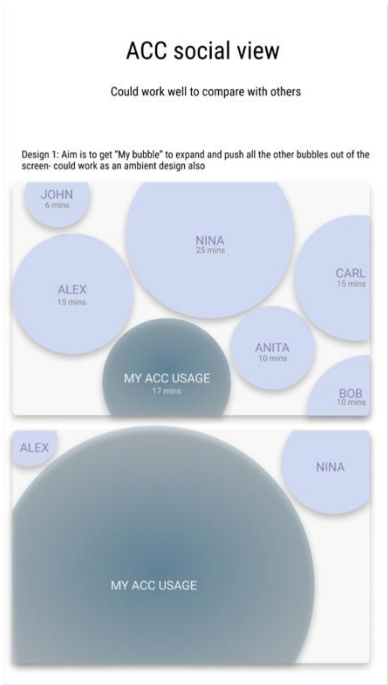



*Figure 49 – social view concept*

As can be seen, ACC is much better at avoiding instances of very short time headway, and hence lowers the risk of distraction related rear end crashes.

## 5.1 Preliminary nudging concepts

With the merits of ACC usage clearly illustrated, the next question is how to make drivers use ACC more in their everyday driving. In the first stage of developing nudging concepts towards increased ACC usage in MeBeSafe, three different high-level app concepts were developed  (Figure 47 to Figure 49 below).

The leftmost figure illustrates a concept where focus is on comparing your current ACC usage with your past week's usage. The concept in the middle shows how you are working towards a daily goal, where you get also a trigger from irregular moving dots to dots that start moving in a more orderly fashion the more you use ACC. In short, going from chaos to order. The last concept applies to a more competitive setup, where you see a social view of other drivers' ACC usage. The more you drive with ACC on, the bigger your "bubble" gets in relation to the others.

For each of these concepts, a complete sequence of events-flow was visualised using low-fi prototyping and then evaluated. A number of employees at Volvo Cars were presented with the consecutive views in each concept and asked to give their option on what they thought was happening in each view, what they thought the driver would have to do to get to that view as well as what would attract them visually.

The concept chosen for implementation and further development was the ambient design view concept (Figure 48). The connection to reaching a daily goal instead of more complex concepts that require keeping track of other parameters (e.g. yesterday's usage or another person's usage) made the early testers prefer it over the other two. This concept was handed over to the front end coding group for implementation, along with a proposal for the logic dictating under which conditions and how the view should change as an effect of the different states ACC can be in.

## 5.2 Creating a method for testing nudging in real traffic

Evaluation of nudging concepts is not trivial, and there is a lack of established methodology. In essence, you want to ask, "Are you being nudged?" which you cannot do, since the participants often do not know they are being nudged. To tune normal ride-along usability testing methods towards a nudging application, a series of pre-pilots was performed where participants were asked to drive a 20 minute route in the Gothenburg area. To create a nudging situation, the fuel consumption view which can be brought up in the centre stack display was set to be visible at all times. During the drive, participants were asked to think aloud about what was happening on the screen. Halfway through the drive, participants were asked to park the car and answer a standardized system usability questionnaire called SUS (Sauro, 2013). Thereafter, the participants drove back, again asked to think aloud about what they were experiencing on that screen. After the drive, they were asked to fill out two questionnaires, SUS and a Post-Study System Usability Questionnaire (PSSUQ). Also, a semi-structured interview was performed where questions involving what was happening on the screen, their impression of it, and their behaviour. Based on participants' responses, the methodology for how to instruct them and what to ask at the end was successively refined until by the fifth pre-pilot, the methodology was deemed to give satisfactory and meaningful input from participants on the nudging design.

## 5.3 Final Nudging Concept – Design and Logic

The implemented ACC nudging application is based on having 10 static "goal slots" in shape of a circle to showcase the progress of the application, and thereby the ACC usage. When up to speed ACC will be available, and there will be dots randomly moving in a grey tone with a variation of speed. Once ACC is activated the dots will turn white, and slow down moving clockwise. For each new minute driving with ACC activated, a "goal slot" will be filled, and when driving with ACC on for 10 minutes, the slots will all be filled, which means the goal for the day has been reached. Whenever the driver, for some reason, deactivates ACC the "goal slots" filled will stay white, but the dots moving will change colour back to grey, and increase speed. Figure 50 shows a series of screen shots presenting each state of the final concept applied on the method developed.

The top left screen shows the first view of the final concept, when starting the vehicle. ACC is Not Available, and the 10 dots are not moving. When ACC is Available and the car is up to speed, the 10 dots will start to move at random speed (second screenshot). Once the driver Activates ACC, the dots will become white, and their speed will decrease. When ACC is Paused, the dots will go back to grey, and their speed will increase (examples in screenshots 4 and 7). In terms of progress, for each minute with ACC Active, one dot will freeze in position (screenshots 5, 6 and 8). Finally, the dots will form a complete circle once you have reached the goal of 10 minutes ACC activation (screen shot 9).

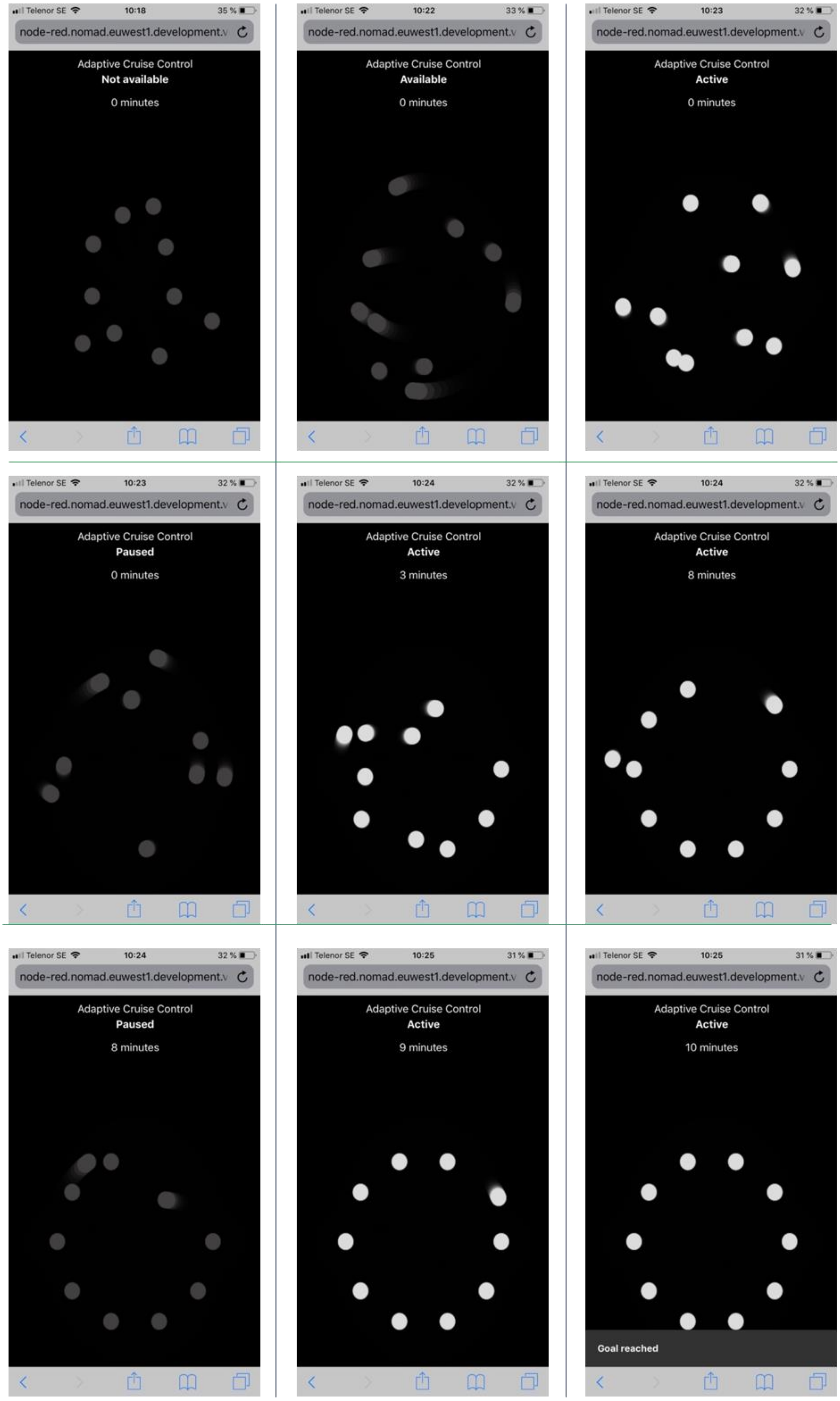



*Figure 50 - Successive state illustrations of the ACC nudging app*

## 5.4 Outcome of final Usability testing

The final usability test was also done with employees of Volvo Cars, following the methodology developed as described above. Table 5 shows the mean SUS score from all participants and in Table 6 one can find the PSSUQ scores.

| Mean SUS Score all test participants | |
|---|---|
| Angered (mid-drive) | **58** |
| Volvo Torslanda (end of drive) | **66** |

*Table 5 - Mean SUS Scores (scale is 0-100, higher is better)*

| PSSUQ | | | |
|---|---|---|---|
| | | Mean | Norm Mean |
| System quality items | 1-6 | **3** | 2,8 |
| Information quality items | 7-12 | **2,27** | 3,02 |
| Interface quality items | 13-15 | **2,67** | 2,49 |
| Total for all items | 1-16 | **2,7** | 2,82 |

*Table 6 – PSSUQ Scores related to the Norm Mean. The scale is 1-7, lower is better)*

As can be seen, at the end of the drive the mean SUS score was 66, which is close to the norm mean of 68 (Sauro and Lewis, 2016). According to Sauro and Lewis, values at or near the norm mean should be interpreted as the perceived usability of the system being good, so this was a good result for the concept. The PSSUQ reads along the same lines with outcomes close to the norm mean, which also should be interpreted as indicating good usability and acts as a corroboration for the SUS score interpretation.

As well as the quantitative data displayed above, the qualitative data also showed some interesting driver behaviours and responses:

- The participants continued driving with ACC activated ever after reaching the goal of the application

- The concept display screen did not take focus from driving in a distracting way
- When asked if they would consider using the application in their own car, participants were quite positive
- When asked how the safety margin to the car in front had been affected by the application, 60 % said it remained unchanged, whereas 40 % said that the safety margin had increased.
- All participants had a positive over-all experience using ACC during the test
- All participants expressed that they had felt safe when driving with ACC activated

To elaborate a bit on the safety margin bullet, one way to interpret that finding is that for the 60% of drivers who reported no change in safety margin, their normal following distance probably overlaps with the default time headway setting of ACC when activated. The 40% who reported an increase on the other hand likely have a shorter normal following distance, and hence immediately perceived that safety margin to increase when activating ACC.

# 6 Design and piloting of the nudge towards taking a break when drowsy

Drowsiness is a large traffic safety problem, even though it may not receive the same level of attention as other crash contributing driver state factors like visual distraction or intoxication. What is interesting about drowsiness is that when it comes to detecting that a driver is drowsy, this problem has been solved technically to a large extent. For example, the Volvo Cars' Driver Alert system has close to 100% detection rate of when drivers are about to go into a long enough micro sleep to leave the lane completely.

The remaining safety problem is thus not the technical part but rather the behavioural one. Put bluntly, very few drivers actually take the break they need when drowsiness has been detected. From interviews with tired drivers, it is clear that the reasons for not taking that break are many and varied; you want to get home, there is no good place to stop, you only have a few minutes left to drive, etc.

However, it is also clear that on a meta-analysis level, all these reasons have one thing in common, and that is an unwillingness to change the current course of action before it is completed. In other words, when you are really tired, you really do not want to exchange your current plan of action for something else. Drowsy people are neither flexible nor willing to re-prioritize, and this is very much human nature.

It follows that to actually get these drivers to stop, one has to present them with something else, something with sufficient inherent attraction to make them change their minds. In MeBeSafe, the idea is that getting something valuable or attractive for free, but limiting the availability of that incentive to a short period following a Driver Alert being given, will be enough to break through the "wall of drowsiness".

The necessary backend for delivering these incentives is further described in Deliverables 5.2 and 5.3. What will be covered here is the incentives themselves, as well as possible means for distributing them.

## 6.1 Incentive distribution

Starting out with the latter, previously collected data from Volvo Cars shows that Driver Alert is a function which activates rather infrequently. Because it is rather precisely tuned to extreme drowsiness, and extremely drowsy driving is rare, drivers do not get these alarms very often. It will naturally depend on who the driver is and when/where they drive, but on a rough average, drivers do not get more than one warning from the Driver Alert system per month of driving, assuming they are average drivers in terms of mileage.

In a test fleet of e.g. 100 persons, this translates to an average of 3 Driver Alerts per day. Initially in MeBeSafe, the idea for distribution was to distribute incentives based on these alerts through collaboration with gas stations or similar entities in the larger area of Gothenburg. However, even though Shell is a partner in MeBeSafe, they do not have that type of connection to the Shell stations in Sweden, as the latter are run as franchises and cannot be coordinate in a simple way for the purposes needed here. Also, given the geographical distribution of these gas stations in Gothenburg, chances of field test participants being closer to a nearby gas station than to their intended destination at the time of receiving the Driver Alert has been determined as not high enough.

With this in mind, it was decided not to spend effort on setting up an elaborate distribution scheme involving companies either within or outside of the MeBeSafe consortium. Instead, a collaboration with the Volvo Cars accident investigation team has been set up. This accident investigation team has a 24/7 response readiness procedure in case there are crashes involving Volvo vehicles reported in the Gothenburg area from the rescue services. The investigator on duty will take responsibility for monitoring the MeBeSafe test fleet data. When a Driver Alert is triggered and if qualifying conditions are met (i.e. the driver actually stops the car within the given time limit), the employee on duty will contact that test person by her/his preferred means (i.e. call, text, e-mail) and deliver the incentive. The time target is to make this delivery happen within 2 minutes of the test person actually stopping the car to take a break.

## 6.2 Incentive types

As for incentives to be provided, the original idea in MeBeSafe was to provide drivers with a free hot or cold drink of choice (e.g. coffee, tea, etc.) at the nearest gas station. Since there will not be an actual distribution network in place for the field trial, this idea will still be adhered to, but the incentive will be in the form of a voucher at the closest workplace cafe which is valid for a beverage and a snack like a cinnamon bun (Swedes are very fond of their fika).

In addition, drivers who do not take that break when given a Driver Alert will be contacted and asked why they did not stop, and in particular, whether the incentive just was not good enough. If the incentive is deemed insufficient, the incentive will be escalated from a cafe voucher to a movie ticket next time they receive a Driver Alert (though of course drivers will not be told about this escalation scheme beforehand, to avoid gaming of the field trial). Also, drivers who stop twice or more in response to the cafe voucher will be descaled to a cafe voucher that only includes a drink of choice but no snack.

The point of the escalation/de-escalation scheme is to understand what the real cost would be of implementing this incentive scheme permanently for Volvo drivers generally. The infrastructure is already in place; Volvo has the Volvo on Call App, which both can be given access to vehicle data and thus now when a Driver Alert has been triggered, and also distribute the incentive vouchers. The research question is therefore more of the nature: can this be done while maintaining a reasonable cost for the incentives? Of course, any vehicle manufacturer that has drowsiness detection installed in some way in their vehicles will be able to do the same, as long as they are able to detect when a drowsiness warning has occurred and can distribute a corresponding incentive.

## References


De Craen, S. et al. (2019, August). *Report on effective feedback (Deliverable 4.5).* Retrieved from MeBeSafe: https://www.mebesafe.eu/results/

Benmimoun, M., Adaptive Cruise Control and Forward Collision Warning.Presentation at euroFOT Final Event, accessible at http://www.eurofot-ip.eu/download/final_event_PDFs/eurofot_session11_mohamed_benmimoun_v7(1).pdf,Brussels, 2012

Dunn, N.; Hickman, J.;Hanowski, R.; Crash Trifecta: A Complex Driving Scenario Describing Crash Causation National Surface Transportation Safety Center for Excellence Blacksburg Virginia, 2014

Kirchbichler, Stefan, et al. (2019). *Report simulation environment (Deliverable D2.2).* Retrieved from MeBeSafe: https://www.mebesafe.eu/results

Kuehn, M., Hummel, T., & Lang, A. (2015). Cyclist-car accidents - their consequences for cyclists and typical accident scenarios. *24th International Conference on the Enhanced Safety of Vehicles.*

MacAlister, A., & Zuby, D. (2015). *Cyclist Crah Scenarios and Factors Relevant to the Design of Cyclist Detection Systems.* Arlington, VA: Insurance Institute for Highway Safety.

Op den Camp, O., van Montfort, S., Uittenbogaard, J., & Welten, J. (2017). Cyclist Target and Test Setup for Evaluation of Cyclist-Autonomous Emergency Braking. *International Journal of Automotive Technology, Vol 18, No. 6*, 1085-1097.

Op den Camp, Olaf et al. (2018). *In-vehicle nudging solutions (Deliverable 2.1).* Retrieved from https://www.mebesafe.eu/results

Prati, G., De Angelis, M., Puchades, V., Fraboni, F., & Pietrantoni, L. (2017). Characteristics of cyclist crashes in Italy using latent class analysis and association rule mining. *PLoS one, 12(2), e0171484.*

# Appendix A Relevant accident scenarios

Many research works and projects addressed the analysis of accident scenarios between cyclists and passenger cars in the last years. One example is the research, conducted by the German Insurers Accident Research (Kuehn, Hummel, & Lang, 2015) that selected accidents in Germany with personal injury from 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 51).

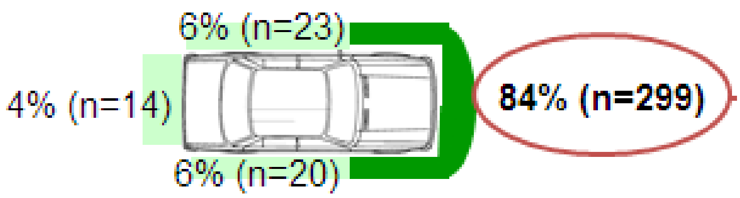



*Figure 51 - Impact distribution on car's part (Kuehn, Hummel, & Lang, 2015)*

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 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 13% of the impacts where found to involve cyclist approaching head-on, and 11% involved bicycle moving in the same direction of the car. The authors analyzed 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 52 They describe the junction scenario as the most common between the analyzed cases and they describe other aspects like the car average speed for each specific 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.

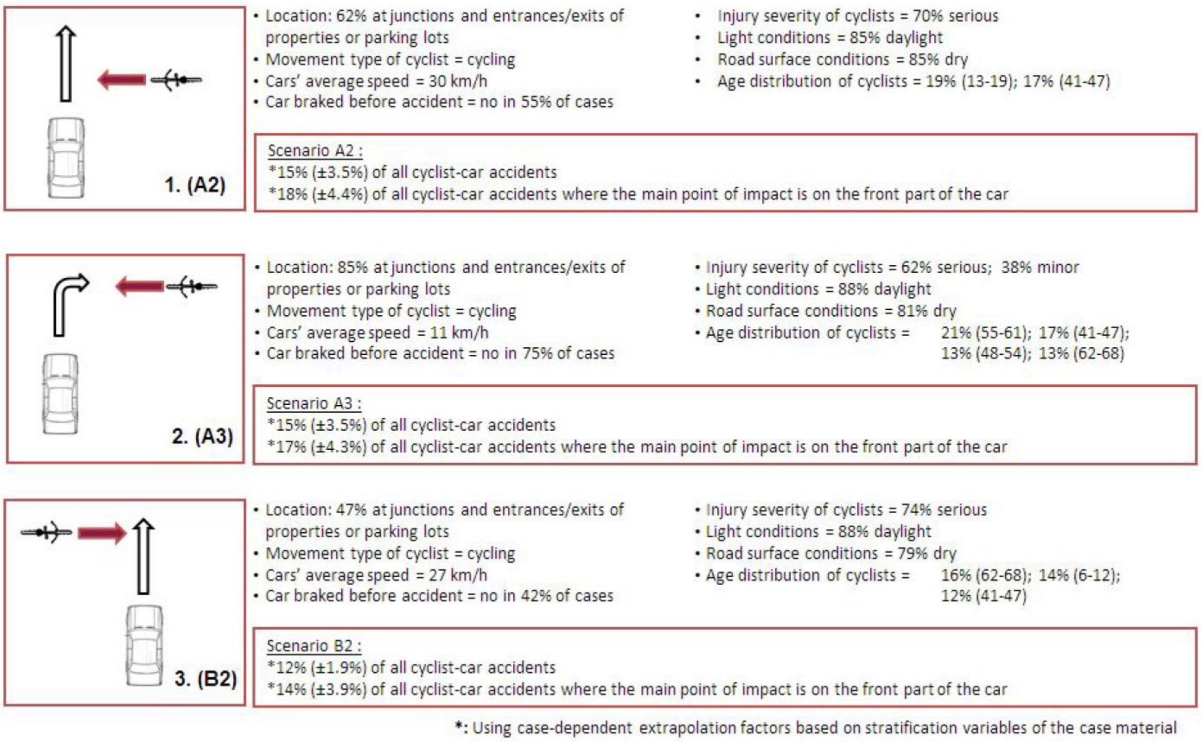



*Figure 52 - Characteristics of the most common accidents scenarios (Kuehn, Hummel, & Lang, 2015)*

Research in the US by the Insurance Institute for Highway Safety (MacAlister & Zuby, 2015) 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 analyzed only the accidents involving one car and one cyclist, selecting 274.000 cases. In recent Italian research, (Prati, De Angelis, Puchades, Fraboni, & Pietrantoni, 2017) 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 53). They identified 35246 accidents that involved cars and bicycles, 71% of the total number of cyclist accidents.


*Figure 53 - Scenarios of latent class analysis (Prati, De Angelis, Puchades, Fraboni, & Pietrantoni, 2017)*

# Appendix B CRF Driving Simulator

The CRF Driving Simulator includes:

1. An I-Space with:
    a. 3 orthogonal rear projected screens, 3m tall and 3m wide allowing for 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 maneuvers, 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$^{TM}$ from Seeing Machines is a fully portable device suitable to be used in several environment and in the High Fidelity Simulator too (Figure 54). The FOVIO$^{TM}$ cylinder gaze angular range is -30° to 30° (Horizontal) and -15° to 30° (Vertical).

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

Thanks to the EyeWorks$^{TM}$ 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 left/right eye to eye tracker.

*Figure 54 - FOVIOTM eye tracker setup*