# D5.6

# Report on integrated CAV demonstration

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# 1 Introduction

As described in CoEXist's Automation-ready framework (D1.1), developing the capability to make structured and informed decisions about the comprehensive deployment of CAVs in a mixed road environment, requires a clear awareness of the technology underpinning CAVs and their functionality, in addition to understanding their potential impacts. However, practitioners and stakeholders often have limited practical experience with CAVs.

Consequently, opportunities to witness automated driving and learn about its functionalities, are of great value. With this in mind, TASS, together with PTV and HELMOND, have developed a demonstrator of an advanced use case of cooperative automated driving in an urban environment. The demonstration has been presented at the ITS in Europe conference 2019 in Eindhoven/Helmond.

To allow for an efficient implementation of the demonstrator, it has been developed in collaboration with partners of the European project Concorda and other partners that have provided ready-to-use solutions that where required to develop a state-of-the-art demonstrator.

## 1.1 Objectives

The objectives of the demonstrator are:

- Raise awareness of the potential impact of automated driving on the safety, traffic efficiency, and comfort of the mobility system in an urban environment
- Demonstrate the tools developed in the context of CoExist to assess the impact of automated driving systems
- Demonstrate measures that can improve the safety, traffic efficiency and comfort of automated driving systems

## 1.2 Roles and Responsibilities

The demonstrator has been developed in collaboration with multiple partners from the European projects CoExist and Concorda, partners from the Dutch project Talking Traffic, and other partners. The following partners have participated in the preparation and execution of the demonstrator with the following contributions:

**Tass International/Siemens** (CoExist and Concorda partner) has been responsible for the overall coordination and integration, for providing the vehicles, and for providing the vehicle simulation environment

**PTV Group** (CoExist partner) has been responsible for providing the microsimulation environment and the impact assessment studies

**Gemeente Helmond** (CoExist partner) has been responsible for providing input to the use cases being demonstrated and has contributed to the alignment with the ITS in Europe conference organisation. Gemeente Helmond also operates the traffic light controller.

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**KPN** (Concorda partner) has been responsible for the cellular communication network, and connectivity to the Dutch traffic light information.

**Siemens Mobility** has been responsible for the roadside systems, including sensors and communication units.

**TNO** has been responsible for the hybrid communication solution and the system integration.

**Monotch** has provided the traffic light data.

**u-Blox** has provided the accurate positioning system integrated in the automated vehicles.

**AB Dynamics** has provided the pedestrian dummy.

## 1.3 Report structure

This document is structured as follows. In chapter 2, the details of the demonstrator are described. Both the purpose, top level design, and message of the demonstrator are described, and the technical details of the implementation. In chapter 3 the results of the demonstration event are described. As part of the demonstration, a small impact study has been made as well for the specific scenarios that were demonstrated. The results of the impact study are also summarized in chapter 3. Finally, in chapter 4, conclusions are drawn.

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# 2 Description of the demonstrator

## 2.1 Purpose and scenarios

The demonstrator illustrates the impact that automated driving can have on the mobility system in an urban environment. It will also show how communication and roadside sensors can improve the performance of the mobility system. To that end, two connected automated vehicles will cross a signalized intersection. Three different scenarios will be developed, both in simulation and in a real implementation. The scenarios differ in the connectivity between vehicles and roadside systems, and in the presence of a pedestrian on the intersection. The simulation will be used in the development phase, and to determine the effects of the differences in the scenarios on the performance of the system. The real-world implementation is used to demonstrate the impact to the audience.

The figure below gives a high-level overview of the environment in which the scenarios are implemented.

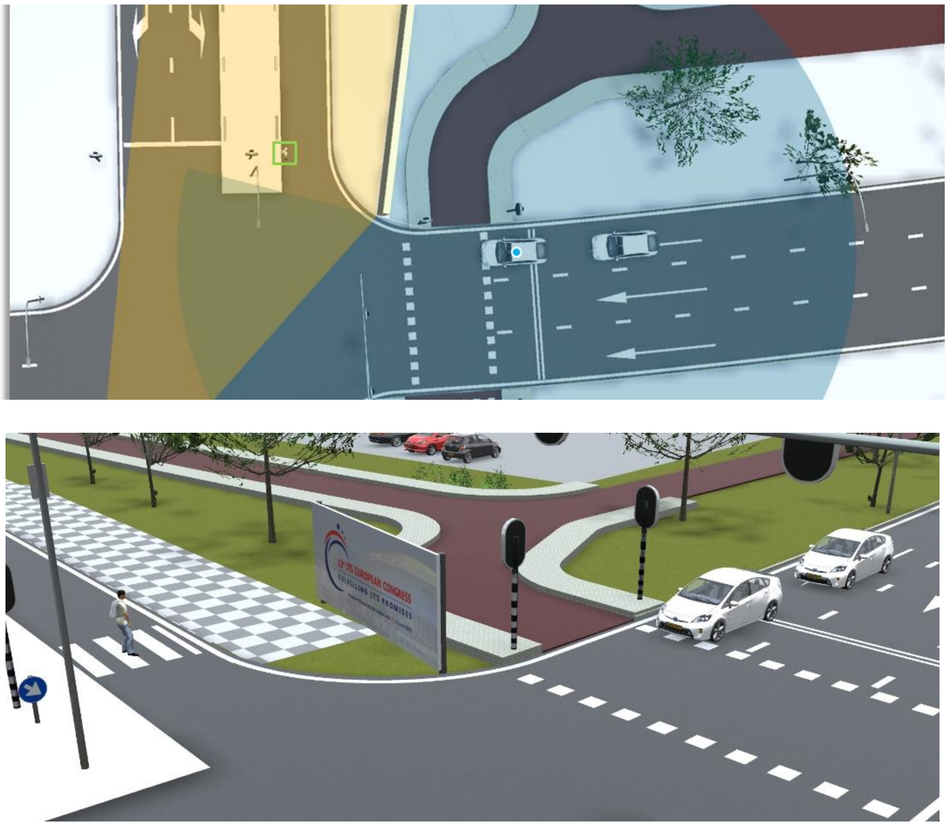

**Figure 2.1 Overview of the environment in which the scenarios are implemented. The top figure gives a bird's eye view, where the 2 automated vehicles approach from the right and make a right turn at a signalized intersection. Also indicated is the coverage of the vehicle sensors of the first vehicle (blue) and of the roadside sensor (yellow). The bottom figure also shows the pedestrian crossing at the intersection**

In the scenarios, 2 automated vehicles approach a signalized intersection and make a right turn. A pedestrian can be crossing the intersection around the corner, but this is out of the view of the vehicle

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sensors. Roadside sensors can detect the pedestrian and can exchange that information to the vehicles. Also, the state of the traffic light controller can be communicated to the automated vehicles, so that the traffic light state can be taken into account.

In all scenarios, the automated vehicles exchange their state information to allow them to drive as a platoon, at a distance of down to 0.3 meters. Traffic light information is always exchanged with the vehicles, and the vehicle can request priority to enable a smooth intersection crossing. The traffic light controller decides whether it is acceptable to grant priority, based on the actual traffic state and the policy of the road operator. Hybrid communication, based on ITS G5 and cellular communication, is used to enhance the performance quality.

Three different scenarios are implemented. They differ in whether a pedestrian is crossing, and whether the roadside systems communicate with the automated vehicles.

1. In scenario 1 the roadside sensors do not communicate with the vehicles, and no pedestrian is crossing the intersection. The vehicles will slow down significantly, as they have no information whether the street is free or not.
2. In scenario 2 the roadside sensors communicate with the vehicles, and a pedestrian is crossing the intersection. In this case, the vehicles will also slow down due to the knowledge of the pedestrian being present. The deceleration will be later than in the first scenario, as the deceleration is aimed at stopping for the pedestrian, instead of slowing down to give the vehicle sensors the ability to observe the street before taking the turn.
3. In scenario 3 no pedestrian is crossing, and this information is exchanged from the roadside sensors to the vehicles. The vehicles will take the turn at much higher speed, similar to what a human driver would do.

The impact on the traffic efficiency and comfort for the people in the vehicle is significantly impacted due to the limited view of the on-board sensors. This will happen in practise a lot in an urban environment, as many obstacles will (partly) block the view of the sensors. In scenario 2, the information exchanged will improve the comfort for the passengers. The efficiency of the traffic is still impacted, but in this case due to the pedestrian crossing, not due to limited view of the on-board sensors.

In the third scenario, the traffic efficiency and comfort are significantly improved due to the exchanged information. In this scenario, the automated vehicle will always make sure it can make an emergency stop in case the roadside information turns out to be incorrect, i.e. the basic safety is still guaranteed by the vehicle system. However, in this scenario it is acceptable to rely on the emergency features of the automated vehicle to guarantee safety, whereas in scenario 1 that would result in too frequent emergency breaking.

## 2.2 Architecture

A technical overview of the setup is depicted in the figure below, focussing on the information exchange between the different actors.

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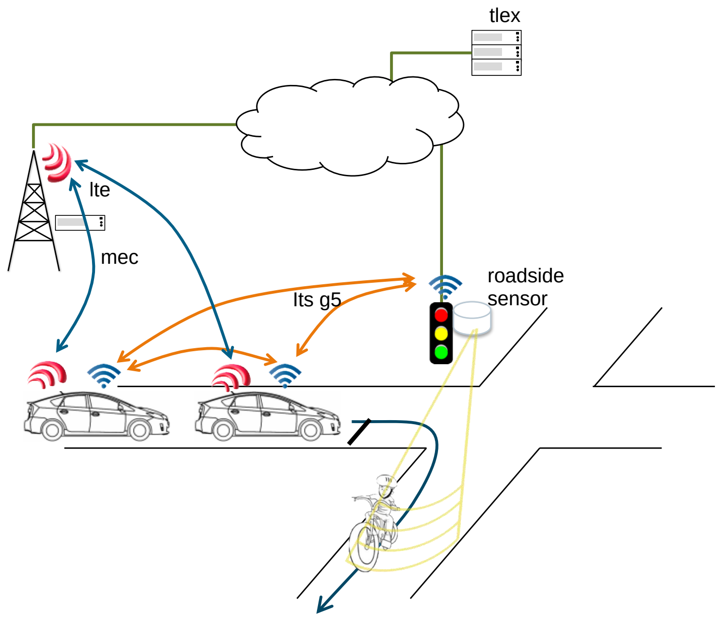


**Figure 2.2 Technical overview of the demonstrator. The vehicles communicate with each other and with the roadside infrastructure based on ITS G5, and on a connection with the mobile network via LTE where the functionality in the network is deploy in a mobile edge computing solution (MEC). TLEX is the traffic light exchange for distributing traffic light information from connected traffic light controllers. Note, that during the actual demonstration a pedestrian has been used, instead of a cyclist.**

The architecture of the demonstrator is depicted in the figure below.

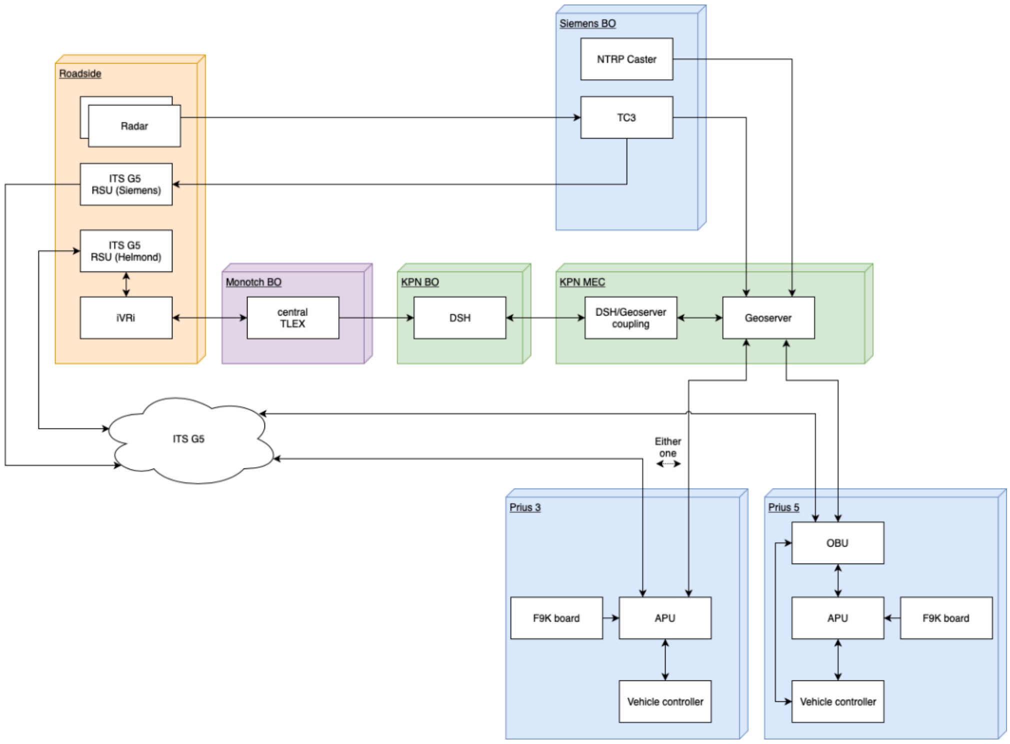


**Figure 2.3 Overall architecture of the real-world demonstrator. See text for details.**

At the roadside (orange, see Figure 2.3), 2 radars are installed, used for pedestrian detection. An ITS G5 based Roadside Unit (RSU) is deployed to exchange the radar information with the automated vehicles. The existing traffic light controller (iVRI) has its own Roadside unit, which is owned and operated by the municipality of Helmond.

The radar data is collected, processed and converted in collective perception messages (CPM) by the TC3 application, deployed in the Siemens back office (blue). The TC3 application sends the CPM messages to the RSU, and to the Geoserver (see later), supporting the hybrid communication solution. An NTRIP caster in the Siemens back office generates correction signals that are used by the automated vehicles to obtain high accuracy positioning.

The iVRI exchanges MAP and SPAT messages, both to the RSU and to the central traffic light exchange (TLEX), deployed in the Monotch back office (purple). Tlex is connected to the data service hub (DSH), deployed in the back office of KPN (green), which in turn sends its information to the Geoserver deployed in the mobile edge computing (MEC) environment of KPN. A dedicated adapter interconnects the DSH and Geoserver.

The rather complex looking data path from iVRI via TLEX to DSH and onwards to the Geoserver is actually chosen to adhere to the deployment in the Netherlands of connected traffic light controllers. This solution allows for large scale deployment and usage of traffic light information by multiple stakeholders and shows the technology readiness of this part of the demonstrator.

The geoserver application in the MEC is responsible for real-time and location-based information exchange between vehicles, and/or vehicles, roadside systems, and cloud servers. The geoserver concept deployed in this demonstrator has been designed initially in the Intercor project (focused on back office communication) and has later been adapted in the Concorda project to fit the needs of real-time vehicle to vehicle communication.

Two automated vehicles are deployed: Prius 3 and Prius 5 (blue). These existing connected automated driving car labs differ slightly in capabilities. Prius 5 is the leading vehicle and has full automated driving capabilities and full hybrid communication capabilities. Prius 3 has more limited capabilities and is focussed on platooning behind another connected automated vehicle. Although it can communicate via all communication means used in the demonstrator, it can not do so simultaneously, and it has been chosen to have only the ITS G5 communication active during the actual demonstration.

Both vehicles have controllers that can drive the vehicles in automated mode. Prius 3 uses vehicle following, which means that it will always follow the path of Prius 5 (taking safety into account by itself). Prius 5 has a vehicle controller that can also do path following and takes into account the traffic light and road sensor information.

The APU implements the communication required for platooning and can use several communication technologies. It cannot, however, use these different communication technologies simultaneously. The OBU, deployed only in Prius 5, has full hybrid communication capabilities (based on ITS G5 and cellular communication), and can also handle the interaction with the traffic light. It can interpret the MAP and SPAT messages originating from the traffic light controller, and it can request priority at the traffic light.

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The F9K boards implement high accuracy positioning and are based on a state-of-the-art integrated GNSS-IMU system. The correction signals from the NTRIP caster in the Siemens back office are used by these boards to obtain a position accuracy down to 1 cm.

## 2.3 Simulation environment

The complete real-world demonstrator has been implemented in simulation as well. The co-simulation environment based on PTV Vissim and Prescan has been used for this implementation. The details of the co-simulation environment have been described in detail in CoExist deliverable D2.2: *Technical report on connecting CAV control logic and CAV simulator*. The difference between the solution described in that report and the simulation environment used for the demonstrator, is that in this case we have integrated the actual vehicle controllers from Prius 3 and 5 in the simulation environment. In that way, we have been able to use the simulation environment both for the impact study, and the development of the real-world demonstrator. This also implies that 2 ego vehicles are simulated in Prescan (both Prius 3 and Prius 5), instead of only 1 as described in D2.2.

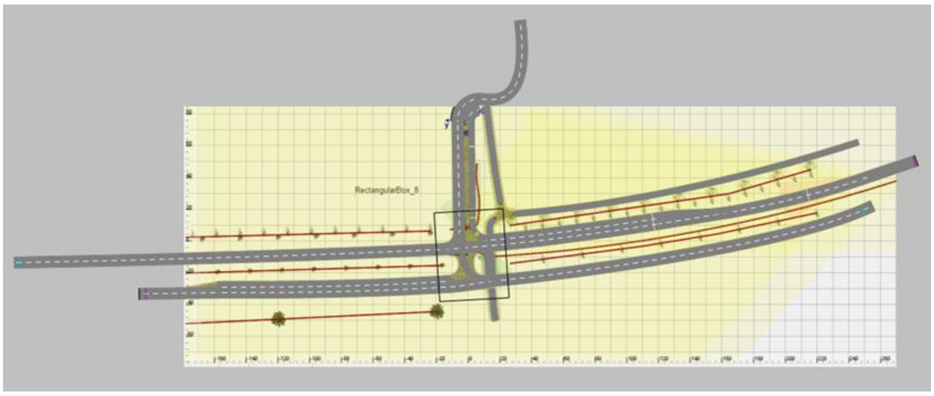

**Figure 2.4 World scenario implemented in the co-simulation environment of Vissim and Prescan.**

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# 3 Demonstration results during the ITS in Europe conference

## 3.1 Demonstrations

The real-live demonstration and simulation have been demonstrated during the ITS in Europe conference 2019 in Eindhoven/Helmond. Demonstrations have been given at three different locations:

1. As part of the implementation visit of the Traffic Innovation Center
2. As part of the 5G fieldlab on the Automotive Campus, a permanent setup operated by KPN
3. A driving demonstration, part of the demonstration program of the conference.

During the implementation visit of the Traffic Innovation Center, the demonstration has been explained with a focus on the simulation solution and results of the impact study (see next section). The schedule of the implementation visit of the Traffic Innovation Center was as follows:

**Table 3.1 Time schedule of the demonstrations during the implementation visit of the Traffic Innovation Center.**

| Day | Time | Remarks |
|---|---|---|
| Sunday | 13:00-17:00 | Free walk-in |
| Tuesday | 12:00-13:00 | 1 slot of 15 min |
| | 15:15-17:00 | 2 slots of 15 min |
| Wednesday | 12:00-13:00 | 1 slot of 15 min |
| | 15:15-17:00 | 2 slots of 15 min |
| Thursday | 12:00-13:00 | 1 slot of 15 min |
| | 15:15-17:00 | 2 slots of 15 min |

The group size of the different slots was between 5 and 25 people. The total number of visitors was estimated to be in total about 100-150 people, excluding the free walk-in on Sunday.

The 5G fieldlab has been open during the complete conference and allowed for free walk-in of visitors. It also allowed to have a further discussion with visitors of the implementation visit and/or driving demonstration. At the 5G fieldlab also other demonstrations where given. Therefore, the unique number of visitors for our demonstration at the 5G fieldlab is difficult to estimate. Many people have visited, and the demonstration and the project has received significant exposure also at the 5G fieldlab.

**Table 3.2 Time schedule of the 5G fieldlab.**

| Day | Time |
|---|---|
| Sunday | 13:00-17:00 |
| Monday | 09:30-16:00 |
| Tuesday | 10:00-17:00 |

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| Day | Time |
|---|---|
| Wednesday | 10:00-17:00 |
| Thursday | 10:00-15:00 |

The Driving demonstration has been presented on Wednesday and Thursday, according to the schedule below

**Table 3.3 Time schedule of the driving demonstration.**

| Day | Time |
|---|---|
| Wednesday | 10:00-10:30 |
| | 12:00-12:30 |
| | 14:00-15:00 |
| Thursday | 10:00-10:30 |
| | 14:00-14:30 |

The number of visitors per sessions was between 10 and 75 people, and the total number of visitors was between 150 and 200 people.

Both the simulation and the live demonstrations were well received, and often lead to lively discussion on the impact of automated driving on the urban environment.

Pictures taken during the Demo are shown in appendix A and a video of the simulation has been uploaded on the CoEXist YouTube channel on this address: https://youtu.be/aY15DUIiSis

## 3.2 Impact study

An impact study has been performed to assess the differences in the three scenarios. In addition to the two automated vehicles, eight additional *normal* vehicles (non-automated) has been added behind the automated vehicles, also making a right turn. Additional surrounding traffic has been simulated as well.

In the table below, the averages over all simulation runs of the vehicle delay, stopped delay, average and maximum queue length and fuel consumption are presented. Vehicle delay is measured from 100 m in front on the intersection, up to the exit of the intersection. A simplified model is used to estimate the fuel consumption and can only be used to make a comparison between the different scenarios.

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**Table 3.4 Simulation results for the vehicle delay, stop delay, average and maximum queue length and fuel consumption for the three scenarios.**

| Scenario | | VehDelay [s] | StopDelay [s] | QLength [m] | QLengthMax [m] | Fuel consumption [liter] |
|---|---|---|---|---|---|---|
| 1 | no peds, no comunication | 11.2 | 0.0 | 1.2 | 22.8 | 0.167 |
| 2 | peds with communication | 15.4 | 2.7 | 8.5 | 44.0 | 0.398 |
| 3 | no peds with communication | 7.9 | 0.0 | 0.0 | 0.0 | 0.147 |
| 3 vs. 1 | communication on vs. off | -3.3 | 0.0 | -1.2 | -22.8 | -0.020 |
| | | -29% | 0% | -100% | -100% | -12% |

From these results, it can be concluded that communication with the roadside sensors reduces the vehicle delay by 29%, illuminates in this experiment the queue completely, and has a significant impact of about 12% on the fuel consumption.

The overall travel time and distance of the eight vehicles making the right turn are also investigated, from 100 m in front of the intersection, up to 10 m after the intersection. The travel distance is not affected in these simple scenarios. The travel time is reduced by as much as 16 % due to the addition of the roadside sensors and communication to the automated vehicles, see Table 3.2.

**Table 3.5 Simulation results for the travel time and distance for the three scenarios.**

| Scenario | | TravelTm [s] | DistTrav [m] |
|---|---|---|---|
| 1 | no peds, no comunication | 20.4 | 128.5 |
| 2 | peds with communication | 24.7 | 128.5 |
| 3 | no peds with communication | 17.2 | 128.5 |
| 3 vs. 1 | communication on vs. off | -3.2 | 0.0 |
| | | -16% | 0% |

Overall, it can be concluded that in scenarios where automated vehicles have an obstructed view on their path, roadside sensors in combination with roadside to vehicle communication can have a significant impact on the traffic efficiency of automated vehicles.

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# 4 Conclusions

A demonstrator consisting of both a live demonstration and a virtual version in a simulation environment have been successfully developed and demonstrated. It has clearly demonstrated the impact of automated driving on the urban mobility system. It has demonstrated how roadside sensors and V2I communication can be applied to mitigate the negative effects.

The simulation environment extended and improved in CoEXist has been used to simulate the demonstration. It has been used to develop the live demonstration, and it has been used to determine the impact for the specific scenarios.

The live demonstration has been developed in cooperation with partners from Concorda, and with partners not involved in either European project.

Both the virtual and live demonstrator has been shown to visitors during the ITS in Europe conference 2019, with in total between 200 and 400 visitors. When a new feature or technology is launched, it is difficult to get a grasp of its benefits or challenges unless the users try them out first-hand. This demonstration enabled participants to better understand and appreciate the potential impacts of the Cooperative, Connected and Automated Mobility (CCAM), and through its comprehensive methodology with a real-life and a simulation environment, enhanced their understanding of the functionality and how its impacts can be measured.

Both versions of the demonstrator were well received by the audience, created significant awareness of the impact of CCAM on urban mobility, of possible solutions to mitigate the negative effects, and of the tools developed in CoEXist to assess the impact.

# 5 Partners involved

## 5.1 CoEXist partners

tass international A Siemens Business

PTV GROUP the mind of movement

Gemeente Helmond

## 5.2 Concorda partners

kpn

SIEMENS Ingenuity for life

## 5.3 Other partners

monotch SMART MOBILITY PLATFORMS

TNO innovation for life

ublox

AB Dynamics

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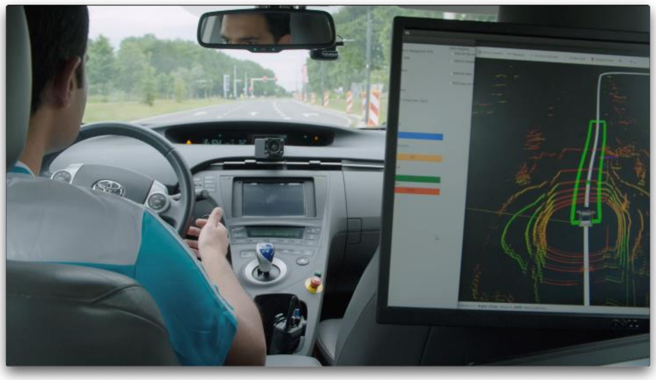
# Appendix A Demonstration Impressions

The images below have been recorded during the live demonstrations.







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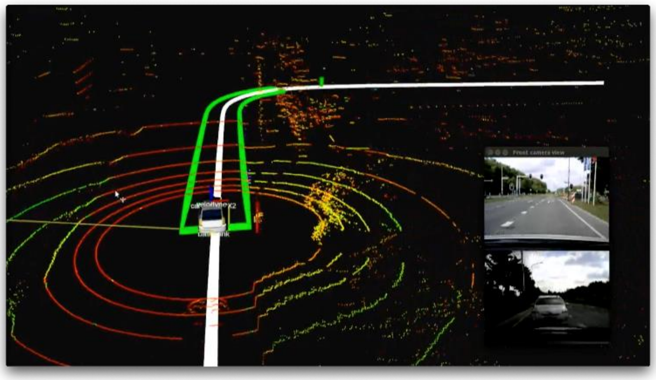

# 6 Partners

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