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Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
AAE	Autopistas España
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
ASECAP	European Association of Operators of Toll Road Infrastructures
ASF	ASFINAG
ASFINAG	Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft
ATE	AustriaTech
AV	Automated Vehicle
API	Application Programming Interface
AWC	Adverse Weather Conditions
BMW	BMW AG
ADT	Average Daily Traffic
CAN	Controller Area Network
CAV	Connected and Automated Vehicle
CB	Citizens Band
CCV	Connected Conventional Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CPU	Central Processing Unit
CV	Conventional Vehicle
DGT	Dirección General de Tráfico – Spanish Authority on Traffic regulations
DLA	Dynamic Lane Assignment
DoA	Description of the Action
EC	European Commission
ECU	Electronic Control Unit
ENI	Enide Solutions SL

EU	European Union
GA	Grant Agreement
Gbps	Gigabits per second
GPS	Global Positioning System
GPU	Graphics Processing Unit
ICCS	Institute of Communication and Computer Systems
I2V	Infrastructure to Vehicle
IMC	INFRAMIX Management Centre
IMIS	Intelligent Mobile Information System
ISAD	Infrastructure Support to Automated Driving
LKA	Lane Keeping Assistance
MTFC	Mainstream Traffic Flow Control
MWC	Motorway Chauffeur
OBU	On-Board Unit
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PK	Punto Kilométrico - Milestone
PO	Project officer
RSU	Road Side Unit
RTK	Real Time Kinematic
RWW	Road Works Warning
SAE	Society of Automotive Engineers
SCT	Servei Català de Trànsit – Catalan Authority on Traffic regulations
SIE	Siemens Mobility
TMC	Traffic Management Centre
TP	Trajectory Planner
TOM	TomTom Location Technologies Germany GmbH
TUC	Technical University of Crete
UC	Use Case
V2X	Communication from Vehicle to Everything (X represents any entity capable of receiving C-ITS communications)
VDE-SF	Verkehrsdatenerfassung Sensorfusion (Traffic data acquisition sensor fusion)
VSL	Variable Speed Limits
VMS	Variable Messages Signs
VuT	Vehicle under Test
WP	Work Package

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Executive Summary

The EU project INFRAMIX aims to prepare the road infrastructure to support the coexistence of conventional and automated vehicles, targeting the transition period when the number of automated vehicles will gradually increase, to handle the transition period and eventually become the basis for future automated transport systems. A “hybrid” road infrastructure concept will be the project outcome after defining the necessary upgrades and adaptations of the current road infrastructure as well as designing and testing novel physical and digital elements. In order to ensure uninterrupted, predictable, safe and efficient traffic, novel technologies are designed, diverse components are incorporated, and different technologies are combined. All these steps are directed to make a number of relevant demonstrations, one of the main interests of the project, in order to expose the solutions developed within the INFRAMIX project in real-life operational conditions. The demonstrations took place at the two main test sites in Austria and Spain, and addressed all the INFRAMIX pre-selected traffic scenarios: “dynamic lane assignment”, “roadworks zones” and “bottlenecks”. On the German test site, integration tests were executed as preparation for the tests on the two other test sites.

This deliverable focuses on the integration and demonstration of INFRAMIX developments at the two test sites as well as at the proving ground and, on the data delivery report, including a description of the collected and aggregated data, following the procedure described in the document "Field Tests: Terms of reference"[1]. The main objectives are listed below:

- Define a common methodology for demonstration and testing
- Integrate and test the modules delivered by WP2 and WP3 at the two test sites
- Demonstrate the three selected traffic scenarios within the test sites, including mixed traffic estimation and control algorithms
- Collect data and experiences from the demonstrations and deliver it to WP5 for its evaluation

In accordance to these objectives, this document consists of six major chapters. Chapters 2, 3, 4 and 5 present the Spanish demonstrator, the Austrian demonstrator, the hybrid testing and the German demonstrator respectively. In every of these chapters, section 1 present their location, the available equipment, and infrastructure measures in specific scenarios in terms of road safety and traffic efficiency; section 2 contains the methodology and plan for the demonstrations and the preparation of the test environment configuration to reflect the reality on the test sites; section 3 highlights the performance of the demonstrations and the results obtained. Chapter 6 lists the collected data of the project according to Task 4.1 and the data management plan specified in D1.3. Chapter 7 presents the conclusions of this demonstration phase. The two annexes show three examples of the surveys used during the tests and an example of a day2 C-ITS message.

[1] https://dtc.jrc.ec.europa.eu/field_tests_docs/ToR-Field%20Tests-V%202.0%20FINAL.pdf

1 Introduction

1.1 Aim of the project

Over the last years, significant resources have been devoted to developing new automation technologies for vehicles, whereas investment and resources for road infrastructure, in general, have not gone at the same pace. INFRAMIX is preparing the road infrastructure to support the transition period and the coexistence of conventional and automated vehicles. Its main target is to design, upgrade, adapt and test both physical and digital elements of the road infrastructure, ensuring an uninterrupted, predictable, safe and efficient traffic. Towards this objective, different technologies are deployed; mature simulation tools are adapted to the peculiarities of automated vehicles, new methods for traffic flow modelling are developed to study the traffic-level influence of different levels of automated vehicles in different penetration rates, and traffic estimation and control algorithms are tested. Moreover, ways of informing all types of vehicles about the control commands issued by the road operator are developed and new kinds of visual and electronic signals are proposed for the needs of mixed scenarios. The project outcomes are assessed via simulation and in real stretches of advanced highways as well as an enclosed proving ground.

Designing such a diversified and novel concept makes the capture of the infrastructure as well as the various component requirements challenging and at the same time crucial for the project outcomes. INFRAMIX selects a bottom-up approach. Instead of working with generic solutions with questionable impact, it builds on the specific high value (in terms of importance regarding traffic efficiency and safety) traffic scenarios: dynamic lane assignment, roadworks zones and bottlenecks. INFRAMIX addresses mainly highways, as they are expected to be the initial hosts of mixed traffic.

1.2 Purpose of Document

The purpose of this document is to provide a description of the demonstrators and the result obtained, which is the data delivery report including the data collection and aggregation plan and a description of the collected and aggregated data. The demonstrations will also include the traffic estimation and control approaches developed in WP2 (modelling, simulation and control for mixed traffic). Furthermore, this document covers the integration and interaction of the modules delivered by WP2 and WP3 (integrated infrastructures and traffic management capabilities) and the data collection from all the demonstrations to be delivered by WP5 (evaluation, users' appreciation and safety performance).

This deliverable includes a description of the demonstrators and the results obtained, (Tasks 4.2, 4.3 and 4.4), the data delivery report including the data collection and aggregation plan, and a description of the collected and aggregated data (Task 4.5).

2 Spanish demonstrator

This chapter defines the test site areas and all the installations, signals, materials and actions in detail in order to get the most accurate view of how Autopistas with the support of the partners involved in the demonstrations, managed the emulation of each use case of the three scenarios.

2.1 Description of the demonstrator

2.1.1 Purpose of Tests

The test sites in Girona (Spain) will demonstrate in the real-world the three traffic scenarios: dynamic lane assignment, roadworks zones and bottlenecks. These scenarios, explained in section 2.2, are adapted for safety, quality of service, road efficiency and to allow test persons to experience the new technology.

2.1.2 Field test Operator definition

Abertis Autopistas España (AAE) is the Spanish leader in toll roads management. It directly manages more than 1,500 kilometers, which accounts for 59% of the country's toll roads. It also has a non-majority stake in a total of 250 kilometers through other toll roads and tunnel concessions. AAE forms part of the Abertis Group, the world leader in toll road management and one of the first global telecommunications infrastructures operators. Abertis Group now operates in 10 countries in Europe and America. AAE consist of over 1.950 staff, all with the mission of providing the maximum possible safety and comfort to the vehicles circulating every day on the company's roads. Moreover, AAE is constantly extending and updating its infrastructure, incorporating the latest innovations in terms of free-flow, signalling, real-time services and reliable connectivity. AAE has participated in a number of cross-border European Projects, mainly as a major contributor to the definition and deployment of interoperable European Electronic Tolling Systems (EETS). In the context of INFRAMIX Project, AAE is contributing to the definition and deployment of a hybrid infrastructure where automated cars (with different levels of automation) will coexist with connected cars and conventional cars within the highways across Europe.

2.1.3 Test Site Partners

Table 1 lists the partners involved in the Spanish test site activities and provides a detailed description of the partner's responsibility in the form of tasks assigned or expected by each partner.

Table 1 – Description of partner's involvement

Partner	Involvement description
AAE	**Role: Leader and coordinator for the integration and testing at the Spanish demonstrator** **Activities:** • Coordinating the adaptation of the test site and the Spanish demonstrations • Provision and installation of ITS-G5 RSUs • Provision and installation of Magnetometers

	• Provision and installation of new signaling if required and possible, or any other physical element for the demonstrations • Integration with the IMC (DATEX II) • Showing the required information into existing VMS • Managing the demonstrations in Girona (Spain) • Defining a common test protocol for the test sites in Girona and Graz. • Gathering Spanish regulation related to the demonstrations • Provision of vehicles for the demonstrations
ATE	**Role: Support the test site and its activities** **Activities:** • Contribute in testing the ITS-G5 information chain • Provision of the ITS-G5 OBU and development of a corresponding HMI for testing the ITS-G5 link and the new signs • Support during the demonstration on the test site • Support on the OBU installation in the vehicle • Support to the ITS-G5 link testing
ICCS	**Role: Support integration and testing activities in the test site** **Activities:** • User appreciation • Support integration and testing activities • Coordination between the tests and WP5 (make the best of them as inputs for WP5)
SIE	**Role: Deploy new and/or adapt the existing equipment of the test site for the supported Use Cases.** **Activities:** • Coordinating the integration of WP2 and WP3 developments and the corresponding testing in the Spanish test-site • Installation and configuration of the ITS-G5 RSUs • Integration of the RSUs to the INFRAMIX technical architecture • Integration of the AAE interface to the INFRAMIX technical architecture (establishment of the connection to the IMC) • Operation of the ITS-G5 communication (based on IMC control strategies) • Support and preparation on the demonstration plan definition • Preparation of the C-ITS messages (mockups) for the demonstration • Operation of the IMC during the demonstration on the test site in order to run the demonstration tests
TUC	**Role: Involvement in all issues related to traffic state estimation and traffic control algorithms developed in WP2 for the traffic scenarios and being considered in the test site** **Activities:** • Involvement in all issues related to traffic state estimation and traffic control algorithms developed in WP2 • Support on the adaptation of the test-site based on the traffic estimation and control strategies requirements • Support on the demonstration plan definition based on the traffic conditions and the control strategies' impact • Support during the demonstration on the test site
ENI	**Role: Support in preparation and dissemination** **Activities:** • Coordination between the tests and WP6 (make the best of them as inputs for WP6) • Support during the demonstration on the test site

TOM	**Role: Deliver a demonstrator with advanced lane and speed guidance that implements traffic control for human drivers, which can be used in the project test site for experimental evaluations** **Activities:** • Provision of an app including lane information such as open/close, SAE level, variable speed, and acceleration • Support during the demonstration on the test site
BMW	**Role: Support, integration and testing of onboard functionalities which include speed, lane and route recommendations for automated and conventional vehicles based on input from the traffic provider.** **Activities:** • Provide information about lane, speed and gap recommendations through the BMW Backend for the BMWs visualized in an on-board App in the integrated Navigation screen • Support to the cellular link testing • Support during the demonstration on the test site

2.1.4 Field test definition

The Spanish test site is located within the Mediterranean Corridor between Barcelona and the French border, close to the city of Girona. The specific highway segment is over 20km of a four-lane carriageway. Each lane is 3,5m wide. The internal hard shoulder is 1m and the external hard shoulder is 2,5m. The highway median is 5m wide (in average). The test site includes four intersections. The Average Daily Traffic (ADT) in this section was around 30.000 vehicles per day in 2016, and the speed limit is 120km/h.

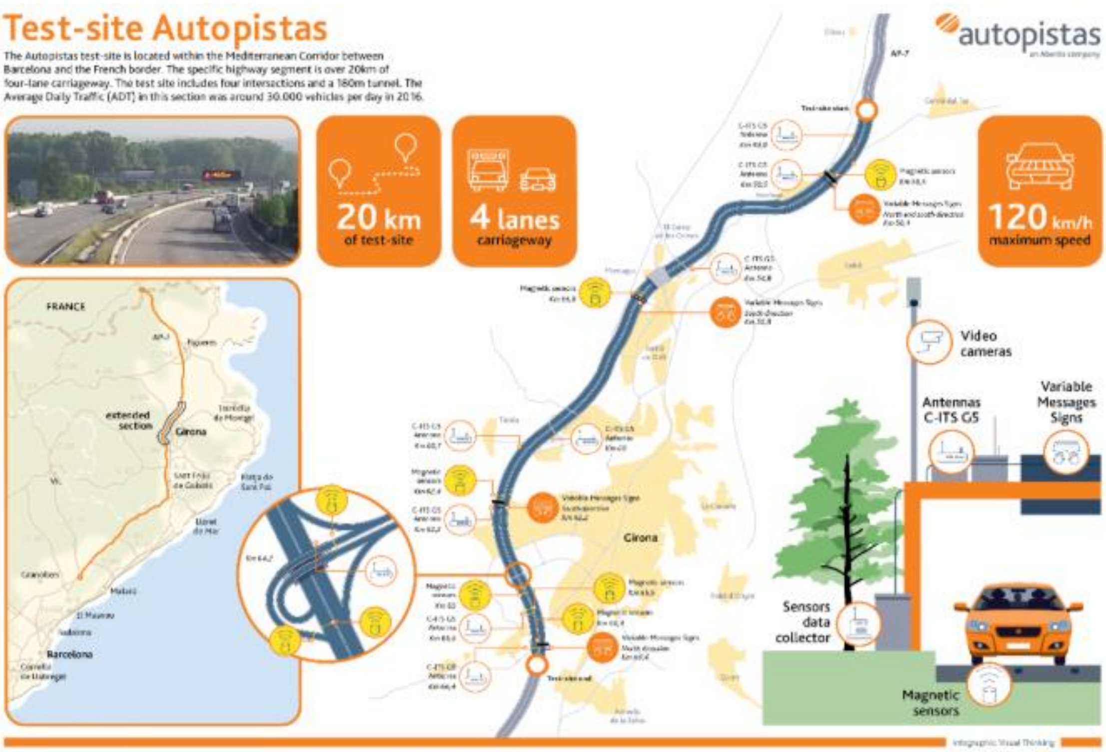

Figure 1 – Schematic view of the Spanish test site

2.1.5 Register – Inventory of equipment

In the interest of demonstrating the three scenarios of the project, several adaptations and extensions to the test site have been made. The currently available ITS equipment includes different types of VMS equipment, video cameras, Bluetooth antennas, magnetic sensors – magnetometers for measuring occupancy and one weather station. ITS-G5 short range communication and cellular communication (4G/LTE) are available at the test site, and a proprietary Fiber Optic ring network with 10 Gbps Bandwidth connects all the equipment from the test site to the TMC in real-time.

The figure below shows a deeper view of the test site through a sketch of the area, where all the equipment installed at the test site is visible. The description of every item is explained in the following sub-sections.

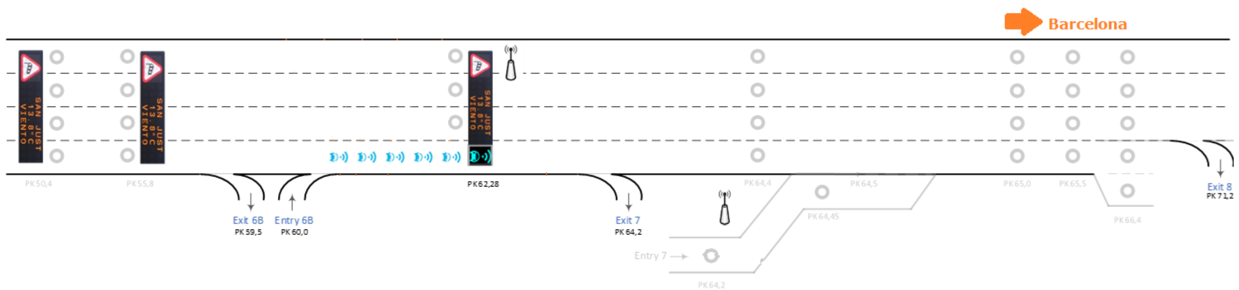

Figure 2 – Detailed sketch of the test area

2.1.5.1 VMS Equipment

The test site is equipped with 4 Variable Message Signs, where one of them was acquired for the project needs. The location of these 4 VMSs is detailed in the following Table 2:

Table 2 – VMS location at the Spanish test site

Location (PK)	Location – Coordinates	Description	Application
50,4	42.047833, 2.870714	A pictogram on the left and three lines of text	Shows information of the test area & Roadworks
55,8	42.024507, 2.819324	A pictogram on the left and three lines of text	Shows information of the test area & Roadworks
62,28	41.975917, 2.778560	A pictogram on the left and three lines of text	Shows information of the test area & Roadworks
62,28	41.975926, 2.778458	A new full-colour pictogram	Scenario 1

a) b)

Figure 3 – PK 62,28: a) VMS with a pictogram on the left and three lines of text b) VMS plus full-color pictogram added for the project

Besides the VMS equipment described in Table 2, **all the entries of the highway that give access to the test site area inform over VMS about the running test area**, as they also indicate possible roadworks in advance. Furthermore, an operational trolley from AAE was available for additional signalling for the roadworks scenario.

Figure 4 – Trolley Panel

2.1.5.2 ITS-G5 RSUs

For the demonstrator of the INFRAMIX project, three ITS-G5 Road Side Units (RSUs) have been acquired. These RSUs will be connected to the IMC and will send and receive ITS-G5 messages to an ITS-G5 On Board Unit (OBU) installed in a test vehicle.

The location of these RSUs is detailed in Table 3. Two of them are mounted on the VMS infrastructure. The third one is portable and is mounted on a trolley/assistance vehicle and located in different places based on the different use cases' requirements.

Table 3 – ITS-G5 RSUs location at the Spanish test track

Location (PK)	Location (Lat-Lon Coord.)	Application
62,4	41.975924, 2.778463	Scenario 1 & 3
64,4	41.959750, 2.783600	Scenario 3
Portable	Portable	Scenario 1 - 2 & 3

2.1.5.3 Magnetometers

60 magnetometer sensors were installed in the test site during 2018. These wireless vehicle detectors allow to count the number of cars per lane, the speed per lane, detect different types of vehicles and the (time) gap between them. The following table details their location, description and intended application.

Table 4 – Magnetometers location at the Spanish test track

Location (PK)	Location (Lat-Lon Coord.)	Description	Application
62,2	41.978023, 2.779072	2 lines of 7 sensors per line, totally **14 sensors**	Scenario 1 & 3
64,4	41.957749, 2.784328	2 lines of 7 sensors per line, totally **14 sensors**	Scenario 1 & 3
64,45	41.957562, 2.784235	**4 sensors** in the ramp merge	Scenario 1 & 3
65	41.952784, 2.786754	2 lines of 7 sensors per line, totally **14 sensors**	Scenario 1 & 3
65,5	41.947655, 2.788229	2 lines of 7 sensors per line, totally **14 sensors**	Scenario 1 & 3

The data from these magnetometers is collected by the Autopistas Hub and shared with all partners over an API. All the documents related to the magnetometers specifications and the API were provided to the consortium.

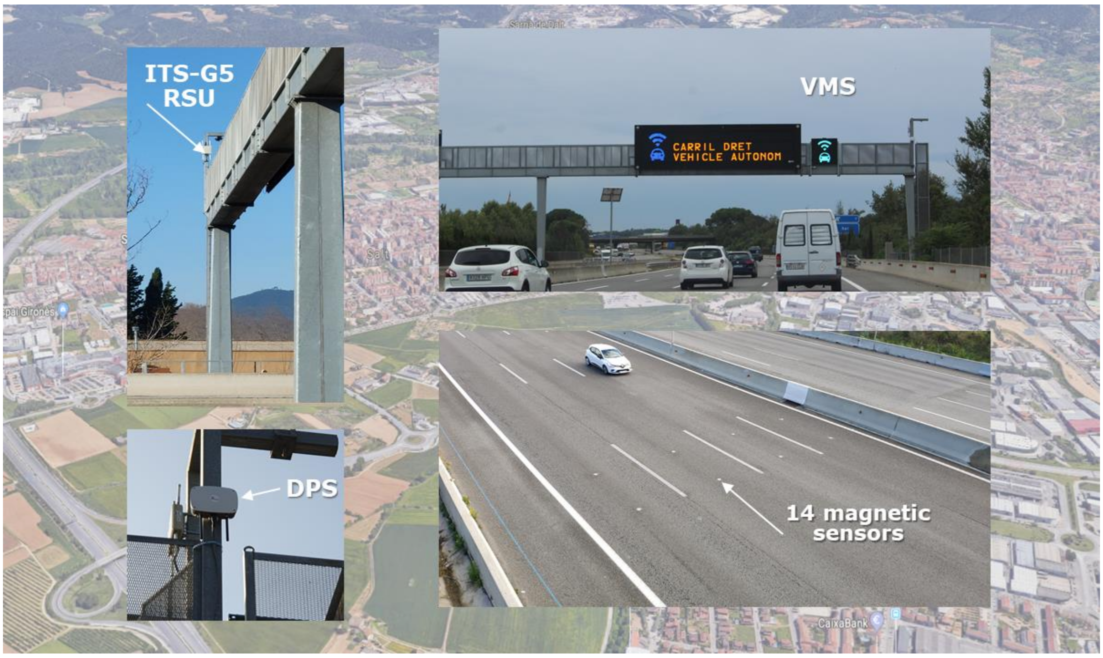

Figure 5 – Equipment of the Spanish test site

2.1.5.4 Paintworks

For the demonstrations, AAE painted the new pictogram on the floor of the fourth lane (the right one), to emphasize the entrance to a dedicated lane. The pictograms were painted every 100 meters, starting in PK 61,8 (500 meters in advance) a total of five times, until PK 62, 2, just 100 meters before the VMS that is located at PK 62,28.

Figure 6 – Entrance of the dedicated lane

2.1.5.5 Signalling

Continuing with the idea to keep drivers informed redundantly, AAE planned to install four vertical signals, three of them in preview to warn about the proximity of the dedicated lane and the fourth one at the end of the dedicated lane, in PK 63,4. All the signalling is shown in the figure below.

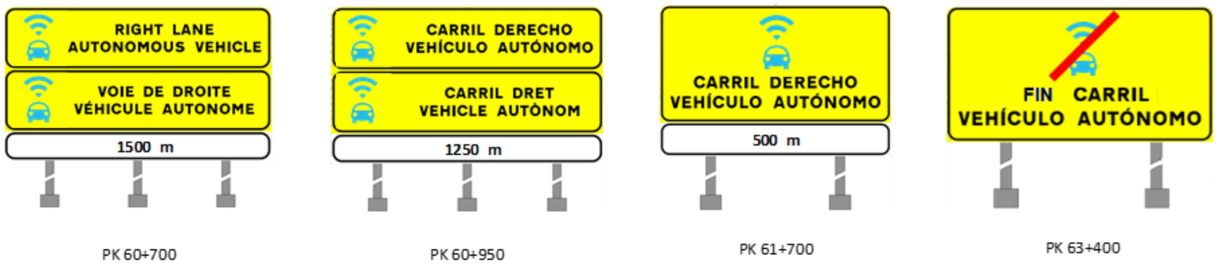

Figure 7 – Signalling informing of the dedicated lane

2.1.6 Vehicles, Drivers and Passengers

To maximize the effectiveness of the tests according to the current equipment described in this chapter, 3 BMWs were organizedwith the exact specifications[2] provided by BMW in order to ensure the communication. BMW's vehicles are the only ones in the tests, which can communicate in unicast mode (as opposed to broadcast mode), sending the specific location per lane to the IMC and giving to the tests the chance to verify a bigger number of options. Additionally, AAE used for the tests two more vehicles of their fleet, one equipped with the OBU provided by the partner ATE and the other that used a tablet with the application developed by TOM.

In order to increase the results of the project and enhance the safety, the order of the vehicles was planned as in the figure below. Firstly, an AAE vehicle with the OBU, secondly another AAE vehicle with the TomTom App and, all followed by the three BMW vehicles.

Moreover, AAE hired three professional drivers for driving the BMW vehicles during the demonstration period, while the other two vehicles were driven by AAE staff.

In order to get as many as possible filled surveys about the users' evaluation during the demonstration, AAE transferred every day part of their staff to the test site in two different groups, morning (10:00 am - 13:30 pm) and afternoon (15:00 pm - 18:00 pm), to participate as passengers inside the vehicles during the tests. Furthermore, some of the partners of the project participated actively during the test days on-site in Girona giving support; these partners were ATE, ICCS, SIE, TUC, ENI, TOM, and BMW.

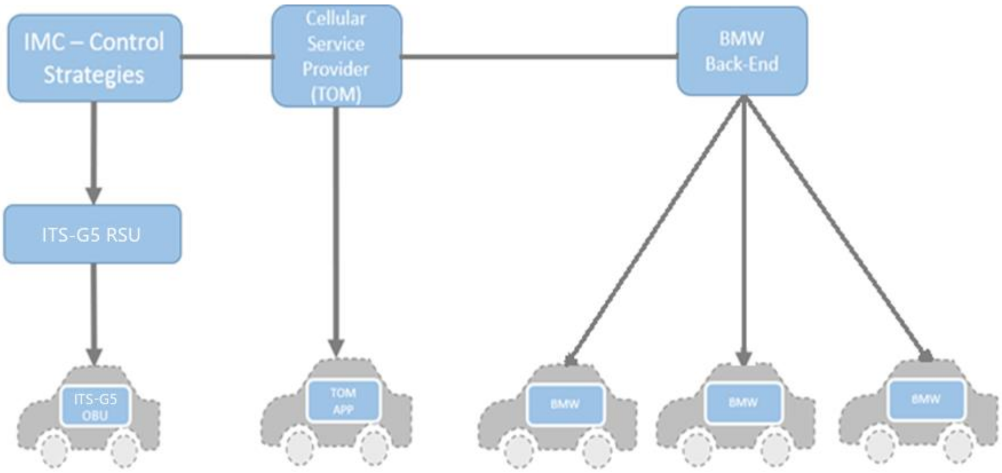

Figure 8 – Communications between the five vehicles during the demonstrations

2.1.7 Surveys

More than ten survey models were prepared and distributed on different days, according to the use cases tested per lap. Table 15 details the list of the surveys, by use case, lap and turn. In the annexes, one copy per scenario is added as an example of a survey.

2.1.8 Video of the demonstration

For the tests in Spain, a video production company was hired to make a promotional video of the

[2] Deliverable 4.1 INFRAMIX plan for systems interaction, integration and testing, Section 6.2.1

project with a direct focus on the scenarios – use cases tested. With a team on the track, they took scenes from different points of view. From inside the vehicle, focusing on the different devices showing the information offered by the IMC through the corresponding communication links. In addition, from another moving vehicle and from a fixed camera on the highway, they captured the manoeuvres of the vehicles that were following the strategies sent.

Figure 9 – Camera set-up for filming the INFRAMIX scenarios on the highway

The video, as the project dissemination ambassador, was edited and shared with the entire INFRAMIX consortium for distribution and is the video is available on the web portal of the project[3].

2.2 Spanish test procedure

This section defines the procedure applicable to the field tests. Some of the main targets of the demonstrations were:

- validate the configuration of the virtual test environment to reflect the reality at the test sites
- demonstration of bi-directional communication between real digital infrastructure and real-world vehicles
- Embed real-world infrastructure elements and a human-driver and/or automated vehicle in the virtual test environment via real-time communication
- Ensure a robust and complete information chain among all actors

[3] https://www.inframix.eu/videos/

- Detailed investigation of the vehicle behaviour in mixed situations
- Ensure and appropriate vehicle/driver behaviour according to the developed infrastructure measures

In order to achieve the objectives of the use cases and because there is no congestion in our test site, the definition and implementation of mockups were established among the partners to be able to force the realization of the uses cases and thus be able to perform the tests according to the objectives of the project. These mockups, defined by lap, is explained in more detail in the following subsections.

The days selected to perform the use cases of all the scenarios were from 12th to 15th of September, between 10 am and 6 pm. The test schedules per scenario and use case are shown in the table below:

Table 5 – Test schedules per scenario and use case

		Day 1 Thursday 12/09/2019	Day 2 Friday 13/09/2019	Day 3 Saturday 14/09/2019	Day 4 Sunday 15/09/2019
Dynamic lane assignment SCENARIO 1	UC1: Real-time lane assignment under Dynamic Penetation Rate Avs			10 Laps	
	UC3: A conventional vehicle drives on a dedicated lane for AVs				10 Laps
Roadworks SCENARIO 2	UC1: Short term roadworks	5 Laps			
Bottlenecks SCENARIO 3	UC1: Automated vehicles (AVs) driving behavior adaptation in real time at Sags	5 Laps			
	UC2: Lane-Change Advice to connected vehicles at bottlenecks		5 Laps		
	UC3: Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles		5 Laps		

A set of tables is presented below with a deeper detail of the schedule in reference to each lap:

Table 6 – Detail of the test schedules per lap

Thursday 12th			
Roadworks - UC1			Circuit: 6B - 7
Meeting		9:30	
Lap 1	10:00	10:35*	
Lap 2	10:35	10:45	
Lap 3	10:45	10:55	Survey: S2-UC1_Q1
Lap 4	11:30	11:45	
Lap 5	11:45	11:55	
Lap 6	11:55	12:05	Survey: S2-UC1_Q2
	13:00	15:00	Lunch Break
Bottleneck - UC1			Circuit: 6B - 8
Meeting		15:00	
Lap 1	15:00	15:45	
Lap 2	15:45	16:00	
Lap 3	16:00	16:15	
Lap 4	16:15	16:30	Survey: S3-UC1_Q1
		18:00	Final

Friday 13th			
Bottleneck - UC1			Circuit: 6B - 8
Meeting		9:30	
Lap 1	10:00	10:15	
Lap 2	10:15	10:30	
Lap 3	10:30	10:45	Survey: S3-UC1_Q2
Bottleneck - UC2			
Lap 4	11:15	11:30	
Lap 5	11:30	11:45	
Lap 6	12:00	12:15	Survey: S3-UC2_Q1
	13:00	15:00	Lunch Break
Bottleneck - UC3			Circuit: 6B - 8
Meeting		15:00	
Lap 1	15:30	15:45	
Lap 2	15:45	16:00	
Lap 3	16:00	16:15	
Lap 4	16:15	16:30	Survey: S3-UC3_Q1
		18:00	Final

Saturday 14th			
DLA - UC1			Circuit: 6B - 7
Meeting		9:30	
Lap 1	10:00	10:35*	
Lap 2	10:35	10:45	
Lap 3	10:45	10:55	Survey: S1-UC1_Q1
Lap 4	11:30	11:45	
Lap 5	11:45	11:55	
Lap 6	11:55	12:05	Survey: S1-UC1_Q2
	13:00	15:00	Lunch Break
DLA - UC3			Circuit: 6B - 7
Meeting		15:00	
Lap 1	15:00	15:15	
Lap 2	15:15	15:25	
Lap 3	15:25	15:35	
Lap 4	16:10	16:25	Survey: S1-UC3_Q1
		18:00	Final

Sunday 15th			
DLA - UC1			Circuit: 6B - 7
Meeting		9:30	
Lap 1	10:00	10:35*	
Lap 2	10:35	10:45	
Lap 3	10:45	10:55	Survey: S1-UC1_Q3
DLA - UC3			
Lap 4	11:30	11:45	
Lap 5	11:45	11:55	
Lap 6	11:55	12:05	Survey: S1-UC3_Q2
	13:00	15:00	Lunch Break
			END

The AAE test site is a 20 km stretch of highway, from the start point to the final point as showed in the figure below. The meeting point is located at the toll gate of Girona Oest. Each scenario requires driving south towards Barcelona from the start point to a different intermediate point, from where to change sense and drive north back to the start point. Therefore, the laps are longer or shorter depending on the scenario.

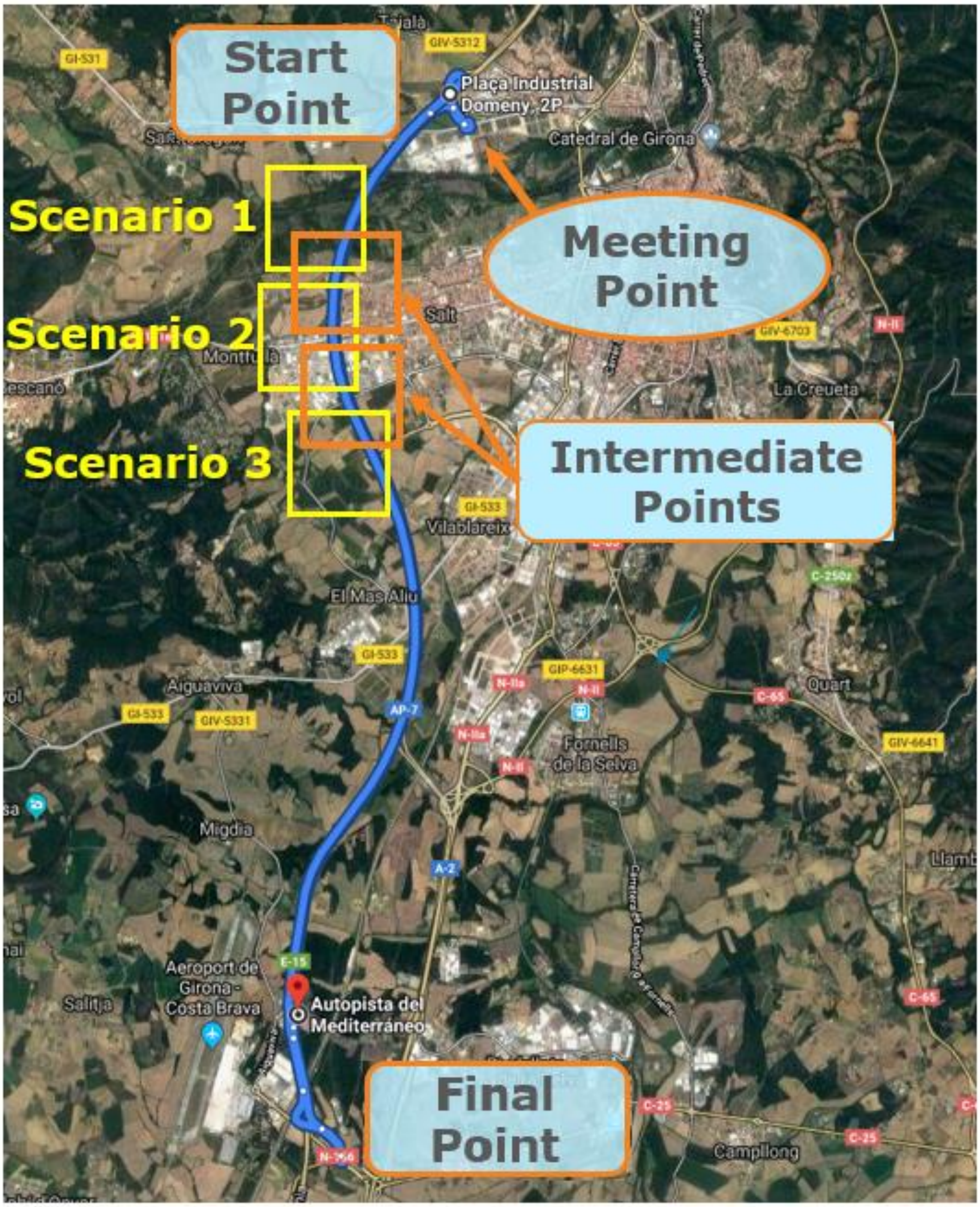

Figure 10 – Key points of the test site area

As mentioned, the meeting point is located at the toll gate - Girona Oest (exit 6B of the highway) which is also the start and end point for each lap. Everyday a meeting was held at the meeting point at 9:30 am to review the plan for the day and check the safety of the highway. The different intermediate points, described in the corresponding sections of the use cases, were chosen to shorten the laps as much as possible and to increase the number of laps.

Figure 11 – Meeting point (left), close to the Toll – Girona Oest (right)

Descriptive singular maps are shown on the coming figures inside of each subsection. The following subsections provide the detailed description of the interactions and planned integration aspects of the aforementioned systems, which were planned to be used for the demonstration and testing of each use case. Everything was ready to perform the tests in real traffic as determined in the Description of the Action (DoA) and therefore, a considerable number of trucks were expected on the highway. Consequently, to guarantee the safety, some minor modifications were taken and are indicated in the subsections of the use cases.

2.2.1 Scenario 1: Dynamic Lane Assignment (incl. speed recommendations)

The target of this scenario is to assign dynamically an exclusive lane to automated traffic. The main advantage of a dedicated lane for automated vehicles is found in an increased traffic flow, provided there is a minimum number of automated vehicles on the road, and possibly also a reduction of safety problems related to the different driving behaviours between automated vehicles and conventional vehicles driven by humans.

For Scenario 1, Dynamic Lane Assignment (DLA), a number of magnetometers were already available from the C-Roads project in order to gather information from traffic at lane level in all the VMS of the test site. Furthermore, a full-colour VMS was acquired and installed in the exact start point of the DLA, on top of the right lane in order to project-specific signs for the dedicated lane as for example, the new pictogram that the INFRAMIX project created to signal the dedicated lane (Deliverable 3.5[4]). So far, the VMS in AAE's highways do not have specific pictograms per lane but rectangular panels with three lines of text, and a pictogram on the left. These AAE VMS will be used during this scenario to inform to the vehicles of the test that will take place during September. Also, on top of the same VMS an ITS-G5 RSU has been installed, as well as for validating the hybrid communication infrastructure of the project. Finally, the new painting was added in order to provide a realistic scenario of a possible dedicated lane, and some extra signalling during the tests as required by the Public Administration in order to guarantee safety. The full demonstration set up is detailed in the following two sections, use case 1 and 3.

[4] Deliverable 3.5 - New visual signs and elements

In order to manage the communications with the vehicles, two different segments were prepared for this scenario as can be seen in the figure below. The Detection Zone, where the received relevant messages get activated in the vehicle in order to prepare corresponding actions to be taken for the related traffic information, and the Relevance Zone where the received traffic information becomes valid and vehicles have to adapt their trajectories, speed and time gaps. .

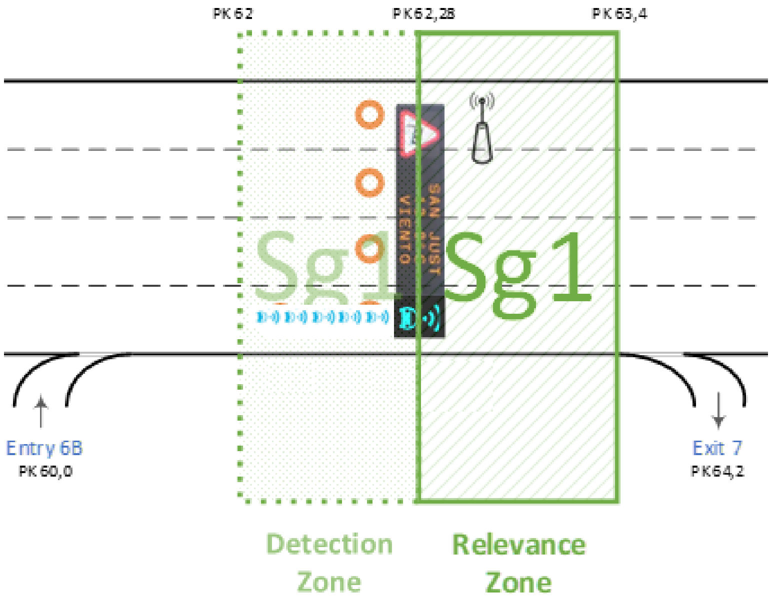

Figure 12 – S1 Detection and Relevance Zones

2.2.1.1 Use Case 1: Real-time lane assignment under dynamic penetration rate of automated vehicles

Based on the information of deliverable "4.1. INFRAMIX plan for systems interaction, integration and testing"[5], the figure below presents a detailed architecture that reveals the interactions and planned integrations required for this use case.

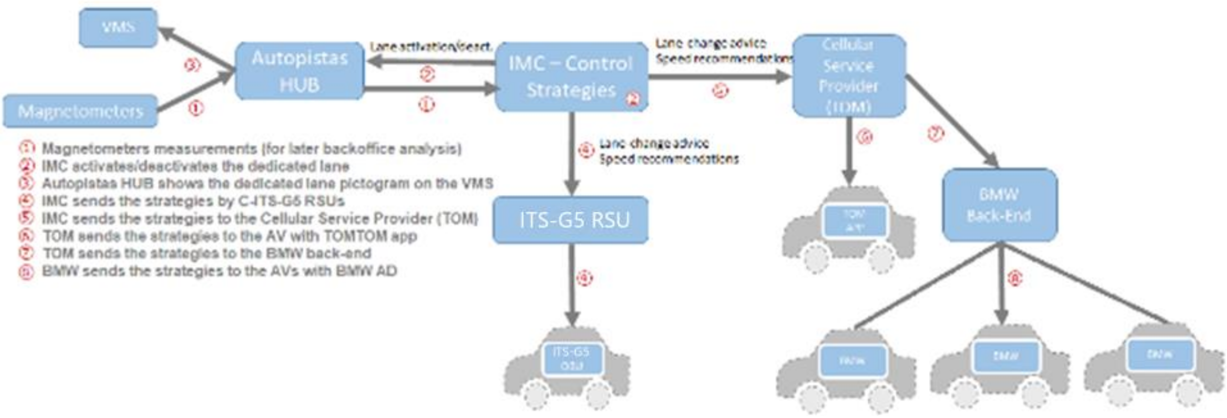

Figure 13 – Systems interactions and planned integrations S1 UC1

This test was scheduled for Saturday 14th of September from 10:00 am to 1:00 pm and 3:00 pm to 6:00 pm. It was planned to do ten laps, entering and exiting from the meeting point Toll-Girona Oest. The figure below shows the test site area that the vehicles drive through for this use case

[5] https://www.inframix.eu/wp-content/uploads/D4.1_INFRAMIX-plan-for-systems-interaction-integration-and-testing.pdf

- scenario. The vehicles enter the highway in entrance 6B and find the dedicated lane starting in the PK 62,28 and for a kilometre of length. After the dedicated lane, they take exit 7 (intermediate point) to come back to the meeting point. The timing of one complete lap is estimated in 15 minutes.

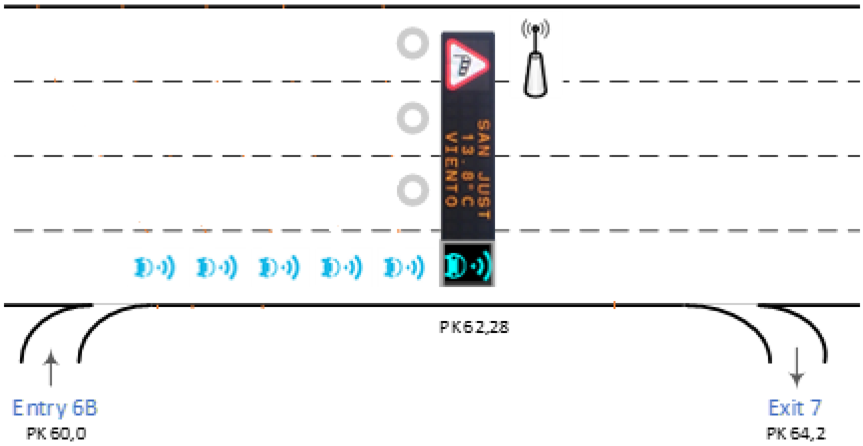

Figure 14 – Test site Area – Scenario 1 / Use Case 1 & 3

In the sketches below with a bigger scale, a detailed description of each lap is shown, in terms of the exact length of the lap, the messages to be displayed and the order of the vehicles before entering in the dedicated lane.

Lap 1: Dynamic Lane Assignment

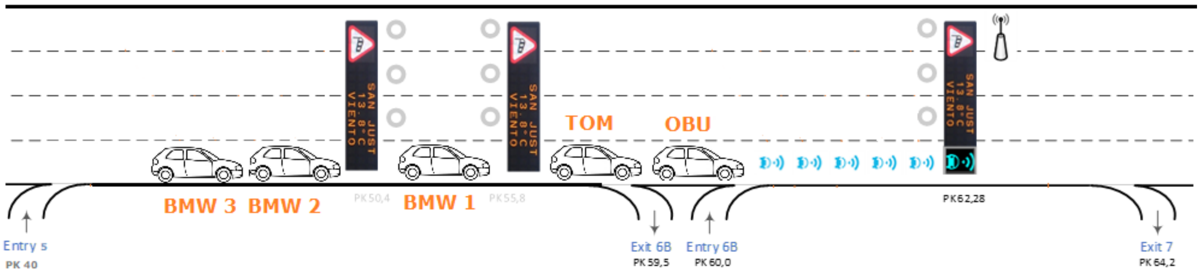

Figure 15 – S1/UC1 – Lap 1

The first lap is the only one that the vehicles enter by the entrance 5 to the test site area (direction to Barcelona) in order to check the information that AAE as a Road operator displays in previous VMS (PK 50,4 and 55,8) related to the autonomous vehicles tests that are taking place in the right lane, at the respective distances of each VMS. These messages are reproduced in the figure below. Besides, the figure shows the information displayed in the VMS located in the entry 6B and the information displayed in the VMS located at the start point of the dedicated lane.

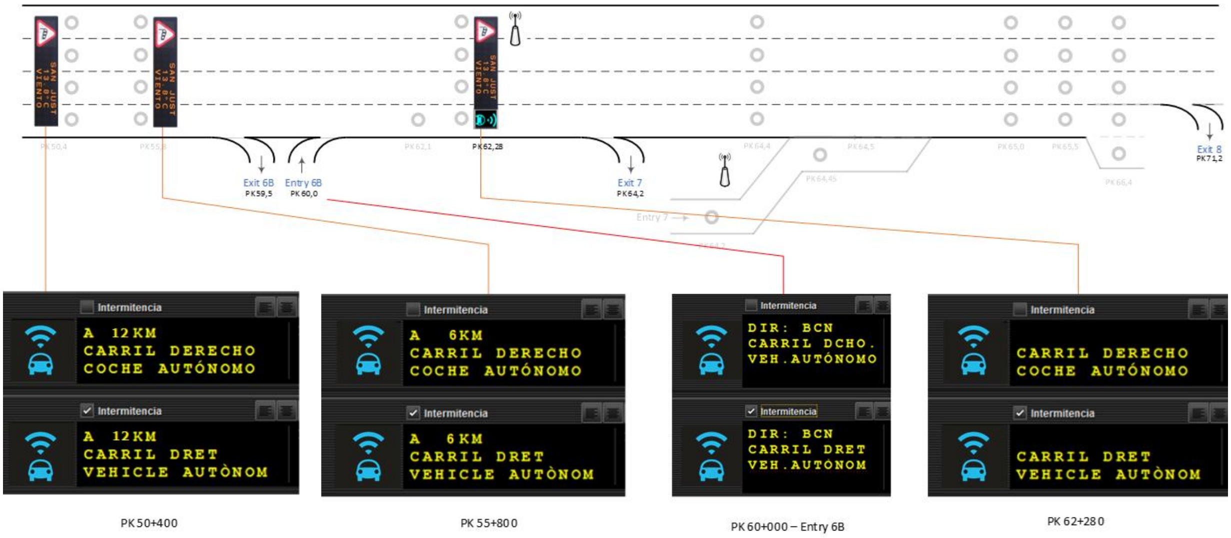

Figure 16 – S1/UC1: Information displayed in previous VMS

Further, in order to increase as much as possible, the safety of the tests, AAE planned to install for scenario 1, four yellow vertical signs (Figure 7) informing the drivers/users of the highway that the tests are going on in this area. Additionally, Figure 7 shows the signal that indicates the end of the dedicated lane, located after approximately one kilometre of the start point, at PK 63,4. The total length of the first lap, since the vehicles enter in entrance 5 and exit as in the rest of the laps in exit 7, is about 35 minutes.

Lap 2, 8 and 9: Dynamic Lane Assignment

In these three laps, the objective is to check when the vehicles that are driving in different lanes, receive the information to change the lane as many times as needed in order to arrive at the dedicated lane (the right one).

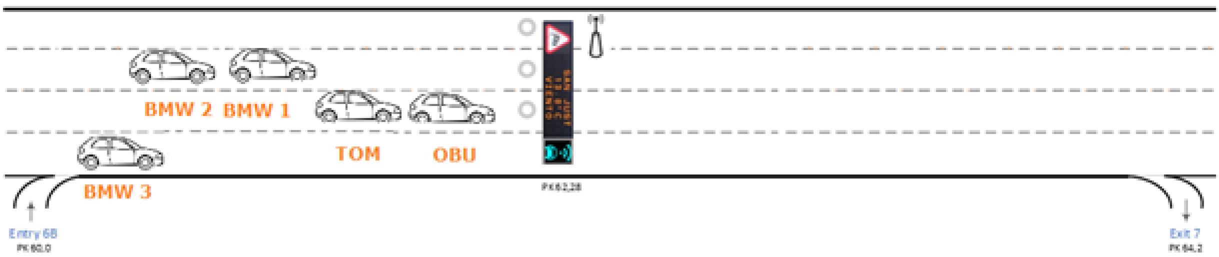

Figure 17 – S1/UC1 – Lap 2

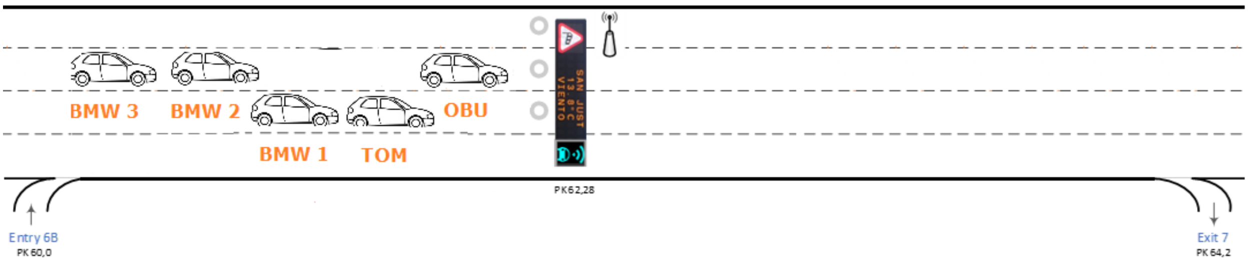

Figure 18 – S1/UC1 – Lap 8

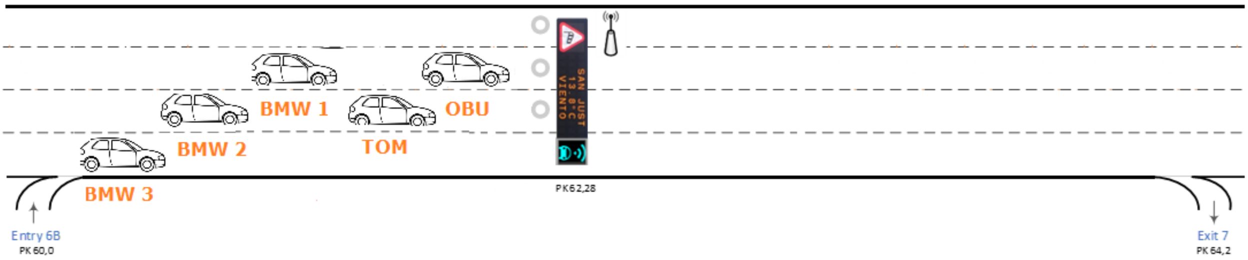

Figure 19 – S1/UC1 – Lap 9

Lap 3, 4, 5, 6, 7 and 10: Dynamic Lane Assignment, plus Speed Limit, Speed Recommendation and Time Gap

In these laps, the vehicles were planned to enter in entrance 6B in the order and position showed in the figure below and receive different messages depending on each lap as described below until taking exit 7:

· Lap 3: Speed Limit 100 km/h

· Lap 4: Speed Recommendation 110 km/h

· Lap 5: Time Gap

· Lap 6: Speed Recommendation 110 km/h + Time Gap

· Lap 7: Speed Limit 100 km/h + Time Gap

· Lap 10: Speed Recommendation 100 km/h

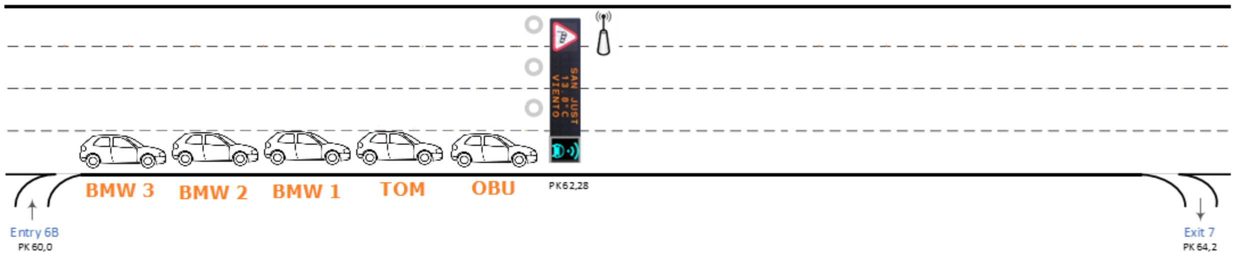

Figure 20 – S1/UC1 – Laps 3, 4, 5, 6, 7 and 10

2.2.1.2 Use Case 3: A conventional vehicle drives on a dedicated lane for automated vehicles

Based on the aforementioned knowledge from deliverable 4.1, the figure below presents a detailed architecture that reveals the interactions and planned integrations required for this use case.

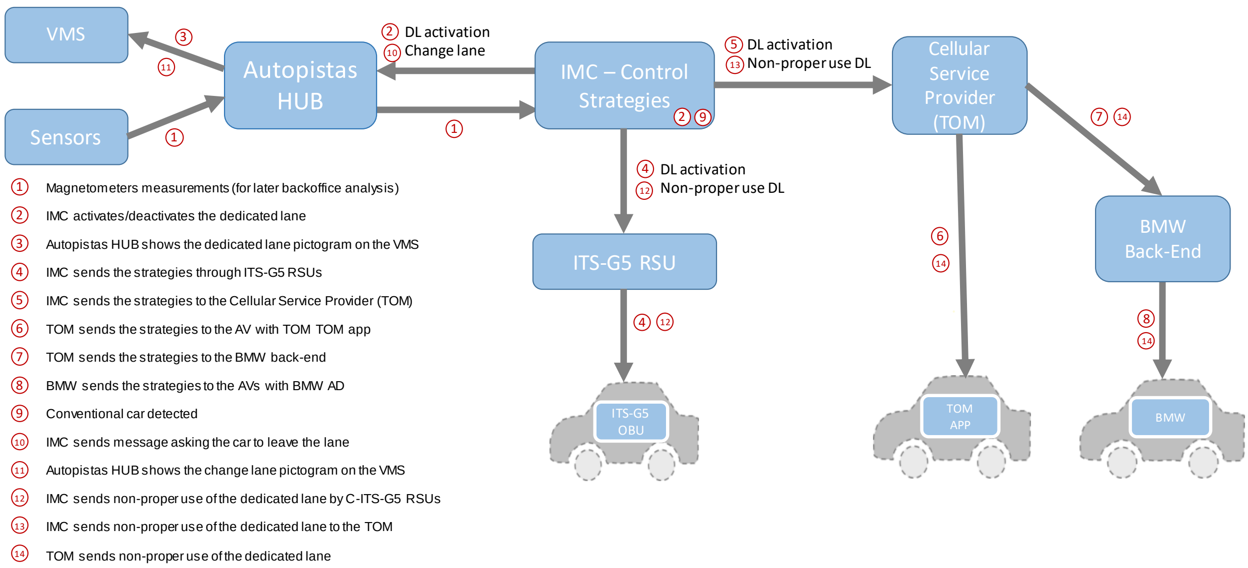

Figure 21 – Systems interactions and planned integrations S1 UC3

This test was scheduled for Sunday the 15th of September from 10:00 am to 1:00 pm and from 3:00 pm to 6:00 pm. As in use case 1 of this same scenario, i.e. DLA, it was planned to do ten laps, entering and exiting from the meeting point Toll-Girona Oest.

In this use case, a conventional vehicle is detected driving on the dedicated lane for autonomous vehicles. At that moment, a signal should be displayed in the VMS asking the conventional vehicle to change the lane. However, to carry out this use case following the safety guidelines of the department "Traffic Operations and Safety Management Centre"[6] , it is not possible to display this pictogram in the VMS. In agreement with the partners and in order to guarantee the DoA and the safety Spanish standards, it was decided that one of the BMWs, the second one in the driving order, would act as a conventional vehicle. A pictogram asking to change the lane would be displayed in the screen of this vehicle (see figure below) that, for this use case, would be called connected conventional car (CCV).

Figure 22 – Message to the CCV driving on the dedicated lane

6 https://blog.autopistas.com/los-centros-de-operaciones-y-seguridad-vial-de-autopistas-la-seguridad-que-no-descansa/

This third use case uses the same test site area as use case one, Figure 40. Vehicles enter the highway in entrance 6B, and find the dedicated lane starting in the PK 62,28 and for a kilometre of length. After the dedicated lane, they take exit 7 (intermediate point) to come back to the meeting point. The timing of one complete lap is estimated to be 15 minutes. These ten laps were planned as in use case one regarding the messages and the order of the vehicles. The only difference is that the second BMW was planned to act as CCV.

In the sketches below with a bigger scale, a detailed description of each lap is shown, in terms of the exact length of the lap, the messages to be displayed and the order of the vehicles before entering the dedicated lane.

Lap 1: Dynamic Lane Assignment with a conventional vehicle detected

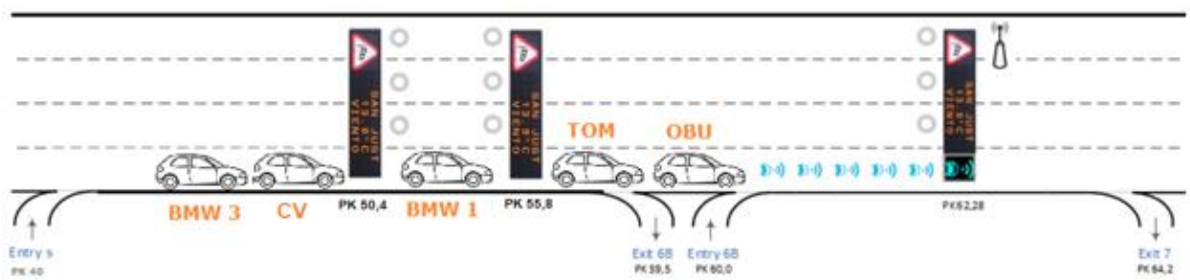

Figure 23 – S1/UC3 – Lap 1

The first lap is the only one that the vehicles enter by entrance 5 to the test site area (direction to Barcelona) in order to check the information that AAE, as a road operator, displays in previous VMS (PK 50,4 and 55,8) related to the autonomous vehicles tests that are taking place in the right lane, at the respective distances of each VMS, as is shown in Figure 49 and in Figure 42.

Further, in order to increase as much as possible, the safety of the test, AAE planned to install for scenario 1, four vertical signs (Figure 7) informing the drivers/users of the highway that the tests are going on in this area. Additionally, Figure 7 shows the signal that indicates the end of the dedicated lane, located after approximately one kilometer of the start point, in the PK 63,4. The total length of the first lap, because the vehicles enter in entrance 5 and exit as in the rest of the laps in exit 7, is about 35 minutes (a little bit longer).

In Figure 49, as the vehicles are driving on the right lane, when the vehicles enter in the dedicated lane, a signal of change lane will appear in the screen of the CV and that vehicle will leave the lane.

Lap 2, 8 and 9: Dynamic Lane Assignment with a conventional vehicle detected

In these three laps, the objective is to check when the vehicles that are driving in different lanes, receive the information to change the lane as many times as needed in order to arrive at the dedicated lane (the right one). In all three laps, the CV should not receive any message as long as it is not driving on the dedicated lane.

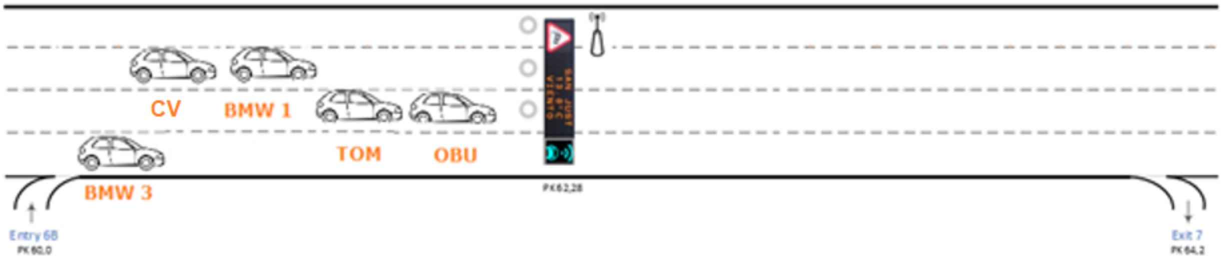

Figure 24 – S1/UC3 – Lap 2

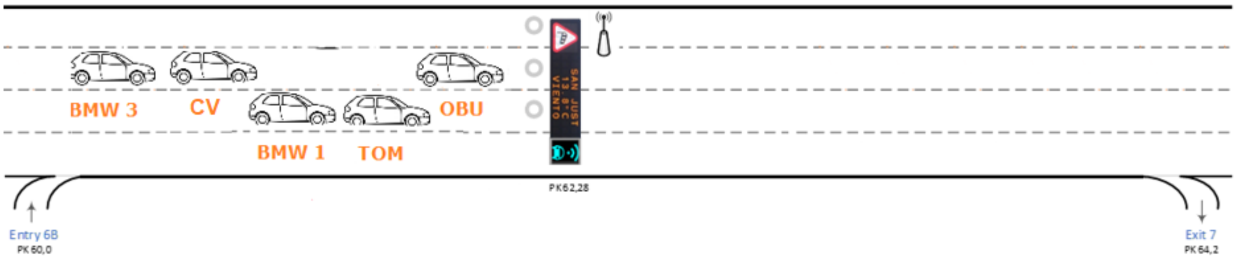

Figure 25 – S1/UC3 – Lap 8

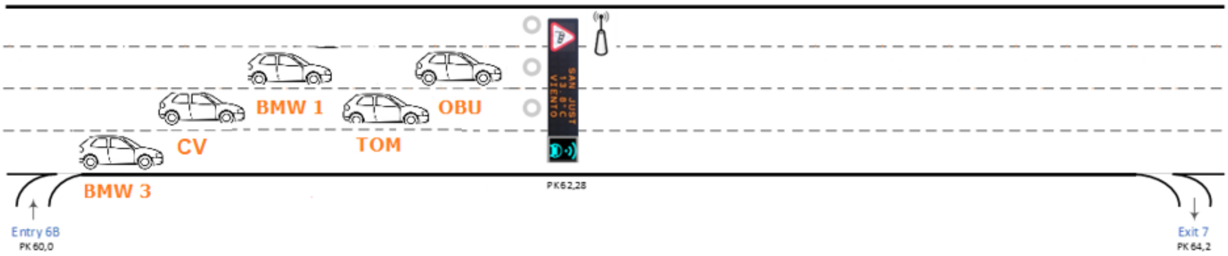

Figure 26 – S1/UC3 – Lap 9

Lap 3, 4, 5, 6, 7 and 10: Dynamic Lane Assignment with a conventional vehicle detected, plus Speed Limit, Speed Recommendation and Time Gap with a conventional vehicle detected

In these laps, the vehicles enter in entrance 6B in the order and position showed in the figure below and they receive different messages depending on each lap as described below until taking exit 7:

- Lap 3: Speed Limit 100 km/h
- Lap 4: Speed Recommendation 110 km/h
- Lap 5: Time Gap
- Lap 6: Speed Recommendation 110 km/h + Time Gap
- Lap 7: Speed Limit 100 km/h + Time Gap
- Lap 10: Speed Recommendation 100 km/h

None of these messages is sent to the CCV. When all the vehicles are on the right lane (dedicated lane) a signal of change lane is displayed on the screen of the CCV asking to leave the lane.

Figure 27 – S1/UC3 – Laps 3, 4, 5, 6, 7 and 10

2.2.2 Scenario 2: Roadworks

The target of this scenario is to guide in an efficient and safe way mixed traffic through roadworks zones by providing accurate information in these areas both to automated vehicles through electronic signals and up-to-date digital maps, and to conventional vehicles through guidance to their nomadic devices, visual signs and other physical elements (e.g. cones). Innovative control strategies will be employed based on the number of automated vehicles present and the prevailing traffic and weather conditions.

Roadworks zones are major safety hotspots with many accidents both for vehicles and for the staff on site. They pose interesting challenges for efficient coordination of mixed traffic flows, where the infrastructure should help the vehicles by providing extended information in real-time like updated (minimally SD- and possibly also HD-) maps, additional traffic signs, reference points on the spot for accurate localization for automated vehicles, new traffic control measures, etc., in the affected area. Both the physical and the digital infrastructure should be prepared to accommodate for such situations.

In order to manage the communications with the vehicles, two different segments were prepared for this scenario, as can be seen in the figure below. The Detection Zone, where the received relevant messages get activated in the vehicles in order to be able to prepare corresponding actions to be taken about the roadworks information, and the Relevance Zone, where the received information becomes valid and vehicles have to adapt their trajectories, speed and time gaps.

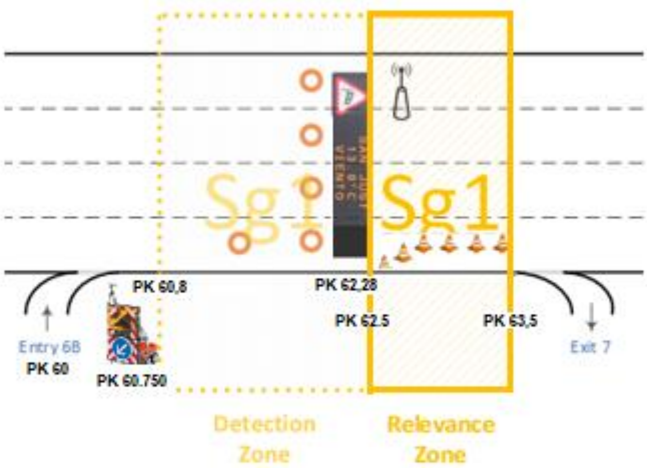

Figure 28 – S2 Detection and Relevance Zones

2.2.2.1 Use Case 1: Roadworks zone in mixed traffic

Based on the aforementioned knowledge from deliverable 4.1, the figure below presents a detailed architecture that reveals the interactions and planned integrations required for this use case.

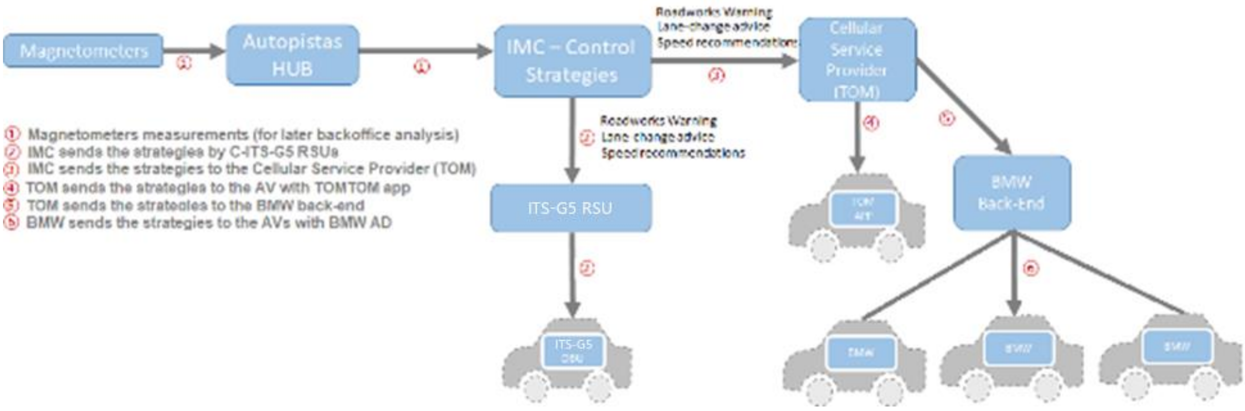

Figure 29 – Systems interactions and planned integrations S2 UC1

This test was scheduled for Thursday 12th of September from 10:00 am to 1:00 pm. It was planned to do five laps, entering and exiting from the meeting point Toll-Girona Oest. The figure below shows the test site area that the vehicles drive through for this use case - scenario. The vehicles enter the highway in entrance 6B, and find the roadworks starting in the PK62,5 and for a kilometre of length, until PK 63,5. After the roadworks, they take exit 7 (intermediate point) to come back to the meeting point. The timing of one complete lap is estimated around 15 minutes.

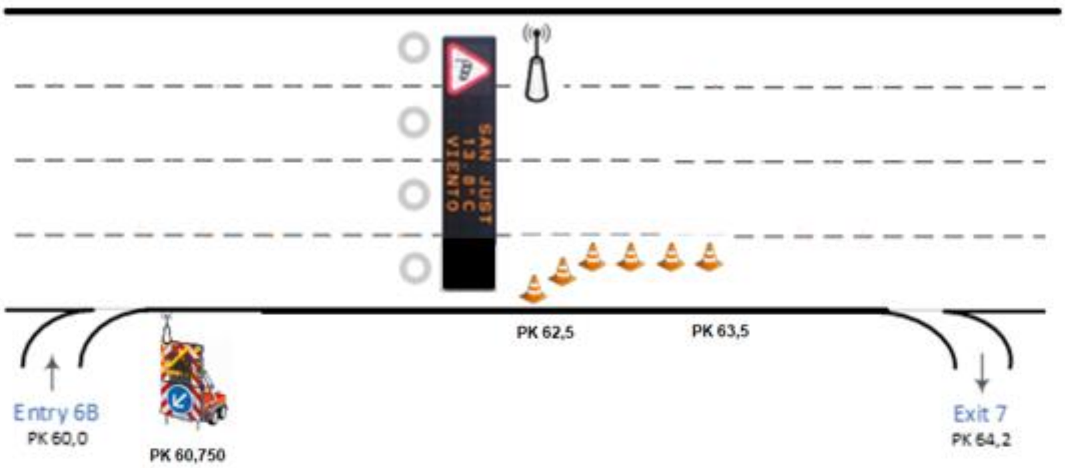

Figure 30 – Test site Area – Scenario 2 / Use Case 1

The figure above also shows, two kilometres before, that AAE will park a trolley located in the PK 60,750 informing the drivers about the proximity to a roadworks zone. Figure 4 shows an example of a trolley. The roadworks zone itself will be signalled with cones.

In the sketches below with a bigger scale, a detailed description of each lap is shown, in terms of the exact length of the lap, the messages to be displayed and the order of the vehicles before entering into the roadworks zone.

Lap 1: Roadworks Warning and Speed Limit at 100 km/h

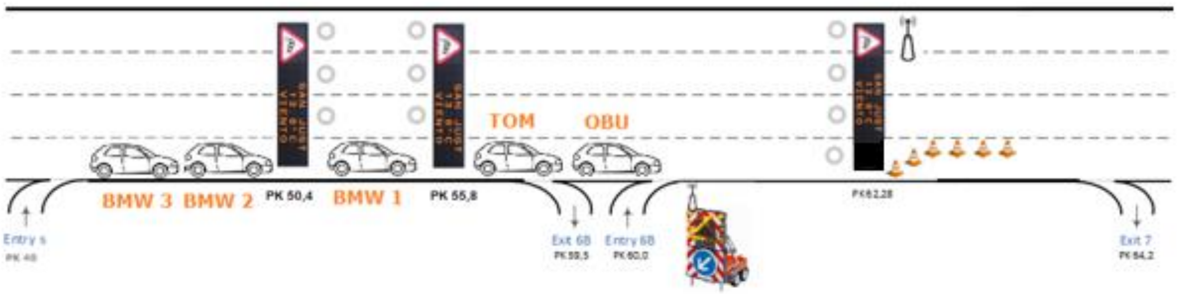

Figure 31 – S2/UC1 – Lap 1

The first lap is the only one that the vehicles enter by the entrance 5 to the test site area (direction to Barcelona) in order to check the information that AAE as a Road operator displays in previous VMS (PK 50,4 and 55,8) related to the roadworks that are taking place in the right lane, at the respective distances of each VMS. These messages are reproduced in the figure below. Besides, the figure shows the information displayed in the VMS located in the entry 6B and the information showed in the VMS located at the PK 62,280. The total length of the first lap, since the vehicles enter in entrance 5 and exit as in the rest of the laps, in exit 7, is about 35 minutes (a little bit longer). The messages that the vehicles will receive are Roadworks Warning and Speed Limit at 100 km/h.

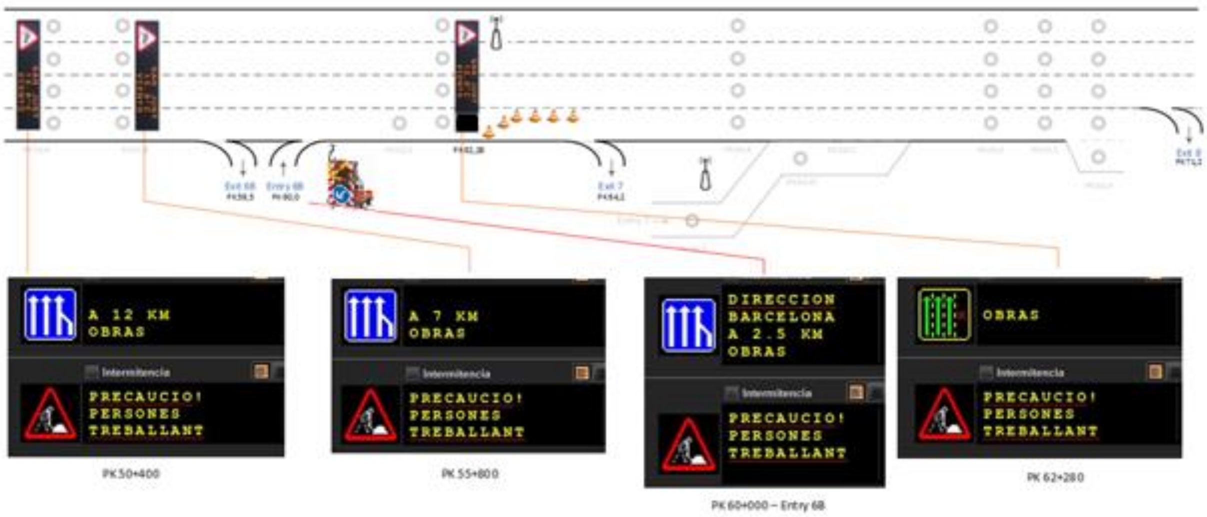

Figure 32 – S2/UC1: Information in previous VMS

In the next laps, the vehicles will enter in the entry 6B in the order showed in the figures below and will receive different messages per lap, until the exit 7.

Lap 2: Roadworks Warning and Speed Recommendation at 90 km/h

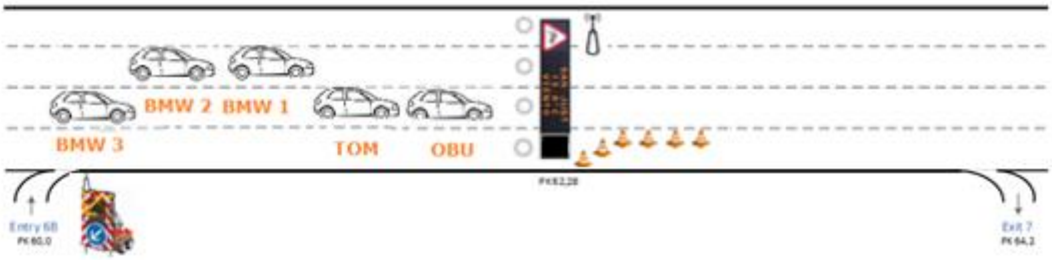

Figure 33 – S2/UC1 – Lap 2

Lap 3: Roadworks Warning and Time Gap

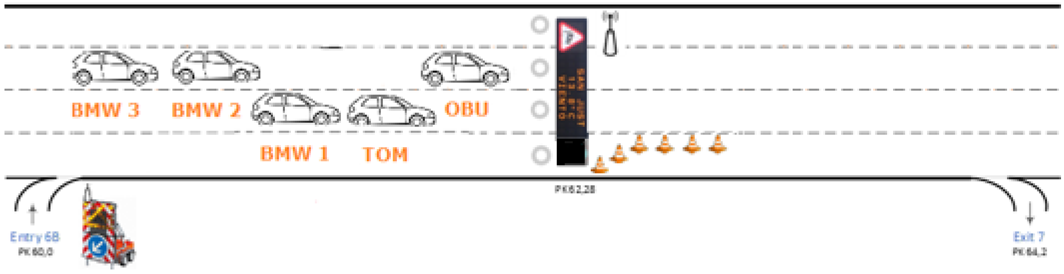

Figure 34 – S2/UC1 – Lap 3

Lap 4: Roadworks Warning and Speed Limit at 100 km/h and Time Gap

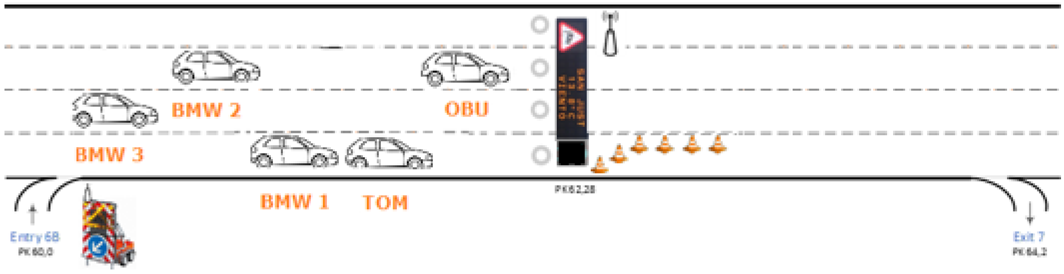

Figure 35 – S2/UC1 – Lap 4

Lap 5: Roadworks Warning and Speed Limit at 110 km/h and Time Gap

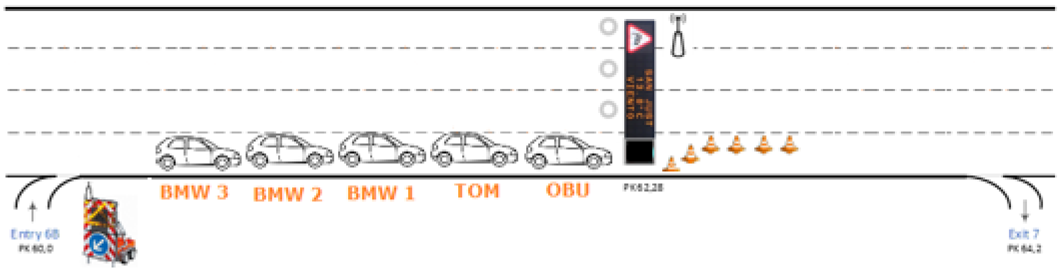

Figure 36 – S2/UC1 – Lap 5

2.2.3 Scenario 3: Bottlenecks

The scope of this scenario is to investigate real-time controllers, involving a variety of control measures, such as dynamic speed limits, dynamic lane assignment and merge assistance to manage mixed traffic situations at bottlenecks and avoid traffic flow degradation. The goal is to examine solutions for in-vehicle and on-road signage in different uses cases: Automated Vehicles (AV) Driving Behaviour Adaptation in Real Time at Sags, Lane Change Advice to connected vehicles at Bottlenecks, and Lane Change Advice combined with Flow Control at Bottlenecks for all vehicles.

In order to manage the communications with the vehicles, four segments were planned for this scenario, as can be seen in the figure below. The segments 1 to 4 were defined with respect to the distance to the merge ramp and therefore to the strategies to be carried out. Segment 4 is the area were congestion is first activated, so we need the measurements from this area. Then Segment 2 is located further upstream and is actually the segment where control is applied using lower speed limits. Segment 3 is in between and is used to accelerate and reach Segment 4 (the bottleneck) with higher speeds than those in Segment 2 in order to achieve capacity values. Finally, any segments upstream of Segment 2, i.e. only one in this case (Segment 1), was used as a safety area in order to guarantee that speed limits are gradually decreased as vehicle approach the Mainstream Traffic Flow Control area (Segment 2).

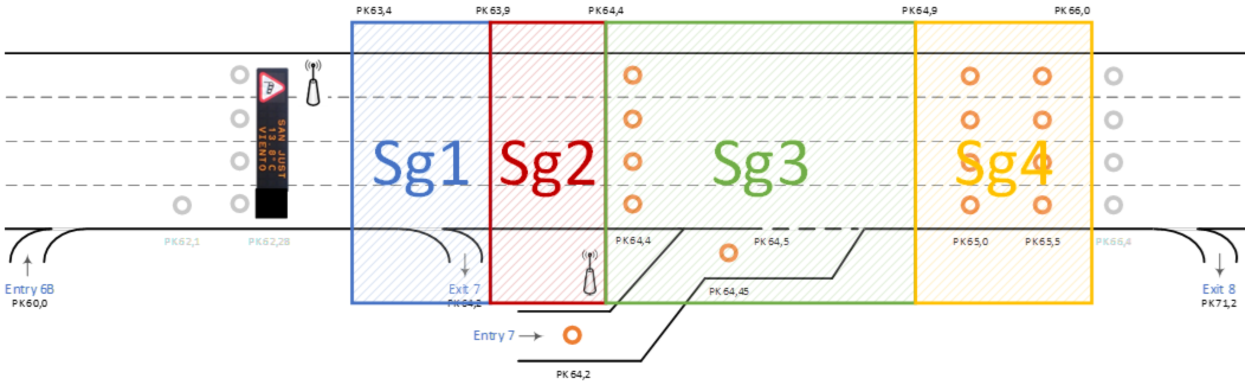

Figure 37 – S3 Detection and Relevance Zones

2.2.3.1 Use Case 1: AV driving behaviour adaptation in Real Time at Sags

Based on the aforementioned knowledge, from deliverable 4.1, the figure below presents a detailed architecture that reveals the interactions and planned integrations required for the three uses cases of this scenario.

The main idea in this use case is that highway capacity may be increased if AVs are asked, when needed, to reduce their time-gap to the respective front vehicles. As a minimum, testing some aspects of the procedures is planned, including passenger feeling with reduced time-gaps, using the small BMW fleet of 3 vehicles with Adaptive Cruise Control (ACC) functionality (the BMWs).

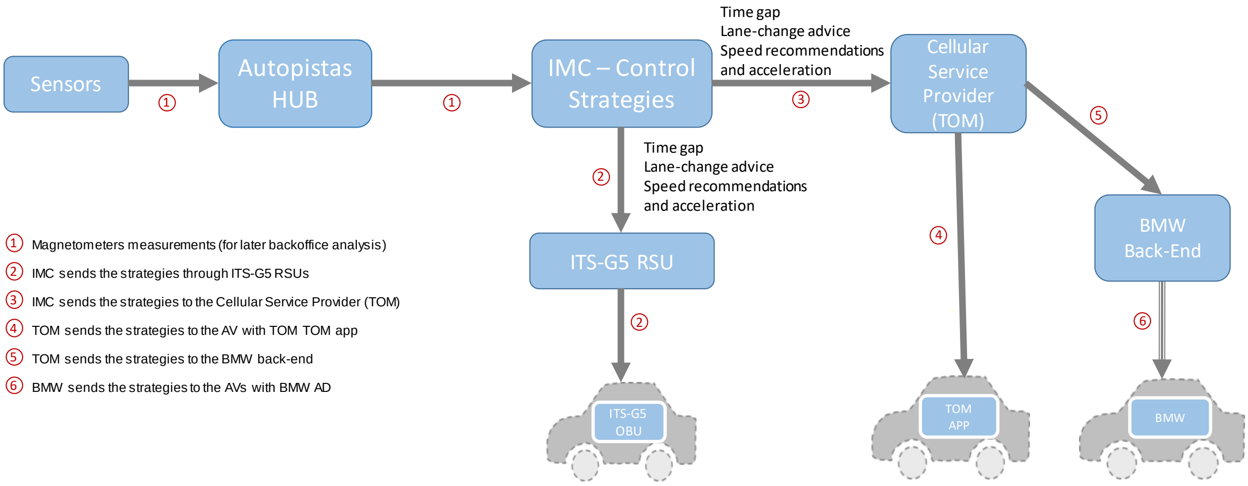

Figure 38 – Systems interactions and planned integrations S3 UC1, 2 and 3

This test was scheduled for Thursday and Friday 12th – 13th of September. It was planned to do 7 laps, entering from the meeting point Toll-Girona Oest. The figure below shows the test site area that the vehicles will drive through for all these use cases, one to three, for this scenario. The vehicles enter the highway in entrance 6B and find the merge ramp (entrance 7) in the PK 64,5. After the merge ramp, they take exit 8 (intermediate point) to come back to the meeting point. The timing of one complete lap is estimated in 20 minutes.

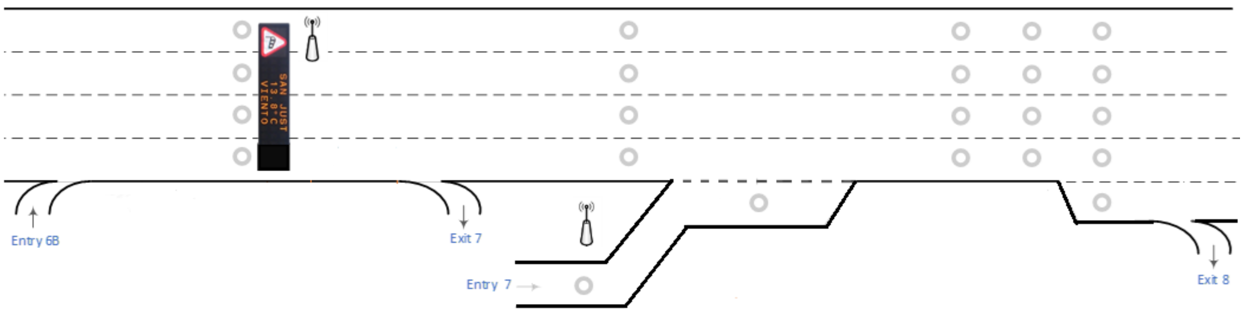

Figure 39 – Test site Area – Scenario 3 / Use Case 1, 2 and 3

Different strategies were analyzed and developed in reference to different scenarios. The following table shows the time gaps among vehicles per lap and segment in accordance with the incorporation of vehicles to the highway.

Table 7 – Detail of the different time gap (s) per lap

	S3/UC1/ Lap1	S3/UC1/ Lap2	S3/UC1/ Lap3	S3/UC1/ Lap4	S3/UC1/ Lap4 B	S3/UC1/ Lap5	S3/UC1/ Lap5 B
Segment 1	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Segment 2	2,5	2,5	2	1,5	1,5	1	1
Segment 3	2,5	2	1,5	1	1 + accel.	1	1 + accel.
Segment 4	2,5	2	1	1	1 + accel.	1	1 + accel.

In two supplementary laps, 4B and 5B, a recommendation to speed up after the bottleneck (in segment 4) was issued to improve the traffic flow.

In the sketch below with a bigger scale, a detailed description of the laps is shown, in terms of the exact length of the lap, the messages to be displayed and the order of the vehicles.

Lap 1 to 5B: Time Gap

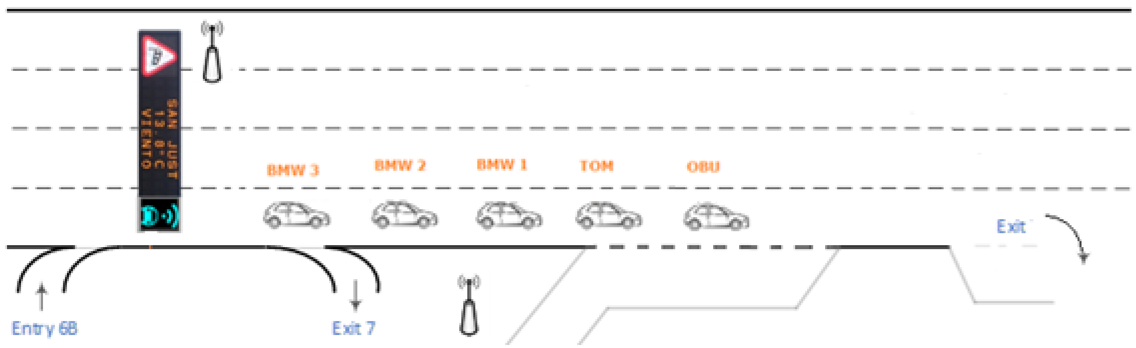

Figure 40 – S3/UC1 – Lap 1 to 5B

2.2.3.2 Use Case 2: Lane Change Advice to connected vehicles at Bottlenecks

The main idea of this use case is that the real-time control strategy for lane change advice to connected vehicles is based on the prevailing traffic conditions in each lane. During the tests the IMC advices the test vehicles to change lane (Figure 67) based on mockups. The purpose of the test is the evaluation of user perceptions regarding lane change advice. Vehicles with lane change Driving Assistance functionality (SAE Level 2) are being used (BMW) for an automated lane change.

This test was scheduled for Friday 13th of September. It was planned to do 2 laps, entering from the meeting point Toll-Girona Oest. Figure 65 shows the test site area. The vehicles enter the highway in entrance 6B and find the merge ramp (entrance 7) in the PK 64,5. After the merge ramp, they will take the exit 8 (intermediate point) to come back to the meeting point. The timing of one complete lap is estimated in 20 minutes.

Lap 1: Lane change advice BMW 2

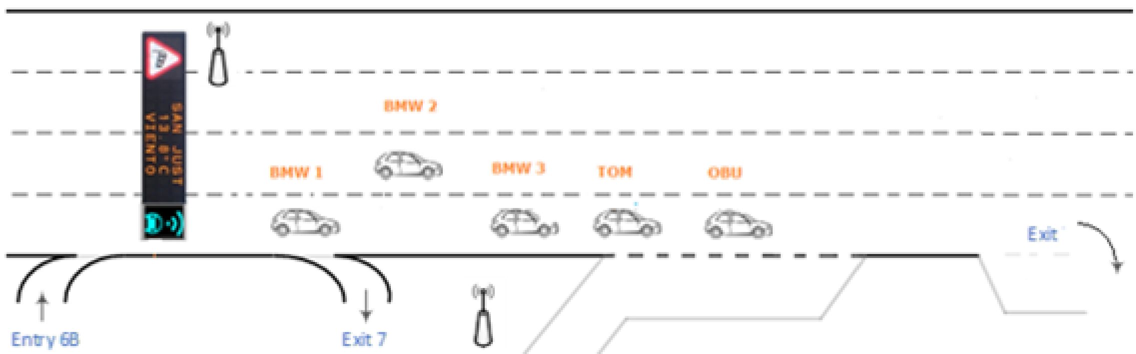

Figure 41 – S3/UC2 – Lap 1

Lap 2: Lane change advice BMW 1 and 3

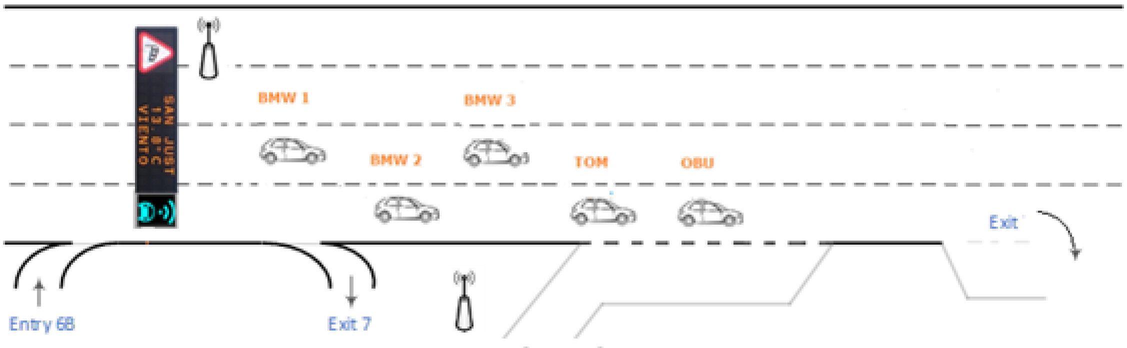

Figure 42 – S3/UC2 – Lap 2

2.2.3.3 Use Case 3: Lane Change Advice combined with Flow Control at bottlenecks for all vehicles

The lane change control may increase the bottleneck capacity by optimizing the distribution of vehicles over all lanes. However, if the arriving demand is higher than the increased capacity, traffic breakdown will occur leading to congestion and degradation due to the capacity drop at the head of congestion. To avoid the traffic degradation, additional flow control measures may be applied, aiming to maintain the traffic flow approaching the bottleneck at capacity values.

The real-time control strategy for combined lane change advice and flow control is based on the prevailing traffic conditions, which are reflected in appropriate traffic data (measurements or estimates) to be specified. In order to evaluate the user perceptions regarding lane change advice in automated vehicles, vehicles with Driving Assistance functionality are used. During the test the BMWs could use this functionality.

Lap 1: Speed Limit and lane change advice

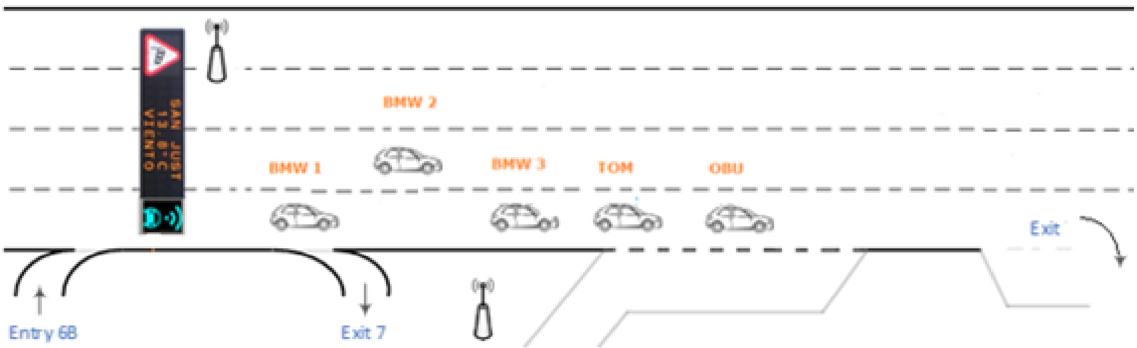

Figure 43 – S3/UC3 – Lap 1

Lap 2: Speed Limit and lane change advice

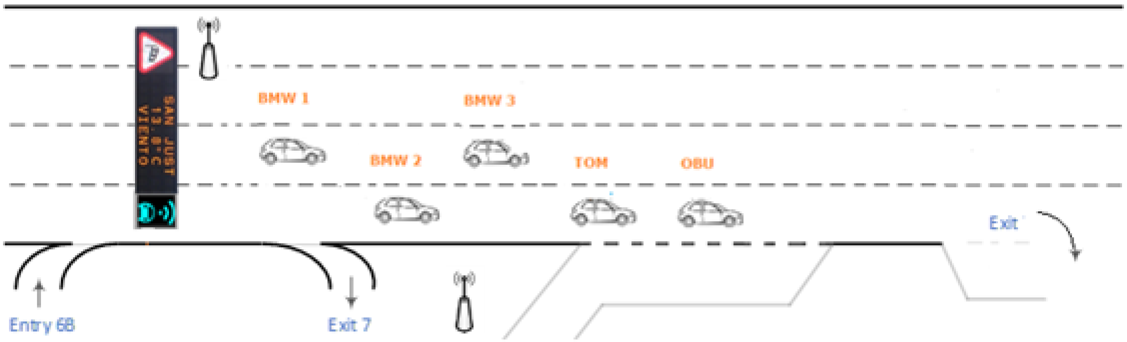

Figure 44 – S3/UC3 – Lap 2

2.3 Results from the Spanish demonstrator

A summary is presented of the results of the tests carried out with details about the number of laps covered regarding the plan described in Section 2.2, the surveys realized, and lessons learned. The following table gives a general overview of the tests performed with location, dates, participants, equipment and devices under test, purpose of the tests, test tools used, and incidences encountered.

Table 8 – General overview Spanish Demonstration

Location	Motorway AP-7 test track Toll Girona Oest direction Barcelona: Entry 6B → Exit 7 & Entry 6B → Exit 8
Date/time	Test DAY 1: 12. September 2019: 9 laps (09:00 am – 19:00 pm) Test DAY 2: 13. September 2019: 14 laps (08:30 am – 18:00 pm) Test DAY 3: 14. September 2019: 6 laps (11:00 am – 17:30 pm)
INFRAMIX participants	Javier Daura, David Porcuna and Juan Salguero (AAE) Hatun Atasayar and Jacek D. Jaczynski (ATE) Stamatis Manganiaris (ICCS) Daniel Toetzl (SIE) Stefaan Duym (BMW) Gunnar Berghäuser and Felipe Teixeira (TOM) Ioannis Papamichail and Vasileios Markantonakis (TUC) David Quesada and Annarita Leserri (ENI)
Equipment under test	INFRAMIX Management Centre One portable Siemens ITS-G5 RSU and two fixed on gantries Siemens ITS-G5 RSUs ITS-G5 OBU and HMI of AustriaTech (ITS-G5 communications) TomTom Cellular Experiments Android App (Cellular communications) BMW communication and HMI device, connected with BMW backend (Cellular communications)
Purpose of the test	Verification of the communication between Autopistas HUB and SIE IMC. Verification of the developed and implemented INFRAMIX communication flow and information distribution via the IMC. Verification of the communication between ITS systems of different OEMs for some ITS messages (CAM / DENM / IVIM) without Geo Net Security Header. Decoding of the extended IVIM messages (incl. AVC Container) with the new ASN.1 Data Base. Verification of the communication Traffic Provider (TOMTOM) and BMW backend.

	Data collection for the evaluation of user's appreciation.
Test Tools	Vector CANoe Car2x test environment with test configuration for receiving ITS messages (IVIM/ DENM). Generation/sending CAM messages in RealBus mode via ITS-G5 without security header in Geo Net protocol
Incidences	Because in the test site there are no congestion problems, to ensure the realization of all the uses cases, it was decided to use mockups.

2.3.1 Day 1: 12th Thursday – Scenario 2: Roadworks

On this first day of tests, 9 laps were covered, and more than 15 surveys were filled by passengers participating in the tests. As scheduled in the test plan, we tested scenario 2, Roadworks - use case 1, with a cut in the right lane for maintenance of the highway. Three situations were tested in which IMC were sent to the vehicles, speed limit, speed recommendation and time gap, as it can be seen in the following table.

Table 9 – S2 / Use case 1: Short Term Roadworks

Number of Laps	Number of Mockup	Message Content	Values
3	S02_UC1_M1_RWW_Speed Limit	RW + Speed Limit	100 km/h
3	S02_UC1_M2_RWW_ Recom.	RW + Speed Recommendation	100 km/h
3	S02_UC1_M3_RWW_Gap	RW + Time Gap	70 m

Figure 45 – Previous VMS indicates the proximity of Roadworks

The results obtained were very positive because many different situations could be tested within the use case and the participants were able to visualize and contrast the content of the messages with the situation on the highway.

Figure 46 – Different screens from the devices

The incidences encountered were solved in the best possible way but delayed the tests with respect to the test plan and only the mockups related to scenario 2 could be covered this day.

2.3.2 Day 2: 13th Friday – Scenario 1: Dynamic Lane Assignment

On this second day of testing, a media event, which was initially planned for a few media channels, suddenly became a great event with more than 25 media channels on site[7]. The presence of the Minister of Digital Policies and Public Administrations of the Generalitat of Catalonia, Mr. Jordi Puigneró, required a lot of dedication from the partners and while being a great opportunity to disseminate the project results, it also delayed the tests with respect to the test plan.

[7] Source of media

Figure 47 – Dynamic Lane Assignment

To respond the media interest, the test plan was changed because scenario 1 is the most visual for the marketing and dissemination of the INFRAMIX project. In the morning, 10 laps were covered with the DLA scenario while assisting the media channels that were gathering information about the tests and the possibilities of INFRAMIX technologies. Overall, it was a dissemination success. In the afternoon, continuing with scenario 1, four additional laps were covered. In total more than 25 surveys were filled by passengers participating in the tests. The three most interesting situations were tested in which IMC were sent to the vehicles, DLA, speed limit and time gap, as can be seen in the following table.

Table 10 – S1 / Use case 1: Dynamic Lane Assignment

Number of Laps	Number of Mockup	Message Content	Values
10	S01_UC1_M1_DLA	Dynamic Lane Assignment	N/A
1	S01_UC1_M5_DLA_Gap	DLA + Time Gap	70 m
1	S01_UC1_M3_DLA_Limit	DLA + Speed Limit	100 km/h
1	S01_UC1_M1 _DLA	DLA	
1	S01_UC1_M5_DLA_Gap	DLA + Time Gap	70 m

The results obtained were very positive, because many different situations could be tested within the use case and the participants were able to visualize and contrast the content of the messages with the situation of the highway.

Table 11 – S1 / Use case 1: Outcome

Mockup	Technology	Lap Number
		1 - 10
S01_UC1_M1_DLA	ITS-G5	OK
	Cellular (TOM)	OK

	Cellular (BMW)	OK
S01_UC1_M5_DLA_Gap	ITS-G5	OK
	Cellular (TOM)	OK
	Cellular (BMW)	OK
S01_UC1_M3_DLA_Limit	ITS-G5	OK
	Cellular (TOM)	OK
	Cellular (BMW)	OK
S01_UC1_M1_DLA	ITS-G5	OK
	Cellular (TOM)	OK
	Cellular (BMW)	OK
S01_UC1_M5_DLA_Gap	ITS-G5	OK
	Cellular (TOM)	OK
	Cellular (BMW)	OK

Use case 3 of the scenario 1: “a conventional vehicle drives on a dedicated lane for automated vehicles”, the difference with the first use case is when a conventional vehicle is detected driving by the dedicated lane for autonomous vehicles. At that moment, a signal is displayed in the VMS asking the conventional vehicle to change the lane. To carry out this use case within the safety of the highway and follow the guidelines of the department "Centro de Operaciones y Seguridad Vial" at the end, was not possible to show this pictogram in the VMS and for this reason, finally we could not carry it out.

Figure 48 – Different screens that display the dedicated lane

2.3.3 Day 3: 14th Saturday – Scenario 3: Bottleneck

Finally, on the third day, Scenario 3 tests were performed.

Figure 49 – Lane Change Advice

During the day they were tested use case 1,2 & 3 of scenario 3: AVs driving behaviour adaptation in real time at Sags, Lane Change Advice to connected vehicles at bottlenecks & Lane Change Advice combined with Flow Control at Bottlenecks for all vehicles. 6 laps were taken, and more than 30 surveys were obtained.

Table 12 – S3 / Use case 1,2 and 3

Number of Laps	Number of Mockup	Message Content	Values
1	S03_UC1_M6	Time Gap	Variable
1	S03_UC1_M7	Time Gap	Variable
2	S03_UC2_M1	Change Line	
1	S03_UC3*_M II 51	Speed Limit + acceleration	Variable
1	S03_UC3_M II 52	Speed Limit+ acceleration	Variable

The results obtained were satisfactory, because different situations could be tested within the use case and the participants were able to visualize and contrast the content of the messages with the situation of the highway.

Table 13 – S3 / Use case 1,2 and 3: Outcome

Mockup	Technology	Number of Lap	
		1	2
S03_UC1_M6	ITS-G5	OK	
	Cellular (TOM)	OK	
S03_UC1_M7	ITS-G5	OK	
	Cellular (TOM)	OK	

S03_UC2_M1	ITS-G5	OK	OK
	Cellular (TOM)	OK	OK
S03_UC3_M II 51	ITS-G5	OK	
	Cellular (TOM)	OK	
S03_UC3_M II 52	ITS-G5	OK	
	Cellular (TOM)	OK	

In the use case 3: “Lane Change Advice combined with Flow Control at Bottlenecks for all vehicles” the flow control signals were only shown to the AV, in accordance with the aforementioned with the guidelines of the department “Centro de Operaciones y Seguridad Vial” related with the safety on the highway.

Within scenario 3, in use case 2, when changing lanes to allow access to the vehicle that is accessing the ramp, mockups were designed in reference to BMW vehicles, since they are the only ones that offer unicast connection (personalized messages for each vehicle).

The ITS-G5 communication technology demonstrated a stable and successful communication between the infrastructure stations (ITS-G5 RSUs) and the vehicle station (ITS-G5 OBU) during all three testing days.

The INFRAMIX partners participating in the Spanish demonstrator unanimously decided to finish the tests at the end of this day due to their success and having tested all the highlight tests.

3 Austrian demonstrator

This chapter defines the test site areas and all the installations, signals, materials and actions in detail in order to get the most accurate view of how Asfinag with the support of the partners involved in the demonstrations, managed the emulation of each use case of the three scenarios.

3.1 Austrian demonstrator

The Austrian motorway operator Asfinag together with ALP.Lab[8] operates a test track with an approximate length of 20 km on the motorway A2 close to the city of Graz. The aim of this test track is to provide an extended physical and digital infrastructure for validating Automated Driving functions and test new traffic management strategies for connected automated vehicles. The digital road infrastructure is based on a fibre-optic network that provides IP-based network connectivity to gantries. HD video-based image processing algorithms, ground-based radar sensors and triple-technology traffic detectors are used to provide information about the traffic flow including anonymized velocity, vehicle type and lane usage. By applying an intelligent sensor fusion algorithm to the data gathered over a distance of 1.8 km, Asfinag can generate trajectory vehicle data which can be used to identify the ego-vehicle movement (see Figure 50a) and to record the surrounding traffic of an automated vehicle in complex traffic situations (see Figure 50b).

[8] https://www.alp-lab.at/

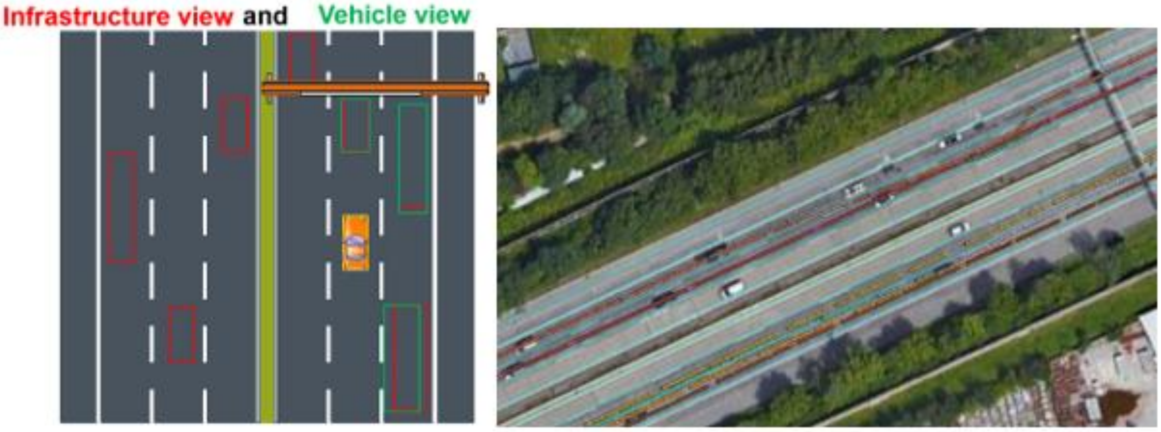

Figure 50 – Combined infrastructure (red) and vehicle (green) view (a) and generated anonymised vehicle trajectories on the real test-site (b)

In addition to the traffic sensor technologies, the test-site is equipped with weather stations, 12 ITS-G5/DSRC road-side units, and intelligent, connected, mobile trailers to provide, e.g., C-ITS Day 1 Services like VMS information, road works warnings and first services for automated vehicles. This data can also be provided via a DATEX II interface to cloud services. This architecture enables the Austrian test-site to validate the hybrid communication (Figure 51a) and user perception of roadwork zone and bottleneck scenarios.

Figure 51 – INFRAMIX hybrid communication model (a) and intelligent roadworks trailer (b)

Furthermore, an intelligent roadworks trailer (Figure 51b) is available on the Austrian test site. It contains a mobile VMS to signal roadworks warnings visually and will be integrated to the backend via cellular communication and support ITS-G5/DSRC for V2X communication.

The novel added value of the Austrian test-site is the available ground truth data (see Figure 52a) and 3D playback for analysis (see Figure 52b) which the ALP.Lab test region provides. Note that also the proving ground Lang/Lebring, which was used for hybrid testing (see Section 4.1), is part of the ALP.Lab test region. The Asfinag road infrastructure, including the sensor fusion trajectories, and the information about the static and dynamic visual signs shape the digital ground truth which can be compared to the recorded vehicle's on-board sensor data and matched with an UHD map. This service can be used by INFRAMIX to gather additional insights into vehicle movements and end-2-end testing for automated and autonomous driving functions and vehicles in a safe, real and hybrid environment.

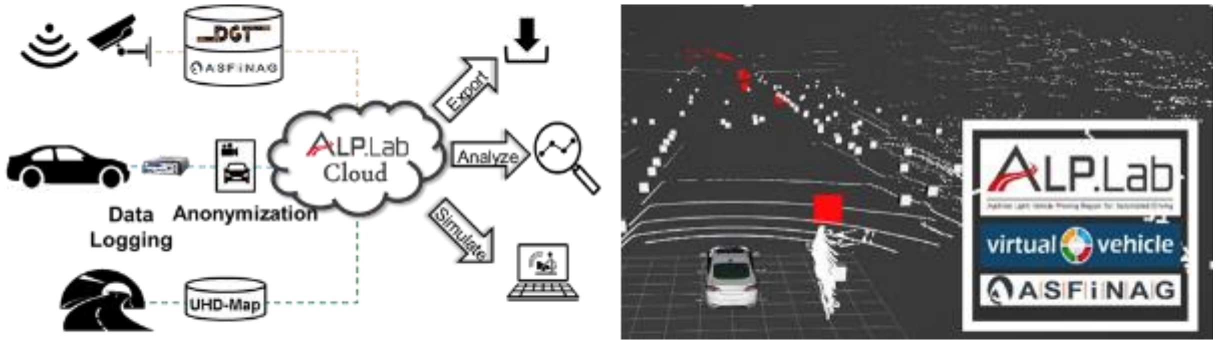

Figure 52 – Collecting Ground Truth (a)
and 3D playback technique of infrastructure data (red) and vehicle data (white) (b)

3.1.1 Purpose of Tests

The test site in Graz, Austria, was used to demonstrate the three traffic scenarios:

- SC1: Dedicated lane assignment,
- SC2: Roadworks, and
- SC3: Bottlenecks,

in real world operational conditions.

3.1.2 Field test Operator definition

Asfinag is the Austrian motorway operator and is owned by the Republic of Austria. More than 2,200 km of road infrastructure are planned, financed, built, maintained, operated and tolled under the responsibility of Asfinag. To provide the best possible infrastructure, Asfinag focusses on:

- Availability,
- Traffic management,
- Traffic information,
- Road safety, and
- Technological innovations.

The network includes 5,192 bridges as well as 166 tunnels and has more than 370 connection points. In total, 31,608 million car km were driven in 2017 on Austria's motor- and expressways. Asfinag works exclusively with the income from motorway tolling.

As a modern motorway operator, Asfinag, is already today thinking about the mobility of tomorrow. In the future, all relevant road traffic information will be directly transmitted into the customers' cars to quickly provide them with information about the traffic situation on the motorways. Therefore, Asfinag uses digital infrastructure along with other elements such as communication devices and displays. This infrastructure includes a variety of sensors which serve to detect traffic and its surroundings in the best way possible. The totality of all information gathered by these sensors make it possible to monitor the entire motor- and expressway area.

3.1.3 Test Site Partners

Table 14 lists the partners involved in the Austrian test site activities and provides a detailed description of the partner's responsibility in the form of tasks/activities assigned or expected by each partner.

Table 14 – Description of Austrian test site partners' involvement

Partner	Involvement description
ATE	**Role: Support the test site and its activities** **Activities:** • Contribute in testing the ITS-G5 information chain • Provision of the ITS-G5 OBU and development of a corresponding HMI for testing the ITS-G5 link and the new signs • Support during the demonstration on the test site • Support on the OBU installation in the vehicle • Support to the ITS-G5 link testing
ICCS	**Role: Support integration and testing activities in the test site** **Activities:** • User appreciation • Support integration and testing activities • Coordination between the tests and WP5 (make the best of them as inputs for WP5)
SIE	**Role: Deploy new and/or adapt the existing equipment of the test site for the supported Use Cases.** **Activities:** • Coordinating the integration of WP2 and WP3 developments and the corresponding testing in the Austrian test-site • Installation and configuration of the ITS-G5 RSUs • Integration of the RSUs to the INFRAMIX technical architecture • Integration of the Asfinag interface to the INFRAMIX technical architecture (establishment of the connection to the IMC) • Support on the demonstration plan definition • Preparation of the C-ITS messages (mockups) for the demonstration • Operation of the ITS-G5 communication (based on IMC control strategies) • Operation of the IMC during the demonstration on the test site in order to run the demonstration test. • Provision and installation of ITS-G5 RSUs
VIF	**Role: Integration of Austrian test site for sub-microscopic simulation and Hybrid testing** **Activities:** • Modelling of an on-ramp of the Austrian test site based on map data provided by ASF • Simulation of the described use cases with this model • Use the road model for Hybrid Testing on the proving ground in Lang/Lebring
TUC	**Role: Involvement in all issues related to traffic state estimation and traffic control algorithms developed in WP2 for the traffic scenarios and being considered in the test site** **Activities:** • Involvement in all issues related to traffic state estimation and traffic control algorithms developed in WP2 • Support on the adaptation of the test-site based on the traffic estimation and control strategies requirements

	• Support on the demonstration plan definition based on the traffic conditions and the control strategies' impact • Support during the demonstration on the test site
ASF	**Role: Leader and coordinator for the integration and testing at the Austrian demonstrator** **Activities:** • Coordinating the adaptation of the test-site and the Austrian demonstrations • Integration with the IMC • Provide test plan (so that SIE can build the messages) • Managing the demonstrations
ENI	**Role: Support in preparation and dissemination** **Activities:** • Coordination between the tests and WP6 (make the best of them as inputs for WP6) •
TOM	**Role: Deliver a demonstrator with advanced lane and speed guidance that implements traffic control for human drivers, which can be used in the project test site for experimental evaluations** **Activities:** • Provision of an app including lane information such as open/close, SAE level, variable speed, and acceleration • Support during the demonstration on the test site
BMW	**Role: Support, integration and testing of onboard functionalities which include speed, lane and route recommendations for automated and conventional vehicles based on fleet data, sensor data and input from the road operator.** **Activities:** • Provide information about lane, speed and gap recommendations through the BMW Backend for the BMWs visualized in an on-board App in the integrated Navigation screen • Support to the cellular link testing • Support during the demonstration on the test site

3.1.4 Field test definition

The Austrian Test site is located in the Graz area on the motorway A2 between Graz West and Lassnitzhöhe. More than 20 km of the motorway segment are equipped with both state-of-the-art and innovative sensory equipment (see Section 3.1.5 Register – Inventory of equipment).

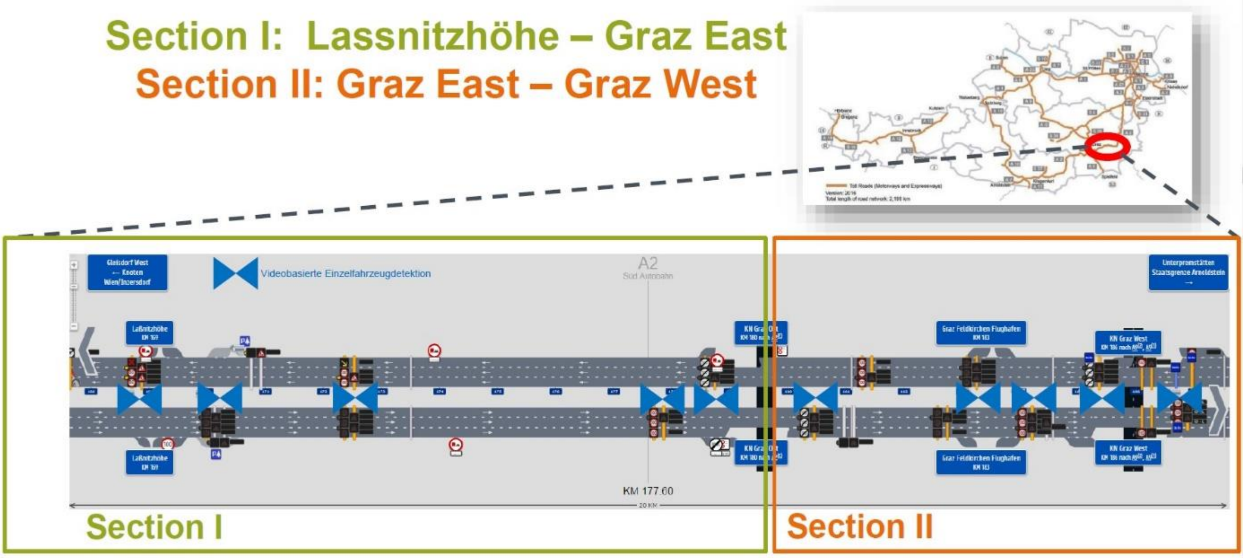

Figure 53 – Location of the Austrian test site (schematic)

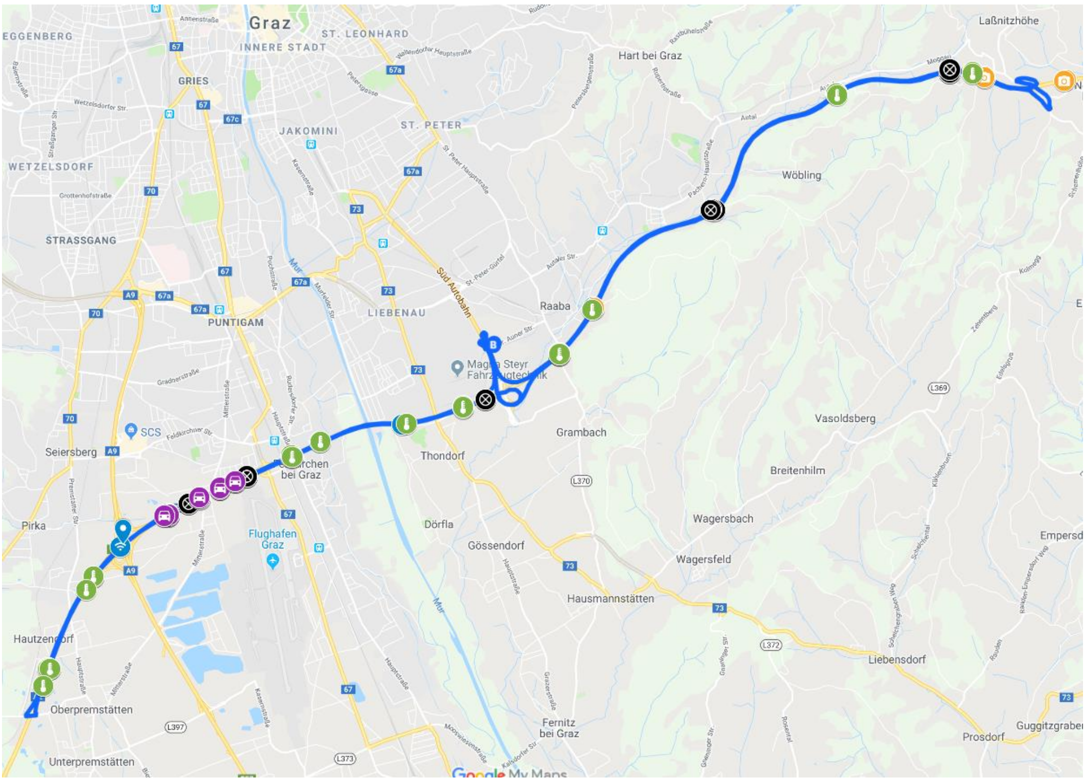

Figure 54 –The Austrian test site with examples of the sensorial equipment. Maps for each of the equipment categories are shown in the following.

For practicality reasons, during the testing, this track was separated into two parts, the **East loop** (Section I in Figure 53) between ABM Raaba (the motorway maintenance centre in Raaba to the south-east of Graz) and Lassnitzhöhe, and the **West loop** (Section II in Figure 53) between ABM Raaba and Graz West / Unterpremstätten.

Different messages were sent out for both driving directions. Driving direction West is DD1 and driving direction East is DD2.

3.1.4.1 East loop (EL)

The East loop is the motorway stretch between ABM Raaba (the motorway maintenance centre in Raaba to the south-east of Graz) and Lassnitzhöhe:

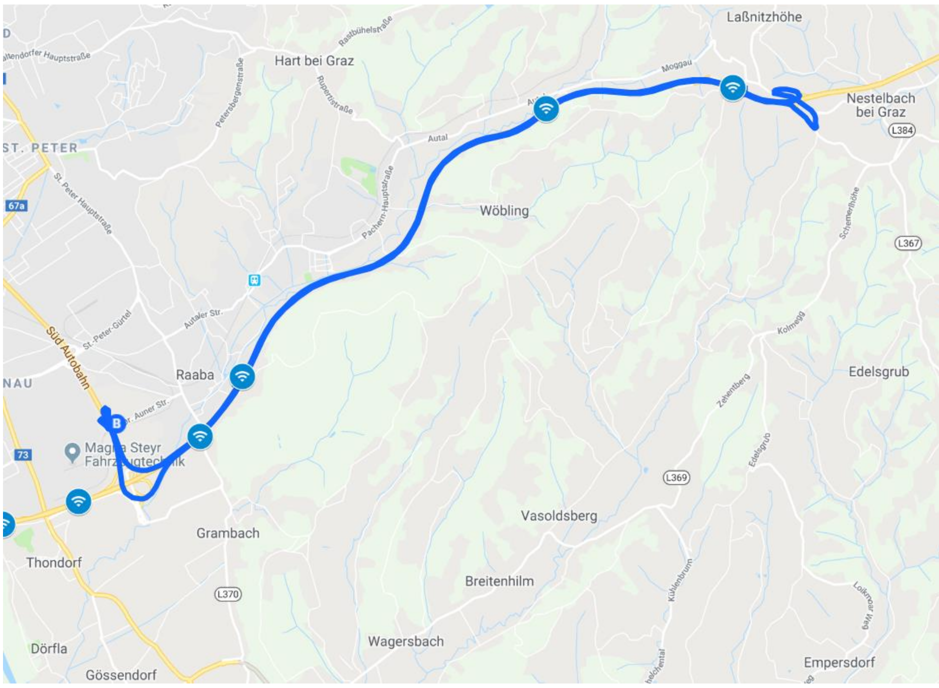

Figure 55 – Austrian test site: East loop with RSUs

3.1.4.2 West loop (WL)

The West loop is the motorway stretch between ABM Raaba (the motorway maintenance centre in Raaba to the south-east of Graz) and Graz West / Unterpremstätten:

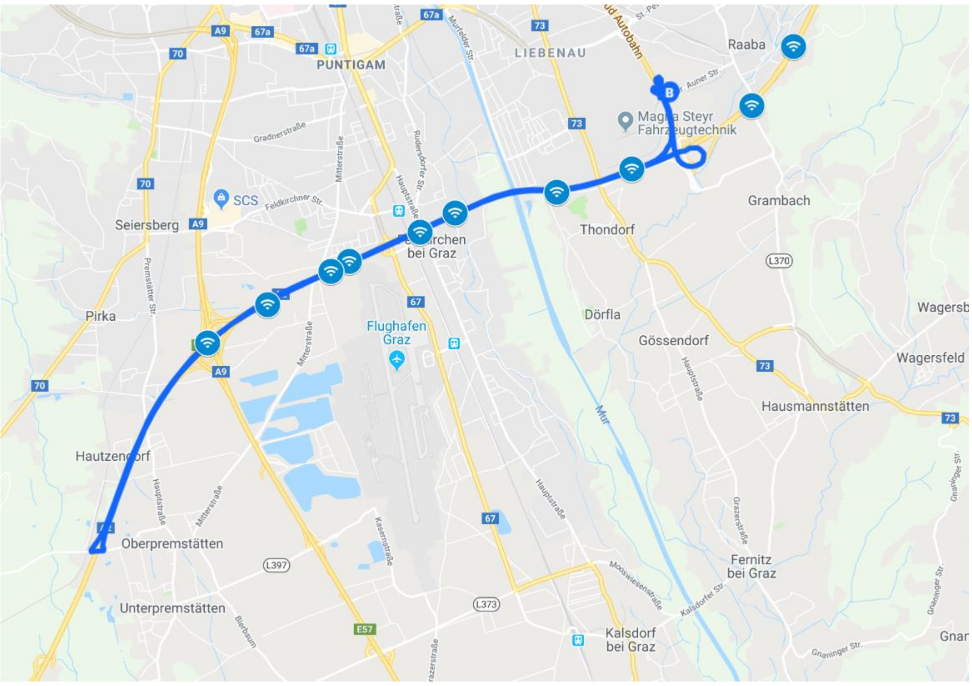

Figure 56 – Austrian test site: West loop with RSUs

3.1.5 Register – Inventory of equipment

The Austrian test site is equipped with gantries in 12 positions. Most of the special sensory equipment is mounted on these gantries.

3.1.5.1 VMS equipment

Figure 57 – Positions of VMS equipment mounted on gantries on the Austrian test site (East loop)

Figure 58 – Positions of VMS equipment mounted on gantries on the Austrian test site (West loop)

15 VMS displays are mounted on all gantries in the 12 positions in both driving directions.

Table 15 – Positions of VMS equipment mounted on gantries on the Austrian test site

15 VMSs at 12 positions at	Driving Direction (1 E->W; 2 W->E)
km 169,897	1
km 172,275	both
km 177,605	1
km 178,480	2
km 180,191	1
km 181,185	2
km 182,487	1
km 182,993	2
km 183,948	1
km 184,200	1
km 185,104	both
km 186,000	both

3.1.5.2 ITS-G5 RSUs

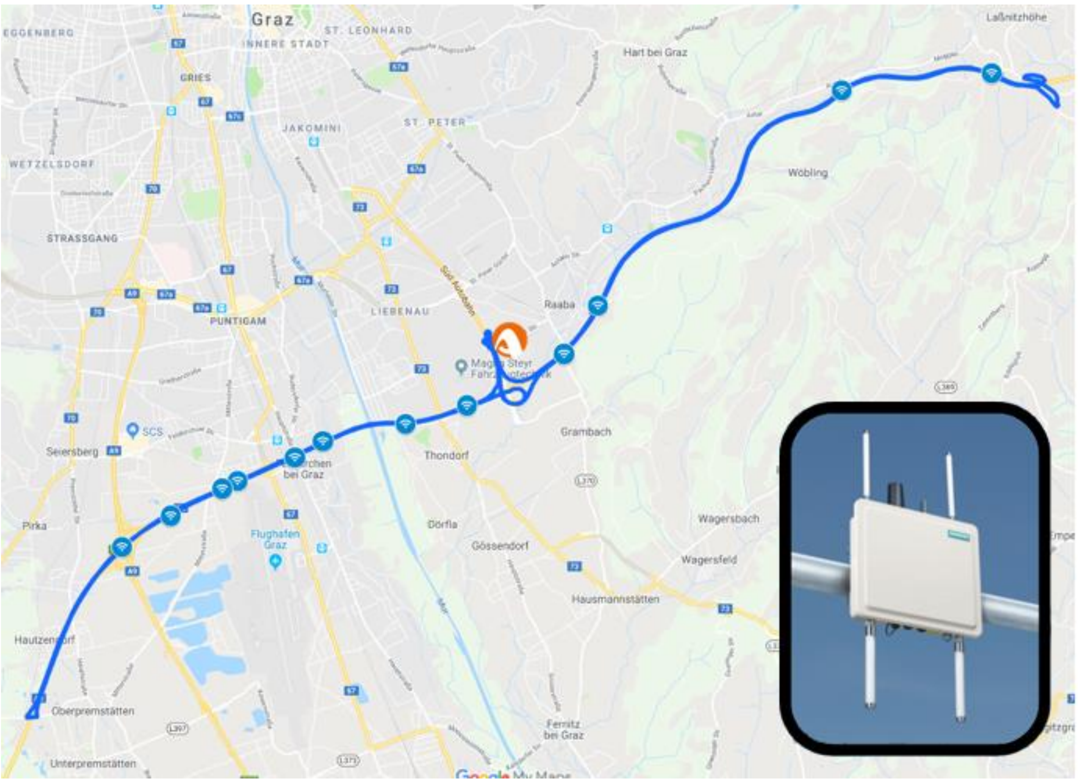

Figure 59 – Positions of RSUs on Austrian test site (schematic)

12 roadside units are installed on the Austrian test site mounted on already existing gantries on the ASFINAG Network.

Table 16 – Positions of Roadside Units on Austrian test site

12 RSUs	km
	169,897
	172,275
	177,605
	178,48
	180,191
	181,185
	182,487
	182,993
	183,948
	184,2
	185,104
	186

3.1.5.3 Radar

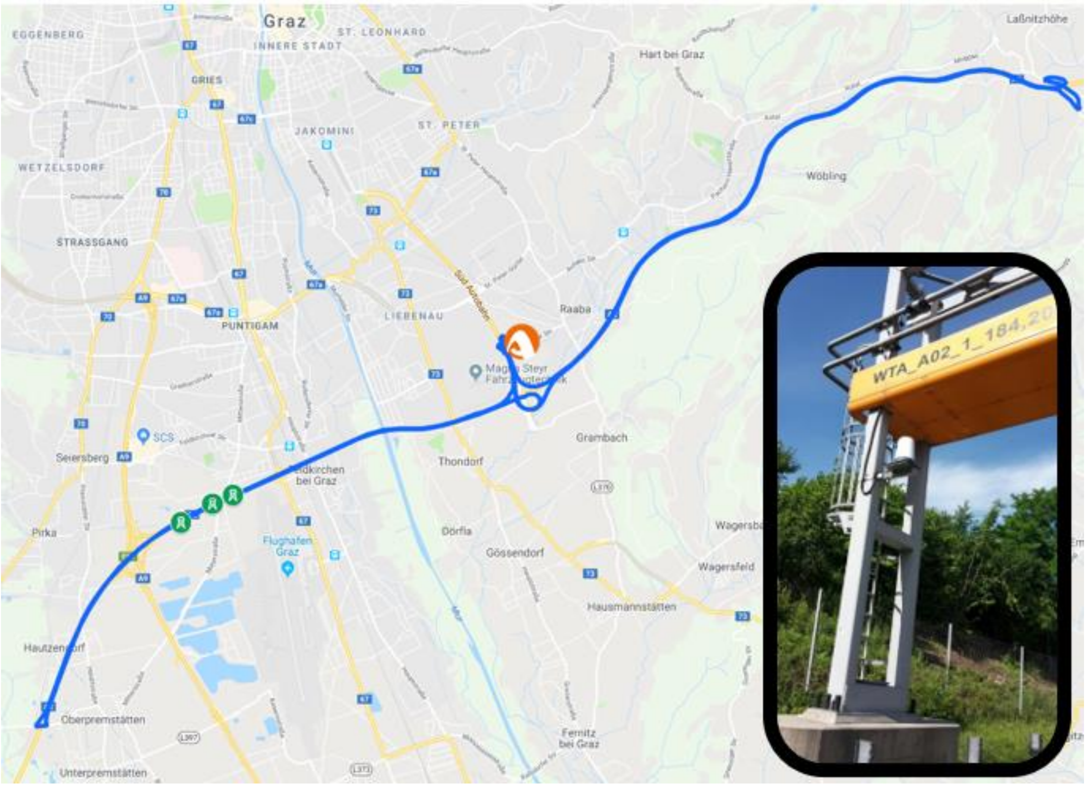

Figure 60 – Positions of ground radar on Austrian test site (schematic)

On the Austrian test site, there are three ground radar units covering a stretch of around 1.5 km of the West loop with high resolution full range (360°) radar detectors.

Table 17 – Positions of ground radar on Austrian test site

Radar 1	WTA_A02_1_184,200
Radar 2	MAS_A02_1_184,550/MAS_A02_2_184,550
Radar 3	AQ_A02_2_185,104

3.1.5.4 Video cameras

Figure 61 – Positions of the video cameras on the Austrian test site (schematic)

26 cameras with incident detection are located on the Austrian test site in both driving directions.

Table 18 – Positions of the video cameras on the Austrian test site

VK_A02_168,610-F1-FL-DHS
VK_A02_168,610-F2-FL-DHS
VK_A02_169,900-F1-FL-DHS
VK_A02_169,900-F2-FL-DHS
VK_A02_172,280-F1-FL-DHS
VK_A02_172,280-F2-FL-DHS
VK_A02_177,610-F1-FL-DHS
VK_A02_177,610-F2-FL-DHS
VK_A02_178,480-F1-FL-DHS
VK_A02_178,480-F2-FL-DHS
VK_A02_182,990-F1-FL-DHS
VK_A02_182,990-F2-FL-DHS
VK_A02_183,950-F1-FL-DHS
VK_A02_183,950-F2-FL-DHS

VK_A02_185,100-F1-FL-DHS
VK_A02_185,100-F2-FL-DHS
VK_A02_186,630-F1-FL-DHS
VK_A02_186,630-F2-FL-DHS
VK_A02_180,195-F1-FL-DHS
VK_A02_180,195-F2-FL-DHS
VK_A02_184,200-F1-FL-DHS
VK_A02_184,200-F2-FL-DHS
VK_A02_184,550-F1-FL-DHS-FRGraz
VK_A02_184,550-F2-FL-DHS-FRGraz
VK_A02_184,550-F1-FL-DHS-FRWien
VK_A02_184,550-F2-FL-DHS-FRWien

3.1.5.5 Weather stations

In 29 positions, sensory equipment for weather and environmental data is installed.

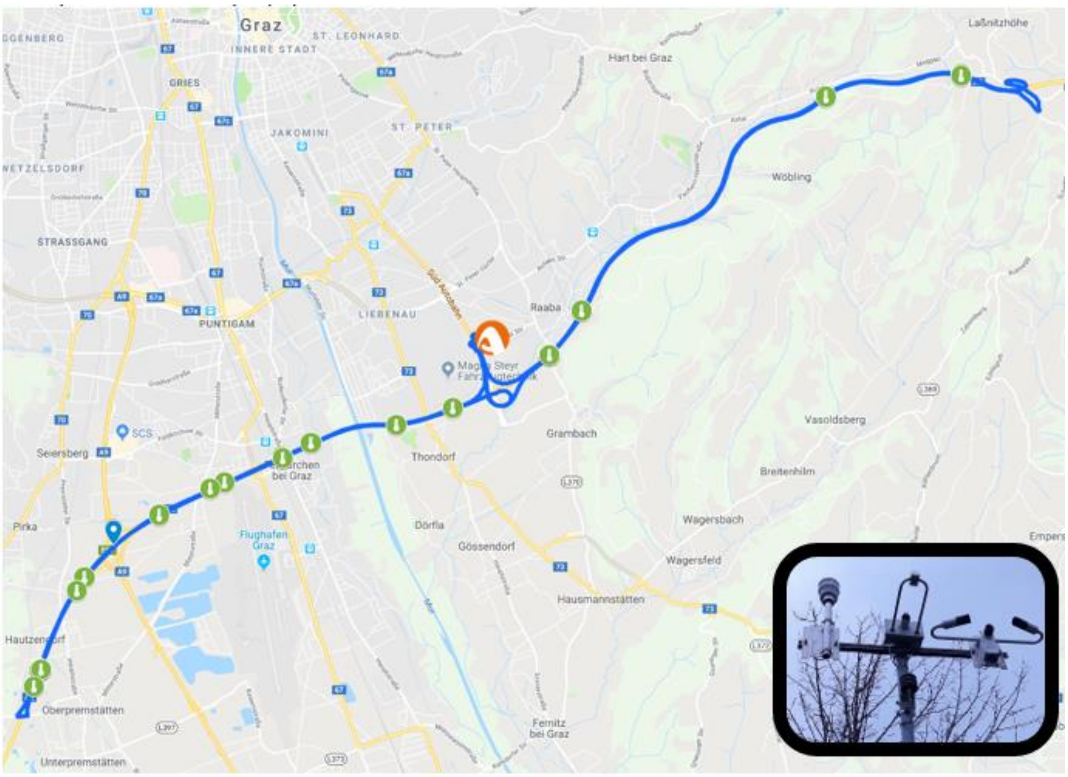

Figure 62 – Positions of the environmental data sensors on the Austrian test site (schematic)

Table 19 – Positions of the environmental data sensors, Austrian test site, driving direction 1

VMIS	UDE_groupedLocation_A02_1_169.897
VMIS	UDE_groupedLocation_A02_1_170.192
VMIS	UDE_groupedLocation_A02_1_172.275
VMIS	UDE_groupedLocation_A02_1_177.605
VMIS	UDE_groupedLocation_A02_1_178.468
VMIS	UDE_groupedLocation_A02_1_178.487
VMIS	UDE_groupedLocation_A02_1_180.191
VMIS	UDE_groupedLocation_A02_1_182.487
VMIS	UDE_groupedLocation_A02_1_182.981
VMIS	UDE_groupedLocation_A02_1_183.948
VMIS	UDE_groupedLocation_A02_1_184.2
VMIS	UDE_groupedLocation_A02_1_186.626
VMIS	UDE_groupedLocation_A02_1_188.208
VMIS	UDE_groupedLocation_A02_1_188.231
VMIS	UDE_groupedLocation_A02_1_188.25

Table 20 – Positions of the environmental data sensors, Austrian test site, driving direction 2

VMIS	UDE_groupedLocation_A02_2_170.568
VMIS	UDE_groupedLocation_A02_2_172.275
VMIS	UDE_groupedLocation_A02_2_178.468
VMIS	UDE_groupedLocation_A02_2_178.48
VMIS	UDE_groupedLocation_A02_2_178.487
VMIS	UDE_groupedLocation_A02_2_181.185
VMIS	UDE_groupedLocation_A02_2_182.981
VMIS	UDE_groupedLocation_A02_2_182.993
VMIS	UDE_groupedLocation_A02_2_185.104
VMIS	UDE_groupedLocation_A02_2_186.864
VMIS	UDE_groupedLocation_A02_2_188.208
VMIS	UDE_groupedLocation_A02_2_188.223
VMIS	UDE_groupedLocation_A02_2_188.231
VMIS	UDE_groupedLocation_A02_2_188.46

3.1.5.6 Landmarks

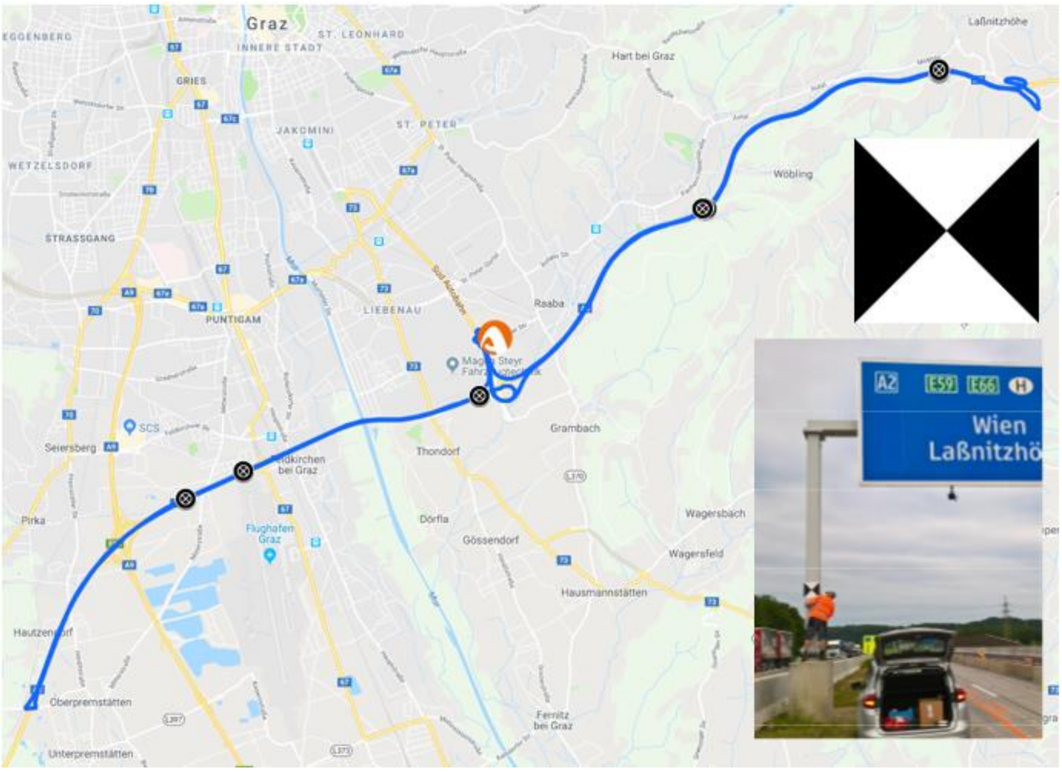

Figure 63 – Positions of the 21 landmarks on the Austrian test site (schematic)

21 landmarks are installed in 5 locations on the Austrian test site.

3.1.5.7 VDE-SF

VDE-SF (Verkehrsdatenerfassung Sensorfusion) – traffic data are captured using several different sensors; the data from these sensors are fused using a complex algorithmic method developed by ASF ("sensor fusion"). The detection is lane specific, as can be seen in Figure 64 bottom right.

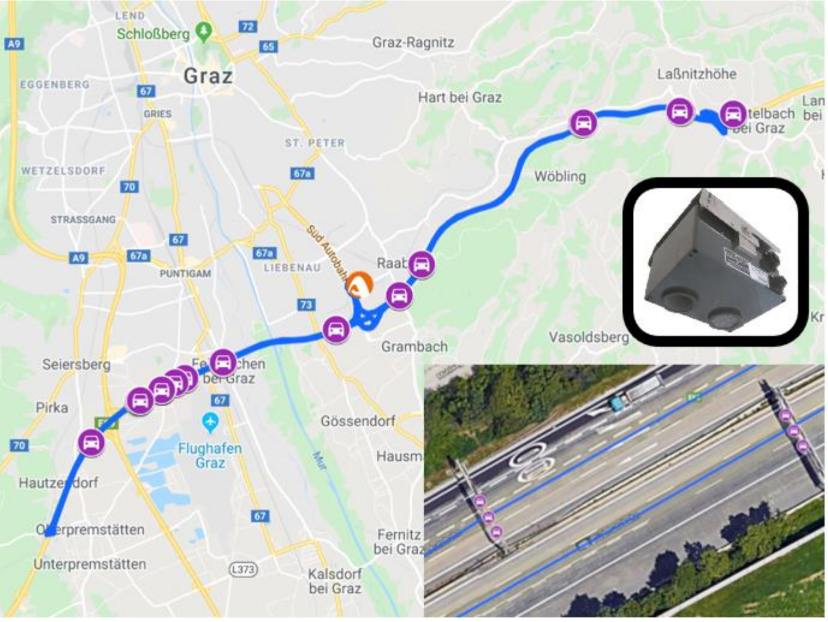

Figure 64 – Positions of traffic data sensor sets for sensor fusion (schematic)

Along a stretch of about 1.5 km, traffic data sensor sets have been installed. They cover both driving directions and each of the lanes.

Table 21 – Positions of traffic data sensor sets for sensor fusion, driving direction 2

NAME	Driving Dir.	KM_POS	LANE_NR
MQ_A02_2_168,613_F1	A02_1	168,613	1
MQ_A02_2_168,613_F2	A02_1	168,613	2
MQ_A02_2_168,613_F3	A02_1	168,613	3
MQ_A02_1_169,897_F1	A02_1	169,897	1
MQ_A02_1_169,897_F2	A02_1	169,897	2
MQ_A02_1_169,897_F3	A02_1	169,897	3
MQ_A02_2_178,480_F1	A02_2	178,48	1
MQ_A02_2_178,480_F2	A02_2	178,48	2
MQ_A02_2_178,480_F3	A02_2	178,48	3
MQ_A02_1_172,275_F1	A02_2	172,275	1
MQ_A02_1_172,275_F2	A02_2	172,275	2
MQ_A02_1_172,275_F3	A02_2	172,275	3
MQ_A02_1_180,191_F1	A02_1	180,191	1
MQ_A02_1_180,191_F2	A02_1	180,191	2
MQ_A02_1_180,191_F3	A02_1	180,191	3
MQ_A02_2_182,993_F1	A02_2	182,993	1
MQ_A02_2_182,993_F2	A02_2	182,993	2
MQ_A02_2_182,993_F3	A02_2	182,993	3
MQ_A02_1_186,626_F1	A02_1	186,626	1
MQ_A02_1_186,626_F2	A02_1	186,626	2
MQ_A02_1_186,626_F3	A02_1	186,626	3
MQ_A02_1_177,605_F1	A02_1	177,605	1
MQ_A02_1_177,605_F2	A02_1	177,605	2

MQ_A02_1_177,605_F3	A02_1	177,605	3
MQ_A02_1_183,948_F1	A02_1	183,948	1
MQ_A02_1_183,948_F2	A02_1	183,948	2
MQ_A02_1_183,948_F3	A02_1	183,948	3
MQ_A02_2_185,104_F1	A02_2	185,104	1
MQ_A02_2_185,104_F2	A02_2	185,104	2
MQ_A02_2_185,104_F3	A02_2	185,104	3
MQ_A02_1_185,108_A1	A02_1	185,108	-1
MQ_A02_1_185,108_F1	A02_1	185,108	1
MQ_A02_1_185,108_F2	A02_1	185,108	2
MQ_A02_1_184,550_F1	A02_1	184,55	1
MQ_A02_1_184,550_F2	A02_1	184,55	2
MQ_A02_1_184,550_F3	A02_1	184,55	3
MQ_A02_2_184,550_F1	A02_2	184,55	1
MQ_A02_2_184,550_F2	A02_2	184,55	2
MQ_A02_2_184,550_F3	A02_2	184,55	3
MQ_A02_1_184,200_F1	A02_1	184,2	1
MQ_A02_1_184,200_F2	A02_1	184,2	2
MQ_A02_1_184,200_F3	A02_1	184,2	3
MQ_A02_1_185,108_A2	A02_1	185,108	-2
MQ_A02_1_184,550_A1	A02_1	184,55	-1

3.1.5.8 IMIS – Intelligent mobile warning trailer with car-to-X interface

Mobile warning trailers are indispensable aids in securing road work areas. The most important features are the display panel and the well-visible warning lights. Approaching vehicles are warned visually by these means. Securing road work zones is essential for traffic safety and for the safety of the workers.

In 2017, Asfinag has acquired so called IMIS mobile warning trailers. IMIS stands for "Intelligent Mobile Information System". The expanded functions of this new generation of mobile warning trailers are:

- LED graphic panel,
- Remote configuration and remote control by the traffic management centre,
- Video camera,
- Support of travel time assessment,
- Traffic detection,
- CB radio warning, and
- Car-to-X communication.

These functions will enable the mobile warning trailers to support even more use cases.

Despite the well-visible colours and the warning lights of the mobile warning trailers, collisions between vehicles and mobile warning trailers happen. Especially collisions with lorries are a safety risk not only for the drivers, but also for the road work personnel. In order to improve the warnings before a road work area, the IMIS warning trailer adds CB radio messages and car-to-

X messages to the visual signage. Via CB radio, which is commonly used by professional lorry drivers, speech messages are transmitted in 6 languages on 4 channels:

- 27.185 FM German – English: "Achtung Gefahrenstelle!", "Attention, danger!",
- 27.055 AM Hungarian,
- 27.285 AM Polish,
- 27.075 FM Czech – Slovak.

The C-ITS service transmits I2V information (using DEN message) on the closure of part of a lane, a whole lane or several lanes (including hard shoulder), but without full road closure. It uses a single warning message ID, as set and distributed by the road operator.

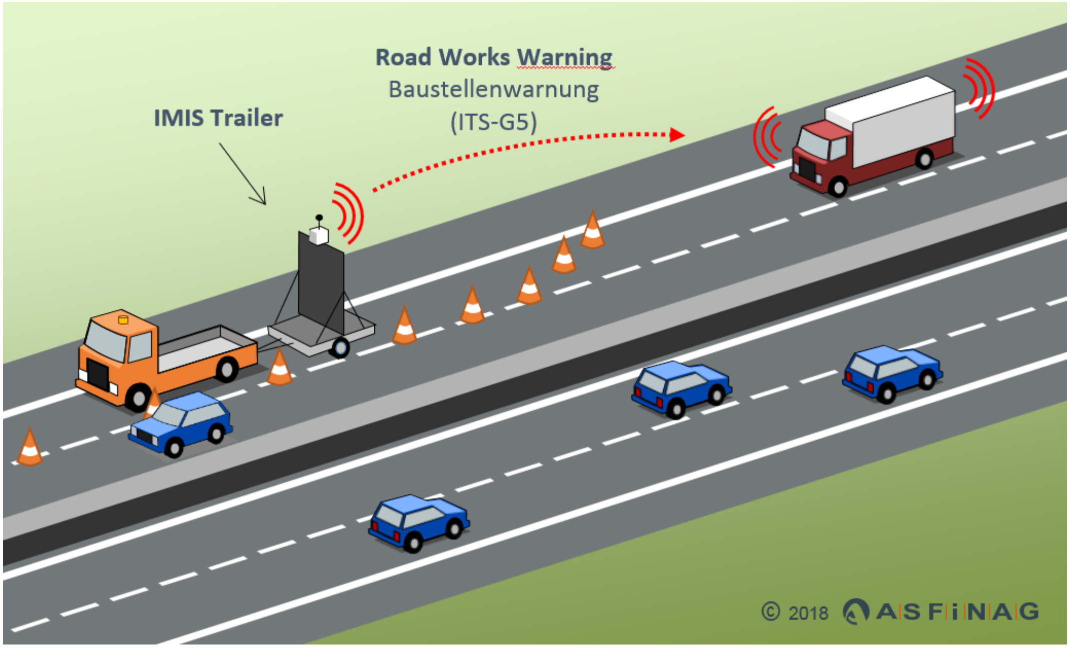

Figure 65 – IMIS trailer securing a roadwork zone

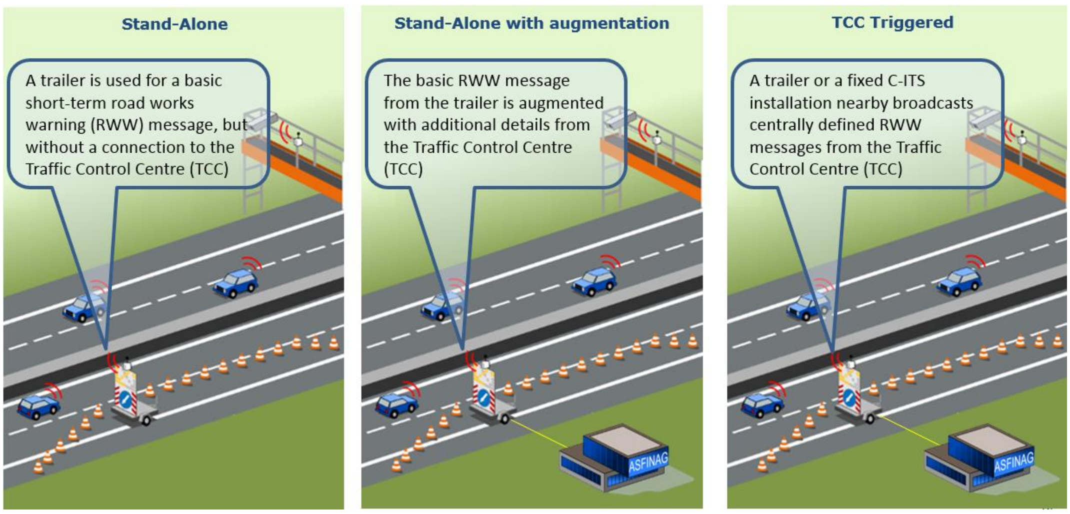

Figure 66 – Different setups of IMIS trailers

Figure 67 – IMIS trailer displaying the INFRAMIX SC1 sign (left) and IMIS components (right)

3.1.6 Vehicles & Drivers / Passengers

The **C-ITS Mobile Lab, a test vehicle of AustriaTech**, can validate the main standardized C-ITS messages, e.g. CAM – Cooperative Awareness Message, or DENM – Decentralized Environmental Notification Message (In standards, the basic components of C-ITS message chain are defined as: ITS roadside stations, ITS in vehicle station, ITS personal station) and their implementations according to the specifications. The C-ITS Mobile Lab can verify whether the full C-ITS information is delivered to the end user according to the latest communication profiles, which have been specified in C-ROADS for Day 1 applications. These messages have been extended with information needed for the INFRAMIX use cases. The vehicle is equipped amongst others with a C-ITS vehicle station, a GPS receiver and cameras linked to an IT system, which allows to show messages on a HMI in real time, but also to analyse received data in post processing.

The **test vehicle of Virtual Vehicle** (VIF) is equipped with an ITS-G5 OBU. It is able to send and receive C-ITS messages based on the first generation of C-ITS messages. Additional INFRAMIX messages were implemented based on the specifications proposed by the INFRAMIX project. The vehicle performed driving manoeuvers based on the received C-ITS messages but carried out by a human driver (due to safety reasons).

Conventional cars equipped with mobile phones (Android) for the TomTom Cellular Experiments App were also used for testing in order to demonstrate the scenarios for the cellular communication link. In addition, Asfinag employees were asked to test the “Unterwegs” app in mobile phones (Android and IOS) in order to demonstrate another cellular communication link to end-users and the availability of infrastructure services for cellular communication.

One **BMW Test vehicle** was already in use in the Girona tests, a detailed description is available there[2].

Asfinag invited **Tier1 and other OEM test vehicles to join the tests already in summer, however no vehicles outside of the project were able to join**.

The drivers of the respective cars were employees of the company the vehicle belongs to, e.g. employees of ATE for the C-Roads vehicle etc. In the case of conventional cars these were typically Asfinag pool cars.

The passengers carried for obtaining user appreciation at the Austrian test site were employees of INFRAMIX partners companies but not involved in INFRAMIX project as well as attendees of the joint stakeholder workshop of INFRAMIX and TransAID (see deliverable D6.10 “Networking and Engagement activities plan”) and attendees of the ACstyria Business Lounge (see Deliverable D6.10).

3.2 Austrian test procedure

3.2.1 ITS-G5 Communication Tests (May 2019)

Table 22 – Messages for the communication test

C-ITS Message	C-ITS Message Type	C-ITS Day1	C-ITS Day2	Scenarios
Vehicle type and lane specific speed recommendation for automated vehicles	IVIM		X	
Vehicle type and lane specific speed limit for automated vehicles	IVIM		X	
Lane recommendation: Dedicated lane assignment SAE level clearance for automated vehicles, level of automation	IVIM		X	
Short term road works warning	DENM	X		
Lane specific time gap advice	IVIM		X	
Long term road works warning/ road works layer lane recommendation: Specification of new lane design in long-term road works zone	MAPEM / IVIM	(X)	X	
Basic hazardous location warnings	DENM	X		
Awareness message about existence of other vehicles/ Collective perception of objects on the road	CPM		X	
Traffic condition (heavy rain)	DENM	X		
GNSS correction data	RTCM		X	

Table 23 – Communication test as carried out on May 9, 2019

RSU	Driving direction	Gantry	C-ITS Message	C-ITS Message Type
1	1 (LH->GO)	AQ_A02_1_182,487	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM

2	1 (LH->GO)	AQ_A02_1_183,948	Vehicle type and lane specific speed limit for automated vehicles	IVIM
3	1 (LH->GO)	WTA_A02_1_184,200	Lane recommendation: Dedicated lane assignment SAE level clearance for automated vehicles, level of automation	IVIM
4	1 (LH->GO)	AQ_A02_1_186_626	Short term road works warning	DENM
5	2 (GO -> LH)	AQ_A02_2_185,104	Lane specific time gap advice	IVIM
6	2 (GO -> LH)	AQ_A02_2_181,185	Long term road works warning/ road works layer lane recommendation: Specification of new lane design in long-term road works zone	MAPEM / IVIM
7	2 (GO -> LH)	AQ_A02_2_178,480	Basic hazardous location warnings	DENM
8	both - Doublegantry	AQ_A02_1_172,275 / AQ_A02_2_172,275	Awareness message about existence of other vehicles/ Collective perception of objects on the road	CPM
9	1 (LH->GO)	AQ_A02_1_177,605	Traffic condition (heavy rain)	DENM
10	1 (LH->GO)	AQ_A02_1_169,897	GNSS correction data	RTCM

Driving direction 1: Lassnitzhöhe -> Graz Ost

Driving direction 2: Graz Ost -> Lassnitzhöhe

As a pretest for the October Test (see next section), the INFRAMIX message set and some additional Day 1 / Day 2 messages were tested on May 9, 2019 on the Austrian test track. The partners involved were SIE, ATE, ViF and ASF. The base was located at the ASFINAG highway maintenance centre in Graz Raaba (ABM Raaba, see e.g. Figure 53). The test comprised the message sets as specified in Table 24 and Table 25, which includes all messages which were identified as relevant for the INFRAMIX project. These tests were the first ones in which C-ITS Day 2 messages were sent out and received successfully in Europe.

Figure 68 shows the test situation as in the C-Roads vehicle (left) and the visualization of the drive within the used development platform (right). The final results were presented at ITSWC 2019

Additionally, the CAM messages containing the positions and timestamps of the C-Roads vehicle were collected in order to check the radar sensor data quality for tracking a single vehicle lane change.

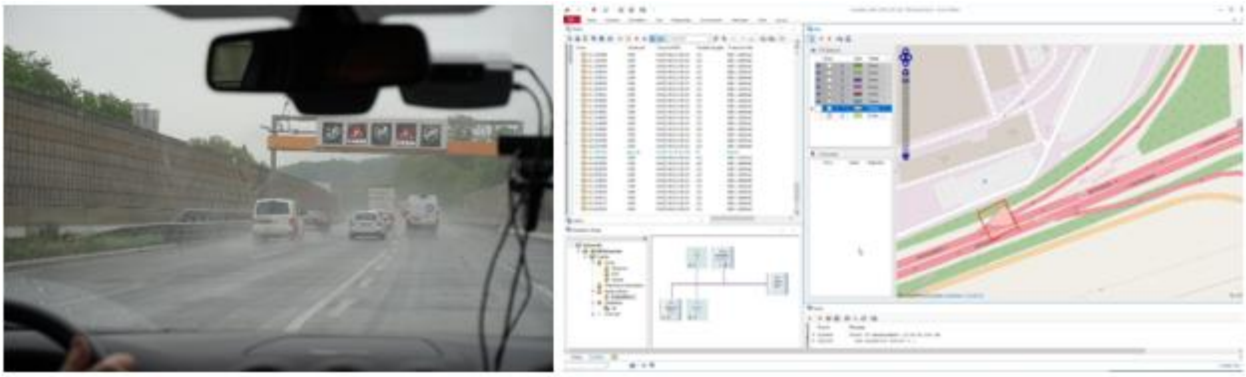

Figure 69 – The VMS (a) and the C-ITS RSUs (b) send the new C-ITS messages for mixed traffic control

3.2.2 October 2019 Tests

The October tests took place from Oct 07, 2019 to Oct 11, 2019 again with basecamp at the ASFINAG highway maintenance centre Raaba (ABM Raaba). The aim of these tests was to mimic the INFRAMIX scenarios and possible related message sets “Mockups” (and the corresponding control strategies). This is laid out in detail in the following sections 3.2.2.2, 3.2.2.3

and 3.2.2.4. The messages on which those “mockups” were built on had all already been pretested in the test in May, so that these tests could focus on the mockups with stable message sets.

The test week was accompanied by attractive side events as the Stakeholder Workshop (see Deliverable D6.10) and the ACstyria Business lounge (see Section 3.3.2.1) and by the INFRAMIX face-to-face meeting. All those side events made it possible to present the INFRAMIX approach to a considerable audience of stakeholders. Also, in all of those events, it was possible to join a test drive of the C-Roads vehicle of ATE. Participants who made use of this offer were asked to fill in questionnaires for the user appreciation; approximately 30 (both in the ACstyria Business lounge and the INFRAMIX Workshop) did so.

3.2.2.1 Schedule

Table 26 – October 2019 test schedule on the Austrian test site

	Morning	Afternoon	Side Events
Monday, 07/10/2019	spare	spare	
Tuesday, 08/10/2019	SC1&SC3	AC Styria	AC Styria
Wednesday 09/10/2019	SC1&SC2	SC1&SC2	INFRAMIX Stakeholder WS
Thursday 10/10/2019	SC1&SC2	SC1&SC2	INFRAMIX F2F Meeting
Friday 11/10/2019	spare day	spare day	INFRAMIX F2F Meeting

3.2.2.2 Scenario 1: Dedicated Lane Assignment (East loop)

Scenario 1 was sent out on the East loop of the test track in order to have longer segments without on or off ramps. As for all scenarios, a different message set was designed for each driving direction.

SC1 UC2 was covered in Driving Direction 2 where there is the adverse weather condition warning within the relevance zone of the DDL.

Figure 70 – Dedicated lane assignment (DLA)

3.2.2.2.1 Driving direction East (DD2)

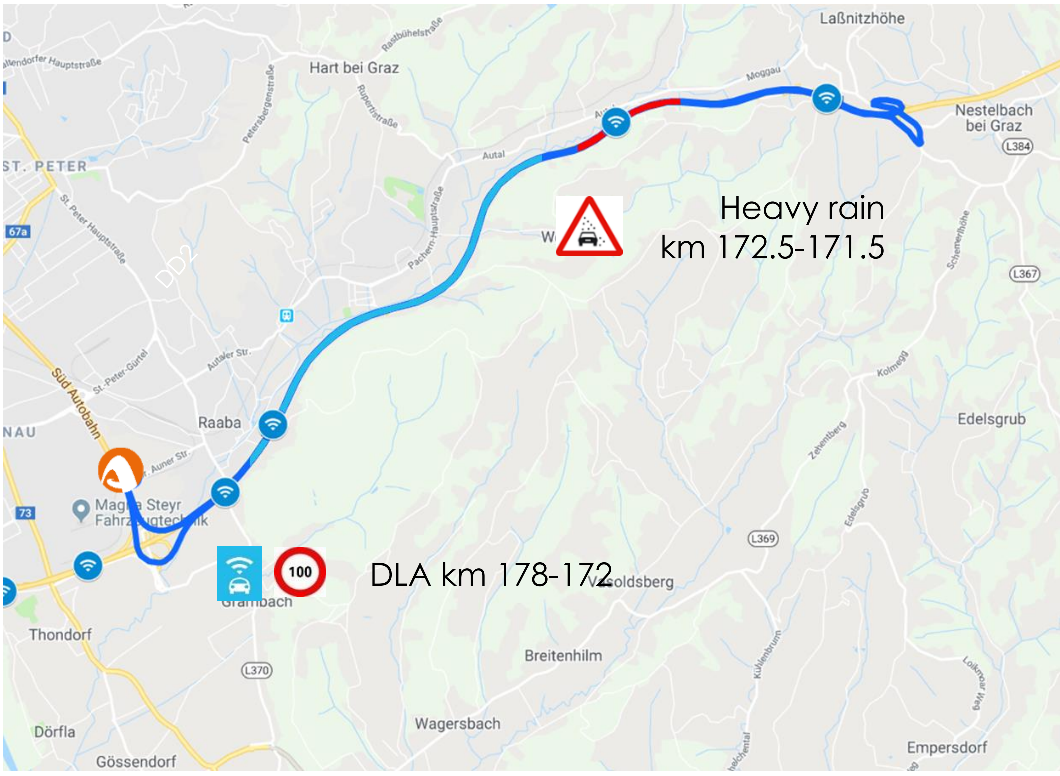

Figure 71 – SC1 DD2 East loop

3.2.2.2.2 Driving direction West (DD1)

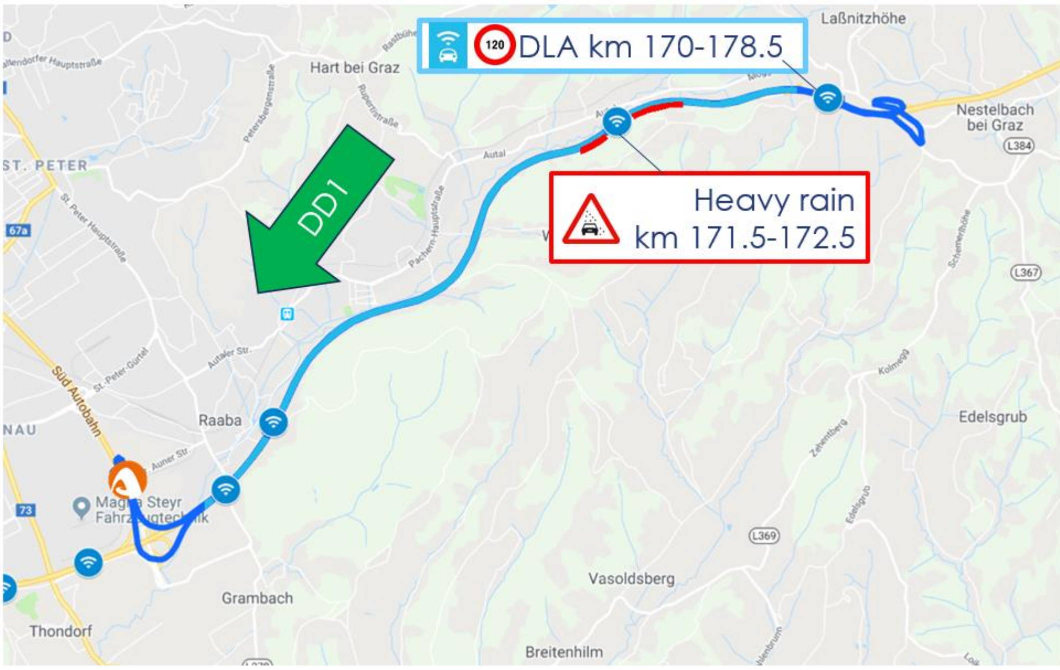

Figure 72 – SC1 DD1 East loop

Table 27 – Scenario 1: details

	Type	ID	Content		Begin		End	
West to East (2)	IVIM	1111	DLA	Speed-Limit: 100kmh	47.0277781	15.5027738	47.0619606	15.5582807
	DENM	1112	Adverse Weather conditions	"Slippery road / snow"	47.0595079	15.5528005	47.0627724	15.5646564
East to West (1)	IVIM	1121	DLA	Speed-Limit: 120kmh	47.0635478	15.5840959	47.0245252	15.4981718
	DENM	1122	Adverse Weather conditions	"Slippery road / snow"	47.0627724	15.5646564	47.0619606	15.5582807

3.2.2.3 Scenario 3: Bottleneck (West loop)

We will first discuss the setup of Scenario 3 before laying out Scenario 2. The reason will become clear in the following. SC3 was sent out on the West loop, the corresponding bottlenecks are the on-ramps around km 183.5 “Flughafen Graz”. Note that this is the same ramp that was used for the sub-microscopic simulations. The different possible control strategies were addressed by sending out a distance gap advice in one driving direction, but a lane change advice in the other one.

Figure 73 – Bottleneck

3.2.2.3.1 Driving direction West (DD1)

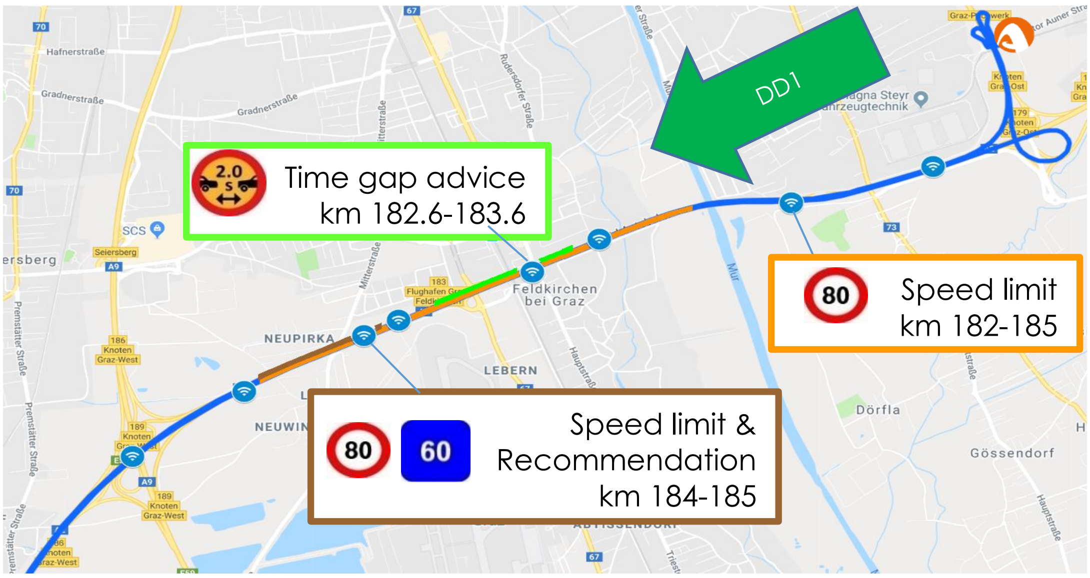

Figure 74 – SC3 DD1 West loop

3.2.2.3.2 Driving direction East (DD2)

Figure 75 – SC3 DD2 West loop

Table 28 – Scenario 3: details

	Type	ID	Content		Begin		End	
East to West (1)	IVIM	3221	Lane Specific limit	80 all lanes, all cars	47.0141576	15.455846	47.0029444	15.4198828
	IVIM	3222	Lane Specific gap advice	67m, all cars	47.0119986	15.4485999	47.0082502	15.4365747
	IVIM	3223	Lane Specific speed + Rec	80 + 60, all cars	47.0067563	15.4317608	47.0029444	15.4198828
West to East (2)	IVIM	3211	Lane Specific limit	80 all lanes, all cars	47.0047242	15.4259302	47.0122037	15.4499559
	IVIM	3212	Lane Specific speed + Rec	100 + 90, all cars	47.0139938	15.4559477	47.0177086	15.481529
	IVIM	3213	lane change		47.0061907	15.4307836	47.0080587	15.43669

3.2.2.4 Scenario 2: Roadworks (West loop)

Since control strategies for the roadworks zone (especially with lane drop) were identified to be very similar as for the bottlenecks, the test setup for SC2 was chosen in a very similar way as for SC3. When comparing Figure 76 to Figure 77 or similar Figure 78 to Figure 79, one can see that they mainly differ in the additional roadworks warning which was added for each driving direction. For indicating the roadworks zone, an IMIS trailer as described in Section 3.1.5.8 was used.

Figure 80 – Roadworks

3.2.2.4.1 Driving direction West (DD1)

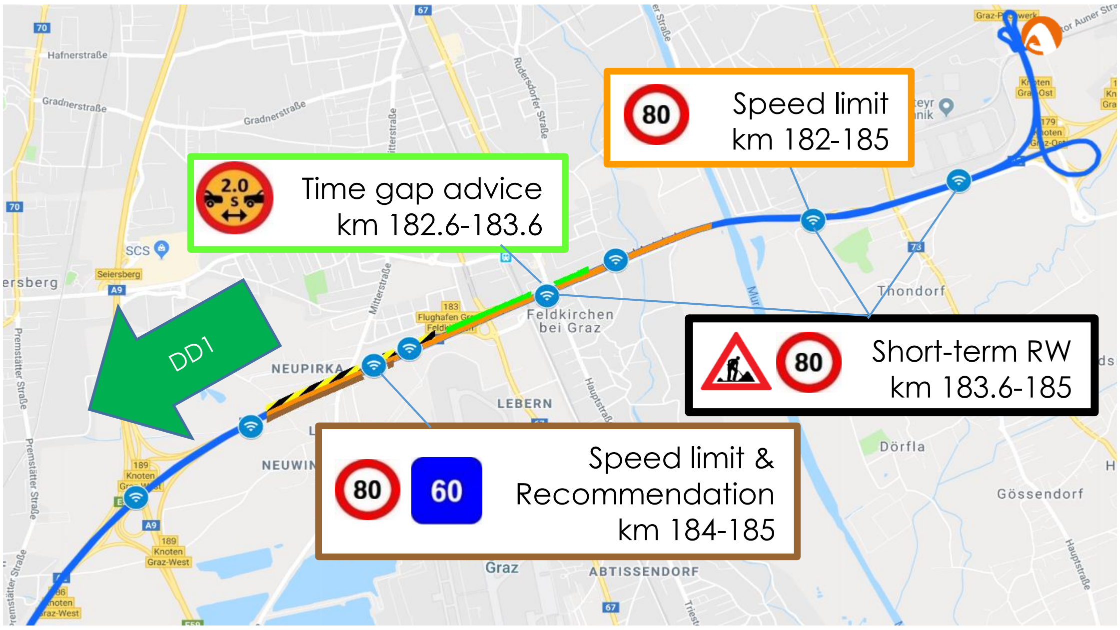

Figure 81 – SC2 DD1 West loop

3.2.2.4.2 Driving direction East (DD2)

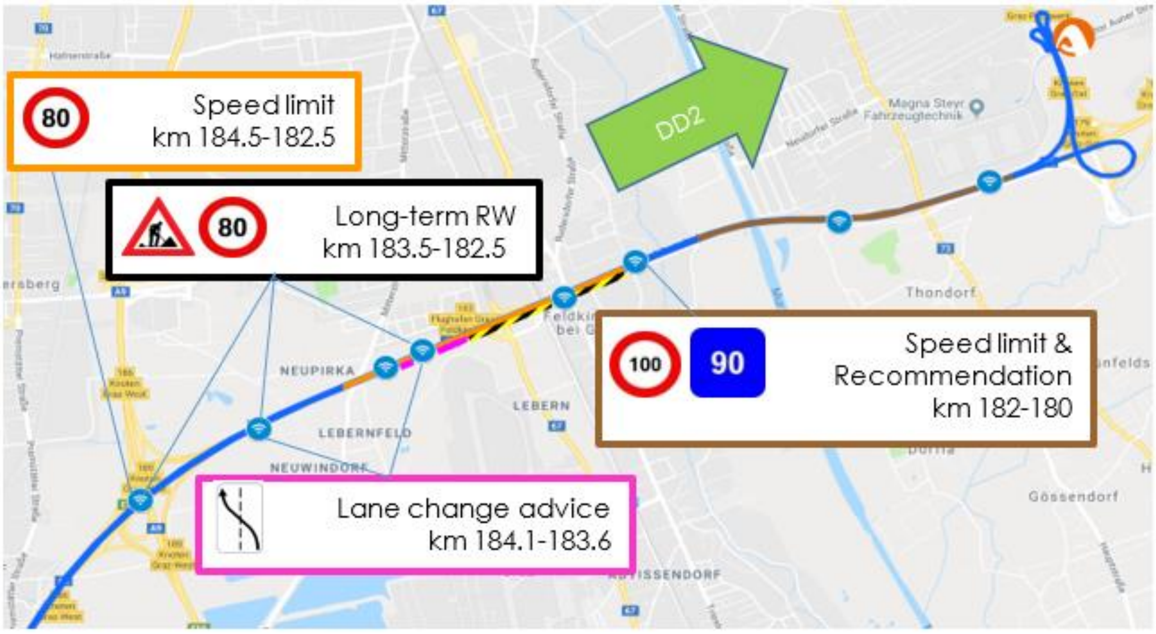

Figure 82 – SC2 DD2 West loop

Table 29 – Scenario 2: details

	Type	ID	Content		Begin		End	
East to West (1)	IVIM	2221	Lane Specific limit	80 all lanes, all cars	47.0141576	15.455846	47.0029444	15.4198828
	IVIM	2222	Lane Specific gap advice	67m	47.0119986	15.4485999	47.0082502	15.4365747
	IVIM	2223	Lane Specific speed + Rec	80 + 60, all cars	47.0067563	15.4317608	47.0029444	15.4198828
	DENM	2224	ShortTermRWW	Speed 80	47.0082502	15.4365747	47.0029444	15.4198828
West to East (2)	IVIM	2211	Lane Specific limit	80 all lanes, all cars	47.0047242	15.4259302	47.0122037	15.4499559
	IVIM	2212	Lane Specific speed + Rec	100 + 90	47.0139938	15.4559477	47.0177086	15.481529
	IVIM	2213	lane change		47.0061907	15.4307836	47.0080587	15.43669
	DENM	2215	RWW	80limit	47.0084277	15.4378978	47.0122037	15.4499559

3.3 Results from the Austrian demonstrator

3.3.1 Communication validation

3.3.1.1 May Tests

The main tests for communication validation for ITS-G5 were very successfully carried out in May 2019, including new, not yet standardized, messages for the first time. Only a few errors were identified and could be corrected in the revision. The INFRAMIX message set could be stabilized and planning for the tests in October could begin.

It was beneficial to include a pre-test of the sensor fusion (lane change tracking) in the May test run using the C-Roads vehicle, because minor problems synchronizing the time stamps between test vehicles and sensors could be identified already then. This assured the success of the ViF and ASF test run.

3.3.1.2 October Tests

3.3.1.2.1 ITS-G5

Due to the successful pretesting and following adaptations, no complications or communication problems occurred. The C-Roads vehicle equipped with the development platform was able to successfully and satisfactorily test the scenarios even ahead of schedule. This stable functionality made it possible to collect a considerable amount of user appreciation from participants of the several side events throughout the test week (see next section).

The HMI programmed by ATE displayed the corresponding pictograms to the received messages to the passengers in the rear of the vehicle. Some examples of this functionality illustrating the different INFRAMIX scenarios can be seen in Figure 83, Figure 84, Figure 85 and Figure 86. An example message (code) is attached to this deliverable in Annex II – Example C-ITS Message.

Figure 83 – HMI of the C-Roads vehicle displaying SC1 dedicated lane

Figure 84 – HMI of the C-Roads vehicle displaying SC1 dedicated lane and adverse weather conditions

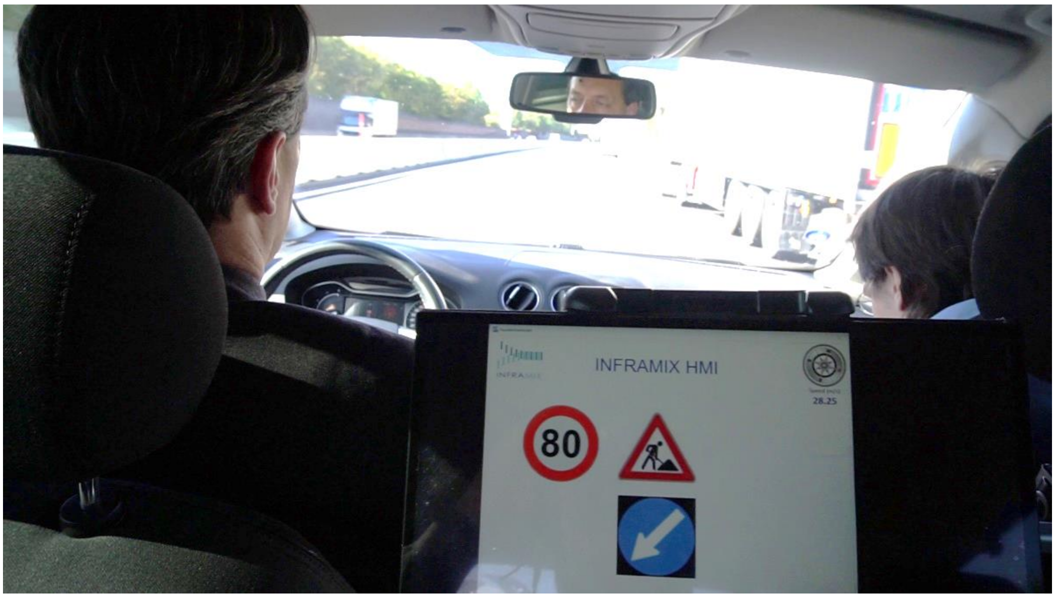

Figure 85 – HMI of the C-Roads vehicle displaying the roadworks zone message

Figure 86 – HMI of the C-Roads vehicle displaying the roadworks zone message in combination with the distance gap advice

3.3.1.2.2 BMW equipped with GenIE App/Backend

For the BMW tests in Graz, the following preparatory works have been done:

a) By **ASFINAG**: definition of use cases for all three INFRAMIX scenarios on the highway A2 near Graz in form of a PowerPoint presentation. This presentation contained the test plan and all the test message visualisation maps as also shown in this report (Figure 87, Figure 88, Figure 89, Figure 90, Figure 91, Figure 92, Figure 96 and Figure 97).

b) By **SIEMENS**: preparation of mockup ITS-G5 message files containing the INFRAMIX recommendations and information as specified in a) to be send in broadcast mode to the vehicles in the specified geofence translated in lateral and longitudinal coordinates. (See Table 30 – Scenario 1: details; Table 31 – Scenario 3: details; Table 32 – Scenario 2: details and Table 33-ACstyria details).

c) By **TomTom**: translation of the mockup files as defined in b) into specific mockup xml-files according to the TomTom interface specification containing a filtered version of the information prepared in c)

d) By **TomTom**: preparation of additional specific mockup xml-files targeting individual vehicles in unicast mode as specified in a). Especially recommendations to (individually) change lanes (as in SC3 WL DD2) are here concerned.

e) By **TomTom**: setting up a web-service which sends the relevant INFRAMIX recommendations and information upon vehicle requests with specific lateral and longitudinal coordinates.

f) By **BMW**: installation of an on-board app (called GenIE-App) which sends in regular time steps (every 5s) a request with the unique Vehicle Identification Number (VIN) to a specific back-end service at the BMW Backend (GenIE-Backend) which returns relevant jpg-images if available for the requesting car in the proper geographical and chronological fence.

g) By **BMW**: installation of a Backend Service which receives geographical coordinates, lane position, driving direction and VIN of vehicles, and forwards these to the TomTom web-interface as implemented in e). For easy testing (with a standing vehicle), this service was complemented by a mockup where arbitrary numbers (independent of the actual position of the vehicle under test) could be sent for simulating a drive over the specific highway segments as defined in a) (LaneChoiceSimulator).

h) By **BMW**: installation of a Backend Service (called INFRAMIX Backend) which receives upon request from the TomTom interface as implemented in e) xml-files containing the information as prepared in c) and d). The received xml-files are then immediately after reception converted in appropriate jpg.images which are then send to the GenIE backend service.

i) By **BMW**: installation of a backend service (GenIE-Backend Service) to serve vehicle requests as provided by f) with proper images as compiled by h).

After extensive testing, all 9 parts were actively running on Monday evening, 7 Oct 2019, for following use cases:

i. SC1 EL DD1
ii. SC1 EL DD2
iii. SC3 WL DD1

Upon (simulated) vehicle request from component g), images with proper INFRAMIX information and recommendations were received successfully by the vehicle and displayed on the (integrated) navigation screen in the BMW test vehicle.

Figure 93 – BMW OBU displaying SC1 when simulating the test drive on the parking lot

A discrepancy was observed between specification a) and the image (see Figure 94) shown on-board by f) in the case of SC3 WL DD1 at position km 184.0. According to the ASFINAG specification, a speed limit of 80 km/h and a distance gap of 2 s should be respected. The image only showed the time gap recommendation, but not the speed limit.

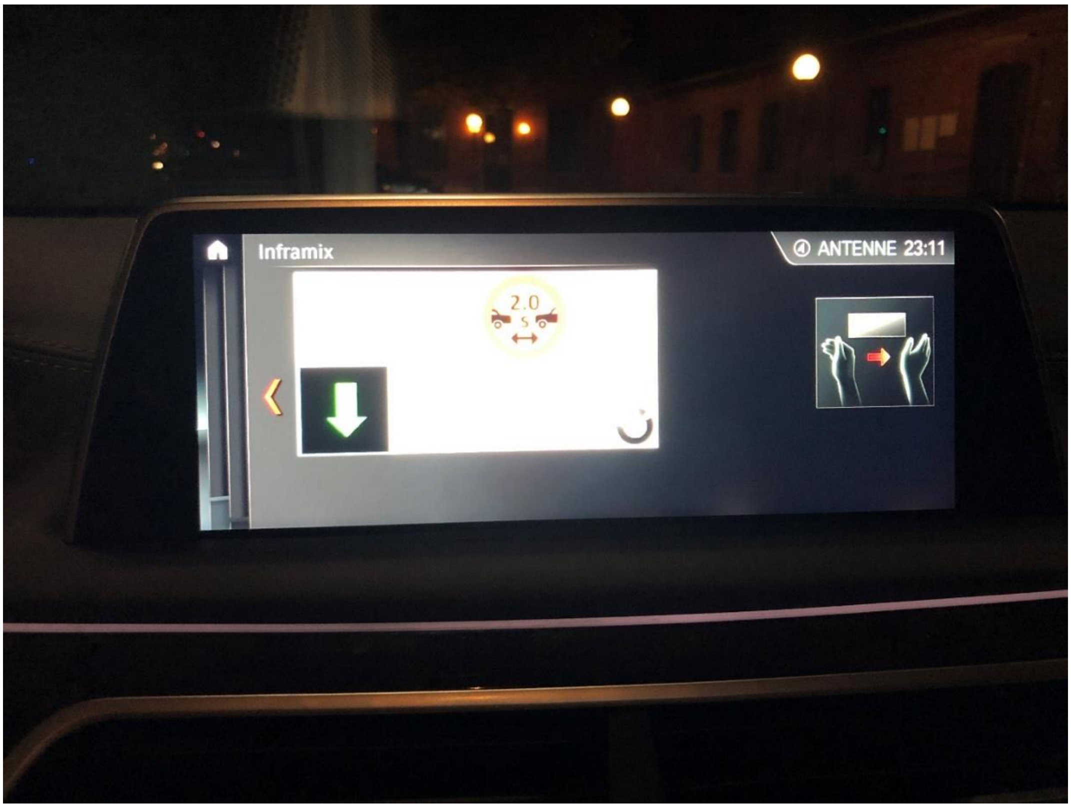

Figure 94 – BMW OBU displaying only the gap recommendation

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3.3.1.2.3 Tomtom app

The Tomtom app was installed by partner ASF on different devices. For the test, there were three different test devices in use running the app for reasons of redundancy and comparability:

- Samsung Galaxy S2 Tab running Android 7.0
- Huawei P10 lite running Android 8.0.0
- Nokia 8 running Android 9.0.0, SP02

Test partners installed the app themselves in preparation of the test week. Due to the short period between the tests in Girona and the ones near Graz, sufficient pretesting on the Austrian Test site was not possible.

SC1 could be demonstrated positively, but unfortunately too late in the week to collect user appreciation. SC2 and SC3 could not be demonstrated or tested in the October test week since the corresponding messages were not operational.

Figure 95 – TomTom app screenshot from the Android 8.0.0 device displaying SC1 during a test drive

3.3.2 User appreciation

User appreciation was collected during the October tests. Due to the very stable performance of this setup, the test vehicle of AustriaTech built the backbone for user appreciation on the Austrian test site and carried all passengers who filled in a questionnaire on the Austrian test site. The questionnaires and their detailed analysis are presented in D5.2 and D.5.3.

The HMI programmed by ATE was especially useful for testing, demonstration and also dissemination activities. The HMI displayed the corresponding pictograms to the received messages to the passengers in the rear of the vehicle. The display of the messages is clear and works very reliably, which made it a key component for the user appreciation (see below).

3.3.2.1 ACstyria Business Lounge

User appreciation was collected for the INFRAMIX use cases as described above, but also during the ACstyria event on Tuesday. These events typically attract a rather high management audience and therefore offered a unique chance to present the INFRAMIX approach also to this group of stakeholders. During the event, there was the possibility to join a demo-run of INFRAMIX scenario related C-ITS messages using the C-Roads vehicle. In order to also collect user appreciation from this group, a much shorter questionnaire was offered focused on the signage and benefit. This questionnaire too is presented in D5.3. Of approximately 30 people who made use of this offer, only 10 filled in the questionnaire (further supporting the approach of greatly reducing the number of questions for this event).

The short loop driven for this event started at the highway maintenance centre in Graz (ABM Raaba), with the turnaround point already at the exit “Flughafen Graz” and comprised one message for each INFRAMIX use case. The message set and their locations are depicted in Figure 96 and Figure 97. The participants of the test drives were very interested, and it can without doubt be described as the main attraction of the afternoon event of the ACstyria Business lounge.

Figure 96 – ACstyria Demo DD1

Figure 97 – ACstyria Demo DD2

Table 33 – ACstyria message set: details

	Type	ID	Content		Begin		End	
East to West (1)	DENM	4221	S-RW	Speed-Limit 80km/h	47.0163738	15.475202	47.0141757	15.4558228
	IVIM	4222	Lane Specific gap advice		47.0119986	15.4485999	47.0082502	15.4365747
West to East (2)	IVIM	4211	DLA	Speed-Limit 120kmh	47.0133233	15.4535168	47.017675	15.481533

3.3.3 Other results

In order to investigate in more detail, the guidance of a single vehicle to change lane, test drives on the Austrian test track were carried out by ViF and ASF. The vehicle received ITS-G5 lane change advices, and infrastructure radars tracked the vehicles trajectories. It shall be pointed out that these tests were also “mockups” in which the vehicle was not driving autonomously, but rather was driven by a test driver reacting to the lane change advice.

It was beneficial to include a pretest of this functionality in the May test run using the C-Roads vehicle, because minor problems synchronizing the time stamps between test vehicles and sensors could be identified already then. This assured the success of the ViF and ASF test run.

4 Hybrid testing

Hybrid testing is used to couple virtual traffic with the real-world making use of real vehicles driving through virtual traffic. The aim of this novel testing approach is to provide a total package of physical and digital infrastructure to validate automated driving functions and to test new traffic management strategies for connected automated vehicles.

4.1 Description of the testing

The development of automated driving functions and technologies poses various challenges even at the development stages. Testing the automated or ADAS (Adaptive Driver Assistance System) function and verifying the vehicle behaviour in multiple traffic scenarios poses a major difficulty during the development cycle of such systems. In order to ensure accurate vehicle behaviour several tests must be conducted under safe driving conditions. However, these are in general too costly and often infeasible to perform for verifying every ADAS function before commissioning. The current approach in automotive industry is to employ simulation tools to verify such systems. However, simulation-only verification and testing also have their limitations. For this purpose, we developed in the scope INFRAMIX project an alternative testing concept for automated driving system testing solution named the “hybrid-testing methodology”, where a real vehicle can be combined with virtual ones in a co-simulation framework.

Hybrid testing is a novel testing methodology based on the ICOS co-simulation platform, which was developed in the scope of the INFRAMIX project to test several mixed traffic scenarios involving autonomous and manual driven vehicles. In some respects, hybrid testing is similar to the vehicle-in-the-loop (a.k.a. VEHIL or VIL) systems, where real components and simulated components are combined and, which utilizes co-simulation platform ICOS at its core. This is also a generalization of hardware-in-the-loop (HIL) testing, specifically involving a test vehicle as the “hardware” in a feedback loop with the simulated modules. Other publications suggest calling it scenario-in-the-loop-testing1. Hybrid testing methodology involves the real vehicle driving in an enclosed proving ground using the real ADAS functions running on its real-time ECU (dSPACE-MicroAutobox-II), whereas the driving scenarios and the surrounding traffic as well as the sensor data is simulated on the co-simulation platform using dedicated software components.

In the developed hybrid testing solution, a real-life automated vehicle (AV), which is a generic automated drive demonstrator and development platform from VIF, is driven on an enclosed proving ground. The automated driving function utilized is an in-house developed SAE Level 3 ADAS function with lateral and longitudinal tracking as well as lane change decision capabilities (i.e., Motorway Chauffeur or MWC) enabling the AV to have adaptive cruise control (ACC), lane keeping assistance (LKA) and trajectory planning (TP) functionalities.

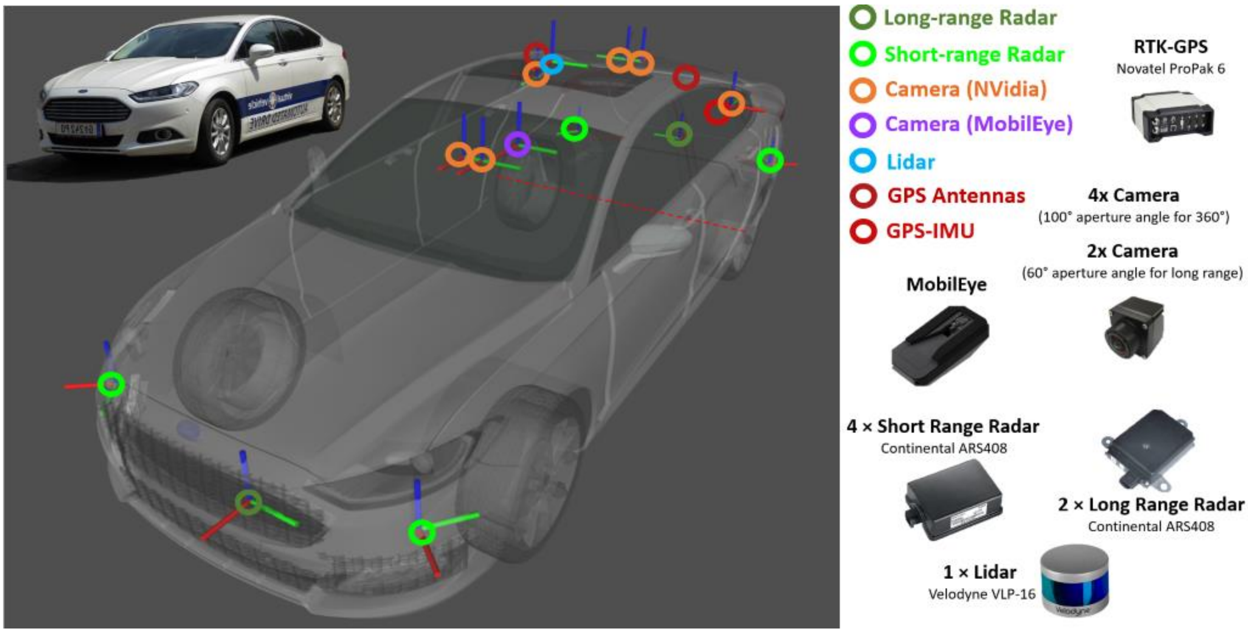
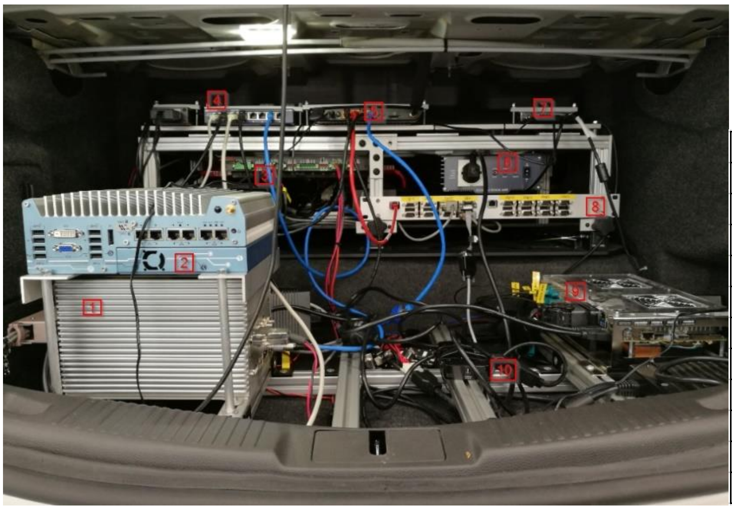


Figure 98 – Virtual Vehicle AV Demonstrator vehicle and additional perception sensors

The Ford Mondeo MY2016 AV test vehicle with a hybrid powertrain utilized for the hybrid testing implementation along with the additional on-board sensor hardware is shown in Figure 28. Among the indicated sensors in Figure 28, only the dual antenna RTK-GPS is utilized in the scope of the hybrid testing. The test vehicle also has many computational hardware for the implementation, where most of the development ECUs are installed at the trunk of the vehicle. The trunk layout is shown in Figure 29 below where numbered items indicate the specific components. Of primary importance in this list is the DataSpeed CAN interface which enables the access to the on-board vehicular sensors and controls of the vehicle. Using this interface, the throttle, brake and steering as well as other parameters can be controlled using a secondary ECU. The data rates for the control specific parameters provided by the DataSpeed CAN interface can be seen in Table 5.



1.	dSpace MicroAutoBox-II (ds1401) realtime ECU
2.	PC Nuvo – 7006 E-PoE PC
3.	Dataspeed CAN and Power distrubution interface
4.	Network switch
5.	W-Lan Router
6.	Power inverter (DC-AC)
7.	USB Multiplexer
8.	Aurix Safety Gateway
9.	Nvidia Drive PX2 ADAS PC
10.	HDMI Multiplexer
11.	High Precision RTK-GPS (Novatel ProPak6)
12.	Inertial Measurement Unit (Novatel IMU-IGM-S1)

Figure 99 – Ford Mondeo AV demonstrator computational hardware at the trunk compartment

Table 34 – DataSpeed CAN data and the corresponding data rates

Feature	Ford Fusion
Platform	FORD CD4
Initial release date	Oct 2015
Throttle control frequency	50 Hz
Brake control frequency	50 Hz
Steering control frequency	100 Hz
Steering angle control	Yes
Steering torque control	No
Gear shift control (PRNDL)	Yes[1]
Turn signal control	Yes
ULC (speed control)	Yes
Individual wheel speeds	100 Hz
3-Axis accelerometer	100 Hz
Roll and yaw rate gyro	100 Hz
Parking SONAR sensors	5 Hz
Tire pressures	2 Hz
GPS	100 Hz

The test vehicle also houses a dSPACE MicroAutobox-II (ds1401) real time ECU that runs the ADAS functions in real time based on the provided sensor data from on-board sensors as well as the simulated one from the co-simulation platform. The ADAS functions for ACC, LKA and TP are implemented in MATLAB/Simulink and later exported to C++ code, which is automatically generated by the MATLAB/Simulink embedded coders to run on the dSPACE MicroAutobox real time hardware. Therefore, the ADAS functions running on the MicroAutobox ECU send driving commands to the actuators through the DataSpeed CAN interface so control the vehicle.

There is also a regular PC platform (Nuvo-7006 E-PoE PC) with Windows 10™ operating system that runs the co-simulation framework based on the Model.CONNECT™ (a.k.a. ICOS) software. This PC is a high-performance vehicle-grade fan-less PC with power-over-ethernet ports, SSD storage and high-performance CPU and GPU units. It interfaces directly with the GPS and the C-ITS on-board-unit to process the corresponding data as part of the co-simulation framework. In this scope, the static environment, dynamic Environment (Traffic) and virtual sensor data is calculated and run in real time on the PC. This PC is also interfacing to the MicroAutobox ECU over CAN interface (with a dedicated .dbc file) to send and receive data bilaterally. The complete hardware and software architecture and the internal communication structure implemented on the Ford Mondeo test vehicle for realizing hybrid testing methodology is seen in Figure 30.

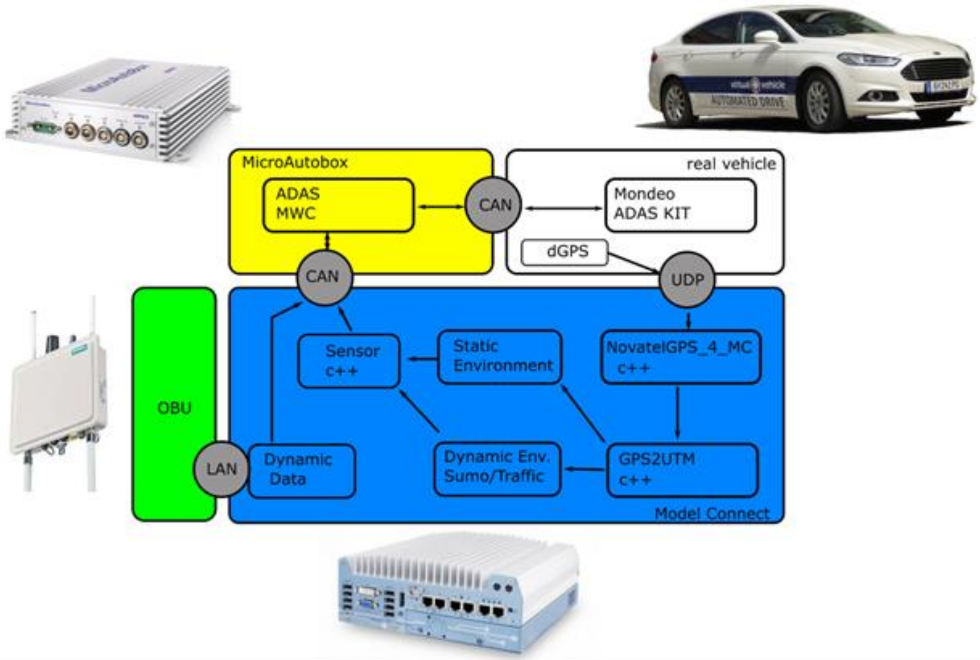


Figure 100 – Hardware and software architecture for Hybrid testing

In hybrid testing, the co-simulation framework runs on the Nuvo 7006 PC that is located inside the vehicle and the RSU (Road Side Unit) is located outside the vehicle as part of the test-site infrastructure. The PC in the Vehicle under Test (VuT) is responsible for running the traffic and environment simulation, sensor models, and object list generation algorithms in a co-simulation environment, while also being connected in real time to the CAN-bus of the VuT to collect variables relevant for representation of the VuT in the traffic simulation on the PC. During the hybrid tests, the ADAS control functions are based on the vehicle (specifically running on the dSPACE MicroautoBox-II platform) as opposed to having an ADAS function block along with vehicle dynamics simulator in the sub-microscopic co-simulation framework. Additionally, the car is equipped with an OBU (On-Board Unit) for bidirectional communication with the RSU. In this context, the communication between the RSU and OBU is unlimited and there can be persistent bidirectional link between the RSU and the OBU during the demonstrations of the specific hybrid testing use case demonstrations planned. That is, when a prespecified traffic control message is sent by the RSU to the VuT, it will act according to this message as soon as the message is received by the OBU in VuT.

In the scope of the hybrid testing methodology, the sensor signals of the test vehicle are simulated, and they sense the virtual objects created in the simulated static environment as well as the dynamic traffic components. The simulated sensor signals exclude the GPS sensor data, which provides survey-grade (i.e., cm-level accurate) position and heading information from the real vehicle to localize the ego vehicle on the digital HD map (i.e., the static environment) used in the co-simulation platform. The position and other vehicle states of the VuT is sent to the traffic simulation, where the simulated vehicles in the traffic simulation reacts to the VuT. The environmental information such as the lane markings, road curvatures, etc. as well as other traffic participants are only virtually present. The virtual dynamic objects consist of the vehicles of the surrounding traffic while the static environment consists features such as the road markings and traffic signs. The concept of the Hybrid-testing methodology is shown in Figure 31, where virtual and real components are illustrated as lumped at the right- and left-hand sides of the figure, respectively. Hybrid Testing Concept was also reported as part of an earlier deliverable “D4.1-INFRAMIX plan for systems interaction, integration and testing” and the reader is kindly referred to this document for further details and description of the testing concept.

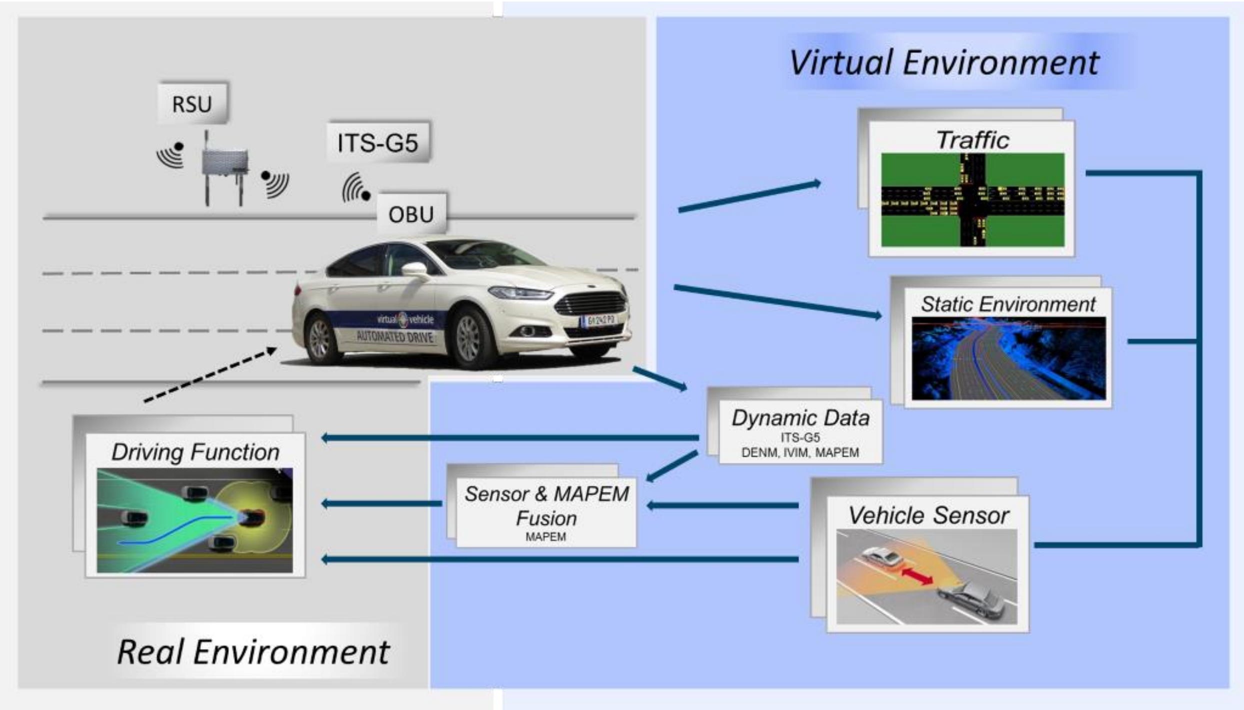


Figure 101 – Hybrid Testing Concept

The use of virtual sensors naturally imply that the vehicle is not able to sense real objects and real road markings in the testing area (i.e., proving ground). Therefore, the hybrid testing needs to be conducted on an open area, large enough to cover the virtual test track with additional buffer zones around the road layout, for safety purposes. Also, real infrastructure components are present in form of a road-side-unit (RSU) that sends ITS-G5 messages to an on-board-unit (OBU) that is integrated to the vehicle. The real vehicle reacts to the virtual elements accordingly, while also taking into account the real-world communication via RSU. Moreover, using the OBU, the status of the real vehicle can be sent back to the RSU for further processing as may be required from the use-case-scenario. When approaching the area of interest (e.g. the road works zone) the AV receives a C-ITS message from the RSU, which will then react according to this message, considering the surrounding virtual traffic.

The RSU and OBU units used in hybrid testing methodology are the same Siemens ESCoS RSU units. There was no specific version of this RSU for in-vehicle-use purposes at the time of implementation, so a second unit of the same type RSU was configured to serve as the OBU on the Ford Mondeo test vehicle. The RSU is mounted on a towed trailer unit and is placed on the proving ground at a suitable location to send various types of C-ITS messages (IVI, CAM, MAP, SPAT, DENM etc.) via the ITS-G5 communication protocol. The RSU that is configured as the OBU on the VuT receives the corresponding messages in the vehicle. At this moment, the Onboard PC (Nuvo 7006 PC) subscribes via a web-socket for various message types. The OBU version used for the test was configured with variable mounting options to conduct stationary laboratory tests as well as vehicle roof mounts for use during hybrid testing. The Siemens ESCoS RSU and OBU units and their mounting structure are shown in Figure 32.

Figure 102 – Siemens ESCoS RSU and in-vehicle configured OBU

The sub-microscopic simulation setup (see deliverable “D2.3-Specification of sub-microscopic modelling for intelligent vehicle behaviour”) is used to prepare the Hybrid testing scenarios for comparison purposes. Moreover, these preparatory sub-microscopic simulations are especially important to test scenarios with the RSU sending C-ITS messages, where TMC can be implemented and tested to define the specific messages to then during hybrid testing. The C-ITS messages used in hybrid testing are sent by the RSU during each scenario, which are pre-scripted and are defined as a result of preparatory sub-microscopic simulation runs involving a traffic management centre (TMC). The corresponding communication structure implemented is shown in Figure 33. The arrived solution requires that the TMC messages will be provided and exchanged between the RSU and OBU bilaterally but are based on an offline simulation of the same scenario. The traffic situation is determined with sub-microscopic simulation and according to this traffic situation the TMC messages are issued. The VuT receives these messages and performs its manoeuvers according to the simulated surrounding traffic and the received ITS-G5 messages.

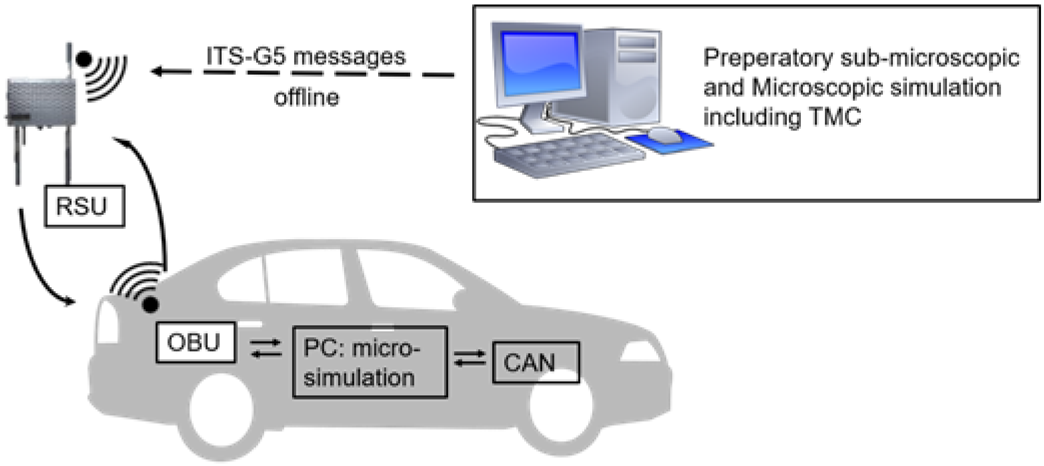


Figure 103 – Hybrid testing communication structure

The results of the hybrid tests are logs of positions and velocities of the VuT and the simulated traffic, as well as the logs of the ITS-G5 message transmissions. Out of these logs, behaviour of the VuT can be investigated. The logged data either come from the simulation tool used for the virtual traffic (SUMO), or the vehicle sensors itself (inertial measurements such as acceleration, yaw rate, steer angle, etc.). During the test runs the vehicle states (position, velocity, acceleration, heading, yaw rate, etc.), the states of the surround vehicles as well as the ITS-G5 messages are recorded and can be used for adapting and validating simulation parameters. Signal processing and evaluation tools are implemented in MATLAB and Microsoft Excel. The resulting investigations can be used to verify the vehicle behaviour (both VuT and the simulated vehicles) in the simulation (parameters of the car-following and lane change model in SUMO) or lead to adaptions of the vehicle behaviour in the real vehicle. With the findings of hybrid testing both the simulation as well as the automated driving function can be validated and improved. Moreover, the effect of the defined infrastructure measures (C-ITS messages) can be drawn from the combined results from hybrid testing and sub-microscopic simulation. The KPIs (e.g. duration lane change, vehicle velocity, time gap to other vehicles, etc.) and complete test metrics analysed in the scope of Hybrid-testing are described in the deliverable “D5.1-Plan for evaluation and users’ engagement”, where the analysis and reporting of this KPIs is given in “D5.3-Evaluation, impact analysis and new safety performance criteria”.

During the test, a qualified test driver supervises the automated vehicle regarding its behaviour on the proving ground, while two test engineers run and observe the simulation and its software modules. The first test engineer is responsible from the co-simulation platform while the second operates the dSPACE ControlDesk software for running the ADAS functions on the MicroAutobox II platform. Behaviour of the VuT within the virtual test track and the simulated traffic can only be observed virtually from a birds-eye perspective based on the SUMO-GUI. The test driver is responsible to start the ADAS function once the co-simulation environment is running, after which the vehicle drives itself based on the behaviour of the Automated Motorway Chauffeur. It should be noted that the test driver in this setup is not aware of the virtual traffic but is only responsible to keep the vehicle within the confinements of the proving ground and to take over control of the vehicle when needed to prevent accidents and/or property damage in dangerous situations. Driver’s viewpoint and the operator panel connected to the in-vehicle Nuvo PC running the co-simulation framework is seen in Figure 34 below, where SUMO GUI is demonstrating the traffic situation to the operator and the driver to monitor the driving scenario during testing instances.

Figure 104 – Operator panel and SUMO GUI running on the Nuvo 7006 PC as used during Hybrid testing

The time frame for hybrid testing scenarios is between 30 to 60 seconds depending on the desired velocity and as restricted by the test site physical limitations. The actual useable stretch of the road section (ÖAMTC Lang/Lebring FT4) used during the hybrid testing demonstrations is about 250 m and assuming an average speed of 50 km/h during a hypothetical test, the entire stretch is covered in less than 30 seconds. For most of the scenarios tested (described in 3.3. Hybrid-testing procedure (VIF)), average speed was ranging between 20 to 30 km/h were. Based on the performed hybrid tests and the corresponding logged data some observation is made that shall be introduced in 5.3. Results from Hybrid-testing (VIF).

As a final remark on the description of the hybrid testing methodology and implementation, it needs to be mentioned that the initial intent for the hybrid testing was to model both the Austrian and Spanish test-sites and conduct tests on the respective test sites accordingly. However, it turned out that it is not possible to do the test on the proving ground with mapped coordinates from either of these test sites. To be able to conduct tests on the respective test sites, the VuT needs to be driving on the corresponding motorway without any interfering traffic. This is obviously impossible as both tests sites are open and subject to quite busy traffic throughout the day and conducting tests on the real motorway would require a total blockade of the traffic for every test run. Therefore, it was decided with the concession and approval of the project partners that the hybrid testing is designed and implemented only at the ÖAMTC Lang/Lebring proving ground so as to assure safe testing conditions in the scope of all the indicated use case studies.

4.2 Hybrid testing procedure

In this chapter, the preparatory work for the proof of concept implementation of the hybrid testing methodology and the tested experiments are described. The results of the tests are presented in Section 4.3 Results from Hybrid-testing(VIF).

4.2.1 Hybrid testing preparation

Within Task 4.4, hybrid testing was demonstrated successfully at ÖAMTC Lang-Lebring proving ground (see D4.1 for details). The implementation of the required HW-components into the Vehicle under Test was described in chapter 2.3 of this deliverable. For simulation modelling and for hybrid testing, two map files (OpenDRIVE-file and SUMO net file) of the proving ground were required. To start mapping, a local reference measurement was done at ÖAMTC. Previous project work showed that a rectangular measurement of two straight road segments delivers satisfying results for the modelling requirements. After the measurement, the OpenDRIVE-file was created semi-automatically based on OpenStreetMaps™ and Google Maps™. Figure 105 shows the test area as satellite picture and the corresponding SUMO net file. The results from the reference measurement was then used to properly scale and verify the drawn OpenDRIVE-file. Once the open drive file is generated, the SUMO net file can be created. Therefore, SUMO provides a converter. It enables the conversion of open drive files directly into SUMO net file.

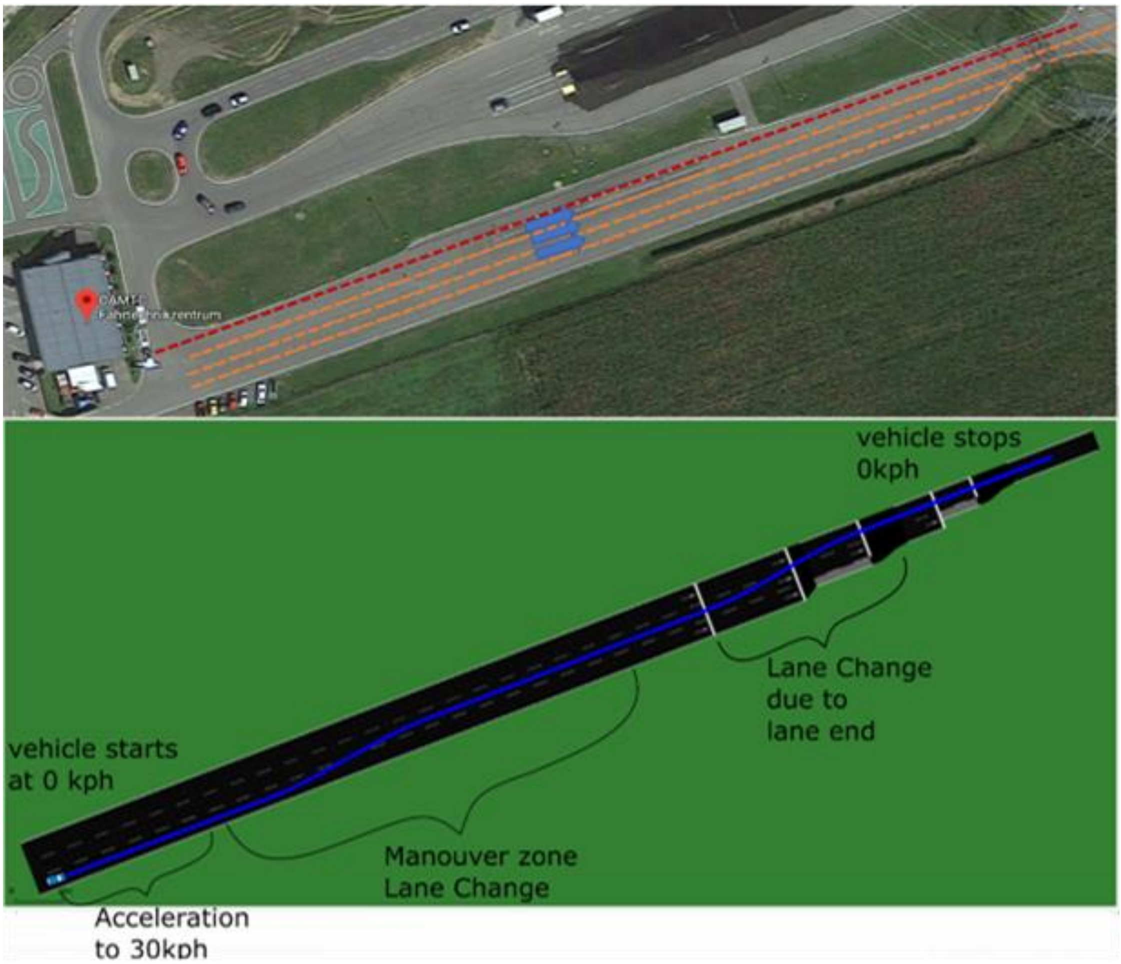


Figure 105 – Manoeuver Zone Satellite Picture & SUMO net file

The simulation framework was parametrized for different scenarios, which are described later in this chapter. The parametrization needed to be prepared and tested in an office environment (sub microscopic co-simulation) before conduction real world test.

4.2.2 Description of Scenarios for Hybrid Testing

Three different experiment stacks were conducted during the hybrid testing task at ÖAMTC Lang Lebring. The first stack focuses on a variation of different lane-change and merging scenarios. The second and the third stack add C-ITS messages to the investigation. In the second stack the effect, of the message was emulated (additional input signals in Model.CONNECT™) and in the third stack the whole communication chain was tested.

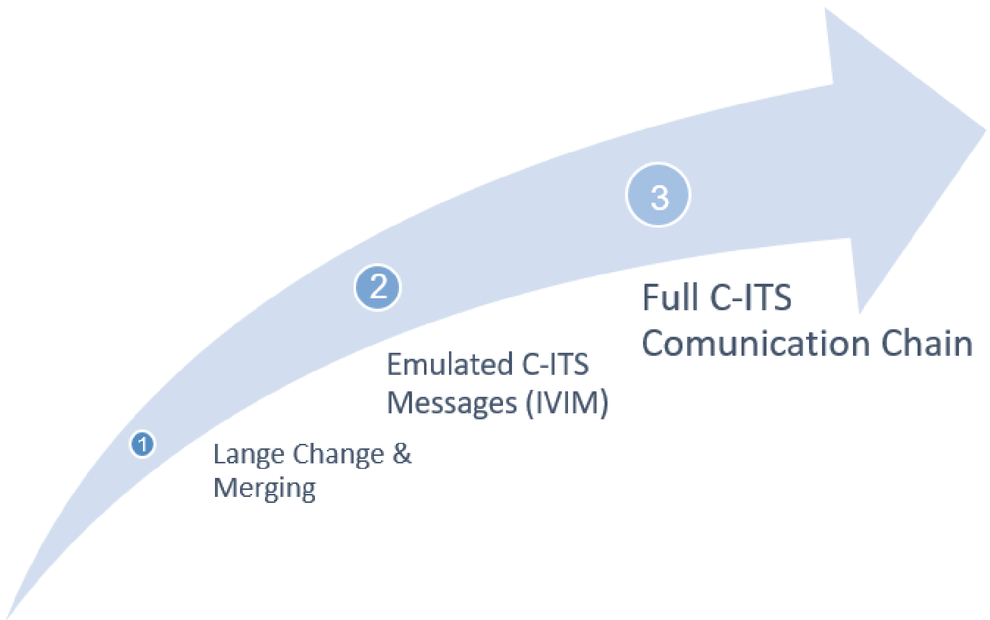


Figure 106 – Hybrid Testing Experiment Stacks

4.2.2.1 Experiment Stack I – Lane Change & Merging

For a sound initialization of the simulation framework and a repeatability of the experiments, the experiments started from the same spot around the dedicated GPS reference point (Figure 83). In the first experiment stack, the following experiments were conducted.

- Onramp – Merge into main road without, traffic
- Onramp – Merge into main road with low traffic
- Onramp – Merge into main road with high traffic

<u>Onramp – Merge into main road without, traffic</u>
The Vehicle under Test (VuT) starts at the rightmost lane, which represents a motorway on-ramp at a speed of 0 km/h. It accelerates to 30 km/h. When the VuT reaches 20 km/h (pre-set MWC parameter), it is permitted to initiate the lane change manoeuver to merge into the main lanes (represented by lane two and three from the right). In the first scenario, there is no traffic hindering the VuT from changing the lane. Since the main road narrows to one lane at the end of the test track, the VuT performs another lane change.

<u>Onramp – Merge into main road with low traffic</u>

The experiment is equal to the previous one, but there are two vehicles driving on lane two. The VuT must take care of the trajectories and behaviour of these vehicles when performing the lane change manoeuver.

Onramp – Merge into main road with high traffic

The experiment is equal to the previous one, but there are several vehicles driving on lane two and three preventing the VuT from performing a lane change manoeuver at all. The Vehicle perceives the difficulty and reacts on its dynamic environment. As a lane-change is impossible, it stops at the end of the rightmost lane.

Figure 107 – Reference Point

4.2.2.2 Experiment Stack II – Emulated IVI-Message

In the second experiment stack, the following experiments are conducted:

- Main road – without traffic
- Main road – with speed recommendation (emulated IVIM) without traffic
- Main road – with speed recommendation (emulated IVIM) with vehicle in front and MWC overtakes
- Main road – with speed recommendation (emulated IVIM) with vehicle in front and MWC adapts speed

Main road – without traffic

The VuT starts on the second lane (from the right), which represents the first lane of the main road. It accelerates to 30 km/h and changes the lane before the lane ends.

Main road – with max speed (IVIM) without traffic

The VuT starts on the second lane (from the right), which represents the first lane of the main road.

The VuT receives an IVIM via its OBU suggesting a new max. speed of 40 km/h. After driving approximately 100 m the VuT reaches the relevance zone defined in the IVIM. According to the suggestion, it accelerates to this speed and changes the lane before the lane ends. The starting position and the relevance zone of the message is shown on Figure 83.

Figure 108 – IVIM Message Relevance Zone

Main road – with max speed (IVIM) with vehicle in front and MWC overtakes
The VuT starts on the second lane (from the right), which represents the first lane of the main road. The VuT receives an IVIM via its OBU. After driving approximately 100 m, the VuT reaches the relevance zone, which is defined in the IVIM, with a suggested new max. speed of 40 km/h. According to the recommendation, it tries to accelerate to this speed, but a slower vehicle in front hinders the VuT to reach the recommended speed. To reach the desired velocity the VuT changes the lane. The starting position and the relevance zone of the message are shown in Figure 83.

Main road – with max speed (IVIM) with vehicle in front and MWC adapts speed
The VuT starts on the second lane (from the right), which represents the first lane of the main road. The VuT receives an IVIM via its OBU suggesting a new max. speed of 40 km/h. After driving approximately 100 m, the VuT reaches the relevance zone defined in the IVIM. According to the suggestion, it tries to accelerate to this speed, but a slower vehicle in front hinders the VuT to reach the recommendation. In contrast to the previous experiment, the VuT stays behind the vehicle and follows it.

4.2.2.3 Experiment Stack III – Full Communication Chain

The procedure of this sub-experiments is the same as described above in stack II. In addition to these experiments, the real communication chain was tested in this stack. Therefore, a real RSU (supported by Siemens) was placed on the proving ground, sending messages to be received by the OBU and parsed on-board in the vehicle.

- Main road – with speed recommendation (real IVIM communication) without traffic
- Main road – with speed recommendation (real IVIM communication) with vehicle in front and MWC overtakes
- Main road – with speed recommendation (real IVIM communication) with vehicle in front and MWC adapts speed

4.3 Results from Hybrid-testing

Due to the complex structure of the framework, no single point to access all data is available. There are three systems that collect data:

- Model.CONNECT™
- dSPACE MicroAutobox™
- SUMO

Model.CONNECT™ (co-simulation environment) generates for each model a data-file for all selected inputs and outputs. The data-file is available as csv-format and can be opened for example with Excel. The sampling step is the macro-time step in which the framework operates. It is the time step when data is exchanged between the models.

On the dSPACE MicroAutobox the ADAS -functions (MWC) are executed. The logging system of dSPACE MicroAutobox™ is used to log vehicle dynamics signals of the MWC and signals which are exchanged between dSPACE MicroAutobox™ and ADAS-kit. The data files are stored in a special dSPACE format which must be converted into a readable format. For this conversion, MATLAB is used. These signals are throttle, brake, steering wheel angle, velocities, accelerations and yaw rate. SUMO (traffic simulation) provides its own logging mechanisms.

The data collection consists of two postprocessing steps. During the first postprocessing step the data, of the different sources, must be collected.

In the second postprocessing step all different time-axis of Model.CONNECT™ and the dSPACE MicroAutobox™ are aligned. Also, some coordinate transformations have been applied. The Sumo-coordinate system (fcd-data) must be transformed to the OpenDRIVE-coordinate system and to the WGS84 coordinate system. This collected data are stored as MATLAB-file and as csv-file.

To make the work easier MATLAB-scripts are available to build up a transparent structure in MATLAB and the csv-file. The MATLAB structure also contains a field with all road markings, which are stored in a separate csv-file.

Data structure is as follows:

- Data,time (time since start of Simulation in Model.CONNECT™ in s)
- Data,vx_ego (longitudinal velocity of the VuT in m/s)
- Data,vx-desired (internal desired velocity, including IVIM information, in m/s)
- Data,ax_ego (longitudinal acceleration of the test vehicle in m/s²)
- Data,ay_ego (lateral acceleration of the test vehicle in m/s²)
- Data,hdg_ego(heading angle in rad)
- Data,yawRate_ego (yaw rate of the test vehicle in rad/s)
- Data,Throttle_ego (internal throttle position)
- Data,Brake_ego (internal brake position)
- Data,Steering_ego (steering wheel angle in rad)
- Data,x_ego (x-position in m)
- Data,y_ego (y-position in m)
- Data,lat_ego (GPS latitude in °)
- Data,long_ego (GPS longitude in °)
- Data,Traffic.Txx_isactive (1 if in this timestep a valid vehicle is present, 0 if no vehicle is present, xx runs from 01 to 10)
- Data,Traffic.Txx_x (x-position in m)
- Data,Traffic.Txx_y (y-position in m)
- Data,Traffic.Txx_hdg (heading angle in rad)
- Data,Traffic.Txx_vx (longitudinal velocity in m/s)
- Data,Traffic.Txx_lat (GPS latitude in °)
- Data,Traffic.Txx_long (GPS longitude in °)

- Data.Roadmarkings.x_rm1 (x-position of the leftmost virtual road marking in m)
- Data.Roadmarkings.y_rm1 (y-position of the leftmost virtual road marking in m)
- Data.Roadmarkings.x_rm2 (x-position of the second virtual road marking in m)
- Data.Roadmarkings.y_rm2 (y-position of the second virtual road marking in m)
- Data.Roadmarkings.x_rm3 (x-position of the third virtual road marking in m)
- Data.Roadmarkings.y_rm3 (y-position of the third virtual road marking in m)
- Data.Roadmarkings.x_rm4 (x-position of the rightmost virtual road marking in m)
- Data.Roadmarkings.y_rm4 (y-position of the rightmost virtual road marking in m)

The positions are in the coordinate system of the OpenDRIVE map. The x-coordinate represents the heading towards east and the y-coordinate represents the heading towards north. The heading angle is measured counter clockwise from the x-axis. The velocities and accelerations are given in the vehicle-coordinate systems. In what follows we describe the specific observations, test data examples and conclusions from the hybrid-testing.

4.3.1 Experiment Stack I – Lane Change & Merging

In Figure 109 the longitudinal behaviour of the VuT is shown. At about ten seconds the vehicle accelerates to the desired velocity of 8.33 m/s (30 km/h). At 33 seconds the vehicle brakes because it reaches the end of the test track.

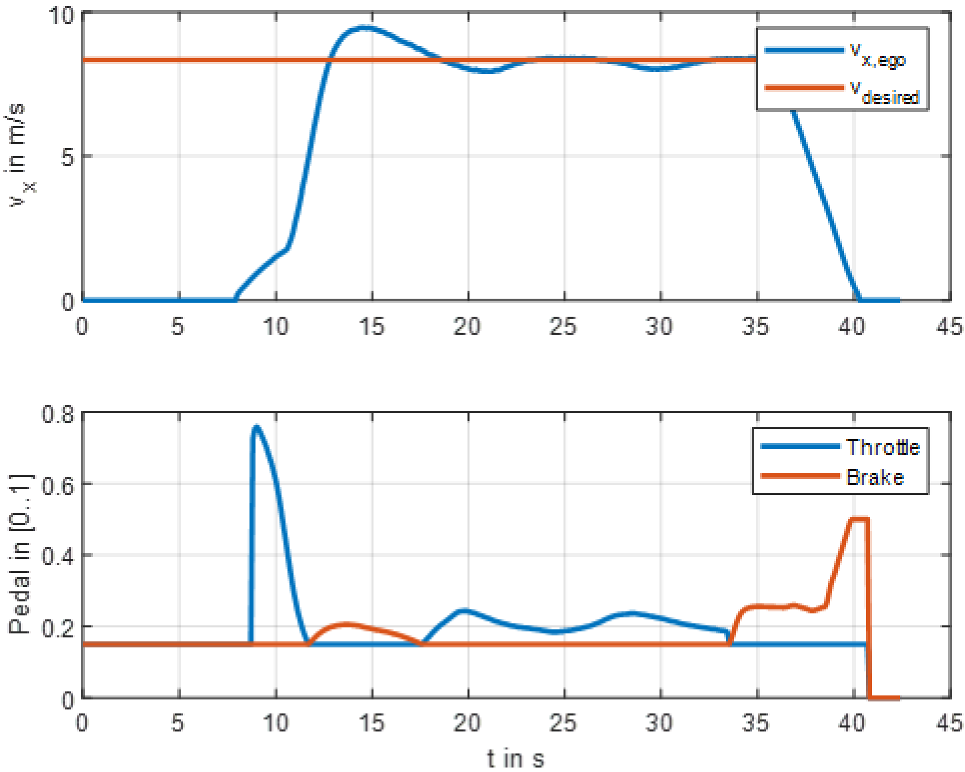


Figure 109 – Onramp / Merge into main road, without traffic / longitudinal signals

Figure 110 shows, in blue, the positions of the VuT. The vehicle starts at the western end of the test track and drives to the eastern end of the test track. It changes the lane twice. The first time it leaves the onramp and merges into the main road. The second lane change is necessary due to the narrowing at the end of the test track.

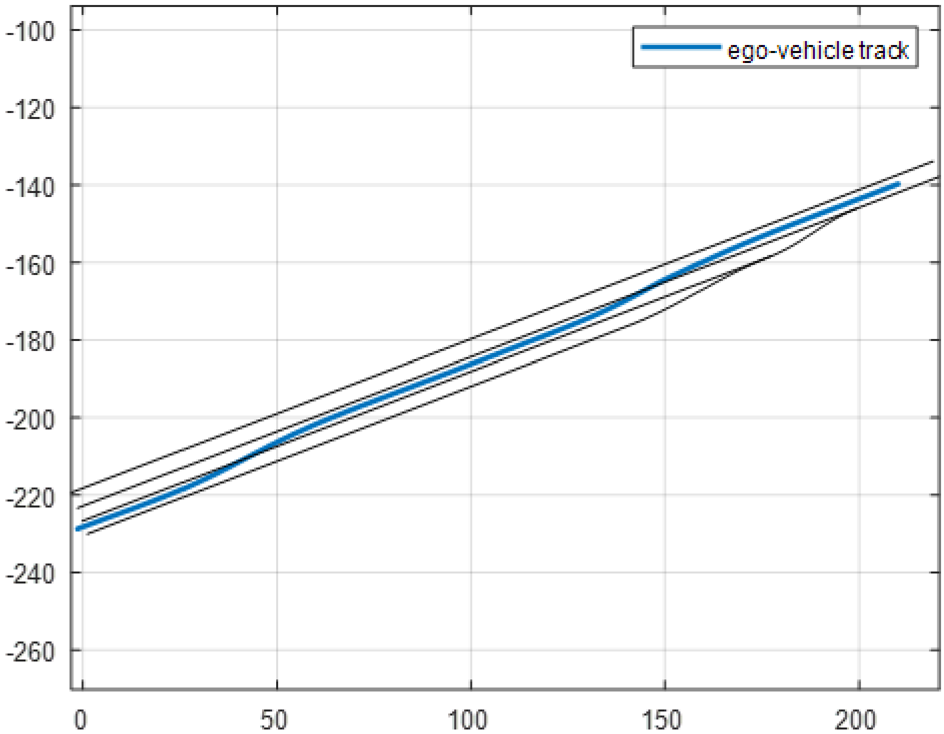


Figure 110 – Onramp / Merge into main road, without traffic / VuT trajectory

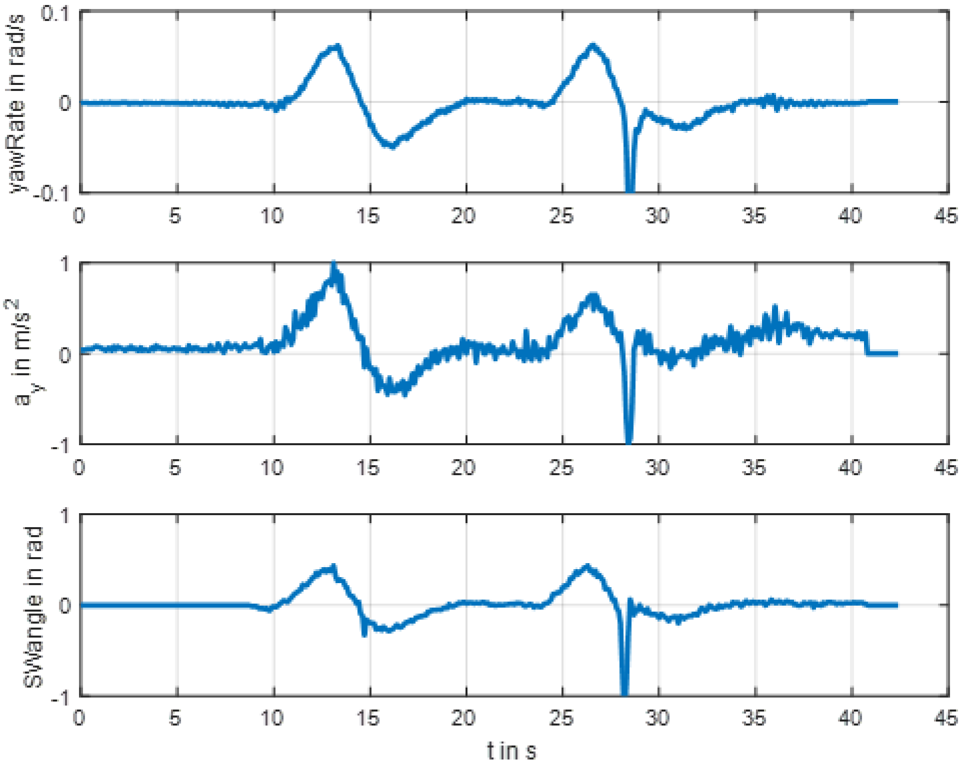


Figure 111 – Onramp / Merge into main road, without traffic / lateral signals

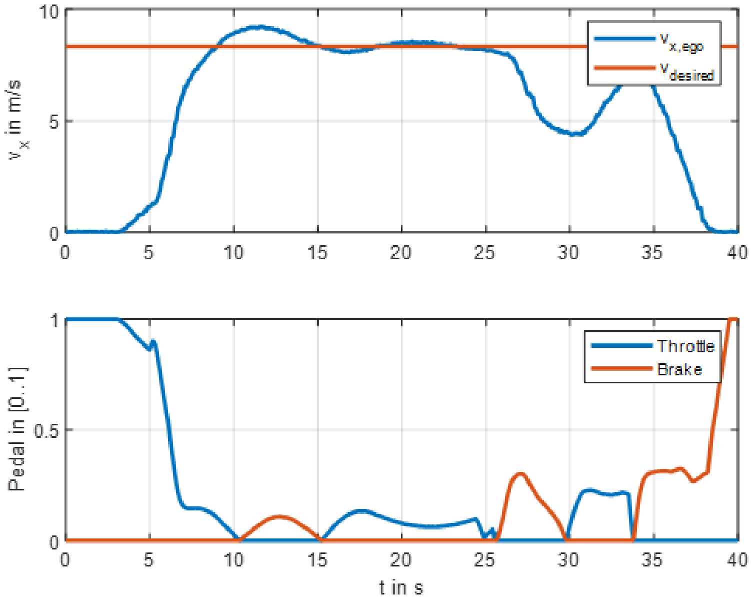


Figure 112 – Onramp / Merge into main road with low traffic / longitudinal signals

Figure 112, Figure 113and Figure 114 show the case where the VuT has to take care about some vehicles on the main road. The VuT changes to the main road as soon as there are free space on the main road and must adapt its speed according to other vehicles at the narrowing at the end of the test track.

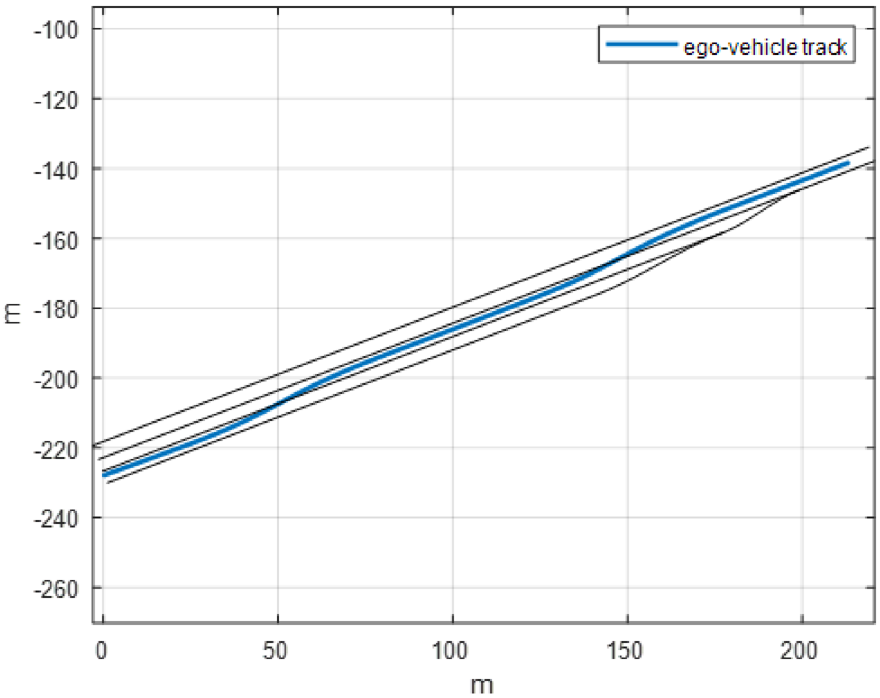


Figure 113 – Onramp / Merge into main road with low traffic / VuT trajectory

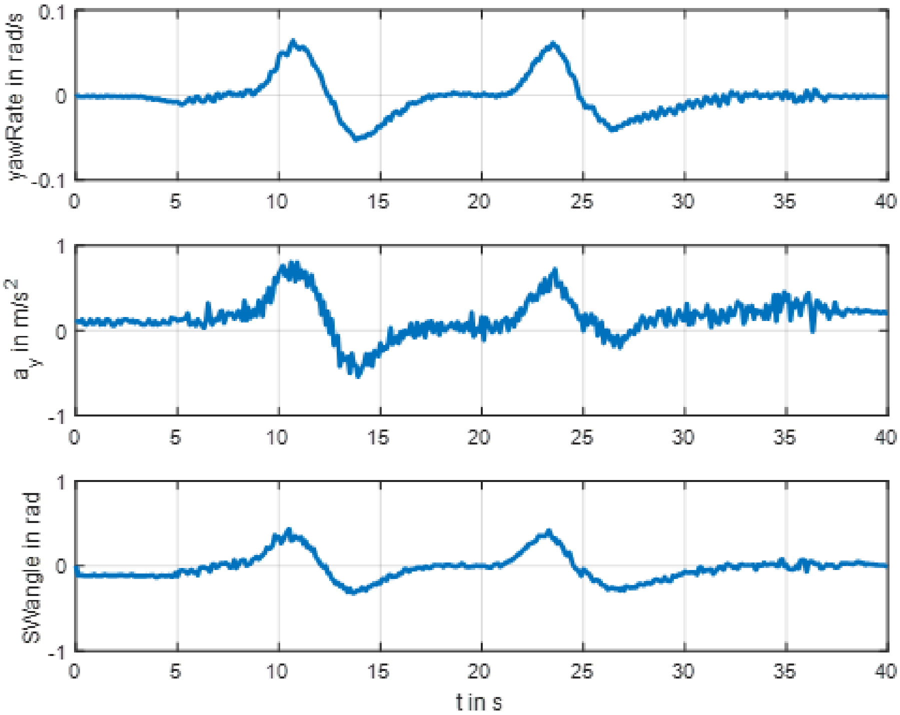


Figure 114 – Onramp / Merge into main road with low traffic / lateral signals

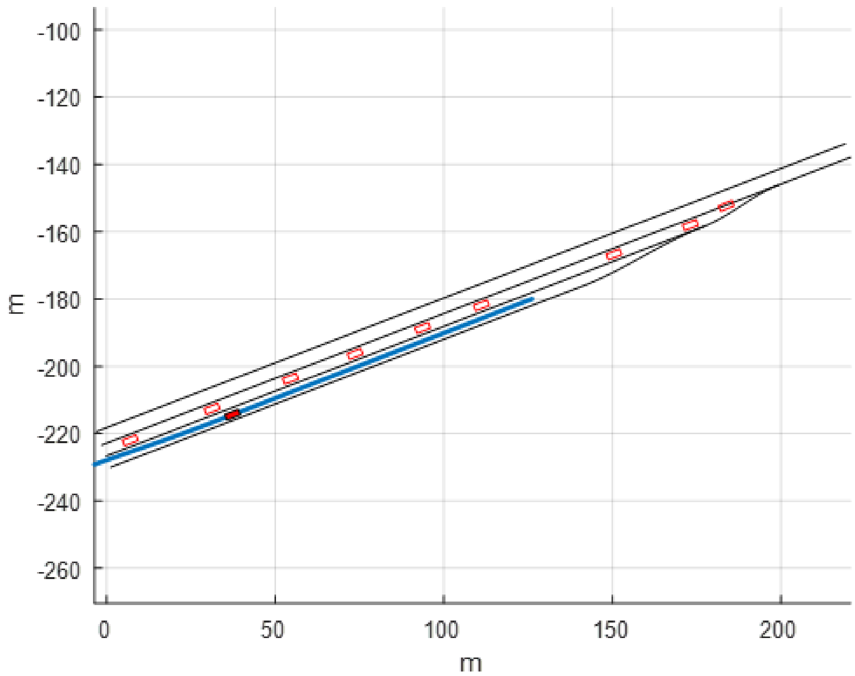


Figure 115 – Onramp / Merge into main road with high traffic / vehicle positions

Figure 115 shows the following situation: "Merge into main road with high traffic". The blue line shows the trajectory of the real vehicle. The test vehicle starts on the left side and come to a standstill at the end of the onramp. The red blocks represent vehicle positions at timestep 14 seconds. The filled red block is the real vehicle, which tries to find a gap between the simulated vehicles on the main road.

4.3.2 Experiment Stack II – Emulated IVI-Message

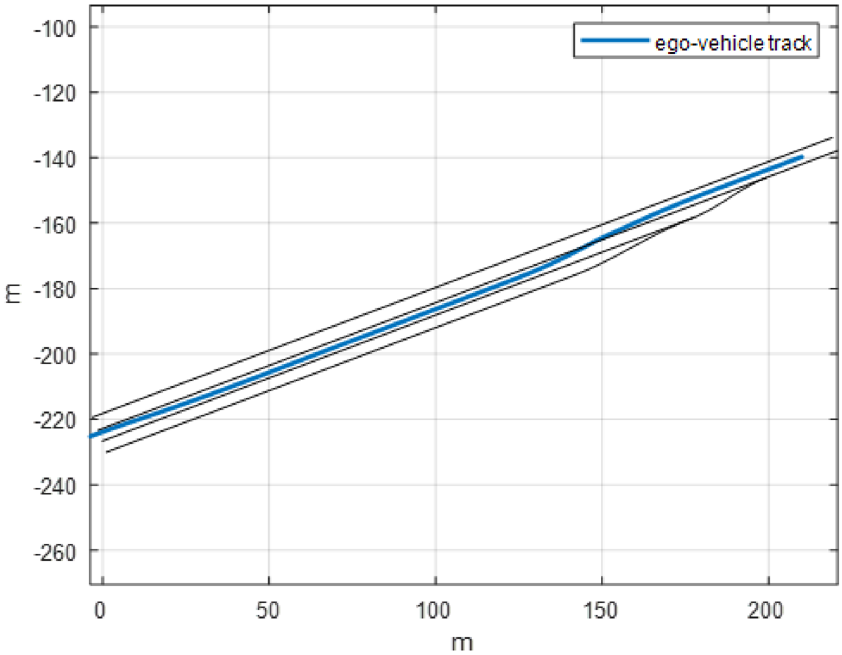


Figure 116 – Main road / without traffic / test vehicle positions

The vehicle positions of the scenario without traffic and without IVIM are shown in Figure 116. In this setup the vehicle starts on the middle lane, which represents the first lane of the main road, and changes to the leftmost lane before the narrowing at the eastern end of the test track.

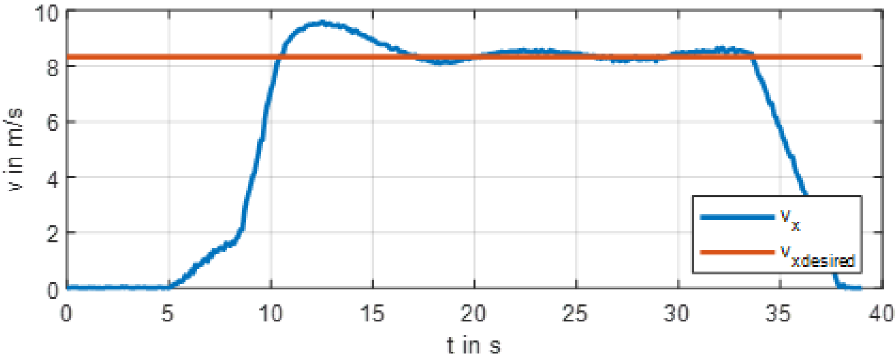


Figure 117 – Main road / without traffic and without IVIM

In Figure 117 the longitudinal velocities of the case without traffic and without IVIM are depicted. The desired speed (orange) is 8.33 m/s (30 km/h). At 5 seconds the vehicle starts on the left side of the test track, accelerates and holds the speed until the end of the test track is reached.

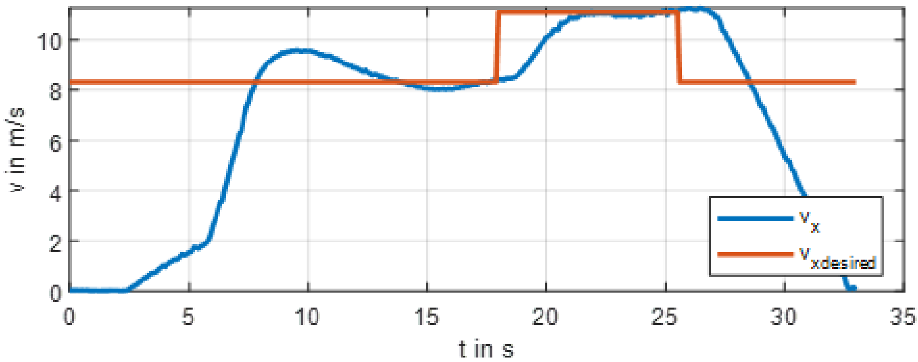


Figure 118 – Main road / with speed recommendation (emulated IVIM) without traffic

Figure 118 shows the case where the test vehicle receives an IVIM with a maximum speed of 40 km/h. The desired speed increases to 11.1 m/s (40 km/h) when the test vehicle reaches the relevance area of the IVIM and decelerates to 8.33 m/s (30 km/h) when the vehicle leaves the relevance area. The test vehicle follows the desired speed with a delay.

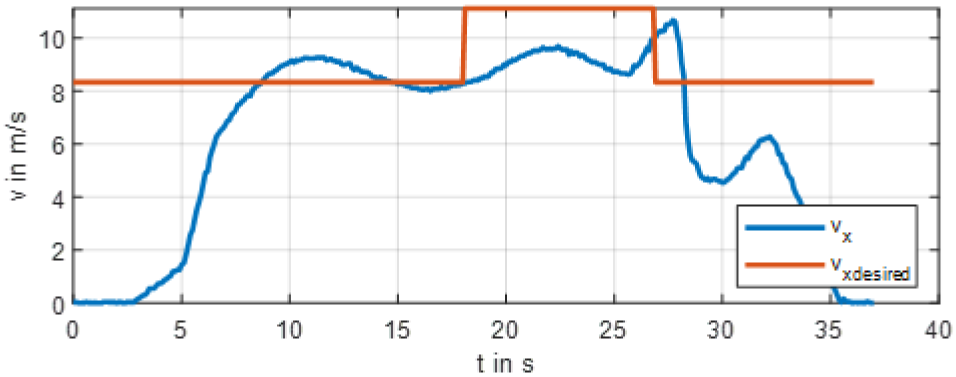


Figure 119 – Main road / with speed recommendation (emulated IVIM) with vehicle in front and MWC overtakes

Figure 119 depicts the case with a change in the maximum speed of the vehicle in a low traffic situation. The vehicle receives the IVIM with a recommendation to accelerate to 40 km/h, but a simulated vehicle travelling with 30 km/h in front of the test vehicle prevents it from accelerating towards the desired velocity.

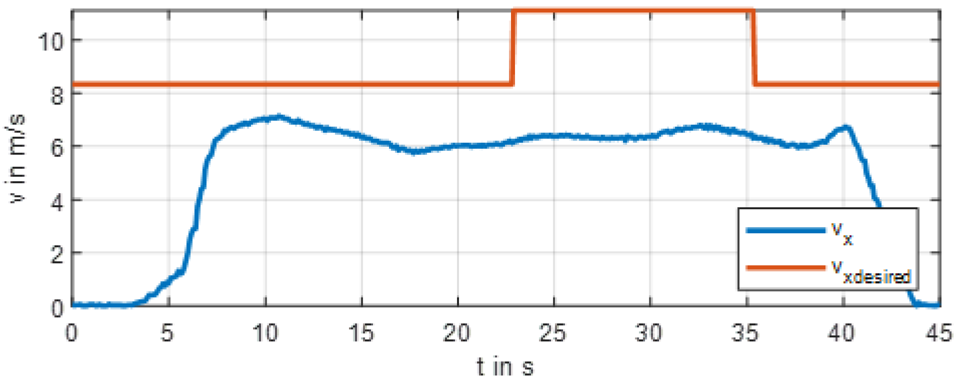


Figure 120 – Main road / with speed recommendation (emulated IVIM) with vehicle in front and MWC adapts speed

Figure 120 shows the case with a change in maximum speed and a couple of surrounding vehicles. These surrounding vehicles (Figure 121) prohibit the test vehicle from reaching its free flow speed (desired speed) and the test vehicle must stay behind the simulated vehicles.

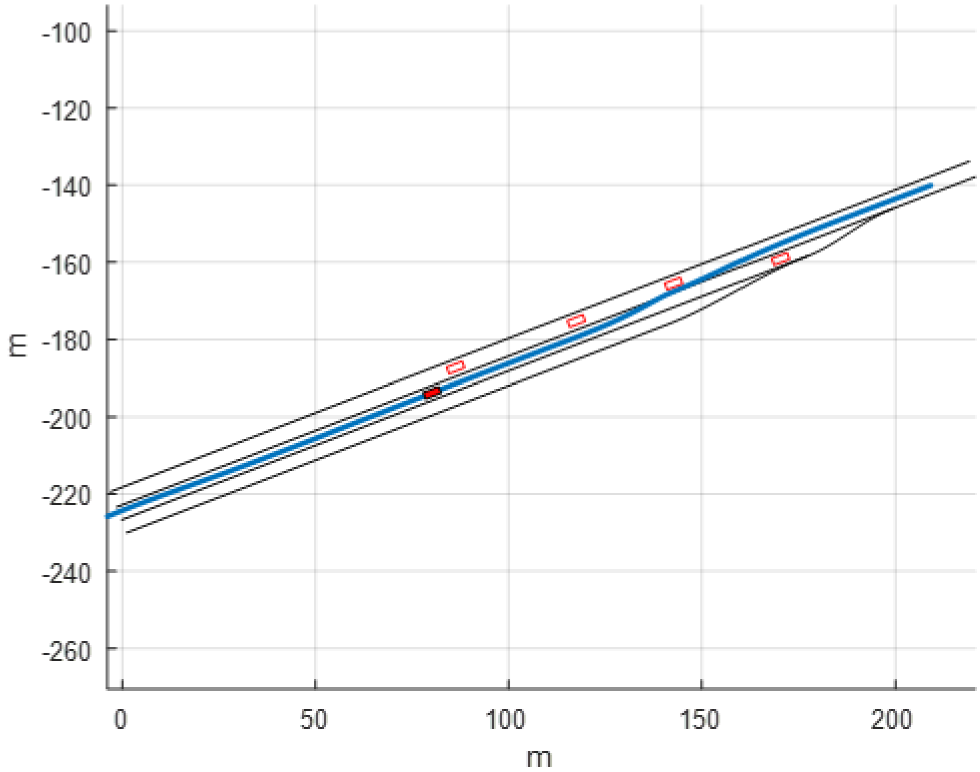


Figure 121 – Main road / with speed recommendation (emulated IVIM) with vehicle in front and MWC adapts speed – positions

4.3.3 Experiment Stack III – Full Communication Chain

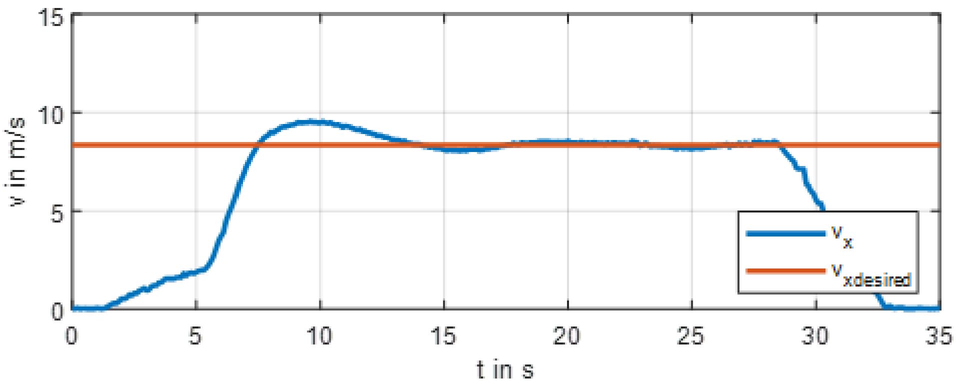


Figure 122 – Main road / without traffic and without speed recommendation

In Figure 122 the velocity of the VuT (blue) and its desired velocity (orange) is shown. The VuT starts from standstill at the western end of the test track, accelerates to 8.33 m/s (30 km/h) and decelerates at the end of the test track.

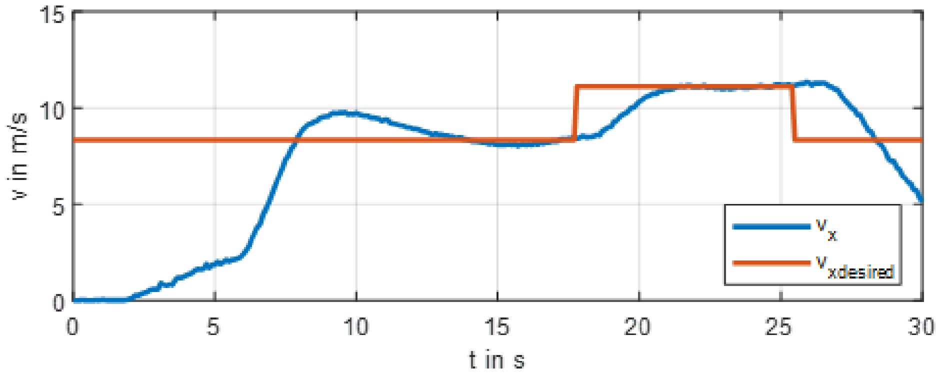


Figure 123 – Main road / with speed recommendation (real IVIM communication) without traffic

Figure 123 shows nearly the same as Figure 118, but now the IVIM is received via the OBU from the RSU and the VuT reacts on the IVIM. After approximately 18 s the VuT reaches the relevance zone of the IVIM and adapts the speed according to the recommendation of 11.1 m/s (40 km/h). As expected, the behaviour is the same to that case of the emulated IVIM.

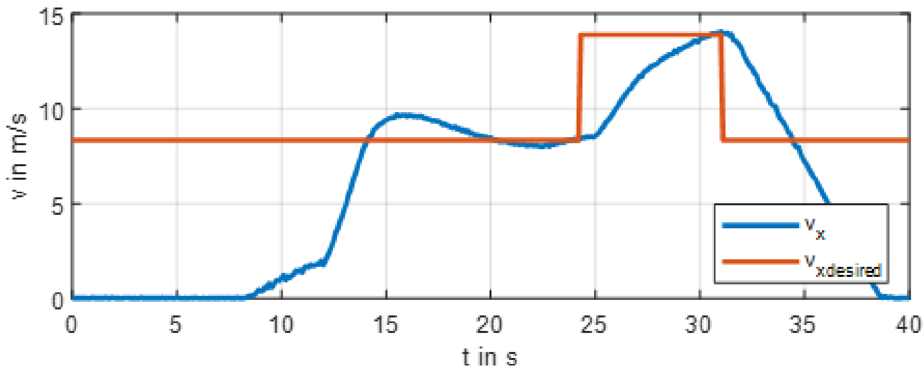


Figure 124 – Main road / with speed recommendation (real IVIM communication) of 50 km/h without traffic

After this successful test, it was decided to increase the speed recommendation to 50 km/h and repeat the test (Figure 124). The VuT receives the message, reaches the relevance zone and adapts the speed as before. The difference is the height of the recommended speed and the resulting speed of the VuT. The VuT reaches the recommend speed of 13.9 m/s (50 km/h) but cannot settle a stable speed because it must decelerate due to the end of the test track.

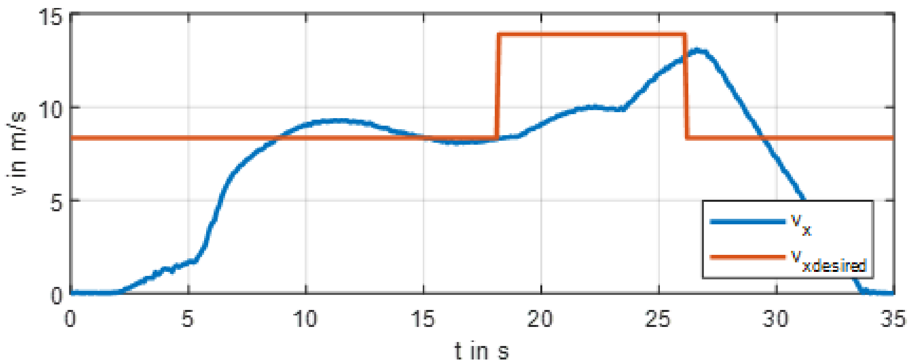


Figure 125 – Main road / with speed recommendation (real IVIM communication) with vehicle in front and MWC overtakes

In the following test (Figure 125) the VuT receives an IVIM with a speed recommendation of 50 km/h. First the VuT adapts the speed to a vehicle in front and then it starts to overtake (Figure 115).

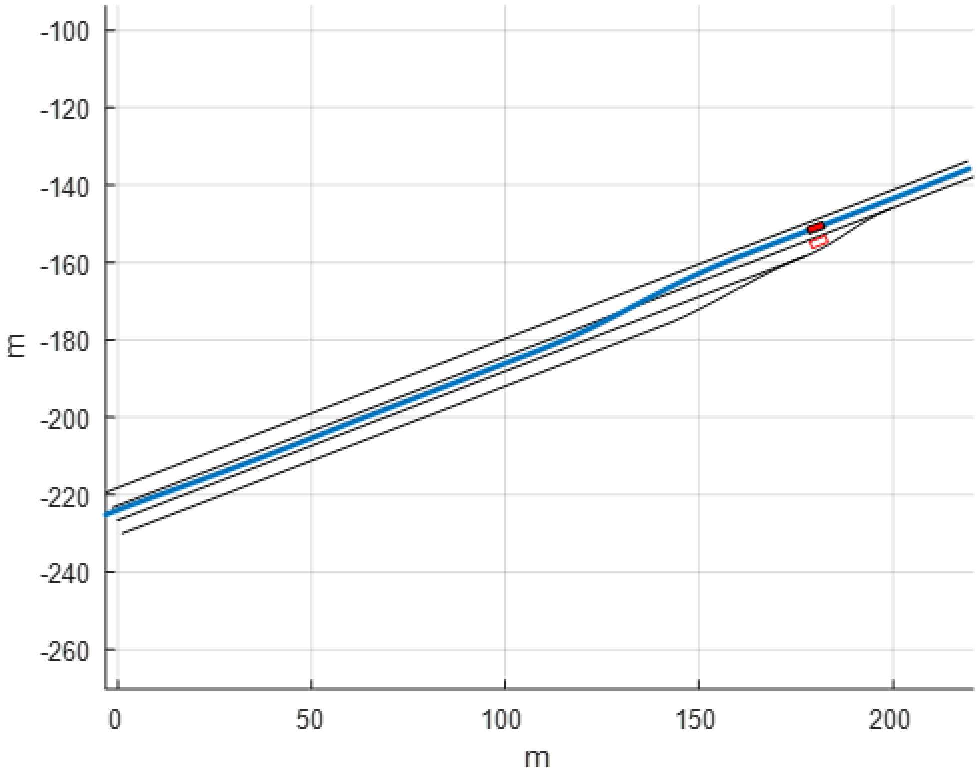


Figure 126 – Main road / with speed recommendation (real IVIM communication) with vehicle in front and MWC overtakes – positions

A result of the last test scenario “Main road – with speed recommendation (real IVIM communication) with vehicle in front and MWC adapts speed” is shown in Figure 127. The VuT accelerates to 8.33 m/s (30 km/h), receives the IVIM with the speed recommendation of 13.9 m/s (50 km/h) and reaches the relevance zone at about 18 s. The VuT cannot accelerate to reach the recommended speed due to a slower vehicle in front of the VuT and several vehicles on the left lane.

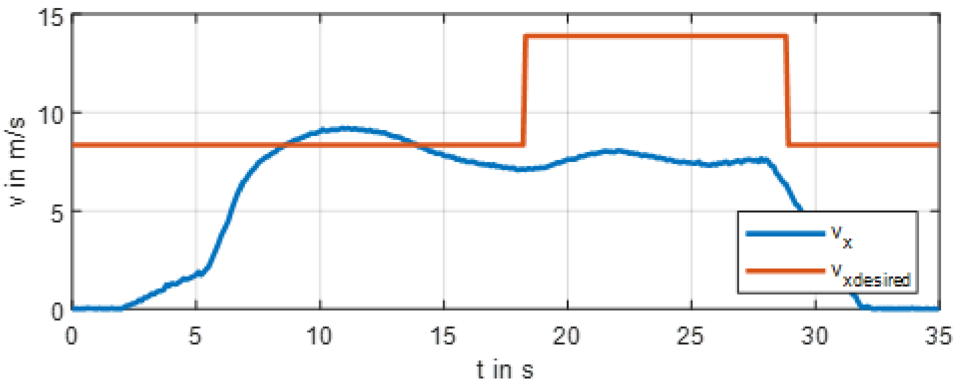


Figure 127 – Main road / with speed recommendation (real IVIM communication) with vehicle in front and MWC adapts speed

As a summary to the preliminary analysis of the Hybrid-testing experiments, we described here the implementation details of this novel testing methodology and conducted the real-world tests for all the relevant use cases defined in section 4.2. Hybrid-testing procedure (VIF). Particularly, we have shown that:

- Successful and repeatable real-world proof of concept Hybrid-testing experiments are achievable on a proving ground, which in this case was the ÖAMTC Lang/Lebring proving ground near Graz (Austria).
- Plenty of real-world experimental data was collected and initial observations were reported.
- The available data was shared with all the partners for further analysis and study, as well as dissemination activities.

In conclusion, Hybrid-testing methodology was realized with the specified toolchain combining a real-world vehicle with real SAE Level-3 automated driving functions to interact with virtual and real traffic elements for testing proof-of-concept hypotheses at an enclosed proving ground. The implementation of the Hybrid-testing based only on the proving ground was purely decided for the purpose of safety, since the current implementation of it does not utilize any environmental sensors other than the RTK-GPS used for positioning of the ego vehicle on the digital HD-map. All the rest of the sensor data is simulated. The initial results demonstrate the feasibility of the suggested methodology for testing ADAS functions in virtual driving scenarios, particularly for analysing the interaction of automated and manual driven vehicles at various penetration rates as conjectured by the project INFRAMIX. The analysis of the collected data the implications of the experiments will be reported as part of the Deliverable D5.3 “Evaluation, impact analysis and new safety performance criteria". Also, there are already several publications in preparation to disseminate the academic aspects of the results.

5 German demonstrator

5.1 Description of the demonstrator

The German demonstrator is the same demonstrator as is being used in the two other test sites (in Austria and Spain), but the testing in Germany mainly serves as preparation for the other two test sites. In particular, integration tests are performed to ensure the successful cooperation of the several building blocks which are:

a) By ASFINAG and AUTOPISTAS: definition of use cases for all three INFRAMIX scenarios on their respective test sites (in Austria near Graz and in Spain near Girona) in form of a PowerPoint presentation (Austria): INFRAMIX_Tests_Handout.pptx or in form of an excel table (Spain). In these documents a series of zones are defined by km-positions, driving direction and specific recommendations or information

b) By SIEMENS: preparation of mockup ITS-G5 message files (IVIM with an AVC extension container in a Datex II Envelope) containing the INFRAMIX recommendations and information as specified in a) to be send in broadcast mode to the vehicles in the specified geo-fence translated in lateral and longitudinal coordinates

c) By TomTom: translation of the mockup files as defined in b) into specific xml-files according to the TomTom interface specification containing a filtered version of the information prepared in a)

d) By TomTom: preparation of additional specific mockup xml-files targeting individual vehicles in unicast mode as specified in a). Especially recommendations to (individually) change lanes (as in scenario 3) are here concerned

e) By TomTom: setting up a web-service which sends the relevant INFRAMIX recommendations and information upon vehicle requests for specific lanes, lateral and longitudinal coordinates

f) By BMW: installation of an onboard app (called GenIE-App) which sends in regular time steps (every 5s) a request with the unique Vehicle Identification Number (VIN) to a specific back-end service at the BMW Backend (GenIE-Backend) which returns relevant jpg-images if available for the requesting car in the proper geographical and chronological fence

g) By BMW: installation of a Backend Service which receives geographical coordinates, lane position, driving direction and VIN of vehicles and forwards these to the TomTom web-interface as implemented in e). For easy testing (with a standing vehicle) this service was complemented by a mockup where arbitrary numbers (independent of the actual position of the vehicle under test) could be sent for simulating a drive over the specific highway segments as defined in a) (LaneChoiceSimulator)

h) By BMW: installation of a Backend Service (called Inframix Backend) which receives upon request from the TomTom interface as implemented in e) xml-files containing the information as prepared in c) and d). The received xml-files are then immediately after receival converted in appropriate jpg.images which are then send to the GenIE backend service

i) By BMW: installation of a backend service (GenIE-Backend Service) to serve vehicle requests as provided by f) with proper images as compiled by h)

Figure 128 – The GenIE App among other onboard Apps in the ConnectedDrive Menu

5.2 German test procedure

The test procedure used in Germany is basically the same as is used on the two other test sites in Spain and Austria.

Based on the national test site scenarios in a), a sequence of test coordinates, heading (or driving direction) and lane position for the testing vehicle are defined where specific INFRAMIX messages are expected. These testing coordinates are then inserted in a simulator script which feeds over the air a backend service (component g).

Table 35 – For the Spanish test site following testing coordinates are defined

Kilometre	Longitudinal	Lateral	Relevant scenarios
62.1	2.778852	41.977426	S1-S2-S3
62.8	2.778124	41.972197	
63.2	2.778801	41.967859	
63.7	2.78014	41.964116	
64.2	2.782655	41.960248	
64.7	2.785214	41.956153	

65.2	2.787097	41.951943	
65.7	2.788302	41.947546	

Table 36 – For the Austrian test site, east loop, following testing coordinates are defined

Kilometre	Longitudinal	Lateral	Relevant scenarios
170	15.5840959	47.0635478	SC1 EL DD1/2
171.5	15.5646564	47.0627724	
172	15.5582807	47.0619606	
172.5	15.5528005	47.0595079	
177.5	15.5060507	47.0316431	
178	15.5027738	47.0277781	
178.5	15.4981718	47.0245252	

For the two driving directions in Austria, the constant heading values of 45° (driving to the northeast) and 225° (driving to the southwest) were used.

Table 37 – For the Austrian test site, west loop, following testing coordinates are defined

Kilometre	Longitudinal	Lateral	Relevant scenarios
170	15.5840959	47.0635478	SC1 EL DD1/2
171.5	15.5646564	47.0627724	
172	15.5582807	47.0619606	
172.5	15.5528005	47.0595079	
177.5	15.5060507	47.0316431	
178	15.5027738	47.0277781	
178.5	15.4981718	47.0245252	

In the ideal case, the whole communication chain then responds to the simulated request within 5 seconds with an appropriate image on the navigation screen, visualizing the INFRAMIX recommendations and information.

In the case no image is shown, it must be analysed whether a component failed or filtered out the information for a particular reason. When the right image is shown within the given time period, the test is successful.

5.3 Results from the German demonstrator

On the German test site, two types of tests were performed:

I. Interface tests: where a manual request was sent directly to the TomTom interface
II. Full integration tests including the vehicle with the navigation screen as testing output

5.3.1 Interface tests

For the interface test, a manual request looks for example like:
https://Serveradress/Vehicle_ID/getAdvice?Lat=47.0595079&Long=15.5528005&Lane=1&Speed=110&heading=45&key=xxx

Figure 129 – Test BMW (G12) standing at the toll gate – Girona Oest

6 Data Collection and Aggregation plan

The main objective of this task was to aggregate and validate the collected data and deliver it to WP5 for its evaluation. The execution of task 4.5 is based on the data collection and aggregation plan as specified in Task 4.1 and on the data management plan specified in D1.3[9].

As far as documents and smaller data amounts are concerned, the Redmine file sharing platform was used successfully. For larger amounts of data, Redmine, would however not been suitable due to file size restrictions. The much more complex and extensive data from tests and simulations is shared among the partners according to the accessibility as already specified in Table 4 in D1.3 (for a summary, see Table 38). It was agreed among the partners not to use a central data warehouse for data storage of this data. This is due to practical reasons (in house analysis, converting and processing tools), hence the consortium agreed not to allocate additional budget for a central data warehouse of presumably low benefit.

Table 38 – Summary of the data storage and sharing provisions of Table 4, Del. 1.3

Data type	Storage	Accessibility
Data from third party services	Aggregated traffic data: TomTom cloud Mobility Data Marketplace platform[10]	Open
	HD maps: TOM backend server	Restrictions: TomTom maps are not open to be used beyond the scope of INFRAMIX following previous agreements in the consortium, including the consortium agreement
Data from vehicle services	eXtended Floating Car Data (XFCD): Cellular backend servers (BMW, TOM)	Restrictions: BMW and TomTom specific restrictions on data sharing according to general agreement. Any sensitive personal data regarding drivers will be handled according to EU guidelines (see Chapter 3.7).
Planning data	Autopistas hub Asfinag's stream	Open only to INFRAMIX consortium. Possible access from external entities under demand.
Road infrastructure sensors data (incl. processed traffic data)	Autopistas hub ASFINAG's stream (The repositories of that data due to their complexity and storage capabilities requirements will be finally decided during the Task 4.5)	*Autopistas hub:* Open only to INFRAMIX consortium. Possible access from external entities under demand. *ASF stream:* Open only to INFRAMIX consortium. Possible access from external entities under demand.

[9] D1.3 Data Management Plan

[10] http://www.mdm-portal.de/en/

C-ITS wireless messages extensions	Data from real demonstration: Autopistas hub ASFINAG's stream Data from simulation: Fraunhofer repository VIRTUAL VEHICLE repository	Open to everyone (the extensions will be proposed to be included in the ETSI standards[11][12])
Processed traffic estimation output data **&** **Processed traffic control output data**	*Research results:* Data for demos from simulation Data for demos from the real-tests (Redmine and Zenodo[13])	Open (Research results expected to be published. Data restricted according to GA)
Sub-microscopic vehicle data **&** **Microscopic traffic data**	Simulation output data: Microscopic traffic data: Fraunhofer repository (FOKUS-SVN) Sub-microscopic vehicle data: VIRTUAL VEHICLE repository (Projectplace)	Data are restricted according to GA. Selected data and demos will be open (e.g. research results). Software: VSimRTI is available to all partners during the project as stated in the CA. After INFRAMIX VSimRTI will be available according to Fraunhofer license[14]. ICOS is available for project partners as described in the CA.
Infrastructure signage	Research results: Redmine and Zenodo	Open (Expected to be published and public and proposed to the regulators.)
Data related to users' **responses**	Redmine	Open only to consortium (see Chapter 3.7).
Test users' **background data**	Redmine	Open only to consortium (see Chapter 3.7).

Table 38 shows a summary of the data management plan according to Table 4 of D1.3.

[11] European Commission Directorate-General for Research and Innovation. Guidelines on Open Access to Scientific Publications and Research Data in Horizon 2020. Version 3.2, 21 March 2017
[12] http://www.eco-at.info/Specification_request.html / "C-ITS for Automated Driving - SWP1.2 - Functional Specification v01.00"
[13] EC's Guide on Open Access to Scientific Publications and Research Data in Horizon 2020:
https://www.openaire.eu/h2020openaccess/
https://www.eugdpr.org/
[14] https://www.fraunhofer.de/en.html

6.1 Data from third party service

Following the development of the project, a test set-up with 3 BMW vehicles is planned where mainly V2X communication is being focused.

The major data to be examined by BMW are the xml-messages from Tom to BMW on request of the BMW vehicles. The log files are stored in text format on an internal TomTom server in case they are needed for the evaluation of the project.

The xml-messages are stored on Redmine for possible analysis.

Images of the GenIE App which are subsequently shown in the navigation screen are also stored in Redmine.

6.1.1 Data for simulation modelling

VIF: For simulation modelling, the following files were necessary:

- A .xodr file was created semi automatically based on data from open street map.
- For the traffic simulation, the .xodr-file was converted to sumo-netfile.

6.2 Data from vehicle services

TOM provided historical traffic data and speed contour plots to identify potential timeslots for increased possibilities of congestion phenomena. The data showed that there is in general rather low congestion probability on both test sides. Due to legal aspects, the TOM data were provided already as plotted diagrams. The main rationale was to confirm the found traffic pattern by our (FOK) work in T3.3. More specifically, it was found that the given data from AAE in the selected timeframe and the selected road stretch of AP-7 around Girona always included only minor congestion, in which case the algorithms from TUC could achieve only minor improvements. This fact was confirmed by the data of TOM.

The fleet used in INFRAMIX does not generate a sufficient amount of data for meaningful analyses of the traffic states. It is therefore not used as planned for the analyses of traffic states. Instead, data of the TomTom fleets is used for any analyses. Here we did not set up a custom INFRAMIX set up but used the existing TomTom infrastructure.

6.3 Planning data

Planning data such as the geometry of the road, the road layout, the lane marking locations etc. were provided from the test sites in Spain and in Austria for incorporating into the co-simulation platform. All files in a VSimRTI scenario directory are planning data. All together form the scenario description, containing the road network, infrastructure and configurations of simulation entities and communication. These files are either stored in JSON or XML format.

6.4 Road infrastructure sensors data (incl. processed traffic data)

Traffic data was provided in alignment with the existing upload generators developed in D3.3. Real-time information regarding the number of vehicles, their speed, time gap, heading and type of vehicle was gathered by a number of road sensors on the two test tracks in Spain and Austria: Further, this data was used to calibrate the traffic models for simulations in order to provide realistic traffic situations. In addition, real time data was collected, aggregated and pushed to a web service at SIE during the INFRAMIX traffic control strategies demonstrations.

As far as the sensor data of the Spanish test site are concerned, the data are stored on Amazon Web Services, the corresponding data format is the Amazon database format.

Real time data was collected, aggregated and pushed to a web service at SIE (simulating the ICC) during the INFRAMIX traffic control strategies demonstrations. The INFRAMIX control strategies are implemented in the ICC, which can therefore give its recommendations according to the input traffic data (see Section 6.7).

Weather data is collected on the ASFINAG network either via environmental data sensors mounted on many VMS Gantries and by additional sensors monitoring the slipperiness danger. Currently ASFINAG is working on a central database to centrally collect and store all the gathered data. Since there are several different sensor types from different manufactures in operation there is no single data format in which this data is delivered, however the aim of the database is to provide such a unified format as output (e.g. .json). the number of sensors on the Austrian network is approximately 300.

Roadworks data were extracted from the ASF internal database, which maintains the roadworks data of the company. From the database interface also the ASFINAG app as well as the traffic information centres obtain their information. The interface provides information in .json and DATEXII format.

Radar trajectories were recorded on the Austrian test track (specific timeslots) in order to improve the quality of the sensor fusion on the ASF test track when compared to the GSP data recorded (CAM messages sent out) by specific test vehicles. The recorded data is stored in the .pcap format, which can be easily parsed and verified using the Coda-Whireshark programme[15].

6.5 C-ITS wireless messages

Several tests were carried out on the Austrian and Spanish test tracks for C-ITS communication test, both via ITS-G5 and the API to cellular services. The test included simple communication tests as well as more complex “mockups” demonstrating the potential message setup of several traffic control strategies explored within the project. The test protocols including the message set and GPS positions (CAM messages) were collected in Redmine. As mentioned above, CAM messages were also used for enhancing the sensor fusion algorithm at the Austrian test site. The data was again stored in .pcap format and analysed using Wireshark or python scripts.

All C-ITS messages (as used in the mock-ups) are stored/uploaded to the IMC and also available as single .xml Files per message to the INFRAMIX consortium..

6.6 Processed traffic estimation output data

No traffic estimation output data is produced/processed (traffic estimation strategies are not implemented at the IMC).

6.6.1 Simulation data

For both 2.6 and 2.7 and only for the simulations TUC will store:

1. The data produced by the simulator (Performance indexes) as well as the state (flow, speed and density) for each segment-lane and for each measurement step of the simulation.
2. The estimates produced by the estimators (for 2.6) and the control decisions produced by

[15] https://www.wireshark.org/

the controller(s) (for 2.7).

3. The parameterization of the simulator (penetration rates, demands, other conditions).
4. The parameterization of the controller (gain values, thresholds, etc.).

6.7 Processed traffic control output data

All processed traffic control output data are stored at the IMC by using a logging system. The received JSON input-data (aggregated sensor-data) are cached as a compressed byte-array at the IMC, including its corresponding receipt timestamp, which furthermore are used by the Traffic Controller to run its traffic estimation and traffic control strategies. An implemented logging-system at the IMC ensures verifiable results of the traffic estimation and traffic control strategies. Therefore, each result of the processed strategies gets stored in a unique .JSON file, which includes the processed values of the detectors as well as the corresponding results.

6.8 Sub-microscopic simulation and real vehicle dynamics data

Input and output data from the inertial vehicle parameters (steering wheel angle, throttle and brake, positions, speeds and accelerations) are saved in a csv-file format as well in Matlab-format .mat.

For each simulation run the vehicle data are stored together with surrounding vehicles of the microscopic simulation, See Section 4.3 for further description of the logged data and input parameters.

6.9 Microscopic traffic data

FOK: Microscopic traffic data is generated during each simulation and is stored in the VSimRTI logs directory. The simulations are run on our simulation server. There the microscopic traffic data is stored either in XML or JSON format.

6.10 Infrastructure signage

Static physical signage data was provided as part of the layout of the test-site.

As far as a new proposed sign within the INFRAMIX project is concerned, the catalogue of signs was extended to display the sign on VMS on the Spanish test track as well as on an IMIS trailer on the Austrian test side in order to gain feedback from the testers or the audience.

6.11 Data related to user’s response

User appreciation on the overall information chain, visual elements, physical elements, electronic signals, developed control strategies for mixed traffic scenarios including different types of vehicles, infrastructure classification scheme etc. Indicators, relevant to users’ appreciation, which will be evaluated are for example comprehensibility, controllability, intuitiveness, learnability, willingness to use, perceived usefulness, and expected impacts. Were gathered throughout the test and especially at the stakeholder Workshops, but also from several experts via mail. The data was collected using questionnaires – either in electronic or paper form. The results of the assessment of users’ appreciation regarding the overall information chain, the visual and electronic signals and the control strategies will be included in deliverable D5.2, which will be a public document.

6.12 Test users' background data

In order to crosslink the user appreciation to user's background data for example driving expertise, age range, etc. was collected additionally to the above-mentioned user appreciation. The security aspect of sensitive data is covered at Deliverable 7.2 [16]. In any case personal data, if any, collected and stored within INFRAMIX, will be permanently and irrevocably erased on the project completion. This kind of data will be collected similarly- through questionnaires. In general, only anonymised information (information that may be processed in a way that inhibits tracing back the individual person) was part of the INFRAMIX activities and will be documented whenever needed according the data protection regulations[17].

User's Response and Background Data are stored as Excel Files for statistical analysis reasons. They are be stored at ICCS Network Server.

The ethical aspect of the test users' background data is covered at Deliverable 7.3 [18].

[16] Deliverable 7.2 - GEN - Requirement No. 2

[17] The Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation - GDPR) comes into force on 25 May 2018

[18] Deliverable 7.3 - EPQ - Requirement No. 3

7 Conclusions

This section summarizes the conclusions and lessons learned, that were derived from the demonstrations carried out in the test sites.

The demonstrations were carefully planned with a pre-test or essay period just before the actual test period in the first demonstration. Within the pre-test, some hypotheses concerning the actions to be carried out were tried in the field such as the logistics, equipment and personnel, necessary for the tests. Some preliminary versions of the communication links, e.g. the ITS-G5 communication, were pre-tested in the field and provided useful feedback for the demonstration. The pre-tests were also very useful to determine the ideal location for personnel on the road beforehand, for their optimal distribution during the demonstrations.

An important lesson learned during field trials was that sufficient pre-testing is a key factor for successful field tests and demonstrations. It is important to highlight that the whole communication chain should be included in such pre-tests in the field. The Spanish demonstration, being the first one that took place, acted as a very complete pre-test for the preceding demonstration at the Austrian test site.

The main focus of the field tests from a technical viewpoint was to test the hybrid infrastructure, the ITS-G5/cellular communication links between sensors, TMC and IMC, and the software integrations. From a human interaction viewpoint, the goal was to gather users' appreciation from the participants.

Overall, the different applied technologies did not show the same state of maturity. However, after some necessary adjustments in the field during pre-test and "real" test, the functionality of all the different types of communication links in the project could be established and the connection goals were achieved as expected. The ITS-G5 communication was successfully tested at both test sites, including standardized day1-services as well as new, not yet standardized, day2-services. Further, an impressive example of standardization was shown in the ITS-G5 communication within the Spanish tests: ITS-G5 equipment in the AAE test vehicle equipped with ATE technology could communicate successful with the INFRAMIX ITS-G5 Road Side Units during the complete Spanish test runs and could furthermore communicate standardized day1-services with other AAE ITS-G5 road side equipment (installed outside of the INFRAMIX project) without special configuration.

Furthermore, in the case of the cellular communication, a unicast mode of communication was successfully exercised using the existing LTE (4G) mobile network but this does not yet confirm the concept since the number of vehicles was very limited. The scaling topic was not a goal of the project, was not addressed at all and should also be investigated when many more vehicles are using this kind of unicast mode.. It should also be remarked that an effective distribution module that decides who will be addressed and who not, was not developed within the project since it was not again a specific goal of the project. Some fundamental, conceptual work still has to be done here. Additionally, it must be remarked that the amount of transferred data over the air was not representative for the real use case, where for autonomous vehicles, HD maps are planned to be transferred to the vehicle. That point is important to bear in mind in the future, not in the scope of the present project.

The number of participants in the tests exceeded all expectations. Hence, it was possible to gather valuable feedback from people of various backgrounds. Further, this also allowed to disseminate the project broadly generating a greater impact. The analysis of the questionnaires is further developed in deliverables "5.2 Users' appreciation in INFRAMIX developments" and "5.3 Evaluation, impact analysis and new safety performance criteria".

As a parallel activity, sub-microscopic simulations as well as hybrid testing were utilized to study interaction of an automated vehicle with manually driven vehicles at different traffic densities. These test-runs analysed various traffic scenarios to understand the behaviour of the automated VUT with and without the infrastructure elements.

The field tests also demonstrated the digital highway concept with the acquisition of real-time traffic data and the provision of these data as an input for partners' research. Both test sites, Autopistas and Asfinag, acquired and processed a large volume of traffic data and processed it creating basic data services for the partners. The acquired traffic data did, however, not present congestion. This is partly also due to congestion risk being a criterion that public administrations tend to avoid when choosing a test track. The traffic conditions in these low-risk sections were simply not dense enough to create congestion during the times the services were tested. As a consequence, the control strategies developed within the project had to be applied using lower traffic volumes to account for congestion. The results obtained are included in the deliverable "3.4 Traffic management".

Overall, the tests on the demonstration sites have helped to create a prototype mixed physical-digital infrastructure capable of gathering real-time data, processing these data also in real-time and providing suitable information through adequate communication links as planned. The results of the demonstrations unravelled many important issues that modified the previous knowledge of the partners and created new and valuable knowledge.

8 References

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[4] Deliverable 3.5 - New visual signs and elements

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https://www.eugdpr.org/

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[15] Deliverable 7.2 - GEN - Requirement No. 2 – CONFIDENTIAL DOCUMENT

https://redmine.iccs.gr/dmsf/files/18836/view

[16] The Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation - GDPR) comes into force on 25 May 2018

[17] Deliverable 7.3 - EPQ - Requirement No. 3 – CONFIDENTIAL DOCUMENT

https://redmine.iccs.gr/dmsf/files/18834

9 Annex I – Surveys

9.1 Survey S1 – UC1:Q1

Scenario 1 – Use Case 1: Q1 First survey of that use case, counting three laps: Dedicated lane assignment x2 and Dedicated lane assignment with Speed Limit.

To be filled in by the Instructor:	*AAE*
Participant ID:	
Test site:	*AP-7 Girona*
Test vehicle:	
Scenario tested:	***S1 – UC1:Q1*** *(A lane is assigned dynamically to automated vehicles in mixed traffic)*

QUESTIONNAIRE

Instructions for the respondents

After the demonstration of this traffic management functionality, please answer the following questions.

ACCEPTANCE PART

1) Based on your current knowledge about this functionality, would you use the information provided by the traffic management (via road signs or in-vehicle application recommendations) in the future?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
					
 					

2) Based on your current knowledge about this functionality, would you consider following the traffic management suggestions (via road signs or in-vehicle application recommendations) in the future?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
					
 					

3) How useful are these functionalities for you?

	Not useful at all	Rather not useful	Neutral	Rather useful	Absolutely useful
					
 					

4) How satisfying are these functionalities for you?

Not satisfying at all	Rather not satisfying	Neutral	Rather satisfying	Absolutely satisfying

5) What is your immediate reaction to these functionalities?

Very negative	Negative	Neutral	Positive	Very positive

6) How would you judge the potential benefit of having access to these functionalities for you?

No benefit	Small benefit	Medium benefit	Large benefit	Very large benefit

7) Are the pictograms/road signs…:

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
…easy to learn?					
…easy to understand?					

8) Is the information provided by the traffic management (via road signs or in-vehicle application recommendations):

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
…correct?					
…potentially distracting you from the driving task?					
Please describe the level of your distraction during the test drives:					

EXPECTED IMPACTS PART

9) Please rate how much do you agree with the following statements:

	Not at all / Very much
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help drivers of conventional vehicles to interact in an easier/intuitive way with the automated vehicles	0 1 2 3 4 5 6 7 8 9 10
The number of times a road sign is missed will be decreased due to the in-vehicle HMI	0 1 2 3 4 5 6 7 8 9 10
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help reduce stress related to travelling in mixed traffic	0 1 2 3 4 5 6 7 8 9 10
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help increase comfort related to travelling in mixed traffic	0 1 2 3 4 5 6 7 8 9 10

	Not at all / Very much
The traffic management control strategies will benefit the transport operators to better perform their daily work	0 1 2 3 4 5 6 7 8 9 10
The traffic management control strategies offer new ways to the transport operators to detect incidents	0 1 2 3 4 5 6 7 8 9 10
The traffic management control strategies offer new ways to the transport operators to react to incidents	0 1 2 3 4 5 6 7 8 9 10
The traffic management control strategies will support the transport operators to solve problems faster	0 1 2 3 4 5 6 7 8 9 10

10) Which will be the impact of this functionality provided by the traffic management (via signs or in-vehicle application) on:

	Very negative	Rather negative	Neutral	Rather positive	Very positive
… traffic safety?					
… traffic efficiency?					
… CO2 emissions?					

11) Do you have any additional comments? What could be improved?

____

____

Thank you very much for your valuable answers and comments!

9.2 Survey S2 – UC1:Q1

Scenario 2 – Use Case 1: Q1 First survey of that use case, counting three laps: Roadworks plus Speed Limit, Speed Recommendation or Time Gap.

To be filled in by the Instructor:	*AAE*
Participant ID:	______________________
Test site:	*AP-7 Girona*
Test vehicle:	______________________
Scenario tested:	***S2 – UC1: Q1*** *(Roadworks zone in mixed traffic – Single Lane Closure)*

QUESTIONNAIRE

Instructions for the respondents

After the demonstration of this traffic management functionality, please answer the following questions.

ACCEPTANCE PART

1) Based on your current knowledge about this functionality, would you use the information provided by the traffic management (via road signs or in-vehicle application recommendations) in the future?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
					
					
					

2) Based on your current knowledge about this functionality, would you consider following the traffic management suggestions (via road signs or in-vehicle application recommendations) in the future?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
					
					
					

3) How useful are these functionalities for you?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
					
					
					

4) How satisfying are these functionalities for you?

Not satisfying at all	Rather not satisfying	Neutral	Rather satisfying	Absolutely satisfying

5) What is your immediate reaction to these functionalities?

Very negative	Negative	Neutral	Positive	Very positive

6) How would you judge the potential benefit of having access to these functionalities for you?

No benefit	Small benefit	Medium benefit	Large benefit	Very large benefit

7) Are the pictograms/road signs…:

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
…easy to learn?					
…easy to understand?					

8) Is the information provided by the traffic management (via road signs or in-vehicle application recommendations):

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
…correct?					
…potentially distracting you from the driving task?					
Please describe the level of your distraction during the test drives:					

EXPECTED IMPACTS PART

9) Please rate how much do you agree with the following statements:

	Not at all — Very much
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help drivers of conventional vehicles to interact in an easier/intuitive way with the automated vehicles	0 1 2 3 4 5 6 7 8 9 10
The number of times a road sign is missed will be decreased due to the in-vehicle HMI	0 1 2 3 4 5 6 7 8 9 10
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help reduce stress related to travelling in mixed traffic	0 1 2 3 4 5 6 7 8 9 10
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help increase comfort related to travelling in mixed traffic	0 1 2 3 4 5 6 7 8 9 10

	Not at all — Very much
The traffic management control strategies will benefit the transport operators to better perform their daily work	0 1 2 3 4 5 6 7 8 9 10
The traffic management control strategies offer new ways to the transport operators to detect incidents	0 1 2 3 4 5 6 7 8 9 10
The traffic management control strategies offer new ways to the transport operators to react to incidents	0 1 2 3 4 5 6 7 8 9 10
The traffic management control strategies will support the transport operators to solve problems faster	0 1 2 3 4 5 6 7 8 9 10

10) Which will be the impact of this functionality provided by the traffic management (via signs or in-vehicle application) on:

	Very negative	Rather negative	Neutral	Rather positive	Very positive
… traffic safety?					
… traffic efficiency?					
… CO_2 emissions?					

11) Do you have any additional comments? What could be improved?

Thank you very much for your valuable answers and comments!

9.3 Survey S3 – UC1:Q1

Scenario 3 – Use Case 1: Q1 First survey of that use case, counting three laps: Time Gap.

To be filled in by the Instructor:	*AAE*
Participant ID:	________________
Test site:	*AP-7 Girona*
Test Vehicle:	________________
Scenario tested:	***S3 – UC1:Q1*** *(Automated vehicles (AV) Driving Behaviour Adaptation in Real Time at Sags)*

QUESTIONNAIRE

Instructions for the respondents

After the demonstration of this traffic management functionality, please answer the following questions.

<u>ACCEPTANCE PART</u>

1) Based on your current knowledge about this functionality, would you use the information provided by the traffic management (via road signs or in-vehicle application recommendations) in the future?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes
				

2) Based on your current knowledge about this functionality, would you consider following the traffic management suggestions (via road signs or in-vehicle application recommendations) in the future?

	Definitely not	Rather not	Maybe, cannot decide	Rather yes
				

3) How useful is this functionality?

	Not useful at all	Rather not useful	Neutral	Rather useful
				

4) How satisfying is this functionality?

Not satisfying at all	Rather not satisfying	Neutral	Rather satisfying	Absolutely satisfying

5) What is your immediate reaction to this functionality?

Very negative	Negative	Neutral	Positive	Very positive

6) How would you judge the potential benefit of having access to this functionality?

No benefit	Small benefit	Medium benefit	Large benefit	Very large benefit

7) Are the signs…:

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
…easy to learn?					
…easy to understand?					

8) Is the information provided by the traffic management (via road signs or in-vehicle application recommendations):

	Definitely not	Rather not	Maybe, cannot decide	Rather yes	Definitely yes
…correct?					
…potentially distracting you from the driving task?					

EXPECTED IMPACTS PART

9) Please rate how much do you agree with the following statements:

	Not at all / Very much
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help drivers of conventional vehicles to interact in an easier/intuitive way with the automated vehicles	0 1 2 3 4 5 6 7 8 9 10
The number of times a road sign is missed will be decreased due to the in-vehicle HMI	0 1 2 3 4 5 6 7 8 9 10
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help reduce stress related to travelling in mixed traffic	0 1 2 3 4 5 6 7 8 9 10
The information provided by the traffic management (via road signs or in-vehicle application recommendations) will help increase comfort related to travelling in mixed traffic	0 1 2 3 4 5 6 7 8 9 10

	Not at all much										Very
	0	1	2	3	4	5	6	7	8	9	10
The traffic management control strategies will benefit the transport operators to better perform their daily work	○	○	○	○	○	○	○	○	○	○	○
The traffic management control strategies offer new ways to the transport operators to detect incidents	○	○	○	○	○	○	○	○	○	○	○
The traffic management control strategies offer new ways to the transport operators to react to incidents	○	○	○	○	○	○	○	○	○	○	○
The traffic management control strategies will support the transport operators to solve problems faster	○	○	○	○	○	○	○	○	○	○	○

10) Which will be the impact of this functionality provided by the traffic management (via signs or in-vehicle application) on:

	Very negative	Rather negative	Neutral	Rather positive	Very positive
… traffic safety?					
…					
… traffic efficiency?					
… CO_2 emissions?					

11) Do you have any additional comments? What could be improved?

____

____

Thank you very much for your valuable answers and comments!

10 Annex II – Example C-ITS Message


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