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D.4.1

INFRAMIX plan for systems interaction, integration and testing

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v5	20/05/2018	test sites overview description	ICCS
v6	25/05/2018	elaborate existing parts and adding on the plans from the Spanish test site	AAE
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v17	14/12/2018	final version of submission after considering comments from all the consortium	ICCS

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
ACC	Adaptive Cruise Control
AD	Automated Driving
ADAS	Advanced Driver-Assistant Systems
AV	Automated Vehicle
AWC	Adverse Weather Conditions
API	Application Programming Interface
BTN	Bottleneck
CAM	Cooperative Awareness Message
CCAD	Cooperative and Connected Automated Driving
CCV	Connected Conventional Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CV	Conventional Vehicle
DATEX	Data Exchange
DEMN	Decentralized Environmental Notification Message
DLA	Dynamic Lane Assignment
DPR	Dynamic Penetration Rate of automated vehicles
EC	European Commission
EU	European Union
FOT	Field Operational Test
GA	Grant Agreement
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
IMC	INFRAMIX Management Center
IP	IP Connectivity
ITS	Intelligent Transport Systems
IVIM	Infrastructure to Vehicle Information Message
KPI	Key Performance Indicator
LCA	Lane change advice
LCAFC	Lane Change Advice Flow Control

MTFC	Mainstream Traffic Flow Control
NLD	New Lane Design
OBU	OnBoard Unit
PO	Project Officer
RSU	RoadSide Unit
RWZ	Roadworks Zone
SLC	Single Lane Closure
S1-DLA-UC1-DPR	Scenario 1 Dynamic Lane Assignment Use Case 1 Dynamic Penetration Rate
S1-DLA-UC2-AWC	Scenario 1 Dynamic Lane Assignment Use Case 2 Adverse Weather Conditions
S1-DLA-UC3-CVDL	Scenario 1 Dynamic Lane Assignment Use Case 3 Conventional Vehicle drives on a Dedicated Lane for automated vehicles
SC2-RWZ-UC1-SLC	Scenario 2 Roadworks zone Use Case 1 Single Lane Closure
SC2-RWZ-UC2-NLD	Scenario 2 Roadworks zone Use Case 2 New Lane Design
S3-BTN-UC1-DBAS	Scenario 3 Bottlenecks Use Case 1 (AV) Driving Behaviour Adaptation in real time at Sags
S3-BTN-UC1-LCA	Scenario 3 Bottlenecks Use Case 1 Lane-Change Advice to connected vehicles
S3-BTN-U3-LCAFC	Scenario 3 Bottlenecks Use Case 3 Lane-Change Advice combined with Flow Control
TEAC	Traffic Estimation and Control (TEAC) algorithms
TMC	Traffic Management Center
VMS	Variable Message Sign
VuT	Vehicle Under Test
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-X (X represents any entity capable of receiving C-ITS communications)
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 to the transition period when the number of automated vehicles will gradually increase. 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. The key outcome will be a “hybrid” road infrastructure able to handle the transition period and become the basis for future automated transport systems. In order to provide specific solutions with clear impact, INFRAMIX builds on specific high value (in terms of importance with regard to traffic efficiency and safety) traffic scenarios, “dynamic lane assignment”, “roadworks zones” and “bottlenecks. The project outcomes will be assessed, through these scenarios, via simulation and real stretches in modern highways.

Extended simulations will be performed using an advanced simulation environment which combines the modelling of the vehicle behaviour with the traffic simulation, thus enabling the testing of the developed traffic control algorithms with increased traffic densities and with various rates of vehicles with different automated capabilities.

Two test sites in Girona, Spain and in Graz, Austria will demonstrate the three traffic scenarios in the real world. Additionally, the A9 test site in Germany and its resources will be used for development and early testing of speed and lane recommendations based on a dynamic electronic road horizon as well as route recommendations for automated vehicles. Coupling virtual traffic with the real world will be realized through hybrid testing, which will make use of a real vehicle driving through virtual traffic.

In this deliverable, the plan for systems interaction, integration and testing the traffic scenarios is reported for the virtual, the real world as well as the hybrid testing.

Chapter 1 presents the project's scope and the purpose of this document. Chapter 2 gives a high-level overview of the tests that will be performed at each test site, in simulation and in hybrid testing. Chapter 3 includes the preparation, the communication, the required training, and a specific plan for testing preparation. The systems and their integration in order to demonstrate INFRAMIX traffic scenarios at the Austrian, Spanish and German test sites are described in Chapters 4, 5 and 6 respectively. Chapters 7 and 8 present the virtual environment, its models and provide a description of the proving ground for hybrid testing. The last chapter consists of the document conclusions.

The plan for the real tests and the respective simulations created in respect with the key project objectives. These are to assess the proposed adaptations in matters of safety, quality of service, efficiency and users appreciation.

1. Introduction

1.1 Aim of the project

The INFRAMIX project aims to propose a road infrastructure which can accommodate mixed traffic flows, consisted of vehicles with various automation capabilities. The design, upgrading, adapting and testing of both physical and digital road infrastructure elements, within the project timeframe, is oriented to the preparation of a "hybrid" road infrastructure able to handle the transition period and become the basis for future automated transport systems. Towards this objective different technologies are deployed; mature simulation tools adapted to the requirements of mixed traffic (various vehicles types, different automated capabilities), new methods for testing like hybrid testing (coupling virtual traffic with real world elements) and innovative traffic flow modelling, traffic estimation and control algorithms. Besides simulation and hybrid testing, the project outcomes will be assessed in real stretches of advanced highways in order to demonstrate the feasibility of the "hybrid" road infrastructure concept. Targeting to have a clear impact and provide specific solutions, INFRAMIX builds on three traffic scenarios: "dynamic lane assignment", "roadwork zones" and "bottlenecks". Eight specific use cases have been extracted out of these scenarios and described in detail at the D2.1"Requirements catalogue from the status quo analysis" deliverable. In D2.1 the high-level infrastructure requirements to address the use cases are listed. Highways are mainly addressed, as they are expected to be the initial hosts of mixed traffic. However, the key results can also be transferred to urban roads.

1.2 Purpose of Document

The project key scenarios and their related use cases will be investigated and demonstrated through extended simulations, hybrid testing and real world tests. This document reports a plan for systems integration at the test sites, including interactions between physical and virtual systems on the road and at the TMC. This plan relies on outputs from WP2 "*Modelling, simulation and control for mixed traffic*" and WP3 "*Integrated infrastructures and traffic management capabilities*", incorporating also the specificities of the test sites in terms of technical and operational capabilities, and the implications of their legal frameworks for the demonstrations. For each single scenario (lane assignment, road works, and bottlenecks) and for all the use cases (as described in D2.1), the plan includes the corresponding testing sequences and their linked subsystems, and simulation tools.

A specific common test protocol in Chapter 3, provides details about the preparation, the communication, the required training, and a specific plan for testing preparation.

Further details about the demonstrators include: the exact location, available equipment, environment conditions, people and vehicles involved and supporting visualization tools to approve the results of the different demonstrators (Chapter 4 - Chapter 6). Specifically, chapter 6 describes the plan for the demonstrations in the German test site along with interactions with the other test sites which will be performed by the common partner of both activities (BMW) and will include the creation of the speed, lane and route recommendations linked to the INFRAMIX traffic scenarios, and the respective data generation. This overall enhances the INFRAMIX view on mixed vehicle traffic situations, without the necessity to build a third full scale demonstration and test site with project resources.

Chapters 7 presents the virtual environment, its models and the simulation aspects for each scenario. This virtual test site is the most important tool for evaluation of INFRAMIX developments as thanks to its capabilities it gives the possibility of assessing the traffic impact. Results for improvement the location and number of infrastructure physical elements are possible to be acquired by simulating mixed traffic flow and realistic road environment.

Chapter 8 includes the methodology of embedding the prototype vehicle in the virtual traffic situation representing scenarios of mixed traffic situations. This includes the specification of infrastructure elements (Task 3.1) and the virtual test environment developed in WP2.

2. Overview of the planned tests per scenario- use cases

This chapter gives a high-level overview of the planned tests for each use case. Specifically, Table 1 summarizes the kind of tests (in simulation, through real demonstration or hybrid testing) that will be performed and the related partners per use case. The symbol " X " marks the association of each use case with the INFRAMIX test site while " (X) " marks the use case which will be potentially implemented in line with the availability of demanding resources (possibly covered by a third party). It is worth mentioning that INFRAMIX resources don't include fleet of vehicles. Therefore within the project framework the assessment of traffic impact via real testing is not feasible. The real testing has the important role of validating and demonstrating the "hybrid" road infrastructure concept. The highly innovative virtual test site allows the assessment of the three project traffic scenarios in matters of traffic efficiency and safety (Chapter 7).
The reader can find a detailed description of each scenario and the related use cases at D2.1 *"Requirements catalogue from the status quo analysis"*[1].

Table 1 – Tests per use case

Scenarios	Use Cases / Test sites	Austrian	Spanish	German[2]	Virtual test site	Hybrid test	Involved Partners
Scenario 1: Dynamic lane assignment	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	(X)	X	X	X		AAE, ASF, SIE, TUC, ATE, TOM, BMW, ICCS, FOK, ENI
	Exceptional traffic situations-adverse weather conditions as an example	X[3]			X[3]		ASF, FOK, VIF, BMW, TOM
	A conventional vehicle drives on a dedicated lane for automated vehicles		X		X		AAE, SIE, TUC, ATE, TOM, BMW, FOK, ICCS, VIF,ENI
Scenario 2: Roadworks	Single Lane Closure (e.g. short term constructions)	X		X	X	X	ASF,SIE,VIF, FOK,BMW,TOM
	New Lane Design (e.g. long term constructions)				X	X	ASF,SIE,VIF, FOK,BMW,TOM, ATE
Scenario 3: Bottlenecks	Automated vehicles Driving Behaviour Adaptation in Real Time at Sags	X	X	X	X		ASF, AAE, SIE, TUC, ATE, BMW, TOM, ICCS, FOK, VIF,ENI
	Lane-Change Advice to connected vehicles at Bottlenecks	X	X	X	X		AAE,SIE,TUC,ATE, BMW,TOM,ICCS,FOK,VIF,ENI, ASF
	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles	X	X	X	X	X	AAE,SIE,TUC,ATE,BMW,TOM, ICCS,FOK,VIF,ENI, ASF

[1] https://inframix.eu/wp-content/uploads/INFRAMIX_D2.1-Requirements-catalogue-from-the-status-quo-analysis.pdf
[2] Within the concept of the three project scenarios the basic functionalities of speed, lane and route recommendations for automated vehicles with fleet data, sensor data, and input from the road operator will be integrated and tested using the German test site A9. These basic functionalities apply to every use case.
[3] A real demonstration of the use case is not planned but real data from the Austrian test site weather station will be used for the realistic use case simulations.

3. Common test protocol

The common test protocol[4] is specified in collaboration with Task 5.1 "*Evaluation methodology and users' engagement process*" so as to be in line with the evaluation requirements. The evaluation analysis has been divided into the domains of traffic impact (efficiency and safety) and user's appreciation. The following subchapters provide guidelines extracted from the requirements of each domain but also from the systems technical implementation. Therefore the first subchapter gives an overview of the general implementation. It is worth mentioning that the testing and validation of the technical implementation itself will be performed in the subsequent tasks of WP4 (4.2, 4.3 and 4.4), based on what the WP3 work specifies.

3.1.1 Technical implementation

Figure 1 depicts a high-level representation of the INFRAMIX hybrid road infrastructure concept as conceived during Task 2.1 "*Status quo analysis"*.

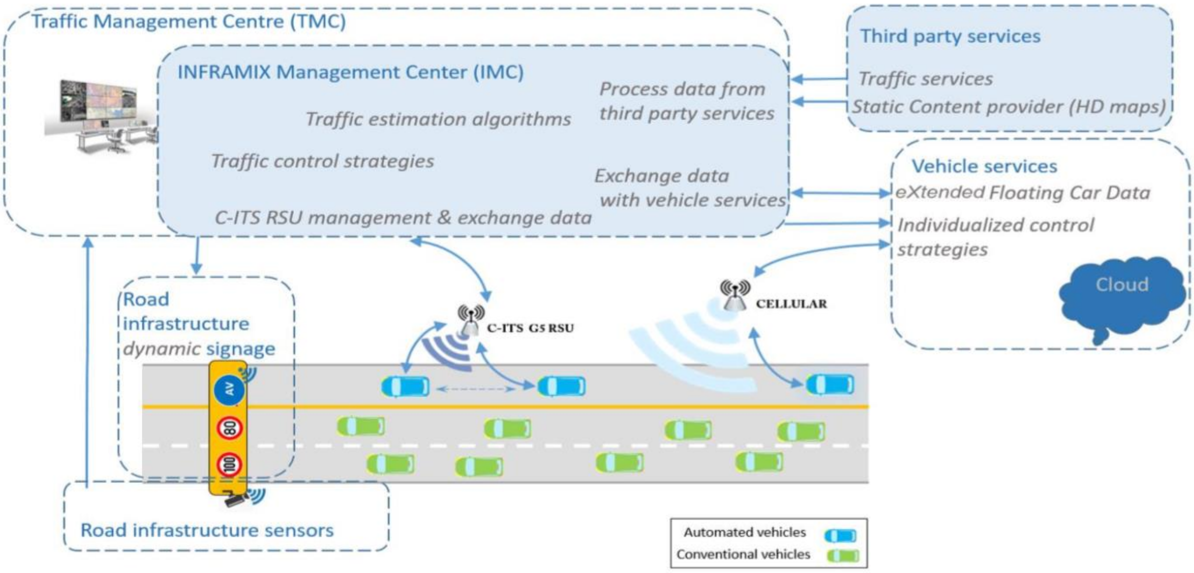

Figure 1 – INFRAMIX high-level architecture (source: D2.1 "*Requirements catalogue from the status quo analysis*")

In order to implement this concept at the test sites, the required modules and the systems interactions are further specified within WP3 "*Integrated infrastructures and traffic management capabilities"*. Figure 2 is the communication flow diagram which shows the various modules along with their interaction in matters of content and interfaces (protocols).

[4] A systematic way to obtain evaluation results across the INFRAMIX test-sites finalised in the Task 4.5 *"Data collection and aggregation"*

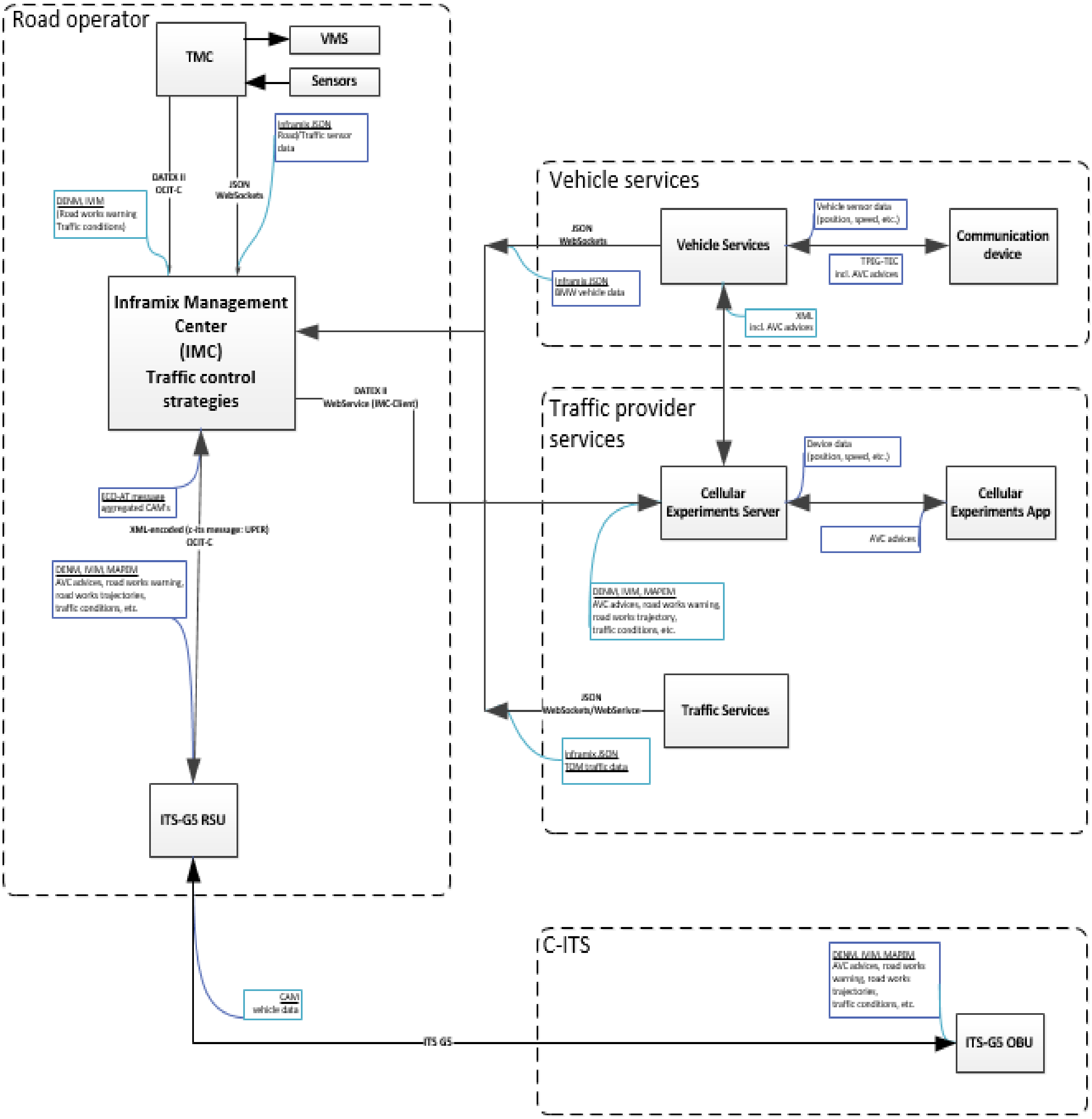

Figure 2 – INFRAMIX communication flow (systems interaction) (source: WP3)

Table 2 gives a short description of the various modules which will be used for the pilot implementation of the “hybrid” infrastructure concept for both test sites. The implementation time schedule though differentiates at each test site based on its needs and limitations. The implementation plan of the communication flow as depicted in Figure 2, has been adapted for each test site and it is provided at Annex I.

Table 2 – Short description of the modules that will be used for the pilot implementation of the "hybrid" road infrastructure concept (in collaboration with WP3)

Module	Description
Traffic Management Center (TMC)	Existing Traffic Management Center : • Receives real-time traffic data from sensors • Provides content to VMS • Communicates bidirectional with IMC
INFRAMIX Management Center (IMC)	This is an extension of the Traffic Management Center (TMC). It is a separate module with bidirectional communication with the TMC. It has following functionalities: • Traffic estimation • Traffic control strategies implementation • Exchange of data with ITS-G5 RSU • Management of ITS-G5 RSUs • Exchange data with Cellular Experiments Server • Receives data from third party services
ITS - G5 RSU	RoadSide Units to implement the V2I ITS –G5 communication • Data exchange with IMC • Data exchange with ITS-G5 OBU of vehicles
ITS - G5 OBU	Vehicle OnBoard Unit that communicates with the RSUs via ITS –G5.
Cellular Experiments Server	Traffic provider cellular server. For the implementation of the INFRAMIX novel use cases, an experimental link will be used. • Receives messages from IMC • Bidirectional communication with an experiment mobile App at the vehicle. • Provides data to vehicle services
TomTom Cellular Experiments App	Mobile App provided by TOM for the visualization of the INFRAMIX wireless messages on vehicles via cellular network
Vehicle services	BMW backend which communicates with IMC via cellular network. • Provides data to IMC • Receives messages from the Cellular Experiments Servers provided by TOM (traffic provider) • Data exchange with cellular OBU
BMW communication device	Communication device mounted on BMW vehicle. Communicates bidirectional with vehicle services via cellular network.
Traffic services	• Provides aggregated traffic information from the traffic provider to IMC

A list of the wireless messages to be implemented in the pilot sites are in Annex II. The concrete list of the messages along with further details will be finalized in the context of T3.2 *"Communication between infrastructure and end users"*.

The co-simulation environment has been modelled based on the real implementation interfaces between the modules, embedding the same latency and using the same wireless messages protocols as in real implementation. This will provide benefits both as support to the real implementation and also to the realistic deployment of the simulation models.

Towards that effort the hybrid testing proving ground will be modelled based on the layout of the real test tracks for emulating the physical testing environment on the proving ground.

3.1.2 Traffic impact

Traffic impact will be assessed through simulation as no FOTs will be performed within INFRAMIX. For the simulation tests, there is a certain concern on the selection of a traffic flow as a baseline for comparing the traffic efficiency KPIs with and without the INFRAMIX developments and especially the novel traffic management strategies.

Firstly, vehicles operate the automated functionalities only under specific road requirements (specific operational design domain) otherwise stay in no-automation mode and due to this fact, there is uncertainty of the number of AVs expected to enter traffic, independently of infrastructure developments. Therefore, there is not a safe estimation of the percentage of AVs in the highways of 2030 or later, without considering the infrastructure deployment. Furthermore, a key project objective is to support an incremental upgrade towards automation-appropriate infrastructure networks and that means that the beginning step towards that incremental upgrade is to consider current traffic flows. Consequently, historical data on the current conventional traffic will be used as a baseline. Traffic data will be collected from the two test sites (in Austria and Spain) and from the productive MDM Platform[5], which concerns the German highway sections. One of the targets of the traffic management functionalities is to support mixed traffic in order to maintain the traffic throughput at least at the same level, as in case of today's traffic consisted of only conventional vehicles. The mixed traffic for the extended simulations will be simulated for various penetration rates of automated vehicles and the KPIs of the traffic efficiency when using the INFRAMIX developments will be compared with the current conventional traffic.

The traffic estimation algorithms and real-time control strategies for various control measures for the project traffic scenarios are described in detail at the technical report of D2.5 *"Traffic state estimation and traffic control algorithms for mixed vehicle traffic".*

For hybrid testing, traffic patterns (specific traffic distribution among lanes, amount of automated vehicles, vehicle types etc.) which are investigated through extended simulation in matters of traffic efficiency, will be selected to be simulated.

3.1.3 User's appreciation – recruiting criteria of test people

Considering user appreciation, common recruiting criteria of test people (e.g. drivers of the vehicles, public that fill in the questionnaire) are given to both test sites. In general, the user-related assessments will illuminate drivers' reactions to the infrastructure developments (new visual signs, wireless messages recommendations etc.) by mainly using naive subjects in relevant driving situations in a vehicle, in real traffic. All tests will be followed by questionnaires or interviews that also will give information about the test drivers' opinions on the infrastructure developments in question[6]. Using naive subjects means that the test drivers have equal experience and prior knowledge of the system as a later road user will have.

Specifically, the test sites are recommended to recruit for tests:

- Drivers: the test person should not be otherwise involved in INFRAMIX or in similar projects or in ICT or ITS development projects
- General public: the test sites are encouraged to recruit general public in order to fill in dedicated questionnaires which will be distributed before and after the test. This also implies that suitable places (e.g. rest areas) should be provided, close to the test area where a considerable sample of people will be prepared for (informed about) the tests and will be asked to fill in questionnaires after the tests.
- Gender specific mobility expectations, needs and requirements are well recognised by the consortium. Special attention will be paid to understand and address users' appreciation based on their gender. Females and males will be equally present among the test groups,

[5] http://www.mdm-portal.de/mdm-nutzen.html

[6] The questionnaires will be finalized in Task5.2 and reported at the D5.2

specifically questionnaires will be distributed in members of both genders equally.

In general, only anonymised information (information that may be processed in a way that inhibits tracing back the individual person) will be a part of the INFRAMIX activities and will be documented whenever needed according to the new data protection regulations (GDPR, May 2018)[7] .
The ethical aspect of the test users' background data is covered at deliverable D1.3 "Data management plan", section 3.7[8] and further details provided in deliverable D7.2 GEN-Requirement No.2.

[7] 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.
[8] Deliverable D1.3 is confidential

4. Austrian test site

4.1 Test Site Description and Partners

4.1.1 Test Site Description

The Austrian road operator, ASFINAG, operates a 2200 km long road network and is fully toll-financed. Focusing on tackling the challenges of mixed traffic scenarios and the development of automated driving, a test track with an approximate length of 20 kilometers called “ALP.Lab”, is deployed on the motorway A2 close to the city of Graz (see Figure 3). The aim of this test track is to provide a total package of physical and digital infrastructure for validating automated driving functions and test new traffic management strategies for connected automated vehicles.

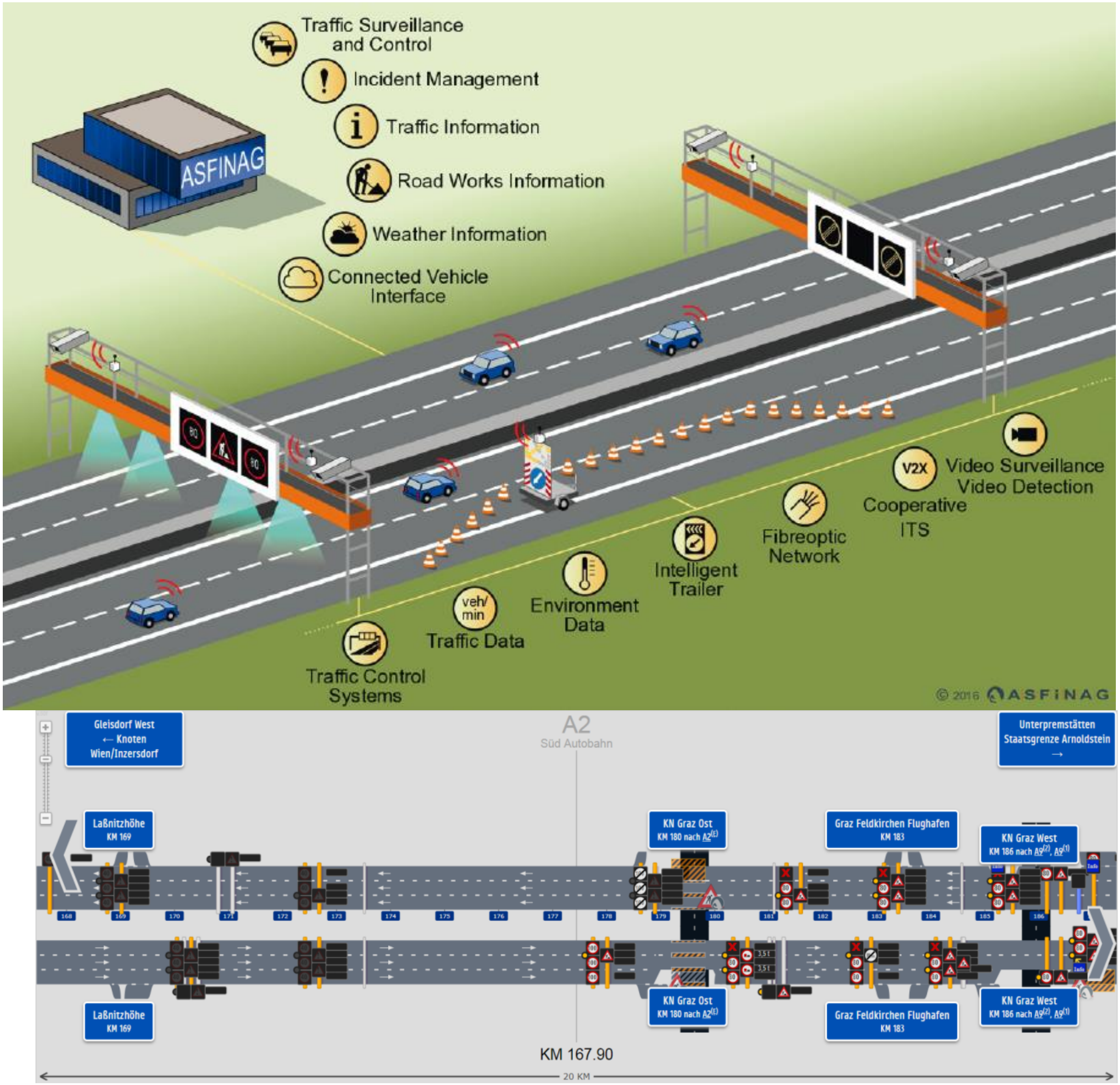

Figure 3 – Schematic view of the Austrian test site and test track

The road infrastructure is based on a fibre-optic network that provides IP-based network connectivity to gantries. HD video based image processing algorithms are used to provide information about the traffic flow and anonymized information about velocity, vehicle type and

lane usage. Additional different sensor technologies, such as Tri-tech traffic detectors and infrastructure radar sensor technology are installed to acquire anonymized single vehicle data. By merging the sensor data, traffic information from a bird's eye perspective can be generated. This highly reliable data can not only be used to validate automated vehicle's trajectories and the surrounding traffic but also support automated vehicles in complex traffic situations. The data can be played back via a 3-D simulation tool for visualization. Information about adverse weather conditions can be provided by road weather stations. This data, the incident data base are used at the TMC to change the 12 VMS accordingly.
Additional to the sensor technology, the test site is equipped with C-ITS road-side units and intelligent, connected, mobile trailers to provide, e.g., C-ITS Day 1 Services like VMS information, road works warnings and additionally first services for automated vehicles. This data can also be provided via a DATEXII interface to cloud services. Consequently, ASFINAG has already the basis to provide road infrastructure data to support automated driving on the test site and will extend the C-ITS messages for automated driving within the INFRAMIX project.
ASFINAG participates in different activities of harmonization of C-ITS services like C-Roads and is also part of the project INFRAMIX in order to guarantee safer and more efficient traffic management of mixed traffic[9].

[9] https://www.asfinag.at/en/

4.1.2 Test Site Partners

Table 3 lists the partners involved in the test site activities and provide a detailed description of the partner's involvement in the form of tasks/activities assigned or expected by each partner.

Table 3 - Description of partner's involvement

Partner	Involvement description
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 • Provision and installation of the physical elements for the real testing; ITS-G5 RSUs, sensors, new signalling if required and possible, or any other physical element for the demonstrations (painted line) • Provision of a demonstrator, the existing ASFINAG "Unterwegs" App in mobile adapted to INFRAMIX needs (speed and lane recommendations based on vehicle SAE level).
SIE	**Role: Deploy new and/or adapt the existing equipment of the test site for the supported Use Cases.** **Activities:** • Installation of ITS-G5 RSUs and integration to the INFRAMIX technical architecture • Implementation of advanced C-ITS messaging for INFRAMIX. Definition of INFRAMIX ITS-G5 messages extensions • Implementation of INFRAMIX scenario 2 on mobile VMS-system (owned by SIE) • Support the OBU (implementation of INFRAMIX messages, extended CAM message) • Implementation of control strategies (algorithm to react on traffic flow, sensor data, extended CAM message V2I, Operation of the ITS-G5 communication based on IMC control strategies)
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 the definition of the control parameters for scenario 1 and scenario 3 considered in Austrian test site • defining based on simulation several aspects of control algorithms implementation such as the timing of sending a wireless message considering the optimum for the traffic and the implementation limitations
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 in mobile (demonstrator) including lane information such as open/close, SAE level, variable speed, and acceleration.
BMW	**Role: Support based on the integration and testing the basic functionalities at the German test site A9. Basic functionalities include speed, lane and route recommendations for automated vehicles with fleet data, sensor data, and input from the road operator.** **Activities:** • Support to the cellular link testing/ based on its implementation at the German test site for the basic functionalities of speed, lane and route recommendations for automated vehicles with fleet data, sensor data, and input from the road operator • Cellular link testing to ASF content • Investigation/Analysis of usage of environmental data and of requirements on infrastructure data (e.g. roadwork zone layout)

ICCS	**Role: Support integration and testing activities in the test site** **Activities:** • Support integration and testing activities • Coordination between the tests and WP5 (make the best of them as inputs for WP5).
VIF	**Role: Integration and testing of V2X communication elements in a real- vehicle** **Activities:** • Provision of a conventional test vehicle with ITS-G5 OBU and proprietary HMI, for the real testing. Integration and testing of V2X communication elements in a real vehicle
ATE	**Role: Moderation of interaction with stakeholders and consistent collection of requirements concerning the Austrian test site; clarification of legal aspects for the Austrian test site** **Activities:** • Support of Austrian test-agreement for INFRAMIX use-cases. Defining a common test protocol, gathering Austrian regulation related to the demonstrations • OBU (implementation of INFRAMIX messages, extended CAM message)

Summary of key roles	Partners affiliation
Leader	ASF
Coordinator	ASF
Test Team	ASF, SIE, VIF, TUC, ICCS,TOM, ATE, BMW
Technical Support	ASF, SIE,VIF,TOM, BMW, ATE, ICCS
Administrative support team	ASF, ATE
legal and ethical adv.	ATE
Public relations and communications advisors	ATE

4.2 Physical and Virtual Systems Used at the Test Site

The Austrian test track will provide various possibilities of testing different aspects of INFRAMIX use cases. The following parts describe the available systems at the test site.

4.2.1 Sensors systems

The ASFINAG test track for CCAD, offers a high density of sensor systems[10]. The existing status quo equipment can provide traffic data (single vehicle detection, vehicle classification, and vehicle velocity), video detection data (vehicle classification, vehicle velocity, incident detection) and road weather data (extreme rain, snow, fog, ice formation). Motivated by INFRAMIX and the goal to obtain detailed single vehicle data, new traffic detection sensors are installed in order to differ between 8+1 different TLS categories [11] . This data is available by Q3 2018. Since 2018 a completely new technology, ground based radar tracking, is used at the Austrian test site which enables to measure the vehicle's velocity and position over a distance of about 1.8km.

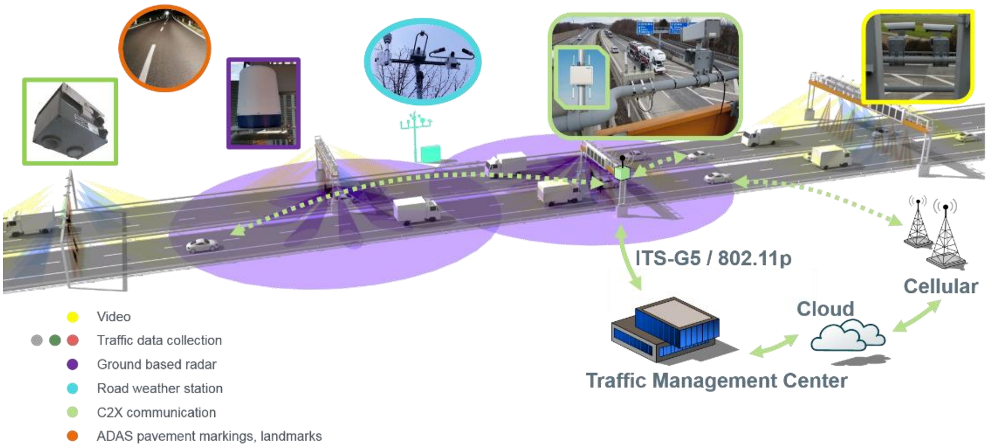

Figure 4 – ASFINAG physical and digital infrastructure for INFRAMIX testing

The special feature of the digital infrastructure of the Austrian test track is the development of a sensor fusion algorithm which can be used for detecting the trajectories of vehicles in real traffic or enlarging the electronic horizon of vehicles and to suit as a kind of virtual sensor to vehicles. Therefore, the fusion of the infrastructure information from a bird's view with the vehicles on-board sensors can be used to generate an overall picture of the traffic flow[12].

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[10] Refer to: https://www.youtube.com/watch?v=LYxkCz96G_4 (Status quo)

[11] Technical Delivery Requirements for Data Collector Outstations . Refer to: https://adec-technologies.com/fileadmin/user_upload/downloads/testreports/FinalReportADEC_TDC381V1.4b_E.pdf

[12] Refer to: https://youtu.be/xxwOSImaQfQ

4.2.2 Passive infrastructure systems

New passive/ physical infrastructure elements are introduced at the Austrian test site.
Landmarks for re-localisation of automated vehicles are installed every 5km between Graz West and Laßnitzhöhe (see Figure 5). The surveying precision of the landmarks is less than +/- 2cm and was conducted in Q2/Q3 2018.

Figure 5 – Landmarks for re-localisation of AVs

Different kind of lane markings are applied on the test track. On the one hand, the full test track has white painting, on the other hand 2 different materials (3M™ Stamark™ Series 380 ESD and a new material not yet homologated) will be applied over a distance of 1.5km (km 185,59 – km 183,83 direction Vienna). Tests concerning the different reflectivity characteristics are organized by the regional coordinator ALP.Lab GmbH.

Nowadays there is an uncertainty of the recognition of the visual signs either from human driver or from a state-of-art vehicle capable of sign recognition. Since the reliability of the recognition of visual signs is not guaranteed, novel signs ‚*smart signs*, will be installed and can be tested on the Austrian test site. These smart signs look like ordinary traffic signs but contain an infrared visible unique code (Figure 6).
These signs could be tested in the frame of the dynamic lane assignment scenario (providing information about a lane dedication to automated vehicles) and also in the roadworks scenario (providing safety related information about the current speed limits and the roadwork layout).

Figure 6 – 3M smart signs

Due to limited project resources for test vehicles, the real testing of the smart signs and the above mentioned lane markings can not be performed with the vehicles currently available at the test site, as they don’t have the necessary equipment. Nevertheless it is worth describing these physical elements in the sense of a futurous use for the implementation of the aspects addressed at the INFRAMIX use cases. Moreover, there is under discussion the possibility of using them in the case that the suitable vehicles will be provided by a third party in the public test weeks.

4.2.3 C-ITS system

At the Austrian test track, 12 ITS-G5 RSUs are mounted on gantries. A video camera on the same gantries supplement the C-ITS system (see Figure 7). The location in coordinates of the C-ITS system at the test site are given in Annex II. The system is connected to the TMC and will be also connected to the IMC for INFRAMIX testing purposes. The indicative list of the C-ITS messages to be implemented through INFRAMIX use cases is in Annex I.

Figure 7 – ITS-G5 RSU and video camera mounted on gantry at the Austrian test site

4.2.4 Test Equipment for Roadwork Zones

Especially for the INFRAMIX roadworks scenario, an intelligent roadworks trailer is planned to be used. It contains a mobile VMS station (roadworks warning) which will be integrated to the backend and it will support the ITS-G5 V2X communication as well as the cellular one with the RSU and the cellular API, respectively. Additionally, a video camera will be used to gather valuable live data on the tests. The video camera is only allowed to provide a live-video stream in order to comply with the Austrian Law. Figure 8 shows the abovementioned equipment.

Figure 8 – Characteristics of an intelligent roadworks trailer

4.2.5 High Definition Maps

Asfinag feeds the maps with incident data. Especially for the roadworks scenario the incident coordinates, provided by Asfinag, feed the HD maps and the content of the wireless messages (IVI message).

4.2.6 Test Equipment for Cellular Tests

Apart from the demonstration via the TomTom Cellular Experiments App (see Table 2 , Figure 2), ASFINAG will deploy in parallel the public App "Unterwegs"[13]. The content of this app will be extended for INFRAMIX purposes and new services will be implemented. New services such as the road infrastructure class and the vehicle speed recommendations are expected to attract more road users.

4.2.7 Test vehicles

In this section a short description of the test vehicles is provided focusing on their communication capabilities.
The following two test vehicles will communicate via ITS-G5 with the TMC/IMC:

- The **C-ITS Mobile Lab, which is a test vehicle of AustriaTech,** is able to validate the main standardized C-ITS messages e.g. CAM – Corporate 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, if the full C-ITS information is delivered to the end user according to the latest profiles which have been specified for day one applications in C-ROADS[14]. It is planned to extend these messages 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) will be equipped with an ITS-G5 OBU. It will be able to send and receive C-ITS messages based on the first generation of C-ITS messages. Additional INFRAMIX messages are implemented based on the specifications proposed by the INFRAMIX project. The vehicle will perform driving maneuvers based on the received C-ITS messages but inducted by a human driver (due to safety reasons).

Conventional vehicles equipped with mobile phones (Android) for the TomTom Cellular Experiments App will also be used for testing in order to demonstrate the scenarios for the cellular communication link. In addition, ASFINAG employees will be 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.

Moreover, **Tier1 and OEM test vehicles** will be invited by ASFINAG for public tests[15]. The vehicles will be equipped with C-ITS G5 OBUs or cellular devices.

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[13] iTunes App Store: https://itunes.apple.com/at/app/unterwegs/id453459323?mt=8, Google Play Store: https://play.google.com/store/apps/details?id=at.asfinag.unterwegs

[14] https://www.c-roads.eu/platform.html

[15] Press release of successful C-ITS tests in Austria: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwjf4fbJluHeAhWJ_iwKHeU3AaIQFjABegQIBBAC&url=http%3A%2F%2Fwww.austriatech.at%2Ffiles%2Fget%2F3519141f75297164277549152b98f975%2F20180912_presseaussendung_c-roads_web_en.pdf&usg=AOvVaw0cwjPvVKd5uODRUKZcxgZ_

4.2.8 Infrastructure for proving ground operators

INFRAMIX will use the ALP.Lab testing infrastructure for testing the use cases carried out by the vehicle provided by Virtual Vehicle (real and hybrid testing) and analyzing the traffic situation with the vehicle's detected interaction.

The ALP.Lab Cloud (Figure 9) is the gateway between the real world infrastructure, vehicles and objects and the digital representative ("digital twin") to enable end2end-testing for automated driving functions and vehicles in a safe, real and virtual environment. The ALP.Lab Cloud is the core component to offer data driven business models to proving ground operators including

- public roads and private test tracks
- logging of in vehicle data
- ultra high definition maps.

and offers customers and partners access to aggregated and fused data of test drives and a growing number of traffic and scenario models.

The open interfaces of the ALP.Lab Cloud enable partners and customers (OEMs, R&D institutions, road operators, etc.) to export and analyse data to simulate AD and ADAS functions at the proving ground and in private simulation environment.

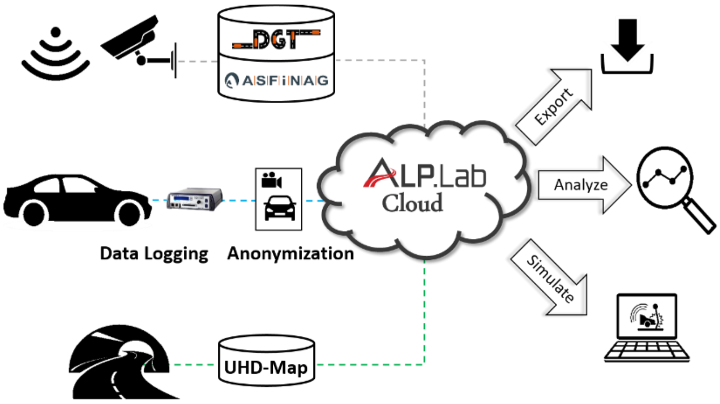


Figure 9 – ALP.Lab Cloud - a comprehensive platform for proving ground operators

4.3 Plan for Systems Interaction and Integration

The following sub-sections provide the detailed architecture that reveals the interactions and planned integration aspects of the aforementioned systems (see Section 4.2), that will be used for the demonstration and testing of the three INFRAMIX scenarios. The specificities of the test site in terms of technical and operational capabilities, and the potential implications of local legal frameworks (or any other restrictions) for the demonstrations of the use cases, are also included in this section (sub-sections 4.3.1 and 4.3.2).

4.3.1 “Hybrid” communication implementation at the Austrian test site

The hybrid communication implies cooperative and connected services which receive the information via the TMC/IMC. This hybrid communication architecture will be implemented and extended by the INFRAMIX messages which are needed to manage the mixed traffic. Figure 10 depicts the integration architecture for the INFRAMIX “hybrid” road infrastructure concept at the Austrian test site. The technical feasibility tests of this architecture are limited to the interaction with human drivers since the control of vehicle powertrain functionalities is not yet in the maturity level to be tested in real traffic according to the regulations.
In Austrian test site there are not test vehicles by BWM as described in Section 6.2.1 but will be provided by third parties which implies that it is not possible to directly visualize wireless messages at their HMIs within INFRAMIX tests. Therefore the cellular communication link will be validated only through the two mobile apps: TomTom Cellular Experiments App (in Android) and the ASFINAG App “Unterwegs” (in both Android and iOS).
The C-ITS G5 communication can be tested with vehicles equipped with ITS-G5 OBUs and visualized on their HMIs.

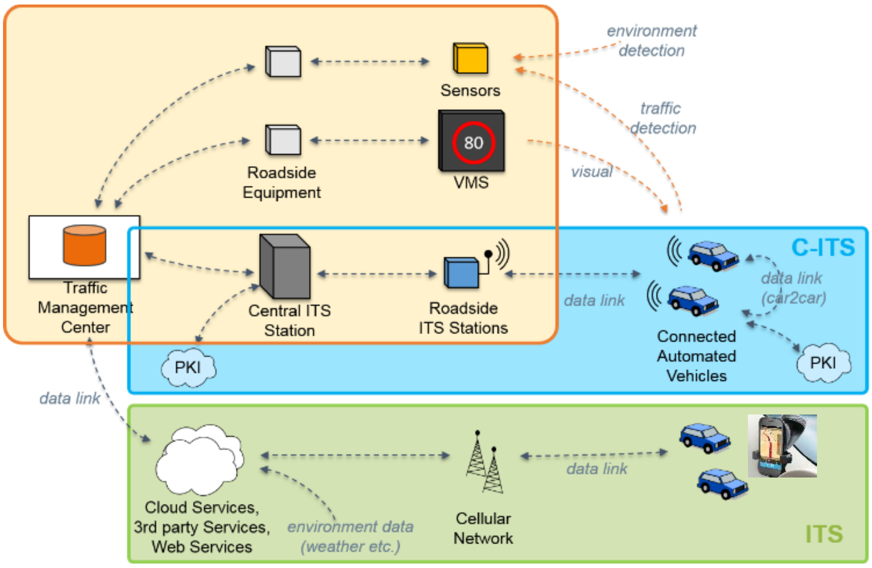


Figure 10 – Representation of the “hybrid” communication structure in Austrian test site

4.3.2 Local Context and Potential Implications on Tests

ASFINAG as public road operator cannot close the motorway for INFRAMIX testing. Reducing the safety risk, road segments which correlate to the specific requirements of each use-case are chosen in order to delude specific traffic and road situations.

Based on local legal frameworks, see the Austrian regulations[16], tests with automated vehicles can only be performed after applying for a test agreement with the Austrian "contact point Automated Mobility"[17].

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

For this scenario communication tests related to the developed and needed C-ITS messages will be performed.
The IMC will send to the RSUs and cellular services I2V IVIM message for "SAE lane clearance" and receive the V2I CAM message of the test vehicles.

4.3.3.1 Use Case 1 Real-time lane assignment under Dynamic penetration of automated vehicles

In 2018, ASFINAG introduced the hard shoulder release in Austria (see Figure 11). The collected data about user acceptance and comprehensibility on new signalling and a new kind of lane release can be investigated. The results can be applied as a prediction to new traffic signs for dedicated lane assignment. Moreover the wireless message for the allowable SAE automation level of driving on the dedicated will be sent for testing and demonstrating purposes.

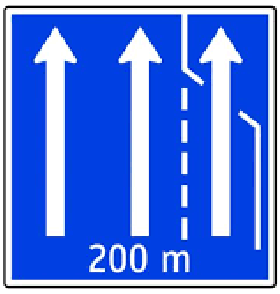


Figure 11 – Austrian new signalling for hard shoulder release

Additionally the smart signs (Figure 6) and the lane markings described in subchapter 4.2.2 could be tested in the frame of the specific use case. The smart signs could provide real-time information about the lane dedication to autonomous vehicles, while the novel design of lane markings could be used as a lane segregation element. However, this testing requires also the vehicle equipment. Due to limited project resources for test vehicles, the real testing of these systems cannot be performed with the vehicles currently available at the test site, as they don't have the necessary equipment.

[16] https://www.austriatech.at/en/activities/point-of-contact-automated-driving

[17] The application form for testing automated vehicles is available under: https://www.austriatech.at/files/get/18a3fe99714e8d4ef8b90406057fccf4/template_testantrag_de.docx

4.3.3.2 Use Case 2 Exceptional traffic situations – adverse weather conditions as an example

ASFINAG has a different kind of ambient sensors installed at the test region (Figure 12). To investigate the required quality of service (QoS) for mixed traffic control and for AVs and to perform offline verification of the real-time data quality, BMW and ASF are analyzing some recorded data.

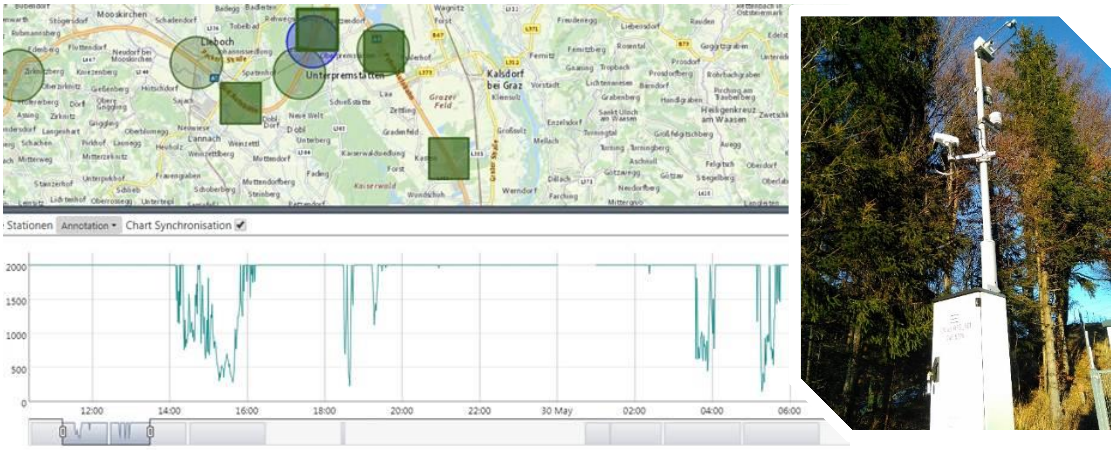


Figure 12 – Ambient weather data

This data will be provided to the simulation environment (virtual test site) to investigate the visibility decrease due to adverse weather conditions in relation with the maintenance of vehicles automation mode.

4.3.4 Scenario 2: Roadworks

Since no roadworks are planned for 2019 on the test track, a roadwork zone will be emulated for the INFRAMIX test purposes.

4.3.4.1 Use Case 1 Single Lane Closure

For the test purposes, a roadworks zone will be emulated at the ramp which its layout provided in the Table 4:

Table 4 – Emulated construction zone layout

Road	Direction	Km	LongWgs84	LatWgs84
A02	1	183,5	15,437798228016	47,0085964422227
A02	1	184,5	15,4258153654478	47,0048653376689

The appropriate signaling of the roadwork zone will be tested using a mobile VMS (physical and digital infrastructure). The intelligent roadwork trailer is connected to the IMC backend and can depict visual signs and also send C-ITS G5 messages. The appropriate ITS-G5 communication along the road will be demonstrated on the complete test-site:

- Situation based distance gap for automated vehicles
- Vehicle type and lane specific speed limit for automated vehicles
- Vehicle type and lane specific speed recommendation for automated vehicles

The RSUs are sending IVI messages on the motorway (reduction from 3 to 2 lanes), the local roadwork trailer will guide through the “fictive” roadwork zone.
The best distance to the roadwork zone to send the C-ITS information and the impact on traffic flow will be investigated via simulation.

Automated manoeuvre demonstration using V2X ITS-G5 communication can be shown by the infrastructure interacting with the OBU and the human driver who conducts the automated vehicle. The communication towards cellular services will be validated in the test-site using the TOM and ASF app. The driver’s reaction will be evaluated based on the advice received by the HMI (OBU) of the car (speed, gap recommendations).

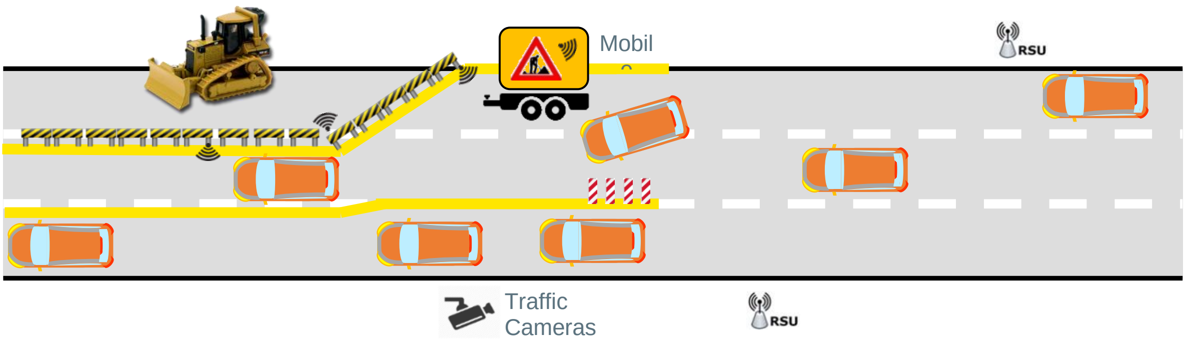


Figure 13 – Roadwork zone

Since also broken down vehicles could force the road operator to close a lane, the subcase will be investigated in theoretical basis by applying new fusion data algorithms to visualize the traffic flow in the road segment in order to detect if there is a broken vehicle. The information about the traffic situation will then can communicated to the current traffic flow participants.

4.3.4.2 Use Case 2 Roadworks - New lane design

The communication flow necessary for the use case implementation will be tested in the Austrian test site. The required details of describing a roadwork zone for avoiding a degradation of AV level and to guide safely an AV through a roadwork zone will be covered by an offline analysis. Therefore, the required wireless messages of the new road topology (high definition) and the roadworks warning message will be subject of testing.

4.3.5 Scenario 3: Bottlenecks

The macroscopic effect of managing an on ramp merge area by

- Modifying the gap between vehicles
- providing lane change and speed advice to individual connected vehicles

will be investigated in simulation. Since the evaluation of the controllers’ performance is not feasible (without a fleet of vehicles), in the Austrian test site only the communication between the IMC and the vehicles will be considered. This will permit the data collection for the evaluation of user’s appreciation related to the new pictogram codes necessary for the novel I2V recommendations. The following subchapters provide a short description of these recommendations per use-case.

4.3.5.1 Automated vehicles Driving Behaviour Adaptation in Real Time at Sags

The RSUs are sending respective ITS messages on the motorway for gap, speed and lane change recommendations. Communication tests with respect to V2X ITS-G5 and to cellular apps are performed. Additional, automated manoeuvre, speed adjustment of (automated) vehicles can be demonstrated using V2X ITS-G5 and cellular TOM and ASF app communication; the infrastructure will be interacting with the human driver who will realize the received suggestion. The driver's reaction will be evaluated based on the advice received by the HMI of the car (speed, gap recommendations) by user appreciation.

4.3.5.2 Lane-Change Advice to connected vehicles at Bottlenecks

Due to a lack of a fleet of vehicles and a high penetration rate of connected vehicles in the overall traffic, the Austrian test site concentrates on single vehicle tests. The test site has the capability to test the V2X guidance of automated vehicles by comparing the vehicle log data with the infrastructure data considered as the ground truth. The result will depict the overall traffic situation by comparing logged vehicle data with the recorded ground truth data (see Figure 14)

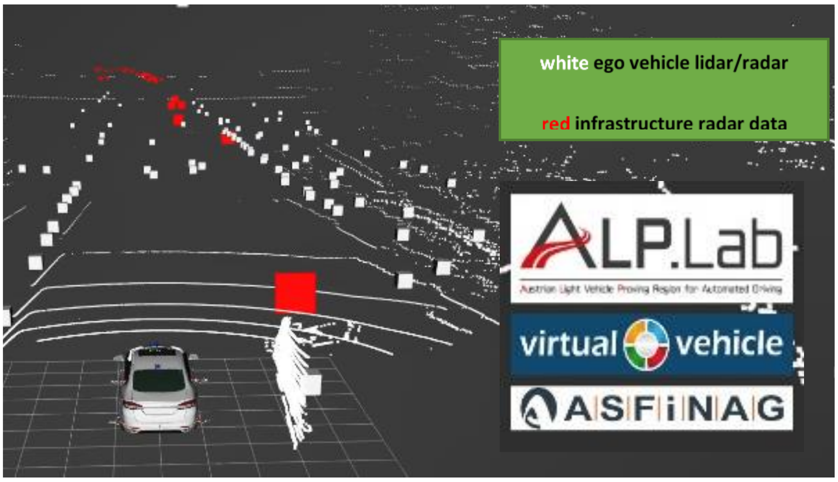


Figure 14 – Offline analysis of ground truth data

Therefore, tests will be performed at the ramp-on merge area at km 183.7 if safety requirements are fulfilled by the probe vehicles (Figure 15). That has to be verified by simulation and closed environment tests first.

Figure 15 – Top view of the ramp for the tests

4.3.5.3 Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles

The test site has the capability to perform offline analysis that will test the guidance of a single (automated) vehicle to change lane taking into the overall traffic flow trajectories (Figure 16). In fact, real-time single vehicle guidance is out-of-scope for INFRAMIX although it calls for additional research effort. Along this line, the Austrian test site seeks in the long-term to analyse the capability of developing data fusion schemes over infrastructure data as a real-time ITS service.

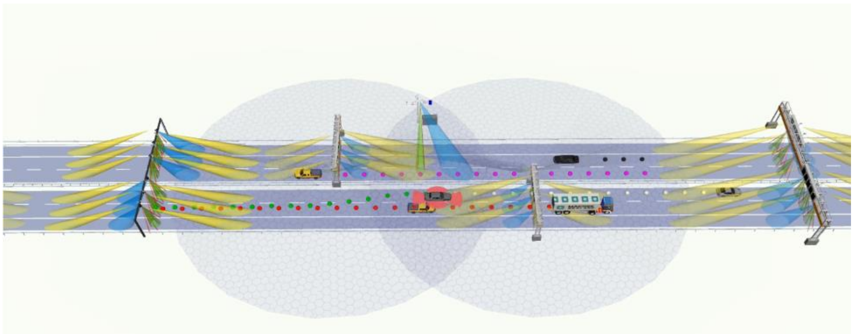


Figure 16 – Sensor fusion data for real-time service approach

5. Spanish test site

5.1 Test site description and partners

5.1.1 Test Site Description

The Spanish test site is located within the Mediterranean Corridor between Barcelona and the French border. The specific highway segment is over 20km of 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 and a 180m tunnel. The Average Daily Traffic (ADT) in this section was around 30.000 vehicles per day in 2016, and the speed limit is 120km/h.

The currently available ITS equipment includes different types of VMSs, video cameras, Bluetooth antennas, and magnetic sensors for measuring occupancy and 1 Weather station. ITS-G5 short range communication and cellular communication are available at the test-site, and a proprietary Fibre Optic ring network with 10 Gb Bandwidth connects all the equipment from the test-site to the TMC in real-time.

Figure 17 shows a detailed view of the test-site and its location.

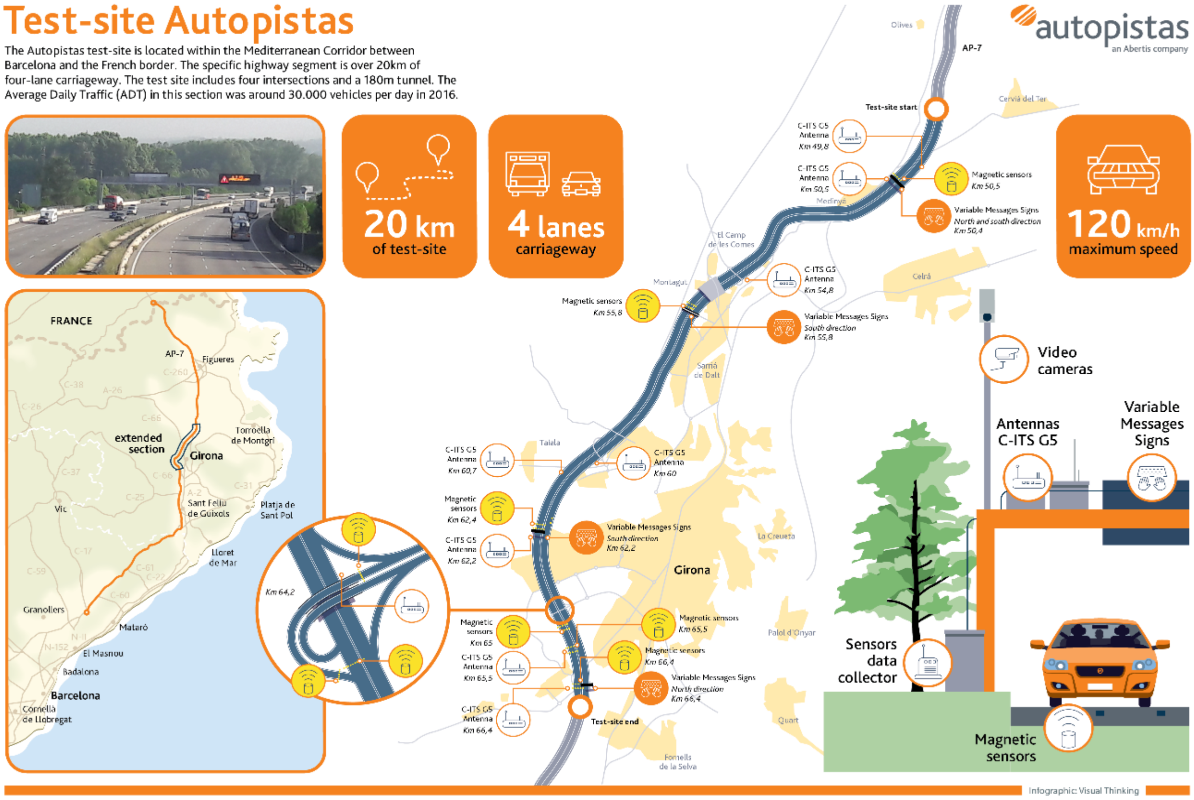


Figure 17 – Schematic view of the Spanish test-site

5.1.2 Test Site Partners

Table 5 lists the partners involved in the test site activities and provide a detailed description of the partner's involvement in the form of tasks/activities assigned or expected by each partner.

Table 5 – 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 G5 RSUs • Provision and installation of sensors • Provision and installation of new signalling if required and possible, or any other physical element for the demonstrations (painted line) • Integration with the IMC (DATEX II) • Showing the required information into existing VMS • Managing the demonstrations • Defining a common test protocol, gathering Spanish regulation related to the demonstrations • Provision of vehicles for the demonstrations
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 Autopistas HUB to the INFRAMIX technical architecture (establishment of the connection to the IMC) • Operation of the ITS-G5 communication (based on IMC control strategies)
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 for two traffic scenarios • 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
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.
ENI	**Role: Support to definition and management of the Girona/Spain demonstrator** **Activities:** • Coordination between the tests and WP6 (make the best of them as inputs for WP6). It will be especially relevant the coordination of the demonstrator with the Stakeholder event in M24.
BMW	**Role: Support based on the integration and testing the basic functionalities at the German test site A9. Basic functionalities include speed, lane and route**

	recommendations for automated vehicles with fleet data, sensor data, and input from the road operator. **Activities:** • BMW will provide information about lane, speed and gap recommendations through the BMW Backend for the BMWs with specific AD functionalities [18]at the Spanish test site • Support to the cellular link testing
ICCS	**Role: Support integration and testing activities in the test site** **Activities:** • Support integration and testing activities • Coordination between the tests and WP5 (make the best of them as inputs for WP5).
VIF	**Role: integration of Spanish test site for sub-microscopic simulation and Hybrid testing** • Modelling of an on-ramp of the Spanish test site based on map data provided by AAE • Simulation of the described use cases with this model. • Use the road model for Hybrid Testing on the proving ground in Lang Lebring
ATE	**Role: Support the test site and its activities** **Activities:** • Contribute in testing the ITS-G5 information chain into the test vehicle. • Provision of the ITS-G5 OBU and corresponding HMI for testing the ITS-G5 link and the new signs • Support on the OBU installation in the vehicle • Support to the ITS-G5 link testing

Summary of the key roles	Partners affiliation
Leader	AAE
Coordinator	AAE
Test Team	AAE,SIE,TUC,TOM,ENI,BMW,ICCS,ATE, VIF
Technical Support	AAE,SIE,TOM,BMW,ATE,ICCS
Administrative support team	AAE, ENI
legal and ethical adv.	AAE, ENI
Public relations and communications advisors	ENI

5.2 Physical and Virtual Systems Used at the Test Site

This chapter describes the existing or extended for INFRAMIX tests purposes physical and virtual systems used at the Spanish test site.

5.2.1 Simulation

In this section the interaction of the real demonstration with virtual systems is described.
The simulation models support demonstration to compensate the lack of automated vehicles in

[18] 5 BMWs will be rented by AAE for the INFRAMIX testing in the Spanish test site

nowadays traffic. In particular, automated cars of SAE level above 3 will need to be simulated; in real we will be able to test the activation/deactivation of a dedicated lane for AVs, or the on-ramp merging with AVs, but the control strategy will be based on simulated/fake information about the penetration rate of these AVs.
Furthermore, due to the novelty of the “hybrid” road infrastructure, the simulation will support the optimization of its implementation. An indicative example is the optimization of the location of the physical elements such as the RSUs, Variable Messages Signs (VMS), sensors, etc. In that sense, several points will be explored through the simulation such as “how long in advance does the TMC need to inform the vehicles about the new control strategies?”
Finally, simulation can be a great support to identify (if possible) the best day/time for the demonstrators for obtaining the most significant results possible.

On the other way around, some results from the real tests as the technical feasibility of some information flows can help to improve the simulators in terms of refining the communication characterization.

5.2.2 Maps

AAE provided an Aerophotogrammetric restitution of the test-site, and has a “living” .kmz updated continuously with the corresponding new installations[19].

5.2.3 INFRAMIX Management Centre (IMC)

The IMC will be responsible of defining and implementing the control strategies to be tested in the Spanish test-site. As described at the beginning of this document, these control strategies include:

- Activation / Deactivation of an AV Dedicated Lane for different SAE levels, and different types of vehicles. Including speed recommendations for the Dedicated Lane and outside it.
- Sensors data fusion and related logic will be developed at the IMC in order to attempt the identification of AVs and non-AVs in an AV Dedicated Lane. Corresponding actions (e.g the required warning signs) when an intruder is detected will be also attempted.
- Automated vehicles adaptation on the on ramp based on gap recommendations.
- Change-lane recommendations to connected vehicles for managing a bottleneck.
- Change-lane recommendations to specific cars with main stream flow control.

Furthermore, the IMC will be the responsible of gathering all the required information for the implementation of the strategies:

- Sensor information from the Autopistas HUB
- G5 messages from the test-site
- Simulated AVs from simulators
- Traffic information from the connected cars

and of transmitting the control strategies to the users:

- To the vehicles equipped with C-ITS G5 OBU through G5
- To the Autopistas HUB to be displayed on the VMS
- To the Cellular Service to be transmitted to the connected vehicles

Further details on the IMC are available in WP3 documents.

[19] AAE also has a high resolution map based on data from LIDAR. The specific map though is not planned yet to be provided to the project.

5.2.4 Autopistas HUB and Autopistas TMC

The Autopistas HUB has a bidirectional communication with the IMC. It collects information from the test-site and distributes it to the IMC, it also receives the output from the traffic control strategies which run in the IMC and communicates them to the road users through VMSs; everything in real-time. In particular, the Autopistas HUB is a Cloud Server hosted by AAE, which collects and shares the data from the 108 sensors installed in the test-site and manages the new VMS that will be installed in the test-site on-line.
The Autopistas TMC is the operational Traffic Management responsible for the area where Spanish test-site is located. It has been involved during all the project in the definition of what can be tested in the AP-7 road and how. The Autopistas TMC is responsible for projecting the necessary signs on the road (based on the Public Administration requirements and regulations), for new paintings and to guarantee the security of all the road users during the demonstrations.

5.2.5 Signalling and segregation elements

As can be seen in Figure 17, the test-site is equipped with 4 Variable Messages Signs, one of them will be acquired for the project needs. The location of these 4 VMSs is detailed in the following Table 6:

Table 6 – VMS location at the Spanish test track

Location (PK)	Location (Lat-Lon Coord.)	Description	Availability
50,4	42.047833, 2.870714	A pictogram on the left and three lines of text (16 characters)	Currently operational
55,8	42.024507, 2.819324	A pictogram on the left and three lines of text (16 characters)	Currently operational
62,2	41.975917, 2.778560	A pictogram on the left and three lines of text (16 characters)	Currently operational
62,2	41.975926, 2.778458	A full-colour pictogram	Acquired for INFRAMIX (February 2019)[20]

Besides VMS described in Table 6, there is also the possibility of using an operational trolley from AAE if further signaling is required.

Regarding the segregation elements, there is the possibility of painting the line of the dedicated lane section during the demonstration[21]. The final confirmation of the color of the dedicated lane and the realization of this kind of segregation will be based on the work within Task 3.5 "Definition of "new" visual signs and elements" and the regulations applied for the Spanish Public Administration permission.
Other physical segregation elements will not be used for the demonstrations as it is not foreseen as a realistic solution. Moreover, there are safety considerations which restrict this type of segregation[22] to be used for testing.

5.2.6 Communication I2V (and V2I)

For the demonstrator of the INFRAMIX project, three ITS-G5 Road Side Units (RSUs) have been

[20] More details regarding the new VMS (pictogram) will be provided in D4.2 "Demonstration phase and data delivery report" as AAE is still negotiating its acquisition.
[21] AAE budget available
[22] preventing encounters between road users and obstacles

acquired (the amount is based on the available budget and a best-value acquisition process). These RSUs will be connected to the IMC and will send and receive ITS-G5 messages to a ITS-G5 On Board Unit (OBU) installed in a vehicle.
The location of these RSUs is detailed in the following table Table 7.Two of them will be fixed in the infrastructure, but the third one will be portable so that we can mount it on a trolley/assistance vehicle and locate it in different places based on the different use cases' requirements.

Table 7 – ITS-G5 RSUs location at the Spanish test track

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

5.2.7 Sensors

108 magnetometer sensors have been 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 gap between them. The following table details their location and their application. Refer also to Figure 17 to see them within the test-site.

Table 8 – Sensors location at the Spanish test track

Location (PK)	Location (Lat-Lon Coor.)	Number of sensors	Provision
50,4	42.047859, 2.870762	**14**: 2 lines of 7 sensors (in the middle of each lane and on each line)	Available from C-Roads Project
55,8	42.024537, 2.819372	**14**: 2 lines of 7 sensors (in the middle of each lane and on each line)	Available from C-Roads Project
62,1	41.978023, 2.779072	**2**: 2 lines of 1 sensor in the middle of the right lane	Acquired for INFRAMIX (SC1)
62,4	41.976001, 2.778557	**14**: 2 lines of 7 sensors (in the middle of each lane and on each line)	Available from C-Roads Project
64,2	41.959651, 2.783517	**2**: 2 lines of 1 sensor in at the beginning of the on-ramp	Acquired for INFRAMIX (SC3)
64,4	41.957749, 2.784328	**14**: 2 lines of 7 sensors (in the middle of each lane and on each line)	Acquired for INFRAMIX (SC3)
64,45	41.957562, 2.784235	**2**: 2 lines of 1 sensor at the end of the on-ramp	Acquired for INFRAMIX (SC3)
65	41.952784, 2.786754	**14**: 2 lines of 7 sensors (in the middle of each lane and on each line)	Acquired for INFRAMIX (SC3)
65,5	41.947655, 2.788229	**14**: 2 lines of 7 sensors (in the middle of each lane and on each line)	Acquired for INFRAMIX (SC3)
66,4	41.941413, 2.788652	**18**: 2 lines of 9 sensors (in the middle of each lane and on each line)	Available from C-Roads Project

The data from these sensors is collected by the Autopistas HUB and shared to all the partners through a simple API. All the documents related to the sensors specifications and the API have been provided to consortium. A document with historic traffic data from the test-site, was also shared with the rest of partners. In particular it contains the entrance point and time, exit point and time, and type of vehicle for all the vehicles during 2017. This document was provided to allow the work on the simulators and traffic models (WP2) before the end of the installations of the sensors (due in October 2018). This information was gathered from all the entries and exits of the AP-7 Mediterranean Corridor (from the toll stations) including the test-site and although it does not provide a lane-level resolution as the sensors will do, it was good enough for developing the initial traffic models from the Spanish test-site.

5.2.8 Vehicles (HMI and electronic horizon)

For the demonstration of the project, in Spain, a vehicle with a ITS-G5 OBU from ATE will be available for 1 week. This vehicle will also include an HMI for visualizing the control strategies and especially the new signs developed within the project.

Secondly, an App from TomTom will be available. It will also allow to visualize some of the control strategies and new signs developed within the project, i.e. open/close lane, SAE level per lane, variable speed, and acceleration. In particular, it will be able to receive and project information broadcasted to all the users, but it will not be able to display information per lane, and neither individualized control strategies.

The previous equipment could be installed in any of the Autopistas assistance cars. Nevertheless, these cars do not have any Automation functionality for driving assistance (such as fixing a distance gap or a speed) and thus might not be suitable for all the intended evaluations.

For the previous reason, and in order to extend our demonstrator to possible individualized strategies, AAE is also planning to rent up to 5 BMW (with the latest automation functionalities for driving assistance) for 5 days. BMW would be able to connect these vehicles through their Backend and send individual recommendations. The driver would be then able to fix a distance gap, a speed or initiate a change of lane.

5.3 Plan for Systems Interaction and Integration

The following sub-sections provide the detailed architecture that reveals the interactions and planned integration aspects of the aforementioned systems, that will be used for the demonstration and testing of each Use Case. A detail description of the current status and the planned upgrades is provided. Additionally, the specificities of the test site in terms of technical and operational capabilities, and the potential implications of local legal frameworks (or any other restrictions) for the demonstrations are included.

5.3.1 Scenario 1: Dynamic Lane Assignment (incl. speed recommendations

The following subchapters describe the detailed architecture that reveals the interactions and planned integrations required for the implementation of each of the use cases of the project scenario ; Dynamic Lane Assignment.

5.3.2 Scenario 1 Use case1 Real-time lane assignment under dynamic penetration rate of automated vehicles

Based on the aforementioned systems that will be used for the demonstration and testing, Figure 18 presents a detailed architecture that reveals the interactions and planned integrations required for this Use Case.

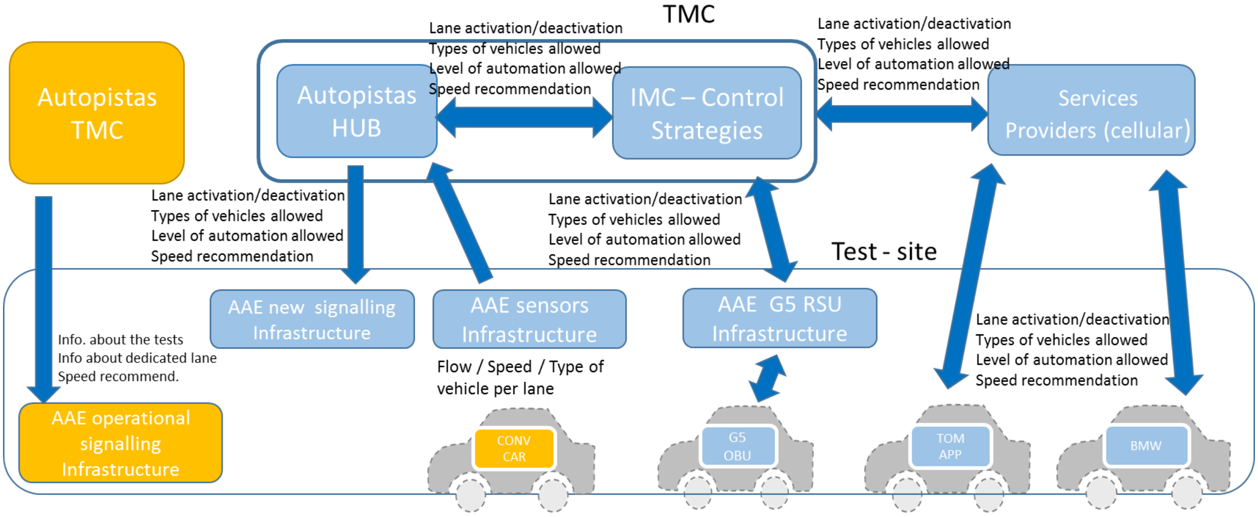


Figure 18 – Systems interactions and planned integrations SC1-DLA-UC1-DPR

In order to have a detailed description of these interactions and planned integrations, a possible representative sequence of actions follows:

- During all the demonstrations, Autopistas HUB will send real time data from sensors to the IMC. And the IMC will share it with TUC for building the control strategies.

In a multilane roadway of mixed traffic, a lane has been assigned to automated vehicles with level of automation equal or higher than 3;

- The corresponding sign of a dedicated lane will be projected in a pictogram on the right lane[23], in VMS PK 62,2. VMS in PK 55,8 and 50, 5 will be used to advise that the right lane will be hosting some tests in 6,4km, and 11,7km.
- The line of a specific section corresponding to the dedicated lane could be painted in another color for the demonstrations.(PK61,7-PK62,5 aprox)
- The corresponding message will be sent from the IMC to the related G5 RSU/s (sending the information by ITS-G5 to ITS-G5 OBU) and to the traffic provider (cellular), which in turn will send this new signaling to the BMW car and TOM app

Speed recommendations are set in real-time to all lanes. The recommendations are based on traffic conditions and safety considerations related to the lane dedication;

- The IMC will send the new speed recommendations for the dedicated lane and for the other three lanes to Autopistas HUB (for the VMSs), to the related G5 RSU/s, sending the information by ITS-G5 to ITS-G5 OBU, and to the traffic provider, which in turn will send these new speed recommendations to the BMW and TOM app
- The pictogram sign on the right lane in VMS PK 62,2 will show speed recommendation assigned to the dedicated lane.
- Speed recommendation signs for the other three lanes can only be activated in PK 62,2 manually by calling the Autopistas TMC, as it is an operational VMS and cannot be controlled by any other under any circumstance. All the operational VMSs include a pictogram on the left with three lines of text.
- VMS at PK 55,8 and 50,5 will be used to advise that the right lane will be hosting some tests in 6,4km and 11,7 km

[23] The right lane is planned to be used for the testing purposes but this doesn't imply that the under investigation use case could not be performed in the left lane. The dedication of the left lane to AVs will be investigated through simulations

The amount of conventional vehicles approaches the capacity of the rest lanes; The traffic management strategy recommends the deactivation of the dedicated lane;

- The IMC will send a message to Autopistas HUB (for the VMSs), to the related G5 RSU/s sending the information by ITS-G5 to ITS-G5 OBUs, and to the traffic provider, which in turn will send these new speed recommendations to the BMW and TOM app, informing that the dedicated lane is going to be deactivated
- The pictogram sign on the right lane in VMS PK 62,2 might show that the dedicated lane is going to be close, or only in the general panel of PK 62,2.
- VMS at PK 55,8 and 50,5 will be used to advise that the right lane will be hosting some tests in 6,4km and 11,7 km and that the next VMS is doing some tests also

Speed recommendations per lane are adjusted for a short period of time when activating or de-activating a dedicated lane, to increase safety (e.g. apply lower speed recommendations);

- The IMC will send speed recommendations for the dedicated lane and for the other three lanes to Autopistas HUB (for the VMSs), to the related G5 RSU/s sending the information by ITS-G5 to ITS-G5 OBUs, and to the traffic provider, which in turn will send these speed recommendations to the BMW and TOM app
- The pictogram sign on the right lane in VMS PK 62,2 will show the new speed recommendation assigned to the dedicated lane.
- Speed recommendation signs for the other three lanes can be activated in PK 62,2 manually by calling the Autopistas TMC, as it is an operational VMS and cannot be controlled by any other under any circumstance. All the operational VMSs include a pictogram on the left with three lines of text.
- VMS at PK 55,8 and 50,5 will be used to advise that the right lane will be hosting some tests in 6,4km and 11,7 km.

The dedicated lane operation is de-activated. TMC communicates that event to all road users;

- The IMC will send a message Dedication lane de-activated to Autopistas HUB (for the VMSs), to the G5 RSU sending the information by ITS-G5 to ITS-G5 OBUs, and to the traffic provider, which in turn will send this information to the BMW and TOM app.
- The pictogram sign on the right lane in VMS PK 62,2 will turn off.
- General VMS PK 62,2 will stop showing speed recommendations.
- VMS at PK 55,8 and 50,5 will stop to advise that the right lane will be hosting some tests in 6,4km and 11,7 km

Lane change and speed recommendations are given by the TMC to the connected vehicles to facilitate smooth traffic flow;

In simulation: The traffic management strategy recommends the activation of the lane dedicated to the automated vehicles when this event would improve the traffic flow in all of the lanes; the penetration rate of the automated vehicles is above a minimum limit considering also the overall ratio of AVs compared to conventional traffic.

The dedicated lane operation is activated. TMC communicates that event to all road users;

- The corresponding sign of a dedicated lane will be projected in a pictogram on the right lane, in VMS PK 62,2. VMS in PK 55,8 and 50, 5 will be used to advise that the right lane will be hosting some tests in 6,4km, and 11,7km.

Speed limits per lane are adjusted for a short period of time according to safety considerations (e.g. apply lower speed limits);

- The pictogram sign on the right lane in VMS PK 62,2 will show the new speed recommendation assigned to the dedicated lane.
- Speed recommendation signs for the other three lanes can be activated in PK 62,2.. in current VMS (manually).. A pictogram with three lines of text
- VMS at PK 55,8 and 50,5 will be used to advise that the right lane will be hosting some tests in 6,4km and 11,7 km

Lane change recommendations are given by the TMC to the connected vehicles to support the separation of the traffic into conventional and automated;

Speed limits are set for all of the lanes. The limits are based on traffic conditions and on safety considerations related to the lane dedication. A lane is permanently dedicated to automated driving.

- The pictogram sign on the right lane in VMS PK 62,2 will show the new speed recommendation assigned to the dedicated lane.
- Speed recommendation signs for the other three lanes can be activated in PK 62,2.. in current VMS (manually).. A pictogram with three lines of text
- VMS at PK 55,8 and 50,5 will be used to advise that the right lane will be hosting some tests in 6,4km and 11,7 km

5.3.2.1 Current Status and Adaptations for INFRAMIX

Current signaling includes three VMS at PK 62,2, PK 55,8 and PK 50,5. These VMS cover all the carriageways and allow to show a pictogram and three lines of text (16 characters per line). Nevertheless, current signaling does not allow to provide information per lane. For the INFRAMIX we will need to install a specific VMS per lane.
Current available traffic information does not provide any information per lane. Sensors will need to be installed to have this information at lane resolution. Finally, information about the speed of vehicles is currently calculated based on travel times (from the movements recorded at the toll stations identifying the entrance and exit of each vehicle). For the project, sensors to acquire the speed of the vehicles at different points of the test-site (also at a lane level) will need to be installed. These sensors will also allow to detect the types of vehicles which is also a requirement for this use case. Finally, another requirement is the distance prior to the VMS we need to have the information from sensors/RSU (max-min distance) in order to process, generate the corresponding control strategy and send it to the VMS with the necessary time for the user to visualize it and to understand it in order to respond adequately. Based on various references and the characteristics of the test-site some sensors will be installed 200m before a VMS.

Regarding the communication I2V no infrastructure is yet available at the test-site. For the INFRAMIX project 3 C-ITS G5 RSUs will be installed at the required locations to address Scenarios 1 and 3.

Regarding the Traffic Management Centre, a new tool (Autopistas HUB) for collecting and sharing the data from the sensors will have to be built. Current Traffic Management Centres of Autopistas introduce the signs in the VMS manually. For this project we will have to build an automatic tool that will show the new defined signs in a new VMS based on the control strategies received from the IMC. All these developments will be hosted in the Autopistas HUB, an emulation of the current TMC.

Finally, current VMSs store a number of standard pictograms for all the necessary situations. In INFRAMIX, new pictograms will need to be designed and implemented for some of the use cases of the project (dedicated AV lane, etc.). And regarding the required segregation elements, if we want to have the dedicated lane more visible for the demonstrations, the corresponding segment will be painted for approximately one month.

5.3.2.2 Local Context and Potential Implications on Tests

Many issues aroused when we discussed the possibility of closing a lane for the demonstrations. This would have been necessary with an AV of level 3 or above, but we do not have this type of vehicles in our test-site. We also thought of closing a lane for simulating the dedicated lane, but with only one G5 C-ITS OBU the logistics would have been complicated as it is not allowed to have vehicles leaving and entering the closed segment several times during the tests. The conclusion was that the evaluations would be much more significant if conducted on real traffic conditions, and thus, the closing of any lane and the corresponding requirements and regulations were discarded.

In order to project new or existing VMS in a highway we need the Public Administration consent. From our experience, it will not be a problem to project new signs on the new pictogram if we fulfill all the safety requirements imposed by the Public Administration. We will propose to install new static signs just before the test to advise that the sign is under testing conditions, and we will project information on the previous VMSs informing all the users about our tests.

For the possibility of painting a line for maximizing the impact of the Dedicated Lane, we should select a short section (around 1km) and make sure we satisfy the Spanish regulations related to lane painting. After the demonstrations it should be easy to paint it back in white. Furthermore, the painting of a line on the highway is as any other installation on the road, and requires especial procedures (closing lanes, new signaling, etc.) which could be very expensive at the end.

In terms of getting User's feedback for evaluation, we would be allowed to make interviews at any of the Rest Areas of the highway, but of course we would have to inform about this on time to the TMC.

Finally, regarding the time/day of the tests, it does not exist any prior restriction a part from the busiest days of the year (beginning and end of main holidays), but it is always the Public Administration who will allow or deny the tests, and this could happen at any time (just before or even during the tests), due to weather conditions, an accident or any other cause related to the traffic efficiency and safety. In case we want to test anything related to trucks, we have to be aware that on Sunday morning and busiest days, they are not allowed to drive on the highway.

5.3.3 Scenario 1 Use Case 3: A conventional vehicle drives on a dedicated lane for automated vehicles

5.3.3.1 Systems Interaction and Integration

Based on the aforementioned systems that will be used for the demonstration and testing, Figure 19 presents a detailed architecture that reveals the interactions and planned integrations required for this Use Case.

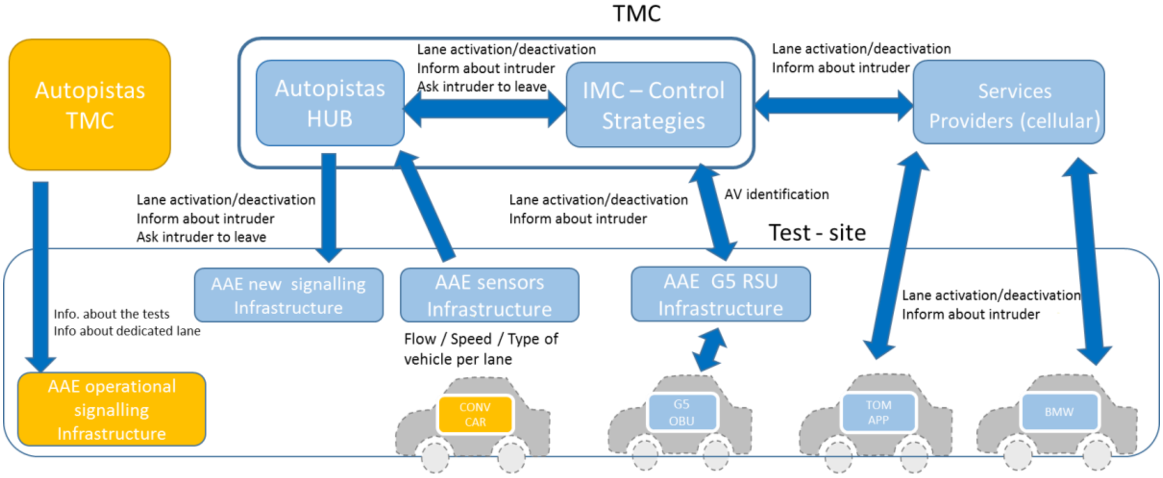


Figure 19 – Systems interactions and planned integrations SC1-DLA-UC2-CVDL

In order to have a detailed description of these interactions and planned integrations, two possible representative sequences of actions follows:

1) Non-proper user is already on the dedicated lane. When the TMC decides to assign a lane, usually there will be non-proper users on this lane. Vehicles are informed about the lane dedication by physical infrastructure and TMC-messages.

- The IMC sends a message about the dedicated lane activation to the Autopistas HUB (for the VMS), to the related G5 RSU/s (sending the information by ITS-G5 to ITS-G5 OBU) and to the traffic provider (cellular), which in turn will send this new signaling to the BMW car and TOM app.
- The corresponding sign of a dedicated lane is projected in a pictogram on the right lane, in VMS PK 62,2. VMS in PK 55,8 and 50, 5 are used to advise that the right lane is hosting some tests in 6,4km, and 11,7km

Non-proper users have to be clearly identified, and are instructed to leave the lane.

- Based on the sensors located 200m before the VMS (PK 62) on the righ lane, and the identification/location of an “automated” vehicle at the same point, the IMC detects in real time if a conventional car is in the dedicated lane.
- The IMC sends a message to the Autopistas HUB (for the VMSs) asking the car to leave the lane. And the IMC sends a message to the G5 C-ITS OBU and to the traffic provider informing that a non-proper user is in the dedicated lane.
- The message will be shown at the VMS PK 62,2

2) A conventional vehicle enters the dedicated lane

The corresponding sign of a dedicated lane will be projected in a pictogram on the right lane, in VMS PK 62,2. VMS in PK 55,8 and 50, 5 will be used to advise that the right lane will be hosting some tests in 6,4km, and 11,7km

In case of a non-proper user entering the AV-lane, the AVs are informed accordingly. Non-proper users are informed properly to leave the lane.

- Based on the sensors located 200m before the VMS (PK 62) on the righ lane, and an RSU located at PK 62,2, the IMC detects in real time if a conventional car is in the dedicated lane.
- The IMC sends a message to the Autopistas HUB (for the VMSs) asking the car to leave

the lane. And the IMC sends a message to the G5 C-ITS OBU and to the traffic provider informing that a non-proper user is in the dedicated lane.

- A message asking the car to leave the lane is projected at the VMS PK 62,2

5.3.3.2 Current Status and Adaptations for INFRAMIX

Current signaling includes three VMS at PK 62,2, PK 55,8 and PK 50,5. These VMS cover all the carriageways and allow to show a pictogram and three lines of text (16 characters per line). Nevertheless, current signaling does not allow to provide information per lane. For the INFRAMIX we will need to install a specific VMS per lane.

Current available traffic information does not provide any information per lane. Sensors will need to be installed to have this information at lane resolution. Finally, information about the speed of vehicles is currently calculated based on travel times (from the movements recorded at the toll stations identifying the entrance and exit of each vehicle). For the project, sensors to acquire the speed of the vehicles at different points of the test-site (also at a lane level) will need to be installed. Finally, another requirement is the distance prior to the VMS we need to have the information from sensors/RSU (max-min distance) in order to process, generate the corresponding control strategy and send it to the VMS with the necessary time for the user to visualize it and to understand it in order to respond adequately. Based on various references and the characteristics of the test-site some sensors will be installed 200m before a VMS. For this particular use case, these sensors located 200m before the VMS will be used to detect the non-AVs on the dedicated lane.

Regarding the communication I2V no infrastructure is yet available at the test-site. For the INFRAMIX project 3 C-ITS G5 RSUs will be installed at the required locations to address Scenarios 1 and 3.
Regarding the Traffic Management Centre, a new tool (Autopistas HUB) for collecting and sharing the data from the sensors will have to be built. Current Traffic Management Centres of Autopistas introduce the signs in the VMS manually. For this project we will have to build an automatic tool that will show the new defined signs in a new VMS based on the control strategies received from the IMC. All these developments will be hosted in the Autopistas HUB, an emulation of the current TMC.

Finally, current VMSs store a number of standard pictograms for all the necessary situations. In INFRAMIX, new pictograms will need to be designed and implemented for some of the use cases of the project (dedicated AV lane, etc.). And regarding the required segregation elements, if we want to have the dedicated lane more visible for the demonstrations, the corresponding segment will be painted for approximately one month.

5.3.4 Scenario 3: Bottlenecks

The following subchapters describe the detailed architecture that reveals the interactions and planned integrations required for the implementation of each of the use cases of the project scenario ; Bottlenecks

5.3.5 Scenario 3 Use case 1: Automated vehicles (AV) driving behavior adaptation in real time at sags

5.3.5.1 Systems Interaction and Integration

Based on the aforementioned systems that will be used for the demonstration and testing, the following Figure 20 presents a detailed architecture that reveals the interactions and planned integrations required for this Use Case. 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. AVs may be ACC-vehicles, which are already on the streets, but full-scale testing in real-world conditions is restricted within INFRAMIX due to the limited resources for test vehicles. As a minimum, testing some aspects of the procedures is planned, including passenger feeling with reduced time-gaps, using a small fleet of 5 vehicles with ACC functionality (the BMWs).

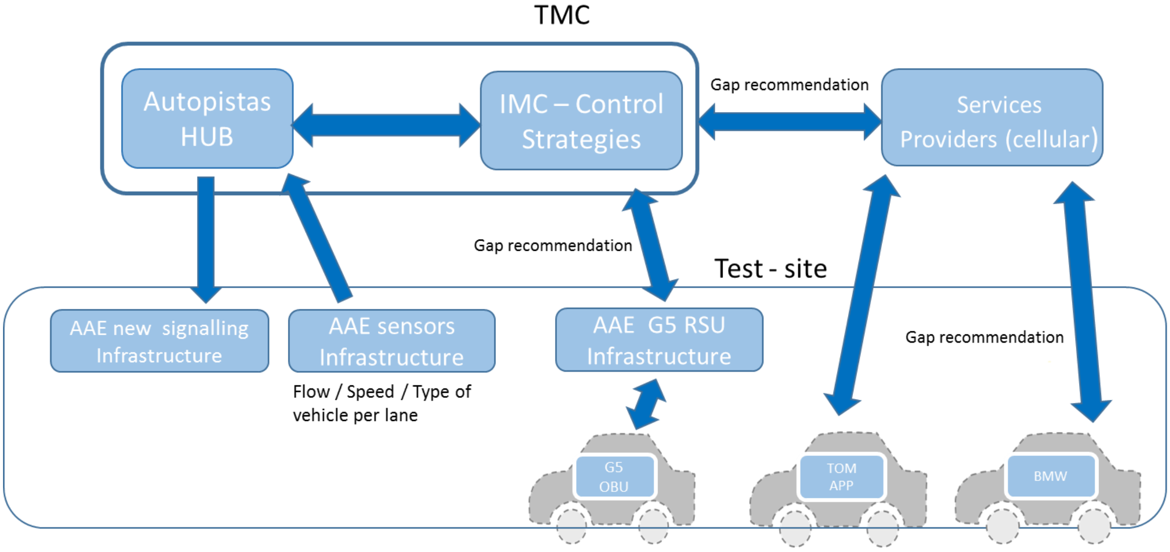


Figure 20 – Systems interactions and planned integrations SC3-BTN-UC1-DBAS

In order to have a detailed description of these interactions and planned integrations, a possible representative sequence of actions follows:

- The IMC sends a message with the new gap recommendation to the related G5 RSU/s (sending the information by ITS-G5 to ITS-G5 OBU) and to the traffic provider (cellular), which in turn will send this new signaling to the BMW car and TOM app.
- The driver will activate the gap recommendation in her vehicle if possible.

5.3.5.2 Current Status and Adaptations for INFRAMIX

Current available traffic information does not provide any information per lane. Sensors will need to be installed to have this information at lane resolution. Furthermore, some sensors will need to be installed at an on-ramp and around this area in order to address the Bottleneck scenario. Finally, information about the speed of vehicles is currently calculated based on travel times (from the movements recorded at the toll stations identifying the entrance and exit of each vehicle). For the project, sensors to acquire the speed of the vehicles at different points of the test-site (also at a lane level) will need to be installed. Especially for the bottleneck scenario it is a requirement to have this information every 500 meters

Regarding the communication I2V no infrastructure is yet available at the test-site. For the INFRAMIX project 3 C-ITS G5 RSUs will be installed at the required locations to address Scenarios 1 and 3.

5.3.5.3 Local Context and Potential Implications on Tests

This use case does not incorporate any specificity of the test site in terms of technical nor operational capabilities. For this reason and because the control strategy sent to a vehicle will always be validated by the driver, there are not potential implications of local legal frameworks (or any other restrictions) for the tests.

5.3.6 Scenario 3 Use Case 2: Lane change advice to connected vehicles at Bottlenecks

5.3.6.1 Systems Interaction and Integration

Based on the aforementioned systems that will be used for the demonstration and testing, Figure 21 presents a detailed architecture that reveals the interactions and planned integrations required for this Use Case. The main concept 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, which are reflected in appropriate traffic data (measurements or estimates)[24]. As it is already mentioned a closed control loop could not be tested within INFRAMIX as there are not resources for a fleet of vehicles. Therefore during the tests the TMC will recommend the test vehicles to change lane but this recommendation will not be the outcome of real time traffic data but emulated ones. The purpose of the test will be the evaluation of user perceptions regarding the lane change recommendation. Consequently, vehicles with the lane change Driving Assistance functionality[25] are required.

In order to have a detailed description of these interactions and planned integrations, a possible representative sequence of actions follows:

- The IMC sends a message with the lane change advise to the related G5 RSU/s (sending the information by ITS-G5 to ITS-G5 OBU) and to the traffic provider (cellular), which in turn will send this change lane advice to the BMW car and TOM app.
- The driver will activate change lane assistant in her vehicle if possible.

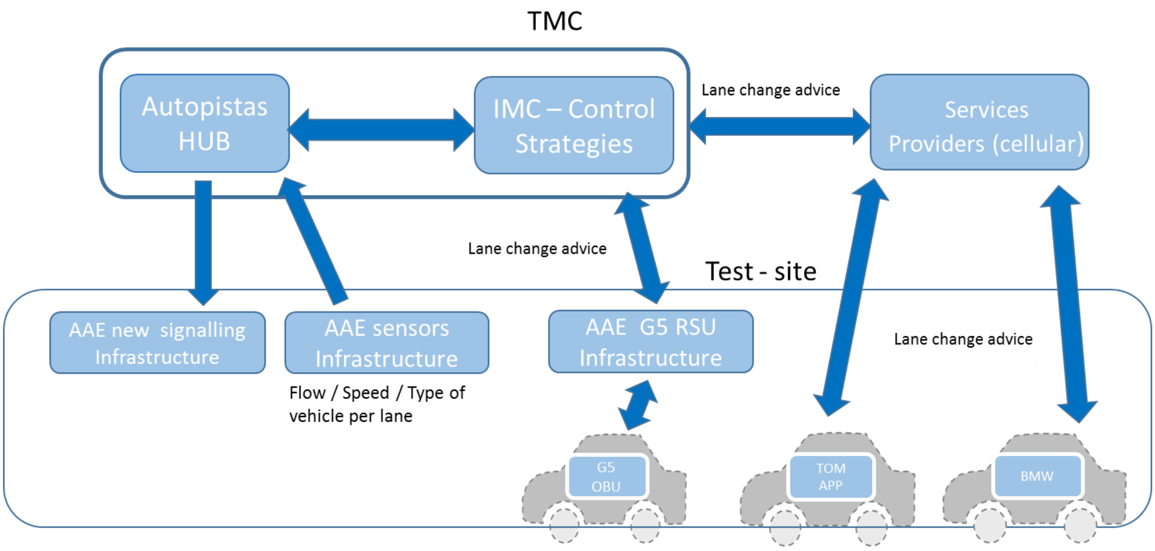


Figure 21 – Systems interactions and planned integrations SC3-BTN-UC2-LCA

5.3.6.2 Current Status and Adaptations for INFRAMIX

Current available traffic information does not provide any information per lane. Sensors will need

[24] For the necessary traffic data to feed the control strategies , the reader is referred to D2.5

[25] For the moment, the rented BMWs would be the only one available for this evaluation.

to be installed to have this information at lane resolution. Furthermore, some sensors will need to be installed at an on-ramp and around this area in order to address the Bottleneck scenario. Finally, information about the speed of vehicles is currently calculated based on travel times (from the movements recorded at the toll stations identifying the entrance and exit of each vehicle). For the project, sensors to acquire the speed of the vehicles at different points of the test-site (also at a lane level) will need to be installed. Especially for the bottleneck scenario it is a requirement to have this information every 500 meters.

Regarding the communication I2V no infrastructure is yet available at the test-site. For the INFRAMIX project 3 C-ITS G5 RSUs will be installed at the required locations to address Scenarios 1 and 3.

5.3.6.3 Local Context and Potential Implications on Tests

This use case does not incorporate any specificity of the test site in terms of technical nor operational capabilities. For this reason and because the control strategy sent to a vehicle will always be validated by the driver, there are not potential implications of local legal frameworks (or any other restrictions) for the tests.

5.3.7 Use Case 3: Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles

5.3.7.1 Systems Interaction and Integration

Based on the aforementioned systems that will be used for the demonstration and testing, the Figure 22 presents a detailed architecture that reveals the interactions and planned integrations required for this Use Case.

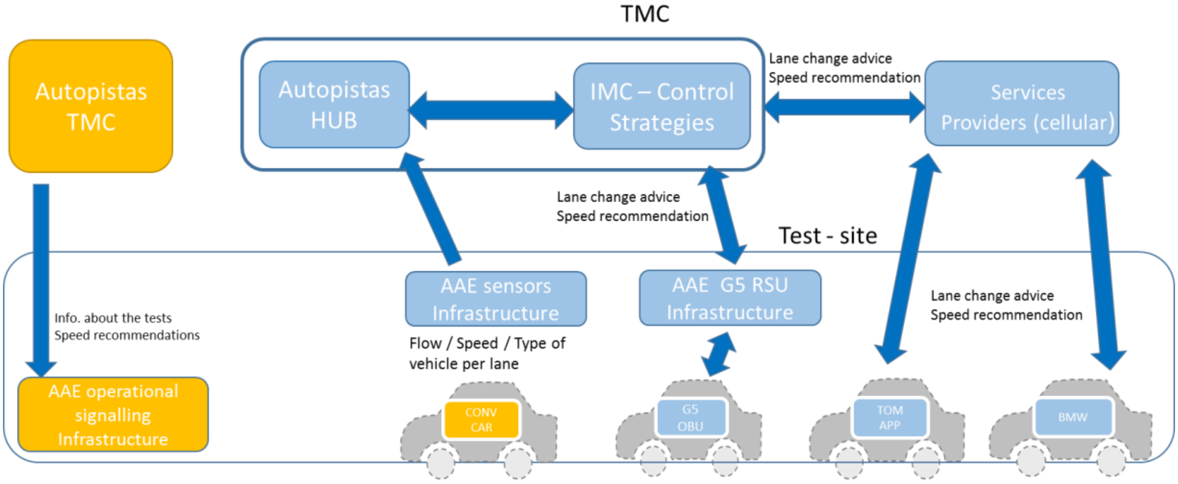


Figure 22 – Systems interactions and planned integrations SC3-BTN-UC3-LCAFC

In order to have a detailed description of these interactions and planned integrations, a possible representative sequence of actions follows:

Based on emulated traffic flow data combined with real traffic conditions, the TMC recommends a speed for all the traffic combined with the change of lane to some vehicles:

- The IMC sends a message to Autopistas HUB (for the VMSs), to the related G5 RSU/s sending the information by ITS-G5 to ITS-G5 OBUs, and to the traffic provider, which in turn will send these new speed recommendations to the BMW and TOM app.

- The IMC sends a message with the lane change advise to the related G5 RSU/s (sending the information by ITS-G5 to ITS-G5 OBU) and to the traffic provider (cellular), which in turn will send this lane change advice to the BMW car and TOM app.
- The driver will activate change lane assistant in her vehicle if possible.
- Speed recommendation signs will be activated in the related VMS manually by calling the Autopistas TMC, as the operational VMSs and cannot be controlled by any other under any circumstance. All the operational VMSs include a pictogram on the left with three lines of text.

In order to evaluate the user perceptions regarding the lane change recommendation, we will need vehicles with this Driving Assistance functionality. For the moment, the BMWs would be the only one available for this evaluation.

5.3.7.2 Current Status and Adaptations for INFRAMIX

Current signaling includes three VMS at PK 62,2, PK 55,8 and PK 50,5. These VMS cover all the carriage way and allow to show a pictogram and three lines of text. No further signaling at lane level is required for this use case.

Current available traffic information does not provide any information per lane. Sensors will need to be installed to have this information at lane resolution. Furthermore, some sensors will need to be installed at an on-ramp and around this area in order to address the Bottleneck scenario. Finally, information about the speed of vehicles is currently calculated based on travel times (from the movements recorded at the toll stations identifying the entrance and exit of each vehicle). For the project, sensors to acquire the speed of the vehicles at different points of the test-site (also at a lane level) will need to be installed. Especially for the bottleneck scenario it is a requirement to have this information every 500 meters.

Regarding the communication I2V no infrastructure is yet available at the test-site. For the INFRAMIX project a number of RSUs will be installed at the required locations to address Scenarios 1 and 3.

5.3.7.3 Local Context and Potential Implications on Tests

This use case does not incorporate any specificity of the test site in terms of technical nor operational capabilities. For this reason and because the control strategy sent to a vehicle will always be validated by the driver, there are not potential implications of local legal frameworks (or any other restrictions) for the tests.

6. German test site

BMW intends to use the A9 test site and its resources for development and early testing of the following developments, which are applicable to all the three INFRAMIX scenarios:

- Speed and lane recommendations based on a dynamic electronic horizon
- Route recommendations

for automated vehicles, covering the entire processing chain from fleet data and data provided by the road operator to recommendations displayed in the vehicle.

That way, it becomes the springboard to generalize and transfer these use cases to the other test sites.

The German test site will firstly focus on the preparation of the tests on the Austrian and Spanish test site using BMW vehicles. BMW cars are equipped with an App that receives information and recommendations from the INFRAMIX Management Center (IMC). Secondly, a routing function hosted in the BMW back end and developed specifically for autonomous vehicles will be sending routing recommendations over web services to the vehicle. On the German test site, these functionalities and communication chain will be tested before any tests start with BMW vehicles on the Austrian and Spanish test site. The main goal for the German test sites are interface tests. Missing components in the INFRAMIX architecture on the German test site will be replaced and emulated by mockups.

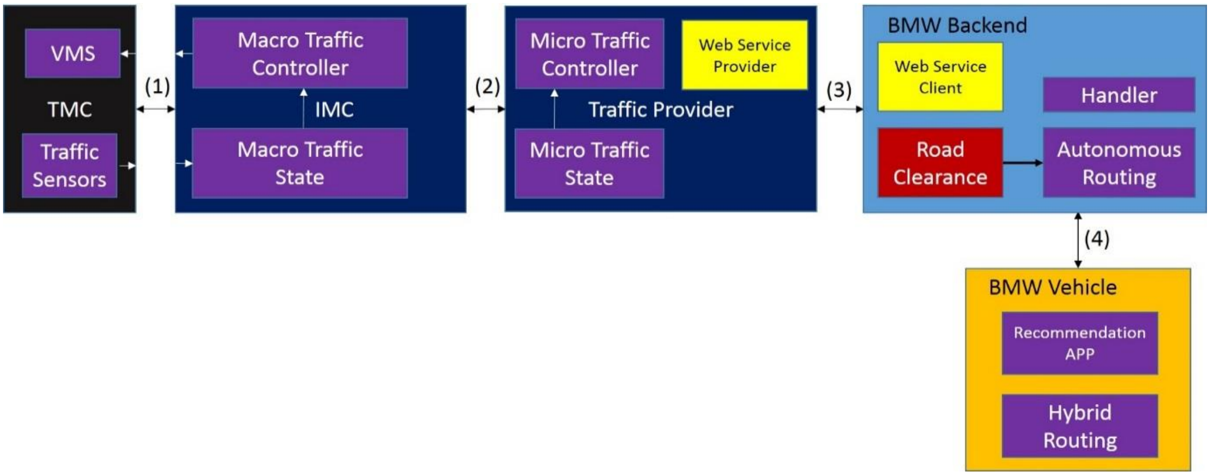


Figure 23 – Overview of the INFRAMIX communication flow for the cellular network

The full communication chain is shown in the figure above. Five components are distinguished:

1) Traffic Management Center (TMC)
2) INFRAMIX Management Center (IMC)
3) Traffic Provider (TP), realized by TomTom
4) BMW Backend (BB), realized by BMW
5) BMW Vehicle (BV), realized by BMW

The TMC gathers traffic information over several types of sensors and transmits it over interface (1) to the IMC where a traffic state observer consolidates this. This first data fusion results in macro traffic values (like flow, density and speed averaged over predefined sections) which are

then used by a macro traffic controller that recommends specific macrocontrol values for the traffic. These recommendations are on the one hand sent back to the TMC (over interface (1)) which display the information and/or recommendations on their Variable Message Signs (VMS), on the other hand forwarded to one or more TPs over interface (3).
The TP possibly enriches the information over its own data sources and refines the recommendations towards customers. Recommendations from the IMC, which imply certain distributions, must be detailed by a micro state observer and a micro traffic controller to form individualized recommendations which are then transmitted over interface (3) to customers.
In our case the recommendations are send to the BB which handles the throughput to the individual vehicles.
Additionally the BB calculates routing recommendations for autonomous vehicles, which are then transmitted to the BV.

6.1.1 Test Site Partners

On the German test site no INFRAMIX project partner stands for the TMC. Therefore TMC and IMC will not take an active part on the German test site.
Only two project partners will be involved in the German test site: TomTom and BMW.
Hereby, interfaces (3) and (4) are in focus.

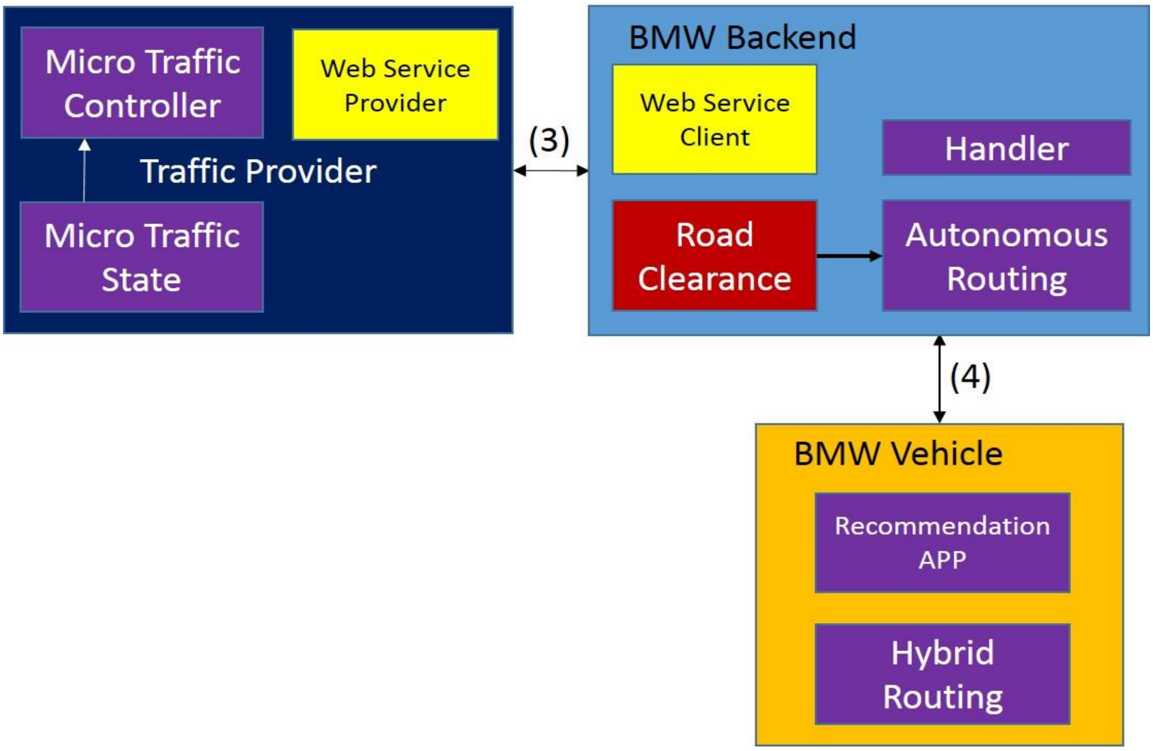


Figure 24 – Modules to be tested at the German test site

The main work of TomTom will be to provide a dummy micro traffic controller which provides over interface (3) to BB traffic information and recommendations for individual test vehicles. First task of BMW will then consist in testing the transmission of this information and recommendations to the vehicle over a webservice where an inCar App will visualize them to a human driver.

The second task of BMW consists in testing hybrid routing for autonomous vehicles. Here the BB calculates an optimal route for an autonomous vehicle based on its actual position and goal position and transmits it to the onboard navigation system.

6.2 Physical and Virtual Systems Used at the Test Site

This section describes the physical and virtual systems (such as simulations, maps, equipment, infra and vehicles) used at the test site.

6.2.1 Real test vehicle

BMW will use a real BMW test vehicle to mainly test the communication between onboard and offboard instances. In particular, interfaces (3) and (4), realized over web services, are tested.

The TP calculates specific recommendations for each connected vehicle based on the actual traffic state. Therefore, vehicles are regularly requesting over interfaces (3) and (4) traffic information and recommendations for their actual position.
The TP can issue following recommendations:

1) Lane choice
2) Speed limit
3) Speed recommendation
4) Time-distance gap between following cars (ACC parameter)
5) Acceleration behavior

In order to prioritize different recommendations and rules, a cause or motivation must also be transferred.
Additionally, an offboard router can suggest routes for optimized autonomous driving.
The recommendations will be visualized over an inCar App in the navigation screen onboard.

The BMW Test Vehicle will not be an autonomous vehicle of SAE Level 3 but rather an emulation over existing driver assistance functions (SAE Level 2). These include following extras:

Table 9 – BMW Test Vehicle attributes

Extra/option	Code
ConnectedDrive Services	S06AK
Navigation professional (EVO)	S0609
Real Time Traffic Information (RTTI)	S06AM
Automatic Cruise Control (ACC)	S05DF
Driving Assistant Plus	S05AT

For the interfacing, the first three extras are necessary.
The two last options are driver assistance functions, which help to emulate autonomous driving. The ACC supports the longitudinal driving behavior. It keeps the vehicle at a selectable velocity by activating the accelerator and eventually gear and braking when the car would accelerate on a downhill slope. Additionally, it is possible with ACC to keep a selectable time-distance gap to the vehicle in front, also by activating the accelerator, (automatic) gear box and brakes. ACC works for a speed range from 0 to 210km/h.

Figure 25 – BMW ACC options on the steering wheel

The driver assistant plus function supports the lateral driving behavior. It holds the vehicle during driving on the actual lane (within the lane markings) or it performs on demand a lane change when the blinker is pushed for a least 3 seconds. Therefore, the environment is scanned by radar and camera to avoid collision with other vehicles. Driver assistant plus can be activated in the speed range from 70 to 120km/h.

Even when the driving assistance functions are active, the driving responsibility remains with the human driver. He is supposed to keep his attention on the traffic situation (Eyes ON) and be ready to take over driving in any case (Hands ON). For security reasons the system is continuously monitoring the presence of the hands on the steering wheel over an inductance sensor and warns the driver in the case of absent hands in three stages. In a first stage (after 3 seconds of hands absence), a yellow steering wheel indicates that the driver should put his hands on the steering wheel. If this is not done within a specified lapse of time (after 13 seconds of hands absence), the steering wheel appears red, an acoustic warning is toned and soon after (after 15 seconds of hands absence), the steering function of the driver assistant plus is deactivated. The ACC function remains however activated.

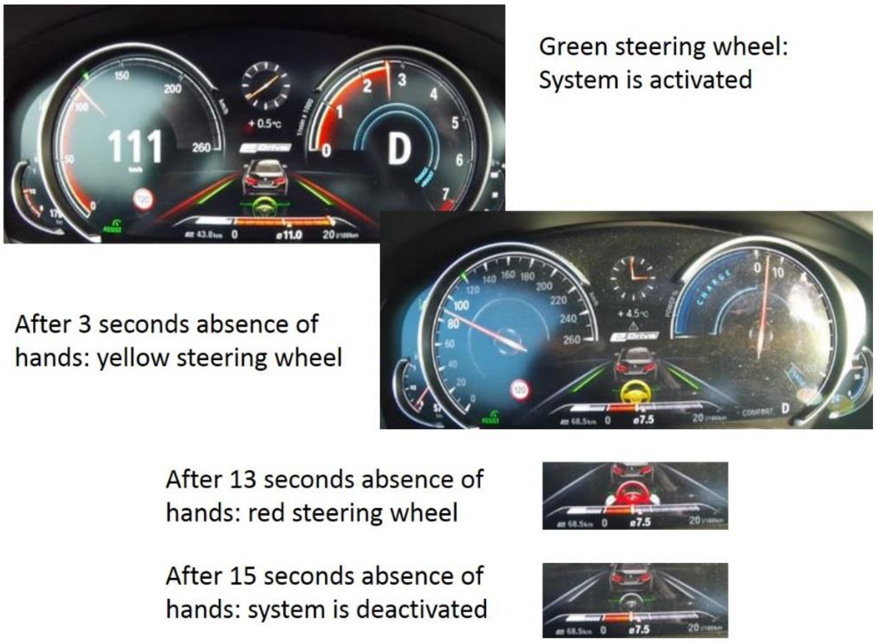


Figure 26 – BMW take over request

6.2.2 Virtual System

In order to test situations where automated driving could be hampered and alternative routing would be recommended, a virtual system is setup. The BMW vehicle is simulated with an actual position and a specific navigation goal. This information is brought to the autonomous routing function that then calculates routes, which are optimized for autonomous driving. This routing is based on the road clearance for autonomous driving which is calculated in real time for all links.

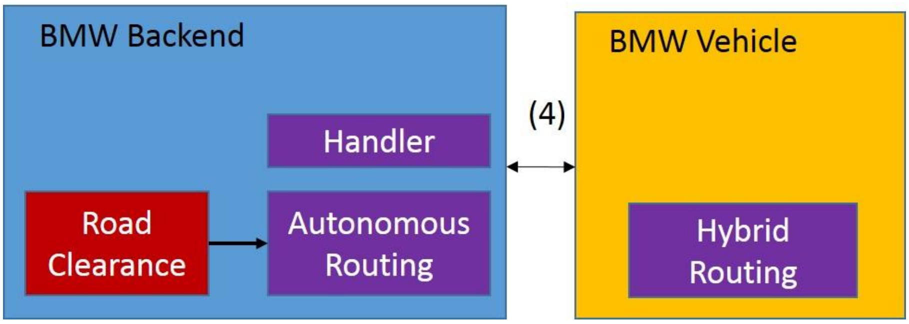


Figure 27 – Detail of the communication flow for the German test sites tests

The road clearance prechecks road sections for their ability for cars to be driven autonomously on. Disturbances like heavy snowfall or road works can cause problems for autonomous driving and therefore these affected road sections are then blocked for autonomous driving. An autonomous vehicle will only be permitted to transit when it is driven manually. The road clearance gives the vehicle the possibility to warn the human driver in advance to be ready to take over the control of the car. If the human driver does not comply to the order to take over (TOR = Take over Request), then the car is subsequently slowed down and eventually stopped.

6.3 Plan for Systems Interaction and Integration

The following sub-sections provide the detailed architecture that reveals the interactions and planned integration aspects of the aforementioned systems, that will be used for the demonstration and testing of the use cases at the German test site.
This section provides a textual detail description of the current status and the planned upgrades. The specificities of the test site in terms of technical and operational capabilities are also incorporated.

6.3.1 All Use Cases

6.3.1.1 Systems Interaction and Integration

The vehicle will communicate over the web service request the following status parameters:

Table 10 – vehicle status parameters (communication over the web service)

Parameter	Description	Unit	Requirement ID
Vehicle ID	Vehicle Identifier (pseudonymized)		S1_DLA_UC1_DPR_F_10
Time stamp	Reference 01.01.2000	ms	
Position	WGS84 coordinates (longitudinal, lateral)	degrees	S1_DLA_UC1_DPR_FE_05
Heading	Driving direction with respect to North	degrees	S1_DLA_UC1_DPR_FE_05
Velocity	Instantaneous speed	km/h	S1_DLA_UC1_DPR_FE_05

Lane[26]	Number		
Type of car	Passenger car, truck, bus, bicycle		
Type of control	Conventional, autonomous		S1_DLA_UC1_DPR_FE_05
Status of control	activated, degraded, deactivated		S1_DLA_UC1_DPR_FE_05
Platooning	Master, Slave, None		S1_DLA_UC1_DPR_FE_05
Goal[27]	Extended driving direction	Same as position	
Environment			S1_DLA_UC1_DPR_FE_05

In return to the request the IMC sends a list of recommendations:

Table 11 – IMC recommendations

Parameter	**Description**	**Unit**	**Requirement ID**
Vehicle ID	Vehicle Identifier (pseudonymized)		S1_DLA_UC1_DPR_F_08
Time Stamp	Reference 01.01.2000	ms	
Speed limit	mandatory	km/h	
Speed recommendation	recommended (scalar or table) per lane	km/h	S1_DLA_UC1_DPR_F_12
Reason for speed recommendation	criticality[28] how must the vehicle prioritize the recommendation?		
Lane recommendation	Number or table		S1_DLA_UC1_DPR_F_04 S3_BTN_UC1_LCA_FE_01 S3_BTN_UC1_LCA_NF_01
Reason for lane recommendation	why should the car follow the recommendation?		S1_DLA_UC1_DPR_F_05
ACC recommendation	time-distance gap between vehicles	s	S3_BTN_UC1_DBAS_FE_02
Reason for ACC recommendation	how must the vehicle prioritize the recommendation?		S3-BTN-UC1-DBAS
Recommendation acceleration behavior	how aggressive should the vehicle accelerate	m/s²	
Reason for acceleration recommendation	how must the vehicle prioritize the recommendation?		S3-BTN-UC1-DBAS

6.3.1.2 Current Status and Adaptations for INFRAMIX

The following time table gives a time plan for the adaptations within the INFRAMIX. It should be also noted that the xml-interface instead of TPEG-TEC is also under consideration. The interfaces will be finalised as the WP3 work specifies.

[26] Availabilty is to be investigated
[27] Privacy has to be considered
[28] Needs further detailing. Dangerous traffic jam ends are more critical as opposed to an efficient traffic flow.

Table 12 – Time plan for the adaptations within IFRAMIX (German test site)

Start	End	Activity	Responsible
01.01.2018	30.03.2018	Proposal TPEG-TEC Extension for INFRAMIX	BMW
01.04.2018	30.09.2018	Proposal TPEG-TEC Web Service for INFRAMIX	TOM
01.07.2018	30.12.2018	Development TPEG TEC Web service provider	TOM
01.07.2018	30.12.2018	Development TPEG TEC Web Service client	BMW
01.10.2018	15.03.2019	Testing TPEG TEC Web service provider	TOM (with BMW)
01.10.2018	15.03.2019	Testing TPEG TEC Web service client	BMW (with TOM)
01.01.2018	30.06.2018	Development Router for Optimal Autonomous Driving	BMW
01.07.2018	30.12.2018	Integration in vehicular environment	BMW
01.10.2018	15.03.2019	Testing ROAD in German test field	BMW

An indicative sequence of actions represented by a schema of TPEG-TEC message is provided hereby taking the first scenario: Dynamic Lane Assignment as an example.

The TPEG-TEC message which is at Annex II is send from the TP to the BV over the BB. Through this message is communicated to the vehicle that on the German highway A9 between the exit Ludwigsfeld and the crossing Feldmoching (see Figure 28) a dedicated lane for autonomous cars is set into place. The georeferencing is realized over TMC.

Figure 28 – Top view of the German highway A9

Autonomous cars should change to lane #1 (rightmost) and the conventional vehicles should leave this lane. Additionally a maximum speed of 100km/h (=28m/s) and a minimal time-distance gap of 2.0s are recommended.

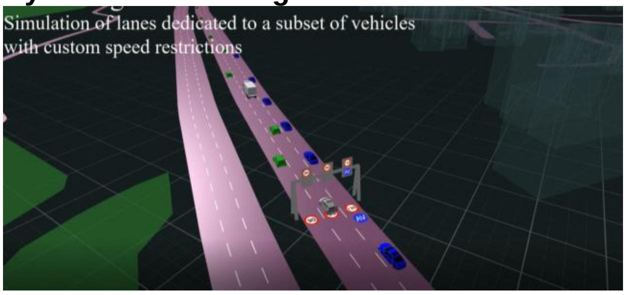
7. Virtual test site

The virtual test site reflects all important aspects, which are evaluated in the real-world test sites, in simulation. Therefore, the INFRAMIX Co-Simulation Environment (consisting of VSimRTI for overall traffic modelling, communication, application entities as well as ICOS for sub-microscopic vehicles) was extended accordingly. The main new features are described in detail in deliverables D2.2 *"Architecture and interface specification of the co-simulation environment"*[29], D2.3 *"Specification of sub-microscopic modelling for intelligent vehicle behaviour"* [30]and D2.4 "*Specification of advanced microscopic traffic flow modelling*"[31] . In summary, these features are:

- Map
- Vehicle Traffic
- Infrastructure and Communication
- Services/Applications
- Sub-microscopic Vehicles

Figure 29 depicts a selection of modelling highlights of the virtual test site for the three scenarios.

Dynamic Lane Assignment



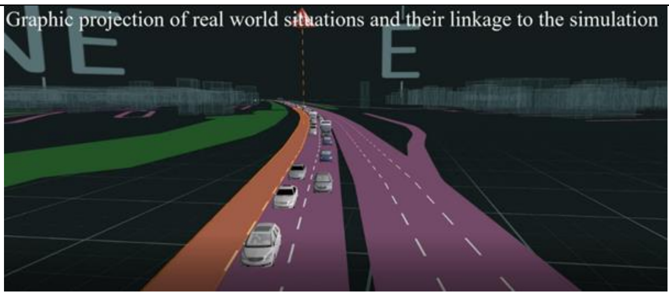
Key features:

- Physical elements: gantries with visual signs (their position may varie) , RoadSide Units (ITS G5 RSUs)
- Vehicles: different vehicle types (trucks, passenger vehicles, etc.) with various communication and automation capabilities (conventional, connected conventional, automated vehicles)

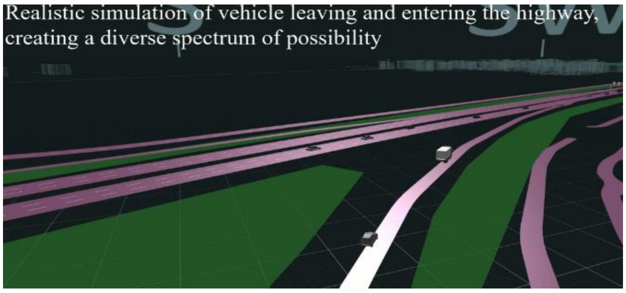
Road Works Zone:

Key features:

- Traffic impact due to complete closure of lanes
- I2V communication (speed recommendations to individual vehicles, lane selections and speed limits warnings)



Bottleneck:



Key features:

- Multiple traffic streams (mainstream, on-ramps)
- Multiple vehicle classes, including different types passenger vehicles, trucks and more
- I2V communication for advice (time-gap and lane recommendations to individual vehilces)
- V2I communication (vehicle communicates as a sensor with : level of automation, aggregated position/speed data)

Figure 29 – Highlights of the virtual test site for the three INFRAMIX scenarios

[29] https://inframix.eu/wp-content/uploads/D2.2_architecture_and_interface_specification_co_simulation.pdf
[30] Confidential
[31] Confidential

7.1 Overview of virtual test site features

Map
The map certainly depicts the road layout from both test sides – A2Graz and AP7Girona – with information such as number of lanes, entries/exits, restrictions etc. Moreover, the position of gantries, sensors and RSUs are modelled. While the road layout is considered somehow as static in the simulation, these other components (mainly the positions) can be configured dynamically. Hence, the virtual test site allows for evaluations where e.g. RSU positions are varied in order to identify the impact of different RSUs coverage characteristics on the efficiency of the Traffic Estimation and Control (TEAC) algorithms.

Vehicle Traffic
The vehicle traffic models two important issues - on the one hand, the different vehicle types (CV, CCV, AV), which are investigated in INFRAMIX and their equipment rate in the scenarios. In simulation, specific applications model the characteristics of CV, CCV, AV. More details about this modelling can be found in the section about applications.
On the other hand, vehicle traffic concerns the surrounding traffic. The virtual test site is calibrated with traffic data from the real test sites. More specifically, the real traffic data (currently without INFRAMIX enhancements for the three scenarios) from dedicated days is used as input to generate the initial traffic pattern for the simulation. As a result, a certain traffic density and vehicle distribution can be modelled. However, when the INFRAMIX TEAC algorithms come into action, they would shape the traffic for a new pattern, which is obviously expected to be more efficient.
Investigations for the dynamic traffic are performed in task T3.3, meaning the results will be expected in M24 of the project. Yet, initial results delivered a distribution of vehicles as outlined in the following table.

Table 13 – Distribution of vehicle classes (modelled according to traffic data from real test sites)

Class	Passenger (fast)	Passenger (slow)	Truck	Trailer	Motorcycle
Percentage	46%	28%	13%	11%	2%

In the classification above, passenger cars account for the biggest portion. Hence, they are split in two groups with individual parametrization. The group of Trucks also includes busses. Trailers include all vehicles with multiple axles (>3).

The real traffic data as encountered today may still have a low density. Thus, the vehicle traffic in general is modelled with 2 parameterizations.
1) The real-world traffic for a characteristic day as baseline
2) A high density parameterization to test the limits of the TEAC algorithms as busy day

Infrastructure and Communication
The Infrastructure models were set up to reflect all needed issues for sensing needed traffic metrics (such as traffic flow and density), for controlling the vehicles with visual signs. Additionally, communication links are modelled RSUs as well as Cellular Base Stations for bi-directional information exchange of connected vehicles (also used for the targets of Traffic Estimation and Control). For all infrastructure elements, error models could be introduced, which are part of the evaluation series. For instance, visibility of signs is configurable in order to investigate different weather conditions of S1_DLA_UC2_AWC, RSU communication range or general communication impairments could be varied for all use cases. Original RSU positions as deployed in the real test sites are possible as well. Therefore, the location data with partners of Abertis Autopistas (for AP7 Girona) and ASFiNAG (for A2 Graz) are used.

Services/Applications
Applications in simulation can be either TEAC algorithms (located in the Infrastructure - TMC/IMC or Web services) or vehicle applications. The virtual site supports variation of the algorithms according to the specific use case, e.g. for the BTN scenario Speed Advice and Gap/Acceleration Advice (DBAS), Lane Change Advice (LCA).
Moreover, applications define the vehicle types – meaning CV, CCV, AV. Conventional vehicles include human behaviour. Connected vehicles are configured with either communication link (ITS G5 and cellular). Automated vehicles are configured with their SAE-level, which can be dynamically adapted during simulation runtime in order to account for aspects like degradation of automated driving functions. The manoeuver characteristics are simulated based on the test vehicle of BMW at the German test site and of VIF which will used for the hybrid testing (further details on the manoeuvre characteristics are described at D2.3 *"Specification of sub-microscopic modelling for intelligent vehicle behaviour").* Those characteristics will be fine-tuned in WP5 according to the capabilities of microscopic modeling.

Sub-microscopic Vehicles

The sub microscopic simulation part consists of a vehicle dynamic simulation model, an automated driving function, a sensor model and static environment. For vehicle dynamics simulation IPG CarMaker is used. With this model complex vehicle dynamics can be investigated. The automated driving function can be used for different SAE levels (ACC, Lane Keeping and Lane Change). The static environment passes information about road markings and traffic signs from the map to the sensor. More details about the sub microscopic simulation can be found in Deliverable 2.3 *Specification of sub-microscopic modelling for intelligent vehicle behaviour*[32]*.*

[32] confidential

Summary

As a summary of this section an initial plan is provided for simulation series in Table 14. Table 15 gives an overview of the real data to be used in simulation per simulation model and per use case.

Table 14 – Parameter variation of the simulation series to be performed in the virtual test sites

Domain	Parameter Variation	Scenario
Map	Position of gantries (impact on traffic)	S1-DLA-UC1-DPR
	Position of sensors (impact on data provided to traffic estimation)	ALL
	Position of RSUs (ITS-G5 coverage)	ALL
Vehicle Traffic	Average Traffic in A2Graz, AP7Girona	ALL
	Busy Traffic in A2Graz, AP7Girona	ALL
Infrastructure and Communication	Sign visibility (due to weather)	S1-DLA-UC2-AWC
	Communication errors and latencies	ALL
Services/Applications	TEAC algorithm Speed, Gap/Acceleration	S3-BTN-UC1-DBAS
	TEAC algorithm Lane Change Advice	S3-BTN-UC2-LCA
	CCV, CV, AV penetration rate	ALL
	GPS sensor error model	ALL
Submicroscopic Vehicles	w/wo C-ITS assistance Level of vehicle automation Lane marking detection Vehicle thresholds for being in automation mode related to its ODD (precipitation (in l/m²), wind velocity in m/s, wind direction related to driving direction, road friction , visibility)[33]	S3-BTN-U3-LCAFC S2-RWZ-UC1-SLC S2-RWZ-UC2-NLD S1-DLA-UC2-AWC

[33] Modelling of vehicle thresholds related to its ODD is based on literature, VIF experience, OEM (BMW)input-feedback

Table 15 – Modelling based on real values & modular parameters to allow further investigation and support real testing.

	Type of test / Use Cases	required/key models	comments on the models / real data for the modelling	modular parameters/ initial estimations from the test sites
ALL	ALL	MAP	-Spanish and Austrian test site: Road layout, nr. of lanes	
Scenario 1: Dynamic lane assignment	Real-time lane assignment under Dynamic Penetration Rate of automated vehicles	Infrastructure and Communication	-Spanish and Austrian test site: position of the RSUs, sensors, gantries, mobile VMS, location of the toll stations	-position of infrastructure elements on the static road layout : RSUs, sensors, gantries
		Micro-traffic, Services/applications, Communication	-mixed traffic flows incl. vehicles of different automation level Modelled based on test vehicle of hybrid testing -vehicles with various communication capabilities e.g. connected through cellular or ITS G5 -passenger vehicles and trucks are simulated (data from Spanish and Austrian test site regarding the traffic flow incl. types of vehicles)	-penetration rate of the automated vehicles (starting from 0 automated vehicles – conventional traffic as given form the historical data at each test site –busy and average traffic) -percentage of vehicle classes (based on historical data)
	Exceptional traffic situations-adverse weather conditions as an example	Infrastructure and Communication	-Sign/ lane marking visibility due to weather (data from ASF) -Slippery Road -Strong side wind -Heavy rain -Snow	
	A conventional vehicle drives on a dedicated lane for automated vehicles	Communication errors and latencies	-simulation of the real errors and latencies from interfaces at the two test sites	- cellular or ITS G5 V2I or I2V communication
Scenario 2: Roadworks	Single Lane Closure (e.g. short term constructions)	Submicroscopic Vehicles	-vehicle behaviour (consolidated with hybrid testing)	-automated functions
		Services/Applications	-individual control algorithms	
	New Lane Design (e.g. long term constructions)	-Services/Applications -MAP	-individual guidance through MAPEM messages (consolidated with hybrid testing)	-road layout -number of lanes
Scenario 3: Bottlenecks	Automated vehicles Driving Behaviour Adaptation in Real Time at Sags	Services/Applications	-TEAC algorithm which recommends : Speed, Time-gap/ Acceleration (Acceleration advice will be always in conjunction with Gap Advice)	- time-gap recommendation -acceleration recommendation
	Lane-Change Advice to connected vehicles at Bottlenecks	Services/Applications	TEAC algorithm -Lane Change Advice	-lane change recommendation
	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles	Services/Applications	TEAC algorithm -Lane Change Advice - Speed, -Time-gap -Acceleration	

8. Hybrid Testing

The development of automated driving function poses various challenges. One of the main challenges is testing the vehicle behavior in multiple traffic scenarios that can occur when driving on real roads. In order to guarantee accurate vehicle behavior these scenarios have to be passed under safe driving conditions. For this purpose, within the INFRAMIX project hybrid testing is investigated, where one real vehicle drives in a virtual environment. Additionally, to the real vehicle the OBU and the RSU are physically present. The other systems and parts are simulated (see chapter 8.2).

The idea is to first perform the scenarios in simulation, which will be performed in WP5. Based on these results we perform the same scenarios with hybrid testing on the proving ground. In hybrid testing environmental information, such as lane markings, road curvature, etc. as well as other traffic participants are only virtually present. The real vehicle reacts to the virtual elements accordingly, while also taking into account real world communication via RSU. The RSU sends ITS-G5 messages, which are able to get received by the OBU integrated in the test vehicle (see Figure 30)

The status of the TMC is set by the preparatory simulations and defines which ITS-G5 Messages are sent by the RSU during each scenario.

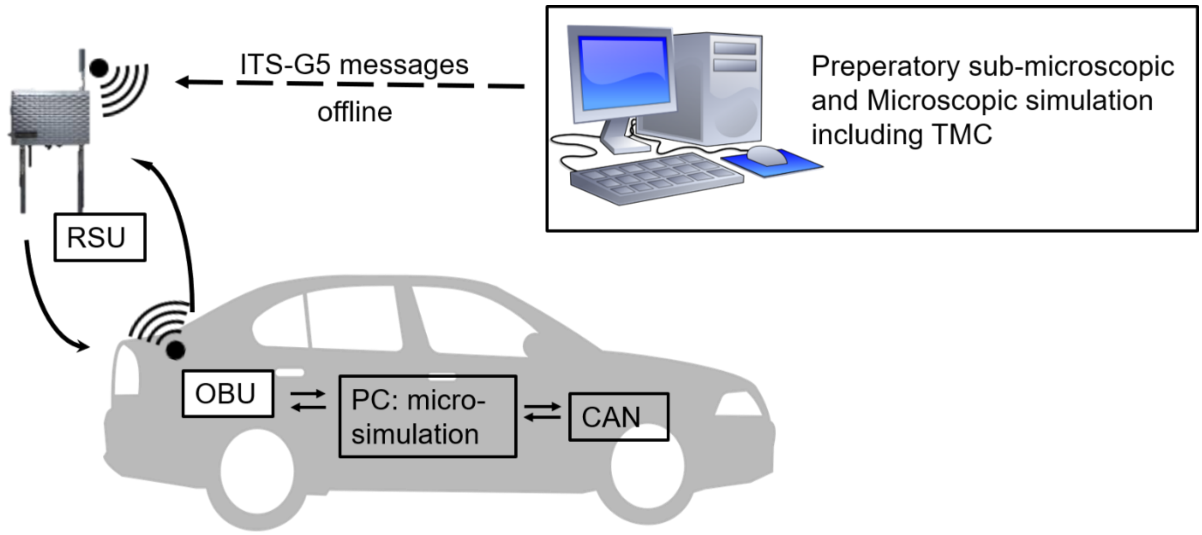


Figure 30 – Hybrid testing

In Hybrid testing, the sub-microscopic simulation runs on a 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 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 realtime to the CAN-bus of the VuT to collect variables relevant for representation of the VuT in the traffic simulation on the PC. For the hybrid tests, the ADAS (Adaptive Driver Assistance System) control functions are based on the vehicle 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 will be persistent bidirectional link between the RSU and the OBU during the demonstrations of the specific hybrid testing use case demonstrations planned in this project. 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.

The arrived solution requires that the TMC messages will be provided and exchanged between the RSU and OBU through an online but based on offline simulation of the same scenario. The traffic situation is determined with a pure simulation and according to this traffic situation the TMC will take its decisions; these will then with the ITS-G5 messages be used during hybrid testing. Therefore for every scenario tested during hybrid testing, there will be specific messages, that are generated by the TMC for this specific situation. The outcome will be the same as if the TMC was linked directly to the RSU.
In addition, the time frame for hybrid testing scenarios is foreseen as 20 to 30 seconds as restricted by the test site physical limitations and vehicle speed desired. The longest straight road section to be used during the hybrid testing demonstrations is about 400m and assuming an average speed of 50 km/h during a hypothetical test, the entire stretch will be covered in less than 30 seconds. During this short time slot, neither a significant change of the traffic pattern nor a rapid change in the TMC-state should be expected. This is why no benefit should be expected if the bilateral communication with the TMC and OBU is included in the hybrid testing.
The AV receives these messages and performs its maneuvers according to the simulated surrounding traffic and the received ITS-G5 messages. The AV also sends CAM-messages with its state to the RSU. 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.
Based on the performed hybrid tests and the therein logged data (e.g. duration lane change, vehicle velocity, time gap to other vehicles etc), the scenarios tested in simulation beforehand can be validated and their applicability to real-world driving can be investigated.

Summarizing all this facts and limitations in hybrid testing short scenarios (20 to 30s), that can be demonstrated on an enclosed test track, are performed. The focus of hybid testing is on the single vehicle under test (VuT), which is physically present on the test site, rather than on the overall traffic flow.
With hybrid testing the following things should be investigated:

- verification/validation simulation models and parameters of the models (vehicle model/parameters e.g. max. acceleration, parameters of the ADAS control functions e.g. time gaps)
- (timing of) receiving and sending of ITS-G5 wireless messages (IVIM, CAM, DEMN, MAPEM, INFRAMIX has proposed extensions)
- performance of real-world merging/lane-change scenarios

8.1 Test Site Description and Partners

8.1.1 Test Site Description

Hybrid testing will take place on an enclosed proving ground, where a straight road section with approximate length of 400m and a width of at least 10m (two virtual lanes with a width of 3.5m plus additional maneuver space) is available. In Figure 31 a picture of the proving ground is shown.

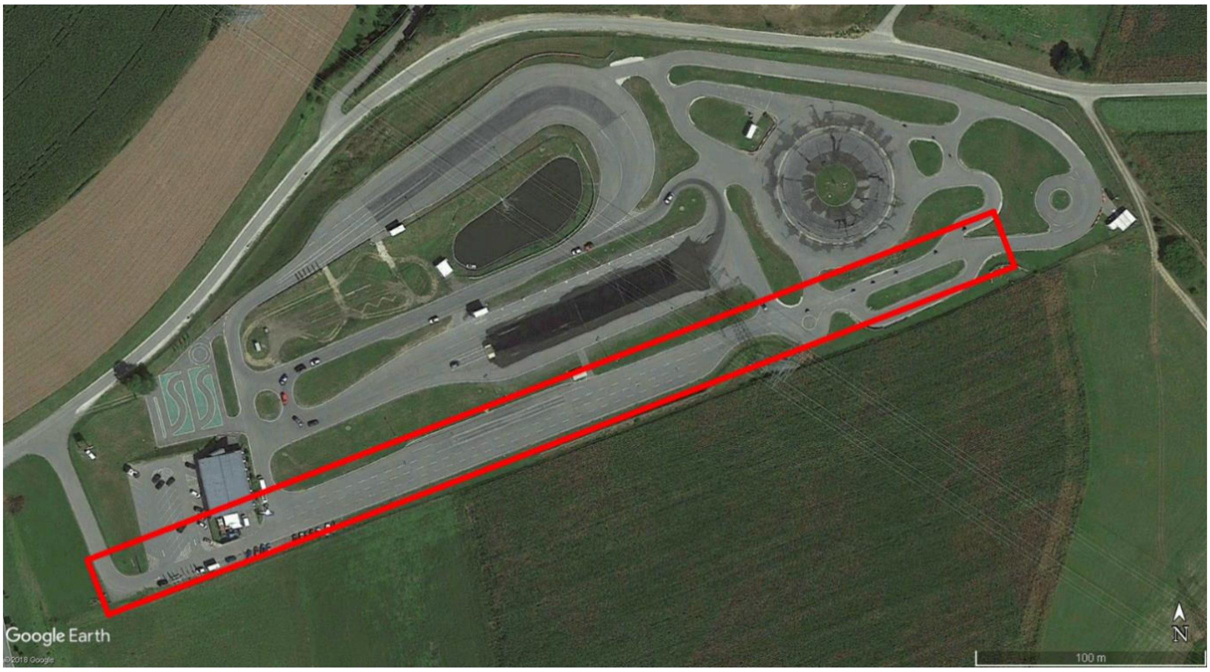


Figure 31 – OEAMTC test track in Lang/Lebring

On the proving ground real road stretches (within the physical limits of the proving ground) and traffic conditions will be modeled. These road stretches reflect highway conditions in Austria and Spain. This means that the VuT percepts the surrounding of the chosen highway segments in Austria and Spain while driving on the proving ground.

For the Austrian test site Km183 of the high way A2 (N47.009° E15.439°) was chosen. The chosen highway section consists of a road segment of approximately 1km with three lanes with lane widths of 3.5m to 3.75m and an on-ramp. Beside its typical character of an on-ramp, this section was chosen because it is covered with stationary radar sensors of Asfinag to observe the traffic. And this section is also equipped with ITS-G5 RSUs.

Figure 32 – Road stretch of the Austrian test site to be modeled on proving ground

For Spain an on-ramp at PK64,5 (41°57'28.40"N; 2°47'3.74"E) of the Spanish Test Site was chosen. The main road has 4 lanes with an overall width of 14m. The on-ramp has one lane with approximately 4m and a maneuver length of about 285m. As additional feature on this on-ramp and before and after the on-ramp are sensors installed. (for more information about the sensors see subchapter 5.2.7).

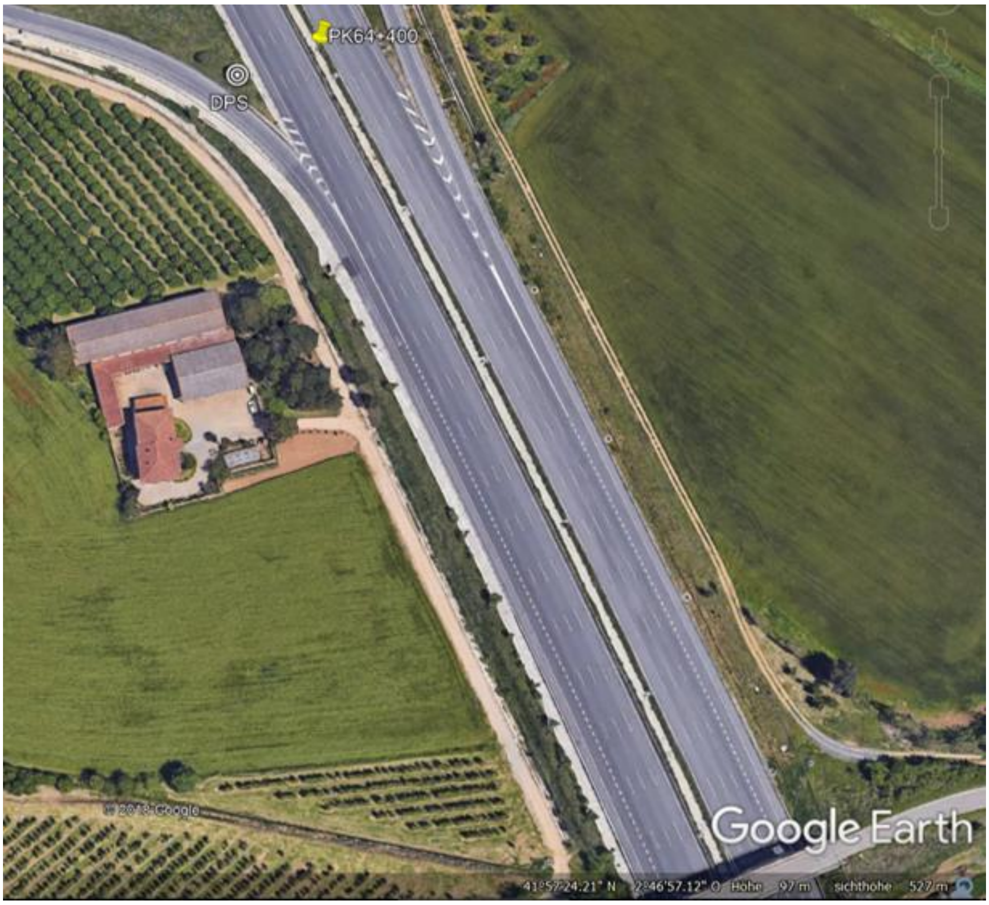


Figure 33 – Road stretch on the Spanish Test Site to be modeled on the proving ground

8.1.2 Test Site Partners

Table 16 lists the partners involved in the test site activities and provide a detailed description of the partner's involvement in the form of tasks/activities assigned or expected by each partner.

Table 16 – Description of partner's involvement

Partner	Involvement description
VIF	**Role: Leader and coordinator for the integration and testing for hybrid test** **Activities:** • Interaction plan for VIL-testing method; • configuration of environment model of the simulation framework for hybrid testing; • modelling of a scenario representing the real test site; • embedding real-world vehicle in virtual environment; • integration and testing of V2X communication elements in real-world vehicle

ASF	**Role: Test site provision** **Activities:** • identify the test stretches and support with the provision of digital maps and all related infrastructure elements
FOK	**Role:** Contribute to the definition of the methodology and testing on the virtual and hybrid demonstration and testing **Activities:** • the overall simulation environment from WP2 will be employed and a specific demonstration scenario will be set up for the hybrid testing
TUC	**Role: Involvement in all issues related to traffic state estimation and traffic control algorithms developed in WP2 for three traffic scenarios and being considered in the hybrid test site:** **Activities:** • Involvement in all issues related to traffic state estimation and traffic control algorithms developed in WP2 for three traffic scenarios • 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
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 dedicated to hybrid testing • Installation and configuration of the ITS-G5 RSUs • Integration of the RSUs to the INFRAMIX technical architecture • Operation of the ITS-G5 communication (based on IMC control strategies)

8.2 Physical and Virtual Systems Used at the Test Site

It is planned to reuse the models of the virtual testing. In the test vehicle only limited computing power is available and the models must fulfill hard real-time constraints. Therefore, adaptions have to be made.

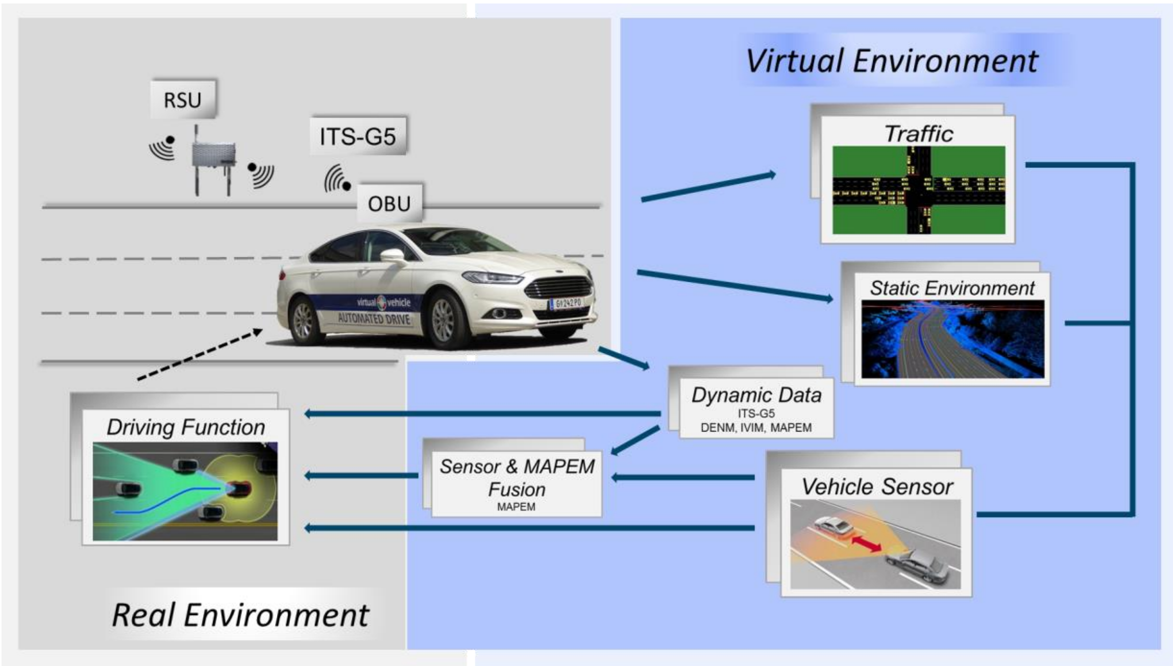


Figure 34 - Physical and virtual systems in hybrid demonstration and testing

8.2.1 Physical Systems

The physical systems in hybrid testing are:

- the Automated driving demonstrator,
- the Automated driving function,
- the RSU and
- the OBU

The automated driving demonstrator is a real car and is equipped with a ADAS-Kit which allows to control the car form algorithms running on an computer. The automated driving demonstrator is linked to a simulation PC, where the models of the virtual systems are running.

The automated driving function (MWC) controls the vehicle. It combines the functionality of a longitudinal guidance system with the functionality of a lateral guidance system (adaptive cruise control, lane keeping assistant, lane change). More information about MWC is given in Deliverable 2.3 Specification of sub-microscopic modelling for intelligent vehicle behavior.

As RSU a mobile VMS from Siemens is used. It will be placed on the proving ground.

An OBU from Siemens will be integrated in the automated driving demonstrator to receive and send the for the different use cases specified ITS-G5 messages.

8.2.2 Virtual systems

The virtual systems in hybrid testing are

- the traffic simulation,
- the sensor module and
- static environment.

It is still not clear if the whole VSimRTI setup is capable to run in real time. Therefore, the traffic simulation during hybrid testing is limited to SUMO. This will lead to the effect that connected vehicles other than the VuT in hybrid testing cannot be simulated. If real time capability is ensured, then VsimRTI will be utilized.
Sensor model and static environment are the same as in the sub microscopic simulation. A more detailed description can be found in Deliverable 2.3. The sensor model takes information about the road markings form the static environment, filters them and passes them to the automated driving function. The sensor also takes information about near vehicles form the traffic simulation and provides the information for the automated driving function.
The Static environment provides map information for the sensor respectively for the automated driving function. It takes information about road markings and traffic signs from the HD-map (Open drive format) and passes it to the sensor.

8.3 Plan for Systems Interaction and Integration

With Hybrid demonstration and testing following use cases are addressed:

- Scenario 2 Roadworks Use Case 1, Single Lane Closure
- Scenario 2 Roadworks Use Case 2, New Lane Design
- Scenario 3 Bottlenecks Use Case 3, Lane-Change Advice combined with Flow Control at

Bottlenecks for all vehicles

8.3.1 Scenario 2 Roadworks Use Case 1, Single Lane Closure (e.g. short term constructions)

The VuT (automated) approaches an area with a single Lane Closure. An RSU submits ITS-messages to inform AVs about the lane closure. When receiving the ITS-message, the VuT will change the lane, considering surrounding (simulated) traffic. The VuT sends its state via CAM-Messages to the RSU.

8.3.2 Scenario 2 Roadworks Use Case 2, New Lane Design (e.g. long term constructions)

The VuT is reaching a road work zone with a new road layout. An RSU is sending MAPEMs with the new road layout. When receiving the MAPEM the VuT follows the new map sent out with the MAPEM.

8.3.3 Scenario 3 Bottlenecks Use Case 3, Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles

The VuT drives through the area of interest, the bottleneck. AVs are informed via ITS-G5 messages and follows the advices, considering the simulated traffic. The VuT sends its position, speed and heading via CAM-messages.

9. Conclusions

The three project scenarios and their related use cases will be investigated and demonstrated through extended simulations, hybrid testing and real world tests. This document reports a plan for systems integration at the test sites, including interactions between physical and virtual systems on the road and at the TMC. This plan relies on outputs from WP2 (*Modelling, simulation and control for mixed traffic*) and WP3 (*Integrated infrastructures and traffic management capabilities*), incorporating also the specificities of the test sites in terms of technical and operational capabilities, and the implications of their legal frameworks for the demonstrations. For each single scenario (lane assignment, road works, and bottlenecks) and for all the use cases (as described in D2.1), the plan includes the corresponding testing sequences and their linked subsystems, estimation, control and simulation tools. This plan is an indispensable step for the project progress as it is necessary for the subsequence tasks of WP4 which consists the real testing.

The Task 4.1 is made in parallel with the Task 5.1 which consists the evaluation plan. Several iterations of the evaluation plan made based on the available equipment and the communication flow chain described in this document. This is because the consortium wanted to mitigate the risk of producing evaluation criteria without having the necessary data to assess them. Therefore this report is a useful reference for the partners involved in WP5 when the evaluation of user's appreciation, traffic efficiency and safety will be performed.

Annexes

- Annex I – Time schedule for systems integration at the Spanish and Austrian test site
- Annex II – Draft list of wireless messages to be demonstrated and RSUs location for the Austrian test site
- Annex III – Indicative TPEG –TEC message for the dynamic lane assignment (German test site)

Annex I Time schedule for systems integration at the Spanish and Austrian test site

Table 17 – Systems integration time schedule at the Austrian test site

Test-Site Austria		2018												2019			
Integration-Plan	involved partner	Jan.	Feb.	March	April	May	June	July	August	September	October	Nov.	Dec.	Jan.	Feb.	March	April
		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
C-ITS RSU Installation	SIE																
IMC Installation	SIE																
DATEX2 Interface (TMC --> IMC)	SIE / ASF																
JSON Interface (TMC --> IMC)	SIE / ASF																
Interface (IMC <--> RSU)	SIE																
IMC Upgrade	SIE																
DATEX2 Interface (IMC --> Cellular)	SIE / TOM																
JSON Interface (IMC <-- Cellular)	SIE / TOM / BMW																
IMC Control strategies	TUC / SIE																
Cellular Experiments Server	TOM																
Cellular Experiments App	TOM																
Vehicle Services	BMW																
Communication device	BMW																
XML Interface (BMW <---> TOM)	TOM / BMW																

Table 18 – Systems integration time schedule at the Spanish test site

Test-Site Spain		2018												2019				
Integration-Plan	involved partner	Jan.	Feb.	March	April	May	June	July	August	September	October	Nov.	Dec.	Jan.	Feb.	March	April	May
		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
C-ITS RSU Installation	SIE																	
Interface (TMC<--new sensors)	AAE																	
Interface (TMC--> VMS)	AAE																	
IMC Installation	SIE																	
DATEX2 Interface (TMC --> IMC)	SIE / AAE																	
JSON Interface (TMC --> IMC)	SIE / AAE																	
Interface (IMC <--> RSU)	SIE																	
IMC Upgrade	SIE																	
ITS-G5 OBU on vehicle	ATE																	
DATEX2 Interface (IMC --> Cellular)	SIE / TOM																	
JSON Interface (IMC <-- Cellular)	AAE/TOM / BMW/SIE																	
IMC Control strategies	TUC / SIE																	
Cellular Experiments Server	TOM																	
Cellular Experiments App	TOM																	
Vehicle Services	BMW																	
Communication device	BMW																	
XML Interface (BMW <---> TOM)	TOM /BMW																	

Annex II Draft List of wireless messages to be demonstrated and RSUs location for the Austrian test site

List of messages to be implemented in the test site

C-ITS messages

Since only standardized C-ITS messages for Day1 are available, the traffic control strategies are realized by combining latest functional description of new developed C-ITS message concepts for automated driving[34].

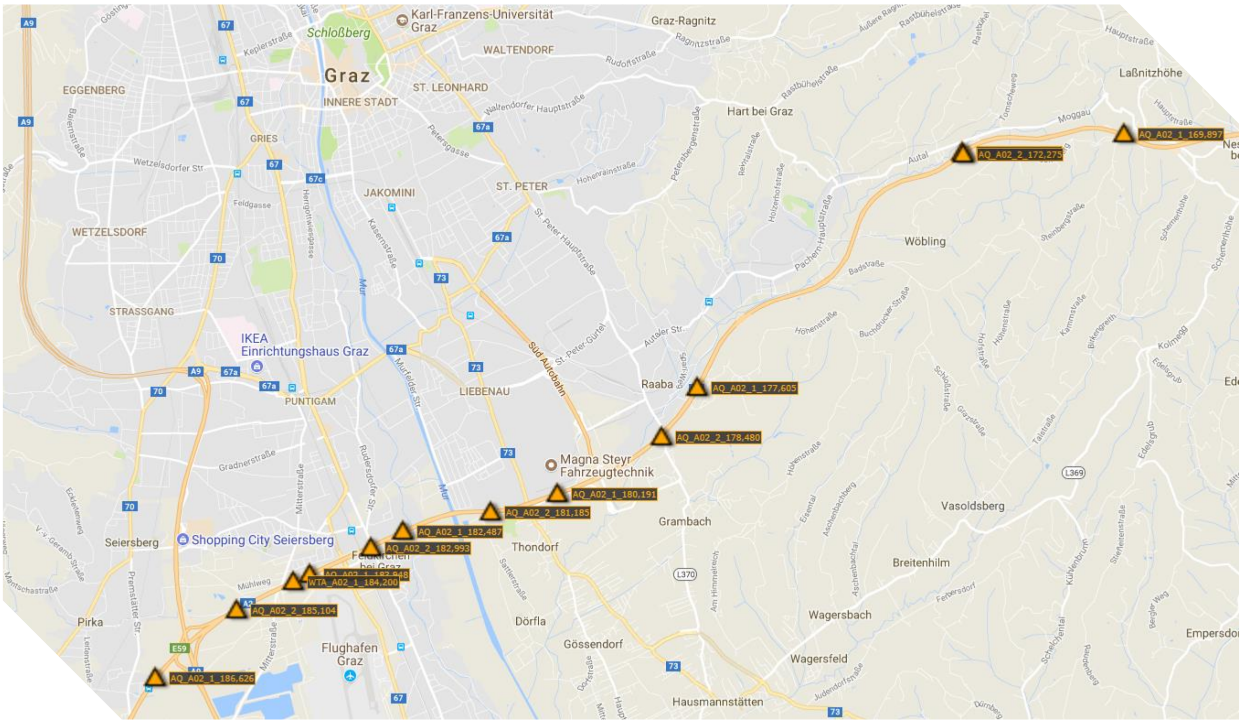
The list of considered messages within INFRAMIX to be possibly tested on the respective test sites:

- SAE level clearance for automated vehicles
- Situation based distance gap for automated vehicles
- Vehicle type and lane specific speed limit for automated vehicles
- Vehicle type and lane specific speed recommendation for automated vehicles
- Collective perception of objects on the road – RWZ-UC1 subcase of broken vehicle
- Long term road works warning
- GNSS correction data

RSUs and video cameras are installed at

Direction 1 (Lassnitzhöhe - Graz Ost)	**km**	**X_WGS84**	**Y_WGS84**
AQ_A02_1_169,897	169,897	15,5854173	47,0631844
AQ_A02_1_177,605	177,605	15,5053573	47,0308771
AQ_A02_1_180,191	180,191	15,4790669	47,0173033
AQ_A02_1_182,487	182,487	15,4500657	47,0124683
AQ_A02_1_183,948	183,948	15,4324811	47,0069945
WTA_A02_1_184,200	184,2	15,4293725	47,0060279
Direction 2 (Graz Ost - Lassnitzhöhe)			
AQ_A02_2_185,104	185,104	15,4187332	47,0025131
AQ_A02_2_182,993	182,993	15,4439071	47,0105533
AQ_A02_2_181,185	181,185	15,4664843	47,0151084
AQ_A02_2_178,480	178,48	15,4983148	47,0246647
Both Direction / Dubpelgantry			
AQ_A02_1_172,275 / AQ_A02_2_172,275	172,275	15,5551004	47,060884
AQ_A02_1_186,000 / AQ_A02_2_186,000	186	15,4090582	46,9978551

[34] http://eco-at.info/tl_files/dynamic_dropdown/uploads/Release 4 and Automated Driving/ECo-AT Release 4 and Automated Driving Documents.zip



Annex III Indicative TPEG –TEC message for the dynamic lane assignment (German test site)

The following test TPEG-TEC message is send from the traffic provider to the BMW vehicle over the BMW backend for communicating the assignment of a dedicated lane:


```
<?xml version="1.0" encoding="UTF-8" standalone="true"?>
<tec:TECMessage xmlns:sfw="http://www.tisa.org/TPEG/SFW_1_1"
xmlns:tec="http://www.tisa.org/TPEG/TEC_3_2" xmlns:mmc="http://www.tisa.org/TPEG/MMC_1_1"
xmlns:tdt="http://www.tisa.org/TPEG/TPEGDataTypes_2_0"
xmlns:lrc="http://www.tisa.org/TPEG/LRC_2_1" xmlns:glr="http://www.tisa.org/TPEG/GLR_1_0"
xmlns:tmc="http://www.tisa.org/TPEG/TMC_1_0" xmlns:dlr="http://www.tisa.org/TPEG/DLR_1_0"
xmlns:olr="http://www.tisa.org/TPEG/OLR_1_0"
xmlns:tfp="http://www.tisa.org/TPEG/TFP_1_0"><tec:mmt><tec:optionMessageManagement><mmc:m
essageID>3</mmc:messageID><mmc:versionID>1</mmc:versionID><mmc:messageExpiryTime>2018-
06-
20T16:00:00.000+01:00</mmc:messageExpiryTime><mmc:cancelFlag>false</mmc:cancelFlag><mmc:
messageGenerationTime>2018-04-
09T17:00:00.000+01:00</mmc:messageGenerationTime><mmc:priority tdt:code="1"
tdt:table="typ007_Priority"/></tec:optionMessageManagement></tec:mmt><tec:event><tec:effectCode
tec:code="2" tec:table="tec001_EffectCode"/><tec:startTime>2018-06-
20T10:00:00.000+01:00</tec:startTime><tec:stopTime>2018-06-
20T15:00:00.000+01:00</tec:stopTime><tec:lengthAffected>2800</tec:lengthAffected><tec:segmentSpe
edLimit>33</tec:segmentSpeedLimit><tec:cause><tec:optionDirectCause><tec:mainCause
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tec:table="tec003_WarningLevel"/><tec:unverifiedInformation>false</tec:unverifiedInformation><tec:sub
Cause tec:code="7"
tec:table="tec116_RegulatoryMeasure"/></tec:optionDirectCause></tec:cause><tec:advice><tec:advice
Code tec:code="18"
tec:table="tec005_AdviceCode"/><tec:adviceValue>1</tec:adviceValue><tec:vehicleRestriction><tec:re
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```

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