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D.3.1

Design and development of infrastructure elements

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Author(s) – in alphabetical order		
Name	Organisation	E-mail
Jacqueline Erhart	ASF	Jacqueline.erhart@asfinag.at
Panagiotis Lytrivis	ICCS	panagiotis.lytrivis@iccs.gr
Salguero Pizaroo Juan Jose	AAE	Juan.jose.salguero.ext@autopistas.com
Daniel Tötzl	SIE	daniel.toetzl@siemens.com
Yannick Wimmer	ASF	Yannick.Wimmer@asfinag.at

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Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
API	Application Programming Interface
AV	Automated Vehicle
CAM	Cooperative Awareness Message
CAV	Connected Automated Vehicle
CB radio	Citizens band radio
CES	Cellular Experiments Server
C-ITS	Cooperative ITS
CPM	Collective Perception Message
CTS	Cellular Traffic Services
CV	Connected Vehicle
DENM	Decentralized Environmental Notification Message
DLA	Dynamic Lane Assignment
EC	European Commission
ERU	Emergency Response Unit
ETSI	European Telecommunications Standards Institute
FCD	Floating Car Data
GA	Grant Agreement
GNSS	Global Navigation Satellite System
HD	High Definition
HTTP	Hypertext Transfer Protocol
HTTPS	HTTP over TLS/SSL
IMC	INFRAMIX Management Center
IoT	Internet of Things
ITS	Intelligent Transport Systems
IVIM	In-Vehicle Information Message
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
OBU	ITS-G5 On-Board Unit
OEM	Original Equipment Manufacturer
PKI	Public Key Infrastructure
PO	Project officer
RSU	ITS-G5 Road Side Unit
TMC	Traffic Management Center
TPEG	Transport Protocol Experts Group
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VMS	Variable Message Sign
VPN	Virtual Private Network
WP	Work Package
XML	Extensible Markup Language

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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.

This deliverable provides the results of the design and development process of the INFRAMIX infrastructure elements. It includes a full designed & developed INFRAMIX system architecture, which forms the basis of the INFRAMIX real-implementations at the Austrian and Spanish test-site.

Chapter 1 presents the project's scope and the purpose of this document. Chapter 2 highlights the results of the deliverable “D2.1”, illustrating the major findings of the conceptual phase and its corresponding requirements, emerged from at the beginning of the INFRAMIX project.

Chapter 3 highlights the INFRAMIX high-level system architecture. This chapter underlines the basic concept of the devised INFRAMIX methods. This contains a high-level description of the INFRAMIX end-to-end solution, including all designated stakeholders of the INFRAMIX system architecture, its major processes as well as a description of the architectures concept.

Chapter 4 contains a description of all physical infrastructure elements. This chapter includes a state-of-the-art description of applied physical infrastructure elements as well as a description of further designed enhancements of the physical infrastructure.

Chapter 5 represents the digital infrastructure. This chapter contains a full description of each designed & developed digital infrastructure-element, which forms the INFRAMIX system architecture. It contains a detailed description of all digital elements, including its functionalities, its communication interfaces and its responsibilities to achieve full coexistence between digital and physical infrastructure elements. Additionally, chapter 5 includes a full description and outlook of the applied communication-channels, in order to form a hybrid-connectivity concept to end-users & end-devices. It also contains a description of the information flow achieved by the INFRAMIX system architecture, including all applied digital messages in order to address the defined scenarios of INFRAMIX.

Chapter 6 contains, as summary, the conclusion of the designed INFRAMIX system architecture and its communication flow. Chapter 7 document concludes the document with a description of applied terms and definitions.

1. Introduction

1.1 Aim of the project

Over the last years, significant resources have been devoted to developing new automation technologies for vehicles, whereas investment and resources for road infrastructure, in general, have steadily dwindled. INFRAMIX is preparing the road infrastructure to support the transition period and the coexistence of conventional and automated vehicles. Its main target is to design, upgrade, adapt and test both physical and digital elements of the road infrastructure, ensuring an uninterrupted, predictable, safe and efficient traffic. Towards this objective different technologies are deployed; mature simulation tools adapted to the peculiarities of automated vehicles, new methods for traffic flow modelling, to study the traffic-level influence of different levels of automated vehicles in different penetration rates, traffic estimation and traffic control algorithms. Moreover, ways of informing all types of vehicles about the control commands issued by the road operator are developed and new kind of visual and electronic signals are proposed for the needs of mixed scenarios. The project outcomes will be assessed via simulation and in real stretches of advanced highways.

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

1.2 Purpose of Document

The purpose of this document is to provide the results of the design and development processes of the INFRAMIX infrastructure elements. This document contains an overview of the outcome of the requirements engineering in deliverable "D2.1", to illustrate the major requirements and findings of the conceptual phase of the project.

In result, the deliverable-document includes the characterization of the INFRAMIX high-level system architecture, which underlines the basic concept of the devised INFRAMIX methods in order to support the transition period and the coexistence of conventional and automated vehicles. This includes the description of a full approach of a common collection of traffic-data, its evaluation & processing to traffic control commands and, in consequence, its dissemination to inform conventional as well as connected (automated) vehicles.

The document contains a description of all physical infrastructure elements, highlighting its state-of-the-art and underlining further designed enhancements. Additionally, as major part of the document, the document contains a detailed description of the applied digital infrastructure and its coexistence to physical system elements. This involves the characterization of all elements of the INFRAMIX system architecture, including an illustration and description of all new designed & developed system elements; enhancements and implementations for the realization of the INFRAMIX project.

The document further contains a description of the coexistence of the INFRAMIX system architecture, illustrating all designed communication-interfaces and its resulting architecture-internal information flow. Additionally, the document highlights the information-flow to end-users & end-devices. This represents all applied communication-channels and digital messages, in order to address all INFRAMIX.

2. Requirements

As result of the INFRAMIX deliverable “D2.1”, known as “Requirements catalogue from the status quo analysis”[1], a status quo analysis has been performed. This analysis includes a high-level conceptual view of the INFRAMIX real-world infrastructure and provides thereby a status overview of the Austrian and Spanish test-site in INFRAMIX. Additionally, a first infrastructure requirements catalogue has been defined, which includes also requirements on the required system architecture.

The deliverable “D2.1” is therefore considered as a guideline and input document for the design and development of physical and digital infrastructure elements, needed for the realization of the INFRAMIX scenarios.

2.1 Status quo analysis

In the first phase of the project a status quo analysis of the two test sites took place. The available equipment was listed and the necessary upgrades, in terms of both physical and digital infrastructure, to test INFRAMIX scenarios and use cases were identified.
The analysis showed that both test sites are well suited to demonstrate and test INFRAMIX scenarios, though the Austrian one was more advanced in terms of already available equipment. Moreover, a result of this analysis was that the necessary adaptations were mainly focused on the enhancement of the digital infrastructure to support the needs of mixed traffic, such as the availability of HD maps, the update of the equipment to circulate the new C-ITS messages proposed by INFRAMIX, and so on.
Another outcome of this analysis was that today, advanced highways in Europe, and beyond, can offer either C-ITS services (see also C-Roads pilots[2]) or 3rd party (normally) cloud services to the drivers through Cellular connectivity (see Figure 1). The idea within INFRAMIX is to extend those highways to accommodate for automated vehicles. The proposed extended INFRAMIX high-level architecture can be seen in Figure 2.

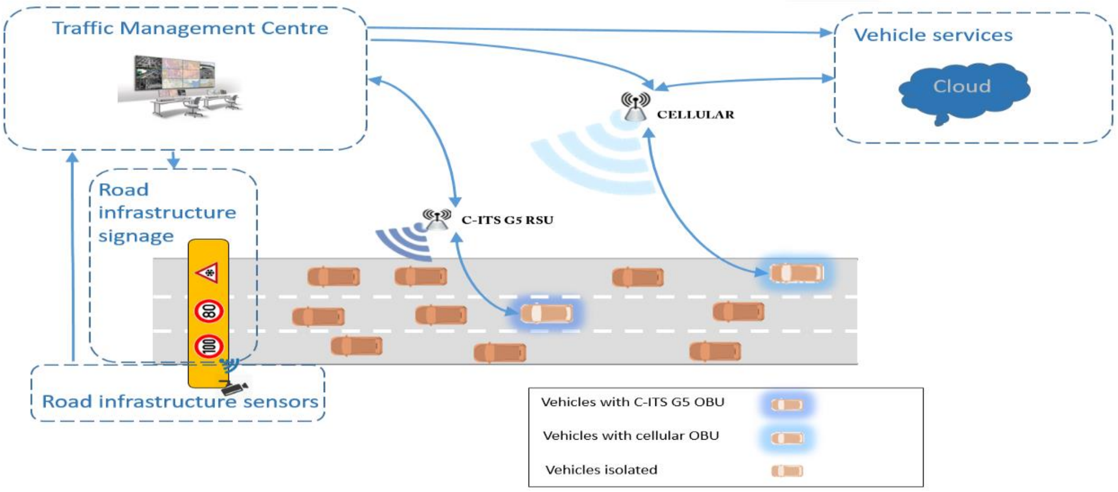

Figure 1 - Existing advanced highways architecture

For more information on the detailed status quo analysis, the interested reader could refer to D2.1.

[1] INFRAMIX, H2020 EU Project, GA No. 723016, Deliverable D2.1 “Requirements catalogue from the status quo analysis”. Available online: https://inframix.eu/wp-content/uploads/INFRAMIX_D2.1-Requirements-catalogue-from-the-status-quo-analysis.pdf
[2] https://www.c-roads.eu/pilots.html

2.2 System architecture requirements

Based on the conducted requirements analysis of D.2.1, each use case of the three INFRAMIX scenarios has been analyzed. As a result, a requirements description for each use case has been achieved, including functional and non-functional requirements as well as feasibility requirements of the infrastructure.

On basis of that defined requirements, physical and digital element needs have been derived in order to specify a first high-level architecture for INFRAMIX (see Figure 2).

This architecture includes the following main components:

- INFRAMIX Management Center (IMC)
- Vehicle services
- Third party services
- Road Infrastructure dynamic signage
- Road Infrastructure sensors

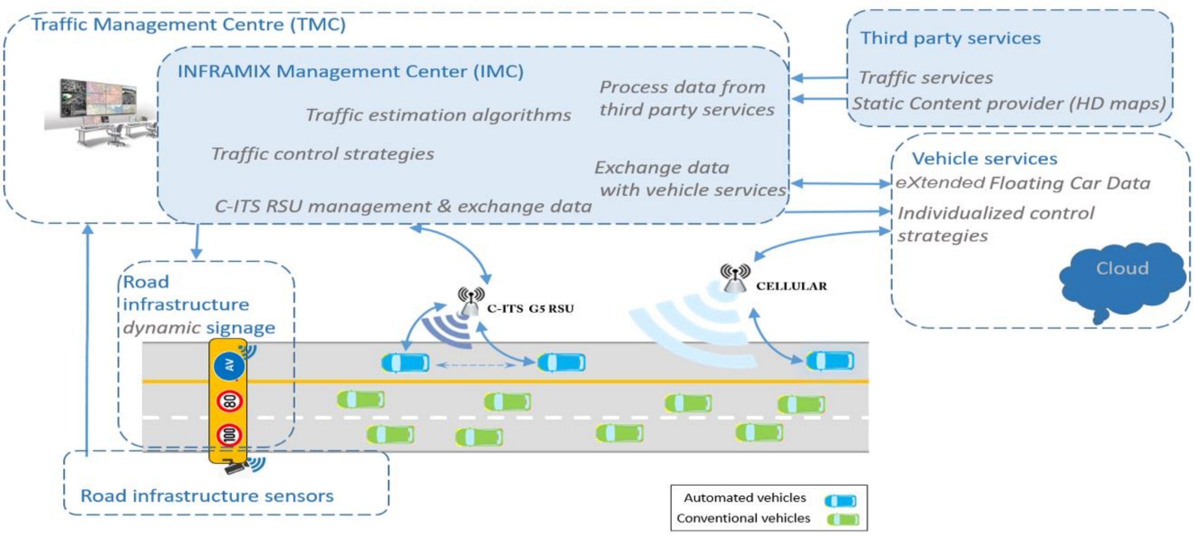

Figure 2 - INFRAMIX high-level architecture (outcome of D2.1)

A brief overview of some examples of the system requirements (functional, non-functional and feasibility) is provided in Table 1 - Indicative system requirements per INFRAMIX component. The full list of requirements per use case can be found in INFRAMIX deliverable: D2.1.

Table 1 - Indicative system requirements per INFRAMIX component

Component	Indicative requirements
INFRAMIX Management Center (IMC)	Functional
	• The TMC should be able to communicate with the AVs and connected conventional vehicles through ITS-G5 messages and/or via Cellular network (communication to centralized backend servers). • Control strategies should decide dynamically about the activation and deactivation of the dedicated lane based on real-time traffic flow information.

	• The TMC should provide beforehand information about a lane closure and the new road layout due to roadworks. • The control strategy should decide dynamically the lane-change flows to be applied by the connected vehicles per lane based on real-time traffic flow information.
	Feasibility
	• The number of gantries or/and mobile VMS should be adequate for ensuring the proper functioning of each use case. • Infrastructure should be equipped with sensors that provide real-time traffic information to ensure that the necessary measurements are obtained. • Infrastructure should consist of a roadway with at least three lanes to perform INFRAMIX scenarios. • Infrastructure should include a TMC to supervise traffic and cooperate with the traffic control and estimation strategies (INFRAMIX Management Center).
	Non-functional
	• Real-time measurements of flow, speed and occupancy should be delivered per lane per specific road segment every 60 seconds. • ITS-G5 communication (air interface) should have a latency which is less than 10 seconds. • The real data from road measurements and the estimated data regarding traffic flow should be consistent, and their combination should be accurate enough to permit the decision making from the traffic control strategies.
Vehicle services	Functional
	• The TMC should be able to provide specific “vehicle-settings” recommendations for individualized traffic control strategy parametrizations to connected vehicles (based on the traffic control strategies from the TMC). • Vehicle services should provide static HD maps to vehicles that contain the information about the lane closure and the new road layout in roadworks zones. • Wireless messages from the TMC to connected AVs should contain information about the time-gap parameter.
	Feasibility
	• Broadcasting wireless messages from the TMC to connected vehicles containing the lane change advice. • An adequate number of sensors for real traffic information of the on-ramp.
	Non-functional
	• V2I communication should support the real-time data exchange between connected vehicles (equipped with ITS-G5 OBU or Cellular communication device) and the TMC. • The TMC should be able to recommend specific ordered AV-settings to all AVs within specific road segments.
Third Party services	Functional
	• Reduced visibility due to rain, snow, smoke, insolation, darkness or others should be recorded, positioned and quantified by the “hybrid” road infrastructure. • The TMC should provide beforehand the information about the lane closure due to roadworks and the new road layout to the Cellular

	backend servers of the 3rd party service providers.
	Feasibility
	• The TMC should include an incident traffic management database. • Wireless messages from connected vehicles to TMC containing information of a vehicle's speed, heading, position in real time, surrounding environment and their level of automation.
	Non-functional
	• The TMC should generate and communicate IVIM message content to centralized backend servers (Cellular network). • The TMC should contain aggregated weather conditions data that permit the recommendation of degradation or not of the level of automation to respective vehicles in real-time.
Road Infrastructure dynamic signage	**Functional**
	• The TMC should inform the road users about the possibility of changing the current speed limit applied to the lane that they use before entering the highway and while using the roadway. • The TMC should inform the road users about the activation and deactivation of the dedicated lane, while using the roadway.
	Feasibility
	• Infrastructure should be equipped with gantries or/and mobile VMS that provide signage of the pictogram implemented for the dynamic lane assignment.
	Non-functional
	• The TMC should communicate dynamically with the road signage equipment (gantries, VMS etc.).
Road Infrastructure sensors	**Functional**
	• A reduced friction value of the road due to rain, snow, ice, oil, or others should be recorded, positioned on a map and quantified by the "hybrid" road infrastructure.
	Feasibility
	• Infrastructure should be equipped with sensors that provide real-time rain information (precipitation in l/m^2).
	Non-functional
	• Real-time count of AVs should be delivered per lane per road segment every 60 seconds.

3. INFRAMIX High Level System Architecture

3.1 Purpose of the INFRAMIX system architecture

The INFRAMIX system architecture specifies the interaction between physical infrastructure elements and digital infrastructure elements, in order to support the transition period and the coexistence of conventional and automated vehicles.
This linking of components enables the interaction of different stakeholders, resulting in a hybrid end-user communication approach by using one reliable central source for traffic-estimation and traffic control strategies.

The INFRAMIX architecture-solution includes the following three major stakeholders:

- Road Operator (in collaboration with an Infrastructure Provider)
- Cellular Traffic Service Provider
- Original Equipment Manufacturer (OEM)

Combined, these stakeholders form the complete INFRAMIX end-to-end solution, which performs the collection of traffic-information, its evaluation & processing and, as a final step, disseminating the resulting traffic-control commands to conventional, connected and automated vehicles.
The collection of relevant information includes the combination of input data by road infrastructure-sensors as well as digital information by connected & automated vehicles. These input-data are combined and evaluated at one central source in INFRAMIX, which further performs the processing of traffic estimation and traffic control strategies. As result, reliable traffic regulations and recommendations are developed in dependency of the current traffic situation, which gets disseminated to physical road infrastructure elements but also to interfaces of digital infrastructure elements. In result both, conventional as well as connected (automated) vehicles (CAV) are so thereby able to get informed about control-commands. INFRAMIX further supports a hybrid end-user/vehicle communication approach, using different communication technologies.

This INFRAMIX end-to-end solution is described in three process-stages, which forms the basis of the INFRAMIX system architecture.
Figure 3 illustrates each process-stage, including its dependencies as well as its responsible contributors.

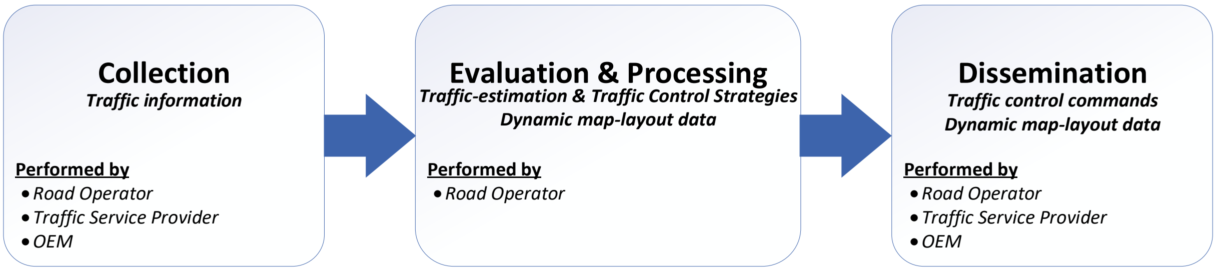

Figure 3 - INFRAMIX process stages of the end-to-end solution

3.2 High-level System Architecture

For a full usage of the INFRAMIX end-to-end solution, existing infrastructure components are enhanced, combined and integrated with new elements. In result, a hybrid communication-concept to end-users was developed, using the road operator as originating source of control-commands. This concept supports conventional vehicles as well as connected vehicles via both digital communication-channels, the ITS-G5 and the Cellular connectivity.

The system architecture includes a coexistence of different infrastructure elements, containing digital as well as physical systems, which are linked together to realize the INFRAMIX end-to-end approach.
The major infrastructure components of the INFRAMIX architecture-solution are defined in Table 2:

Table 2 - INFRAMIX major infrastructure components

Infrastructure element	*In INFRAMIX realized by*
Traffic Management Center (TMC)	Road Operator
INFRAMIX Management Center (IMC)	Infrastructure provider, in collaboration with a Road Operator
ITS-G5 Road Side Units (RSU)	Infrastructure provider, in collaboration with a Road Operator
Cellular Experimental Server & Traffic Services	Traffic Service Provider
OEM Vehicle Services	Original Equipment Manufacturer

The system architecture further includes components which realize the reception of resulting traffic regulations and recommendations. This includes the Variable Message Signs (VMS), which performs a visual signage to conventional vehicles, as well as end-user devices to receive digital information either by the ITS-G5 or the Cellular communication link.

<u>The system architecture includes the following components to perform the information reception:</u>

- Cellular end-user device
- Cellular vehicle communication device
- ITS-G5 On-Board Unit (OBU)
- Variable Message Signs

3.2.1 Concept of the INFRAMIX system architecture

The system architecture concept of INFRAMIX is based on the road operator's "Traffic Management Center" (TMC), which runs the local or national traffic management. For the realization of INFRAMIX architecture, an enhancement of the TMC got designed and developed, named "INFRAMIX Management Center". This infrastructure component forms the core element of the digital system architecture, including functionalities for the evaluation and processing of input information and the dissemination of resulting traffic commands to other systems of the system architecture.

This includes interfaces for receiving traffic data as input and interfaces for the dissemination of resulting traffic control commands. The INFRAMIX system architecture links physical and digital infrastructure elements, which enables the opportunity to communicate resulting control commands to conventional vehicles but also to digitally connected & automated vehicles.

<u>Input data to the IMC is provided by:</u>

- Digital communication infrastructure
  - Cellular Service Provider
  - OEM
  - ITS-G5 Road Side Units

- Physical infrastructure
  - Sensors

<u>Output data by the IMC is provided to:</u>

- Digital communication infrastructure
  - Cellular Service Provider
  - OEM
  - ITS-G5 Road Side Units

- Physical infrastructure
  - Variable Message Signs (along the highway)

INFRAMIX supports two digital communication channels – the ITS-G5 communication as well as the Cellular connectivity. Both digital channels are represented in the system elements of the digital communication infrastructure, which are responsible for the dissemination of digital messages. These messages include information about resulting traffic regulations and recommendations, which gets transmitted to connected & automated vehicles.
The Cellular communication channel is implemented by the Cellular Service Provider and the OEM Vehicle Services. Therefore, a link between the IMC and the Cellular Service Provider is specified and established, in order to transmit control commands and input information between these entities. The Service Provider processes received control commands and forwards them subsequently to its Cellular end-user services (Cellular smartphone application) as well as to a linked OEM Vehicle Service. In contrast, the input data from the Service Provider to the IMC gets provided to inform about the current state of the traffic.
The C-ITS ITS-G5 communication channel forms the second type of the digital communication. This communication type is realized by ITS-G5 Road Side Units, which are, on behalf of the Road Operator, equipped along the highway and linked to the IMC. RSUs receive control commands in a direct way from the IMC and broadcast them to ITS-G5 equipped vehicles. Therefore ITS-G5 messages-types are used to inform connected & automated vehicles about the resulting control commands by the IMC. The ITS-G5 communication further provides traffic information input to the IMC, by gathering received ITS-G5 messages from passing vehicles.

The system architecture of INFRAMIX also supports the distribution of information to conventional vehicles. Therefore, physical infrastructure elements, such as the Variable Message Signs of the road operator, are integrated into the INFRAMIX system architecture. This VMS receives control commands in an equal-way like the digital communication system elements, in order to display required visual signs about resulting regulations & recommendations along the road.

The resulting architecture of the INFRAMIX project is illustrated in Chapter 3.2.2 as Figure 4 - INFRAMIX system architecture. This exemplifies the INFRAMIX concept description, including all specified INFRAMIX system elements.

3.2.2 INFRAMIX system architecture

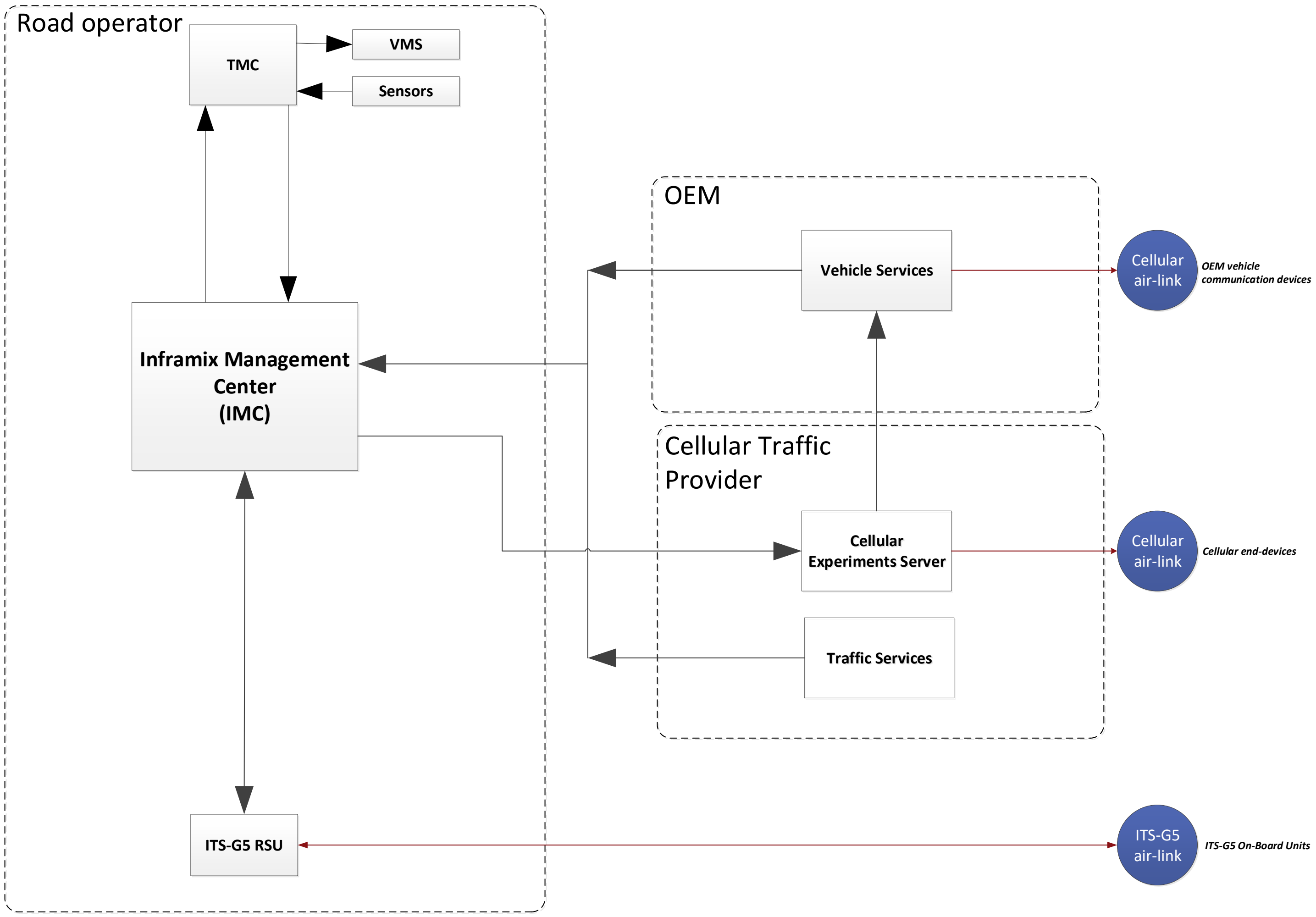

Figure 4 - INFRAMIX system architecture

4. Physical infrastructure elements

In order to compare the technological level of the state of the art on the road infrastructure with the technological level of the INFRAMIX test sites, which are located in Austria and in Spain, the available infrastructure equipment and services are explained in the following sections. At this point, the detail list of equipment and services for the Austrian and Spanish test site is shared only among the consortium.

4.1 State of the art

INFRAMIX is combining research and innovation activities across different areas of transport such as automated driving, traffic flow modelling, connectivity and road engineering; therefore, the proposed work is ambitious. The current state of the art is explained below, while the enhancements required for the implementation of INFRAMIX strategies are explained in Section 4.2

4.1.1 Road Infrastructure

The way physical infrastructure is designed and visualized today is based on the capabilities of conventional vehicles and the cognitive abilities of human drivers. INFRAMIX will propose adaptations of the current road infrastructure, summarized:

- Modern Traffic Management Centers (TMC), including all the existing and new ITS equipment connected in real time;
- Variable Message Signs (VMS), connected to information systems which automatically process gathered data and generate traffic messages or trigger traffic management measures such as speed limits, road works warnings and another event information

The required basic equipment for gathering the TMC relevant traffic data on the basis of which the modern TMC can identify incidents, apply control strategies or communicate between infrastructure and vehicles can be summarized:

- Video cameras, which enable operators to obtain a HD view on the real traffic situation
- Sensor technologies installed on gantries to acquire anonymized single vehicle data
- Emergency Response Unit (ERU)
- Bluetooth antennas measuring travel times
- Geolocalized fleet vehicles for providing floating car data (FCD)

And for V2X communication purpose:

- Fibre optic ring network
- ITS-G5 Road Side Units for vehicle to infrastructure communication (V2X)
- Cellular Road Side Units/ mobile network antennas for vehicle to infrastructure (V2X) communication

4.1.2 Sensors

In order to satisfy all the requirements of the INFRAMIX project, a high density of new traffic detection sensor-equipment on the test track has been installed, which allows to provide traffic data – including:

- traffic volume per lane
- speed per lane,
- detection of vehicle types
- detection of time gaps
- detection of vehicle's trajectories (speed, speed direction)

The special feature of the sensor infrastructure 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 on-board sensor system. Based on a combination of connected data from vehicles (I2V) and the infrastructure sensor data with different stages of sensor expansion, the infrastructure is able to obtain a bird's view with the dynamic information to generate an overall picture of the traffic flow as a basis for speed and lane recommendations as well as collective perception information.

4.1.3 Traffic Management Centre

ASFINAG has for years lead the way in integrating several sensor-based technologies into their infrastructure on Austrian motorways and offering traffic-relevant information to vehicles via multiple channels, be it on VMS on gantries, via traffic information on the radio (with the information provided by ASFINAG), on the ASFINAG mobile phone app "Unterwegs", or via CB radio. This has led to a remarkable decrease in incidents over the years.

An example for a modern traffic management centre can be provided by taking a look at ASFINAG's recently launched VMIS 2.0 programme. Several levels of traffic management are incorporated:

- Signalling and traffic management on the road;
- Traffic information channels towards the customer / driver; and
- Infrastructure-to-Vehicle communication.

In the near past, all sensory and traffic managing units on the ASFINAG motorway network have been connected in a platform. This is the core of a thorough digitalisation of the traffic management.

The operators in the 9 regional traffic management centres in Austria use the controlling cockpit as a new tool for supervising and steering traffic in all regions, including emergency calls and video. For example, all tunnels on ASFINAG's networks are covered by video surveillance. In case of an emergency call from one of these areas, the respective video screen is automatically shown on the operator's cockpit to ensure ideal reaction time. In case of road blocks or congestions, alternative routes including secondary roads (that are not part of ASFINAG's network) are determined and communicated together with the local authorities, on VMS and via traffic information on the radio. In the case of an incident, high quality measures that coordinate and inform all emergency task forces are key to increasing the availability of the motorway network.

Current market trends in Traffic Management, focus heavily on providing mobility capabilities, either through the creation of mobile applications for operators on the road to be able to register incidents, schedule works and maintenances or through access to the back-office of the traffic management applications either on a tablet or a mobile phone. In particular, management access for reporting and following KPIs are being implemented more and more.

Related with the Smart Data topic, it is further important nowadays to be able to integrate information from external information sources such as V2X vehicle information, infrastructure sensor data, weather prediction, floating data as well as native integration with information provided directly by users. The enormous data management necessary for an efficient

control of operations, resources and activities requires mechanisms that allow companies to benefit from all this massive amount of data and obtain relevant information for the operators and users. This includes, for example, Smart processing in real time to support decision making.
The applications that most of the supplier's offer can be acquired in cloud, on-premise or in Edge Computing modes.
Analysis and integration of information originated in different sources, in order to offer the operator an exact perspective on the state of the network. This includes the detection of existing problems and the appropriate measures solve or mitigate them and the possibility to visualize different future scenarios that would originate from the measures taken. In addition to the advanced traffic management capabilities machine learning offers, there are other safety functionalities made possible by this type of intelligence, such as fatigue detection systems, where a traveler's driving pattern is matched with existing data to identify fatigue signs. Sensorfusion based traffic scenario analysis is one of the possible options as starting point for a Deep Learning algorithm and predictive incident prevention methods.
Cooperative Intelligent Transport Systems (C-ITS) consist in exchanging information Vehicle–to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Infrastructure-to-Vehicle (V2I) and Infrastructure-to-Infrastructure (I2I) with interoperability, multimodal and cross-border integration. The standards for these technologies are currently being defined in the European Union, and the objective is to have multi communication platforms to optimize traffic, be it through V2X communication, Internet of Things (IoT) sensors on infrastructure or through information received from driver's mobile devices.
The connected driving systems are key to the safe introduction of autonomous vehicles on daily road traffic. Level three automated vehicles ("eyes off") are predicted to be integrated in a short term, which means the information exchange between vehicles, users and infrastructure is essential to ensure the safety of these new environments and the interoperability of autonomous vehicles. ITS systems will have to evolve in order to integrate the information made available from these cars as it would from a sensor.

4.1.4 Traffic monitoring systems

The automatizing traffic monitoring includes the use of cameras to monitor traffic volumes, usually with the capability to act on the information (for example, redirecting the traffic or adapting traffic light signs to improve traffic flow). In the market there are a few functionalities already in development leading to this type of future capability. It also includes the use of smartphone data over Bluetooth signal analysis or FCD, gathering information to automatically create and enforce actions through a system that has a set of rules implemented into it.

4.1.5 Variable Message Signs (VMS)

Nowadays the traffic control strategies can be applied on open roads and in tunnels by having variable message signs installed on gantries. Neuralgic hot spots are equipped with a dense network of VMS in order to provide changing speed limits, warnings and weather information to all users.

4.1.6 Infrastructure Traffic Signs

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. INFRAMIX will propose adaptations of the current road infrastructure. Since the reliability of the recognition of visual signs is not guaranteed, novel / smart signs, will be installed and can be tested on the test site. These smart signs could be tested in the frame of the dynamic lane assignment scenario (providing information about a lane dedication to automated vehicles) and in the roadworks scenario (providing safety related information about the current speed limits and the roadwork layout).

4.2 Infrastructure enhancements used and tested in INFRAMIX

As the construction of new roads is an expensive and time-consuming project while Europe has already a quite mature road network, and since roads have a quite long lifecycle especially compared with vehicles, the only way to prepare our existing road network for automation is through targeted interventions both physical and digital. This is even more important for the long transition period where we expect a step-by-step introduction of automation and mixed traffic on roads with different capabilities and installed equipment. In this respect, INFRAMIX is expected to have an important impact, as it will deliver specific solutions with tangible integrated interventions, both physical and digital.

For this reason, the test sites are equipped with the latest state-of-the-art sensor systems and complemented with physical infrastructure elements, as illustrated in Figure 5. Additionally different types of high reflective road markings are deployed on the Austrian test site since this is a highly relevant topic in the context of automated driving. As far as INFRAMIX is concerned, the consortium did, however, identify that- as far as INFRAMIX research questions are involved- it is not a major topic to be investigated within the project. Road marking was thoughtfully discussed in the framework of scenario 1 - dedicated lane. Expertise of the different partners (especially road operators) was taken into account for the discussion how to use road markings to declare a dedicated lane, since here also safety aspects (slippery markings when wet) and cost (of applying and maintain the painting) had to be considered.

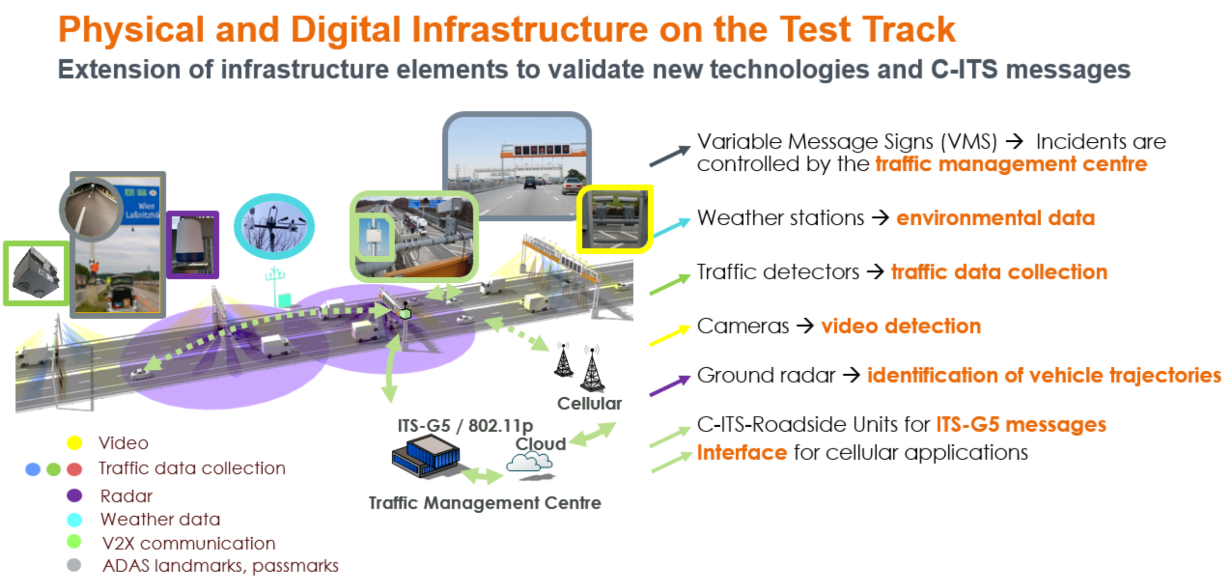

Figure 5 - INFRAMIX physical infrastructure on the Austrian test track, used for the INFRAMIX tests

HD Video cameras, traffic data collection sensors, ground based radar sensors and weather stations, illustrated in Figure 65, are used to automatically generate information about speed, position, type and movement of single vehicles and on single lanes.

The data is anonymized per design and no personalized data like number plates is combined and detected together with the traffic related data. A similar but not localized data can be provided via the vehicle’s connected message broadcast ability in ITS-G5 and for floating car data provided via a connected cloud service to the infrastructure provider. The enhancement in INFRAMIX covers a lane-specific data, the differentiation of 8 different vehicle types and the observation of the moving traffic. Additional new C-ITS messages can be generated in order to support automated vehicles in their on-board decision making and in behaving more efficient in the overall traffic flow.

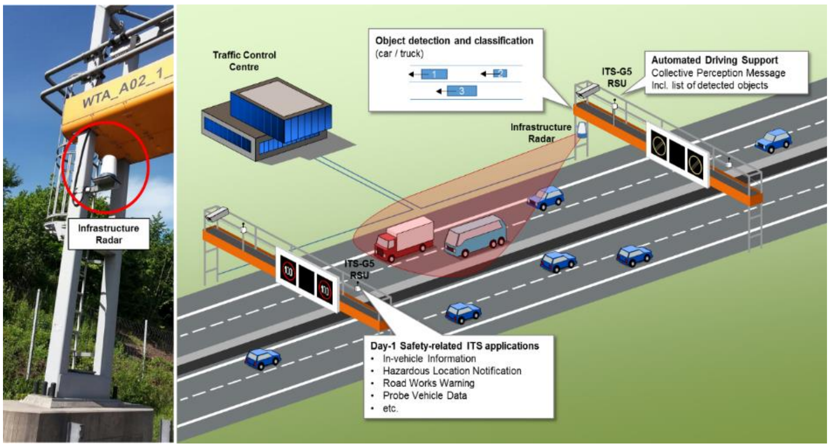

Figure 6 - Illustration of the physical infrastructure

5. Digital infrastructure elements

5.1 Digital system architecture

5.1.1 INFRAMIX Management Center (IMC)

The core-element of the INFRAMIX system architecture is represented by the INFRAMIX Management Center. This system element combines physical and digital infrastructure elements in order to realize the dissemination of the INFRAMIX control commands to conventional as well as to connected & automated vehicles. The IMC is designed as an enhancement of a Traffic Management Center (TMC) to perform traffic estimation & control strategies, in order to regulate the mixed traffic. It acts as a central source of information, which disseminates its resulting control commands via physical infrastructure elements to drivers of conventional vehicles, but also via digital infrastructure elements to inform connected (automated) vehicles as well.

The INFRAMIX Management Center includes capabilities for the reception of traffic input data and its processing & evaluation, realized by implemented INFRAMIX traffic estimation & control strategies. It further includes processes and communication-interfaces for the dissemination of the resulting control commands and advanced dynamic map-layout data. This includes communication-links to physical infrastructure elements, but also to digital communication-elements of the INFRAMIX system architecture.

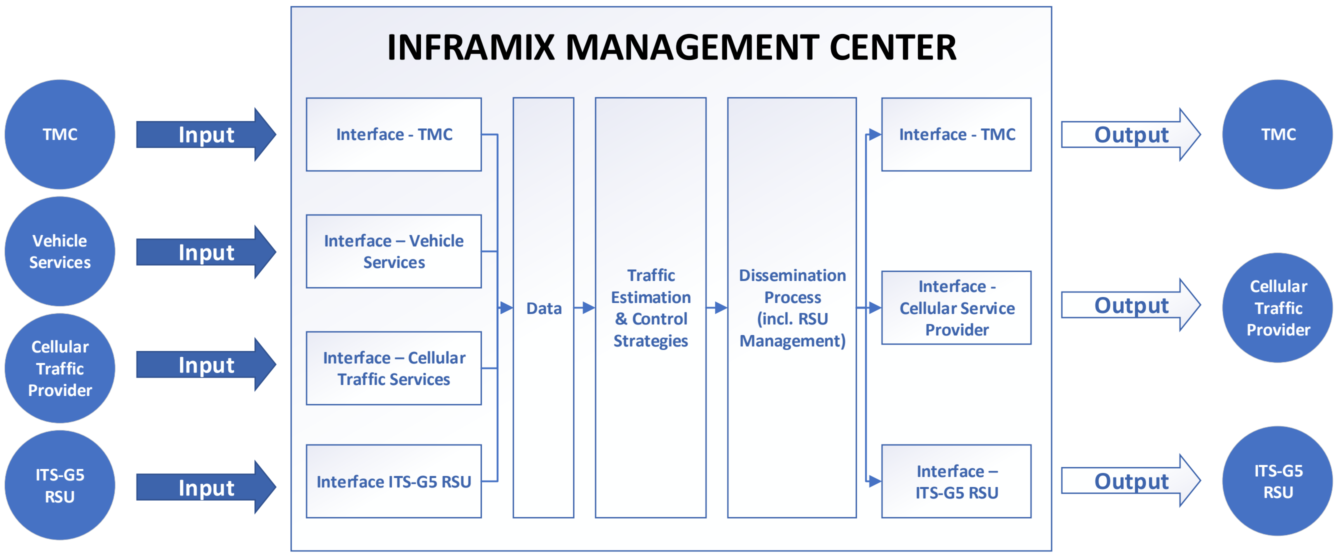

Figure 7 - INFRAMIX Management Center

The IMC is located as central-element in the INFRAMIX system architecture[3]. This includes communication-links to the Traffic Management Center as well as communication-links to the ITS-G5 infrastructure elements but also to the Cellular infrastructure elements of the INFRAMIX architecture.

Figure 7 illustrates the major functionalities of the new designed INFRAMIX Management Center.

On high-level basis, the major functionalities of the INFRAMIX Management Center are:

- the implementation of communication interfaces, to realize INFRAMIX architecture-internal communication.
- the implementation of INFRAMIX traffic estimation & control strategies, to formulate traffic regulations & recommendations.
- the implementation of a message dissemination process, to realize the provision of resulting control commands & dynamic map-layout. This includes additionally the implementation of ITS-G5 Road Side Unit management-functionalities, to configure, control & monitor connected ITS-G5 RSUs

Communication interfaces

The communication interfaces of the INFRAMIX Management Center differs in its communication-directions. This groups the communication links into “input”, having a data communication to the IMC, and into “output”, having a data communication from the IMC to other INFRAMIX system elements.

For the realization of the “input” direction, five interfaces are specified and implemented at the IMC. These interfaces enable the capability to receive dynamic map-layout information as well as traffic input-data, which gets processed and evaluated in a next step at the implemented INFRAMIX traffic estimation & control strategies.

These communication-interfaces realize an input data-communication from following INFRAMIX system elements:

- Traffic Management Center
- OEM Vehicle Services
- Cellular Traffic Services
- ITS-G5 Road Side Units

This requires the IMC to implement & host a JSON-based HTTPS WebService, which enables a traffic data-input from the TMC, the OEM Vehicle Services and the Cellular Traffic Services. The IMC shall be able to receive aggregated traffic information from the Traffic Management Center as well as from the Cellular Traffic Services. Further, the JSON-based Webservice shall realize the reception of single vehicle-data from the OEM Vehicle Services.

[3] In order to highlight the designed tasks and capabilities of the INFRAMIX Management Center, this TMC-enhancement is represented in the system architecture as a single system-element.

Additionally, the INFRAMIX Management Center shall be connected via a DATEX2 XML transfer encoded OCIT-C interface to the Traffic Management Center. The connection shall enable the reception of DATEX2 messages, including dynamic map-layout information of the road. The IMC must therefore establish a connection to the TMC, acting as OCIT-C client.

The fifth input communication-interface to the IMC is realized between the INFRAMIX Management Center and the ITS-G5 Road Side Units. The IMC shall therefore host a XML-encoded OCIT-C Server, which enables an IP based link to ITS-G5 Road Side Units, acting as OCIT-C Client. This link is executed bidirectionally between the IMC and the RSUs, which adds capabilities to receive aggregated CAM data from RSUs and to transmit output-data from the IMC to the RSUs. For security reasons, a VPN tunnel shall be used for the link, to ensure an encrypted communication.

Table 3 gives an overview of the “input” communication to the IMC. This table describes all communication-links to the IMC, including the connected INFRAMIX system-element and its defined communication protocol, its data-interchange format as well as a description of the transmitted data-content.

Table 3 - IMC "input" communication exchange

System-element	Communication-protocol	Data-interchange format	Data-content
Traffic Management Center	HTTPS WebService (The IMC hosts the WebService)	JSON	Aggregated traffic-data, based on a pre-defined detection zone, including: • Average speed • Minimum speed • Maximum speed • Traffic volume
Traffic Management Center[4]	OCIT-C (The IMC is connected as OCIT-C client to the TMC, acting as OCIT-C server)	DATEX2 XML transfer-encoded	Dynamic data objects, including information about traffic events, roadwork and electronic signage.
OEM Vehicles Services[5]	HTTPS WebService	JSON	Single Vehicle Data, including: • Position of the vehicle • Movement-information

[4] This interface is implemented only at the Austrian demonstration-site; but not required for the demonstration tests.
[5] This interface is only specified, but not implemented at the INFRAMIX demonstration sites.

	(The IMC hosts the WebService)		• Vehicle-parameter data
Cellular Service Provider[6]	HTTPS WebService (The IMC hosts the WebService)	JSON	Aggregated traffic-data, based on a pre-defined detection zone, including: • Average speed • Minimum speed • Maximum speed • Traffic volume
ITS-G5 Road Side Units	OCIT-C (The IMC hosts the OCIT-C server)	XML-Encoding	CAM-Aggregation, based on received CAM-Messages, including: • Average speed • Minimum speed • Maximum speed • Traffic volume

For the realization of the "output" direction, three interfaces are specified and implemented at the IMC. These interfaces enable the capability to disseminate the resulting control-commands, based on the processed traffic input-data, and to disseminate dynamic map-layout data, received from the TMC.

<u>These three communication-interfaces realize an output data-communication to following INFRAMIX system elements:</u>

- Traffic Management Center
- Cellular Experimental Server
- ITS-G5 Road Side Units

This requires the INFRAMIX Management Center to connect to established HTTPS WebServices, to fulfil a DATEX2 XML-transfer encoded interchange. Therefore, the Traffic Management Center as well as the Cellular Experimental Server are required to host such a WebService, in order to get connected to the IMC. The IMC transmits the resulting control commands as well as the dynamic map-layout as XML-encoded C-ITS data payload in DATEX2 format to these WebServices.

Additionally, the IMC uses the bidirectional communication-link to the ITS-G5 RSUs, in order to transmit the resulting control commands as well as the dynamic map-layout as XML-encoded C-ITS data payload to the Road Side Units. This OCIT-C communication further enables the communication of configuration and parameter data to the RSU, in order to manage and maintain the connected C-ITS devices. This also includes configuration parameters in order to activate a RSU-local CAM aggregation, having a pre-defined

[6] This interface is only specified, but not implemented at the INFRAMIX demonstration sites.

detection-zone. Table 4 gives an overview of the “output” communication from the IMC. This table describes all communication-links from the INFRAMIX Management Center to its connected INFRAMIX system elements, including defined communication protocol, its data-interchange format as well as a description of the transmitted data-content.

Table 4 - IMC "output" communication exchange

System-element	Communication-protocol	Data-interchange format	Data-content
Traffic Management Center	HTTPS WebService (IMC connects as client)	DATEX2 XML transfer-encoded	C-ITS data payload, including: • Traffic control commands • Validity range ○ Geo-location • Time information
Cellular Experimental Server	HTTPS WebService (IMC connects as client)	DATEX2 XML transfer-encoded	C-ITS data payload, including: • Traffic control commands *or* dynamic map-layout information • Validity range ○ Geo-location • Time information
ITS-G5 Road Side Units	OCIT-C (IMC hosts the OCIT-C server)	XML-Encoding	C-ITS data payload, including: • Traffic control commands *or* dynamic map-layout information • Validity range ○ Geo-location Configuration and parameter data, including: • CAM aggregation-configuration data • RSU management-data

Traffic state estimation & control strategies

The implementation of traffic state estimation and traffic control strategies is one of the major key aspects of the INFRAMIX Management Center. An increased rate of connected (automated) vehicles on the road require new control mechanisms, but also creates opportunities to improve the real-time traffic state estimation.

Connected vehicles includes functionalities to realize a “Vehicle to Infrastructure” communication, which enables a new functionality to provide traffic input-information to the infrastructure. The vehicles V2I communication includes a local real-time transmission of data, including the current position of the sending vehicle as well as its speed, heading and further parameters. INFRAMIX addresses this opportunity by researching new functionalities to collect, processes and fusion such data in order to create new chances to estimate the mixed traffic and to improve current available traffic estimation tools. The INFRAMIX Management Center shall therefore be equipped with such new estimation tools, in order to achieve new traffic estimation findings.

The expected occurring mixed traffic however also requires new traffic management capabilities, in order to optimize an overall traffic-efficiency of the entire road infrastructure. For the implementation of these, the INFRAMIX Management Center includes new traffic control strategies, which encompasses functionalities to set traffic controls to conventional as well as to connected (automated) vehicles. The implementation of these new traffic functionalities at the INFRAMIX Management Center shall therefore enable new opportunities to regulate or to recommend traffic controls to the mixed traffic. This includes control mechanisms to recommend or to regulate time gaps, accelerations, traffic speed or lane changing behavior to the occurring traffic or in an individualized way to connected vehicles.

The implementation of the INFRAMIX traffic state estimation and traffic control strategies provides traffic management capabilities to the IMC, which addresses functionalities to execute new estimation tools on cross-lanes and per-lane, but also new traffic control strategies in order to execute a dynamic lane assignment, time-gap advices, variable speed limits as well as lane-change advices.

In overview, Table 5 illustrates the traffic state estimation & control strategies of the INFRAMIX Management Center, including its specific results.

Table 5 - INFRAMIX traffic state estimation & control strategies

Traffic state estimation & control strategies	Results
Cross-lane estimation[7]	Flow and Density per segment
Per-lane estimation[7]	Flow and Density per lane

[7] This traffic state estimation is only specified, but not implemented at the INFRAMIX demonstration sites due to not available & less available input-data.

"Dynamic Lane Assignment" control[8]	Activation of a dedicated lane for connected (automated) vehicles. The resulting control commands includes additional Lane-change advices in order to fulfil the DLA. The activation of a DLA shall increase the roads capacity and safety.
"Time-Gap and Acceleration" control & recommendation	Time gap recommendations and regulations to connected (automated) vehicles per segment. This control command shall maximize the roads capacity and throughput in critical traffic conditions and near bottlenecks.
"Variable Speed Limit" control & recommendation	Variable Speed limits per segment. This recommendations or controls shall maximize the traffic efficiency in mixed traffic.
"Lane-Change Advice" control & recommendation[8]	Lane-Change advices to connected (automated) vehicles. This recommendations or controls shall maximize the overall traffic flow.

For the integration of the traffic state estimation & control algorithms, an IMC-inner information flow must be realized. This requires inner application programming interfaces (API) in order to provide input data for performing these algorithms. Additional APIs for return-values of the algorithms are required, in order to trigger the dissemination of the control-commands. The INFRAMIX traffic estimation & control strategies requires as input a variety of traffic measurement-data in allocation to its assigned road segments. Each INFRAMIX traffic estimation & control strategy shall perform automatically, depending on a constant pre-defined measurement time-step, which includes an accurate traffic input-data to its event-time.

The specified INFRAMIX system architecture covers all required input measurements for executing the estimation & control strategies, while the implementation & realization at the INFRAMIX demonstrations depends on the available input data at each test-site. The specified architecture includes traffic input data of mixed traffic, provided by the Road Operator, the ITS-G5 infrastructure, the Cellular Service Provider as well as by the OEM Vehicle Services. This encompasses sensor measurement data of conventional vehicles as

[8] This traffic control strategy is only specified, but not implemented at the INFRAMIX demonstration sites due to not available & less-available input-data.

well as data from the digital infrastructure, including ITS-G5 and Cellular “V2I” real-time vehicle parameters.

In order to perform the variety of the specified INFRAMIX traffic estimation state & control strategies, following measurements are required

- Traffic flow per road segment
- Traffic flow per lane
- Speed per road segment
- Speed of connected vehicles per segment
- Speed of connected vehicles per lane
- Lane changes of connected vehicles per lane
- Density per segment
- Density of connected vehicles per segment
- Density per lane
- Density at the bottleneck

Dissemination process

The dissemination process of the IMC consists of two sequential tasks, which performs the processing of the digital messages to be sent and its distribution via the defined communication-channels of INFRAMIX. This process is structured in two major steps, which proceeds in a defined sequence. This includes the processing of the information to a C-ITS data payload and, in further consequence, its distribution to the relevant INFRAMIX system elements.

Following two steps are part of the IMCs message dissemination process:

1. Processing of the C-ITS data payload
2. Distribution of the processed data

The creation of the C-ITS data payload forms the first step of the IMCs dissemination process. This task is based on two different start-parameters, which triggers the composition of the relevant C-ITS data payload. These start-parameters differ on the input of the INFRAMIX traffic control strategies and on the input of dynamic map-layout information, received via the TMC, which both forms the content of the C-ITS data payload.

Based on the return-values of the executed control strategies or on the received dynamic map-layout information, the INFRAMIX Management Center must create a C-ITS data payload. These data payloads are based on C-ITS message-types, in dependency of its content. INFRAMIX applies therefore five different C-ITS message-types, as described in chapter 5.2.1.

According to these triggers, the INFRAMIX Management Center starts the processing of the C-ITS data payload, including all relevant information of the corresponding event. Therefore, the executed trigger must provide information, which contains details about the control commands or the dynamic map-layouts to be sent. This information must contain in a detailed level its referenced events-location, its valid time period and its associated parameters & values of the control command or dynamic map-layout. In overview, following information is required in order to create a C-ITS data payload of a corresponding event:

- Type of the C-ITS data payload
    - Regulative control-command
    - Recommendation[9] control-command
    - dynamic map-layout
- Associated values
    - e.g. speed-limit; time-gap
- Associated parameters to the control-command
    - e.g. applicable lanes, road-direction
- Referenced geo-location(s)
    - Detection zone of the event
    - Relevance zone of the event
- Valid time period
- Pictogram-code (if applicable)

The second step of the message dissemination process is executed by the distribution of the created C-ITS data payload. This is realized via the communication interfaces of the INFRAMIX Management Center, as described in the IMC sub-chapter: “Communication interfaces”.

The IMC must therefore act as a distribution-hub, which triggers the content (C-ITS data payload) to all relevant INFRAMIX system elements. This includes the distribution to the digital communication channels (ITS-G5 and Cellular) as well as the distribution to the TMC, in order to operate the Variable Message Sings of the physical infrastructure. For the dissemination of the resulting C-ITS data payload, the IMC must run its “output”-communication-exchange functionalities, which calls the corresponding communication-interfaces. These communication-exchange functionalities differ between the ITS-G5 communication channel and the others. The message-dissemination to the Cellular network-communication channel as well as the Traffic Management Center is realized by a forwarding from the IMC to static communication-interfaces.

On the contrary, the INFRAMIX Management Center administrates and operates all connected ITS-G5 Road Side Units. Therefore, the IMC must manage the forwarding of the C-ITS data payload to the ITS-G5 RSU dynamically, in dependency of its geo-location content.

Based on the referenced geo-location of the C-ITS data payload, the IMC must include management-functionalities of the Road Side Units in order to provide the data payload to appropriate located RSUs. The data-payloads shall not be distributed to all connected ITS-G5 Road Side Units, only to RSUs that are in the vicinity of the event. This is realized by managed distribution areas, to which ITS-G5 RSUs are assigned to. Based on the referenced geo-location of the C-ITS data payload and these defined distribution areas, an automatically provision to appropriate located RSUs, which are located inside of the distribution area, can be achieved.

[9] In INFRAMIX, recommendations are considered as regulative traffic rules.

The distribution process of the IMC message dissemination is illustrated in Figure 8. This includes the provision of the processed data payload to static communication-interfaces (Cellular Experiments Server and Traffic Management Center) as well as to dynamic distribution areas, based on an ITS-G5 RSU management.

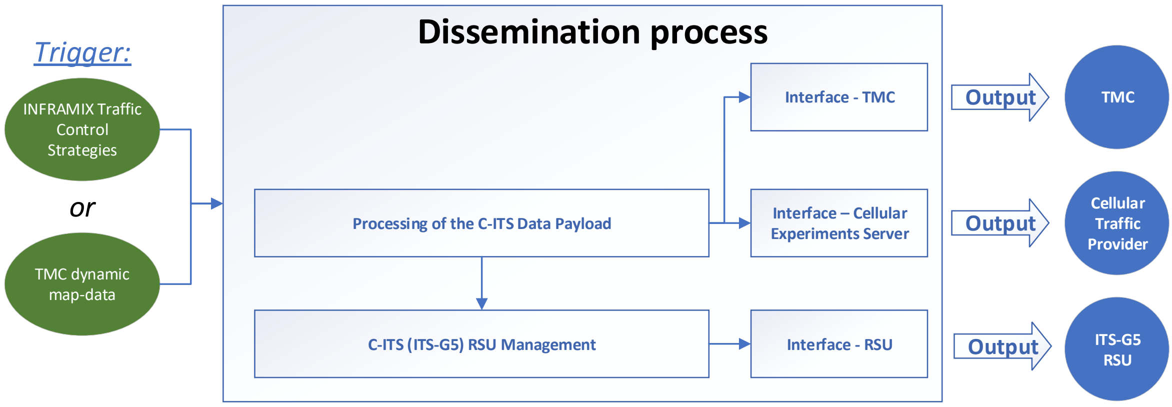

Figure 8 - IMC data-payload dissemination process

5.1.2 Cellular Experiments Server (CES) & Cellular Traffic Services (CTS)

The Cellular Experiments Server as well as the Cellular Traffic Services represents the Cellular Service Provider in the INFRAMIX system architecture. These digital infrastructure components enables the message-dissemination on behalf of the Cellular communication technology, but also the provision of input-data to the INFRAMIX Management Center. The CES acts as main Cellular component in the INFRAMIX architecture, operating as distribution-hub of received traffic control commands & dynamic map-layout data to connected OEM vehicle services as also to connected Cellular end-devices.

For the integration to the INFRAMIX system architecture, the Cellular Experiments Server includes communication interfaces to the INFRAMIX Management Center as well as to the OEM Vehicle Service. Additionally, a communication-interface to Cellular end-devices is implemented, which creates one of the INFRAMIX Cellular end-to-end communication.

Figure 9 illustrates the functionalities of both services of the Cellular Service Provider. This includes implemented capabilities of the Cellular Experiments Server as well as of the Cellular Traffic Services. These functionalities are considered as an essential part of the INFRAMIX system architecture in order to realize the INFRAMIX Cellular end-to-end communication.

<u>Following major functionalities are part of the Cellular Service Provider:</u>

- Communication interfaces
- Data-processing functionalities
- Communication-management functionalities

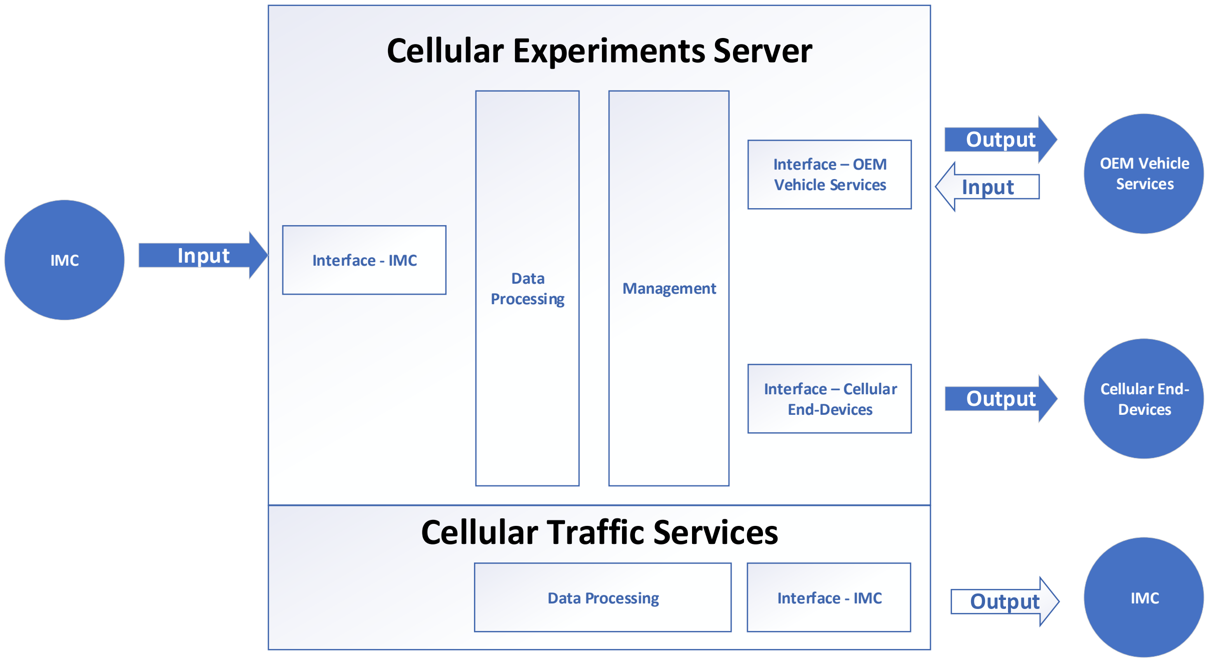

Figure 9 - Cellular Service Provider services

Cellular Experiments Server

The Cellular Experiments Service includes three communication-interfaces. This includes one communication link from the IMC to the CES, for the transmission of traffic control commands and dynamic map-layout information, and one link from the CES to the Cellular end-devices, which implements the capability to forward these received traffic-data to end-devices in real-time. Additionally, the CES includes a communication-interface to OEM Vehicle Services to forward the IMCs' control commands and optional map-layout information to connected OEM Vehicle Services as well. This link is specified as bidirectional, in order to realize the reception of single vehicle data of the OEM Vehicle Service.

<u>In overview, the Cellular Experiments Server includes following communication links:</u>

- INFRAMIX Management Center → Cellular Experiments Server
- Cellular Experiments Server → Cellular End-devices
- Cellular Experiments Server ↔ OEM Vehicle Services

The communication-link from the INFRAMIX Management Center to the Cellular Experiments Server forms the basis of the INFRAMIX Cellular end-to-end communication. This communication-link integrates the capability to receive resulting control commands and dynamic layout-information from the IMC. Therefore, the IMC disseminates its resulting control commands and layout information as C-ITS data payload to the CES, using a HTTPS WebService hosted at the CES. The IMC shall thereby connect to the WebService as client, sending its control commands & dynamic map-layout data encoded in DATEX2 data-interchange format. The CES acts as the recipient, which shall receive and process these data in a next step. This data-processing includes the decoding of the received data-payload and the extraction of the relevant data-fields, following by a converting to its required Cellular data-interchange format.

Subsequently, the CES shall forward the processed data to the connected OEM Vehicle Services, using a XML-based HTTPS Webservice. Additionally, the CES shall forward the processed control commands & layout information in a direct-way via a XML-based Webservice to all connected Cellular end-devices, which are in the vicinity of relevant destination-area. Therefore, the CES has implemented a functionality, which enables the management of its message dissemination to connected Cellular end-devices. Additionally, the OEM Vehicle Service can make use of the bidirectional link to provide single vehicle data to the CES. This link can be used as further data processing as well as an alternative, if the OEM Vehicle Service is not linked in a direct way to the IMC.

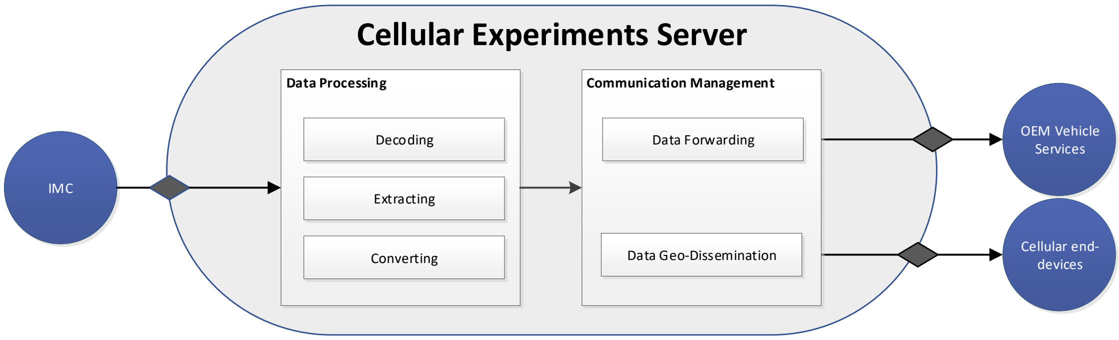

Figure 10 - Illustration of the CES process-chain

Figure 10 illustrates the message dissemination process via the Cellular Experiments Server, beginning at the IMC and ending at the OEM Vehicle Services as well as the connected Cellular end-devices. This illustration highlights the CES's responsibility of being the Cellular dissemination hub, including its communication-process and its communication-chain.

Table 6 illustrates all communication-links of the Cellular Experiments Server, including its applied communication-protocol, its data-interchange format as well as a description of its data-content.

Table 6 - Overview of the CES communication links

System-element	Communication-direction	Communication-protocol	Data-interchange format	Data-content
INFRAMIX Management Center	Unidirectional to the Cellular Experiments Server	HTTPS WebService (Cellular Experiments Server hosts the WebService)	DATEX2 XML transfer-encoded	Control commands & dynamic map-layout information, encoded as C-ITS data payload. This C-ITS data payload is included in DATEX2 data-interchange format.

OEM Vehicle Services	Unidirectional to OEM Vehicle Services	HTTPS WebService (Cellular Experiments Server hosts the WebService)	XML	Control commands & optional: dynamic map-layout information, converted to XML-format.
Cellular End-Devices	Bidirectional	HTTPS WebService (Cellular Experiments Server hosts the WebService)	XML	CES to Cellular end-devices: • Control commands & dynamic map-layout information, converted to XML-format. Cellular end-devices to CES: • Single Vehicle-Data

Cellular Traffic Services

On the contrary, the second backend-system of the Cellular Service Provider – the Cellular Traffic Services, includes one backwards-channel to the IMC, which enables the transmission of aggregated traffic-information, provided by variety of different Cellular end-devices[10].

<u>The Cellular Traffic Services includes following communication link:</u>

- Cellular Traffic Services ➡ INFRAMIX Management Center

The Cellular Traffic Services shall include functionalities for the processing of traffic-data, based on received traffic-information from a variety of connected Cellular end-devices. This data-processing shall include the capability to aggregate received traffic-information, which subsequently gets provided in JSON-format via HTTPS-protocol to the INFRAMIX Management Center. The IMC shall use this data as input to its traffic estimation and control strategies.

The CTS receives captured traffic-data as input via the communication-interface from Cellular end-devices. This data further gets aggregated at the Traffic Services backend, based on pre-defined detection-zones. The aggregated traffic-data includes information about the average speed for certain types of vehicles during a defined collection interval as well as the minimum and maximum speed of the vehicles during a defined interval.

[10] The provision of traffic information by these Cellular end-devices is not in scope of the INFRAMIX project.

Additionally, the traffic volume (number of vehicles within a pre-defined time-interval) is included.

Table 7 illustrates the CTS communication link, including its protocol, interchange-format and content.

Table 7 - CTS communication link

System-element	Communication-direction	Communication-protocol	Data-interchange format	Data-content
INFRAMIX Management Center[11]	Unidirectional to the IMC	HTTPS WebService (IMC hosts the WebService)	JSON	Aggregated traffic-data, based on a pre-defined detection zone, including: • Average speed • Minimum speed • Maximum speed • Traffic volume

5.1.3 OEM vehicle services

The OEM vehicle services represents the infrastructure-service of the Original Equipment Manufacturer (OEM) in INFRAMIX. This service is run by the OEM as a digital backend-service, which enables the communication to its vehicles via a Cellular communication-link. It further includes functionalities to manage the bidirectional communication and the communications content to its vehicles fleet. For the integration to the INFRAMIX system architecture, the OEM vehicle services includes communication interfaces to the INFRAMIX Management Center and to the Cellular Experiments Server. The OEM vehicle services realizes one Cellular end-to-end communication solutions in unicast mode in INFRAMIX. The unicast mode makes it possible to send individualized recommendations and information to each connected vehicle.

Therefore, as illustrated in Figure 11 - OEM Vehicle Services, three major functionalities are included in this system-element, which consist of:

- Communication interfaces
- Data processing functionalities
- Management of its vehicle fleet

[11] This interface is only specified, but not implemented at the INFRAMIX demonstration sites.

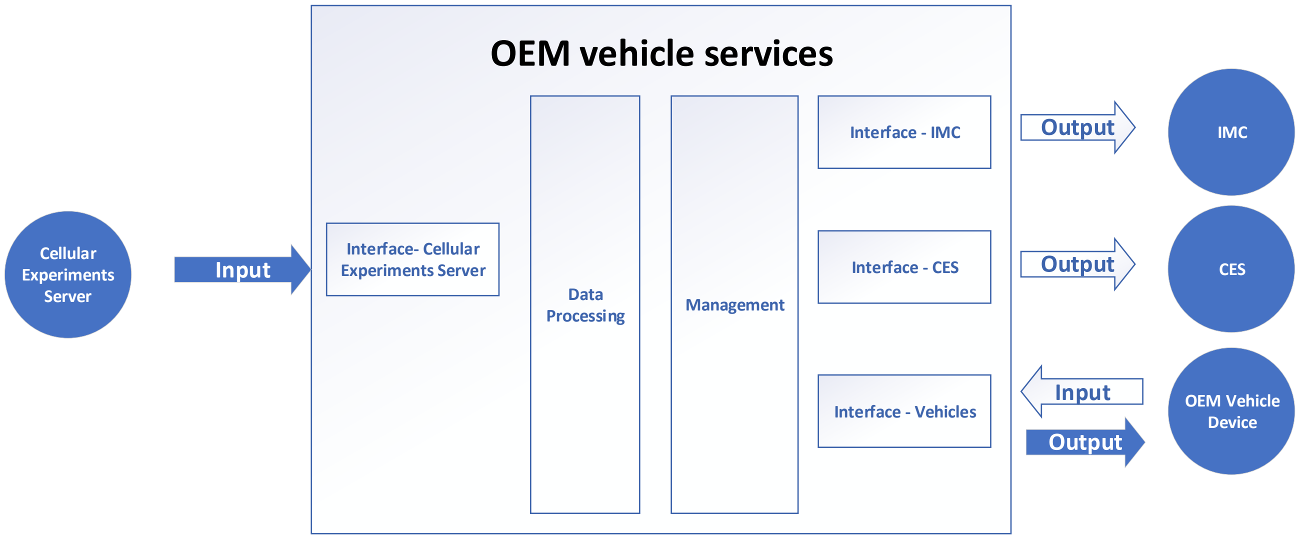

Figure 11 - OEM Vehicle Services

The OEM Vehicle Service consists of three communication-interfaces. This includes one bidirectional communication-link to the Cellular Experiments Server in order to transmit traffic control commands and, if implemented, dynamic map-layout data. One bidirectional communication-link to its vehicles fleet and additionally, and one communication-link to the INFRAMIX Management Center, for the provision of traffic-information as input data.

Both, the bidirectional link to the CES (backwards channels) as well as the direct backwards channel to the IMC, can be used to the transmission of traffic information as input data to the strategies.[12]

In overview, the OEM Vehicle Service includes following communication links:

- Cellular Experiments Server ⟷ OEM Vehicle Services
- OEM Vehicle Services ⟷ OEM Cellular Vehicle Communication-Device
- OEM Vehicle Services ⟶ INFRAMIX Management Center

The connection-link from the Cellular Experiments Server to the OEM Vehicle Service is realized as an XML over HTTPS communication. This link adds the capability to receive resulting control commands and dynamic map-layout data from the IMC via the Cellular Experiments Server. Based on the specified information flow of the INFRAMX system architecture, the IMC disseminates its resulting digital control commands to both communication-channels. The OEM Vehicle Services thereby is part of the Cellular end-to-end solution, which receives the relevant information via the Cellular Service-Provider. Therefore, the Cellular Experiments Server is specified to exchange all traffic-information (regulative commands, recommendations and dynamic map-layout data), originated at the IMC, to the OEM vehicle services.

The OEM Vehicle Service shall receive these data, in order to disseminate it to its connected vehicle-fleet. Therefore, the OEM Vehicle Service must process at first all received

[12] On behalf of the implementations at the demonstration sites, only the communication-link to the CES got implemented. The communication link to the IMC is no implemented, due to the less amount of available vehicles.

information, in order to forward it, as next step, to its connected vehicles fleet. It uses thereby a direct Cellular communication-link to its connected vehicles, which are in vicinity of the information's destination-area (narrowcast mode).

The OEM vehicle services (or the CES in advance) shall therefore include data-processing and communication-management functionalities, in order to meet the requirements of the geo-located message-dissemination. The communication-link between the OEM Vehicle Services and its vehicles is executed bidirectional, which additionally enables a backward-communication. This backward-channel to the backend-service implements a continuously traffic-information flow of each connected vehicle. Each connected vehicle shall be able to send, in real time, parameter-information to the backend, including its position-data, movement-information, vehicle-type and its vehicle control information. Alternatively, the traffic information is transmitted over the CES to the IMC.

Additionally, the OEM Vehicle Services shall include a communication-interface to the INFRAMIX Management Center. Therefore, the INFRAMIX Management Center hosts as a WebService, which creates a functionality to receive the OEMs single vehicle information in JSON-format over HTTPS. The IMC shall use this data as input to its traffic estimation and control strategies.

Table 8 below describes the communication-links in an overview of the OEM Vehicle Services. This table includes its applied communication-protocol, its data layer and the transmitted data-content.

Table 8 - Overview of the OEM Vehicle Services communication-links

System-element	Communication-direction	Communication-protocol	Data-interchange format	Data-content
Cellular Experiments Server	Bidirectional	HTTPS WebService (OEM Vehicle Service connects as client)	XML	<u>To the OEM services:</u> Control commands & dynamic map-layout information, converted to XML-format <u>To the CES:</u> Single Vehicle Data, including • Position of the vehicle • Movement-information

				• Vehicle-parameter data
IMC[13]	Unidirectional to IMC	HTTPS WebService (OEM Vehicle Service connects as client)	JSON	Single Vehicle Data (as described above)
Vehicle Communication device	Bidirectional	OEM specific	TPEG	<u>Vehicle Services to Vehicle:</u> • Control commands & dynamic map-layout information <u>Vehicles to Vehicle-Services:</u> • Single Vehicle Data

5.1.4 ITS-G5 Road Side Units

ITS-G5 Road Side Units represents the infrastructure-element of the ITS-G5 communication. RSUs are physical C-ITS communication-devices, which are equipped, on behalf of the Road Operator, at gantries on the highway but also on road-works safety trailers or any other mobile devices. These infrastructure-devices are linked bi-directional to the INFRAMIX Management Center to exchange data for the message dissemination over the ITS-G5 air link but also to forward received traffic-data from connected vehicles, equipped with C-ITS stations.

Figure 12 illustrates the major tasks of the RSU. This includes four functionalities for the implementation of the ITS-G5 Road Side Units in the defined INFRAMIX system architecture. Following major functionalities are required of the ITS-G5 Road Side Units:

- Management functionality
- Data processing functionality
- Communication interfaces
- Security – PKI management

[13] This interface is only specified, but not implemented at the INFRAMIX demonstration sites, based on less available vehicles.

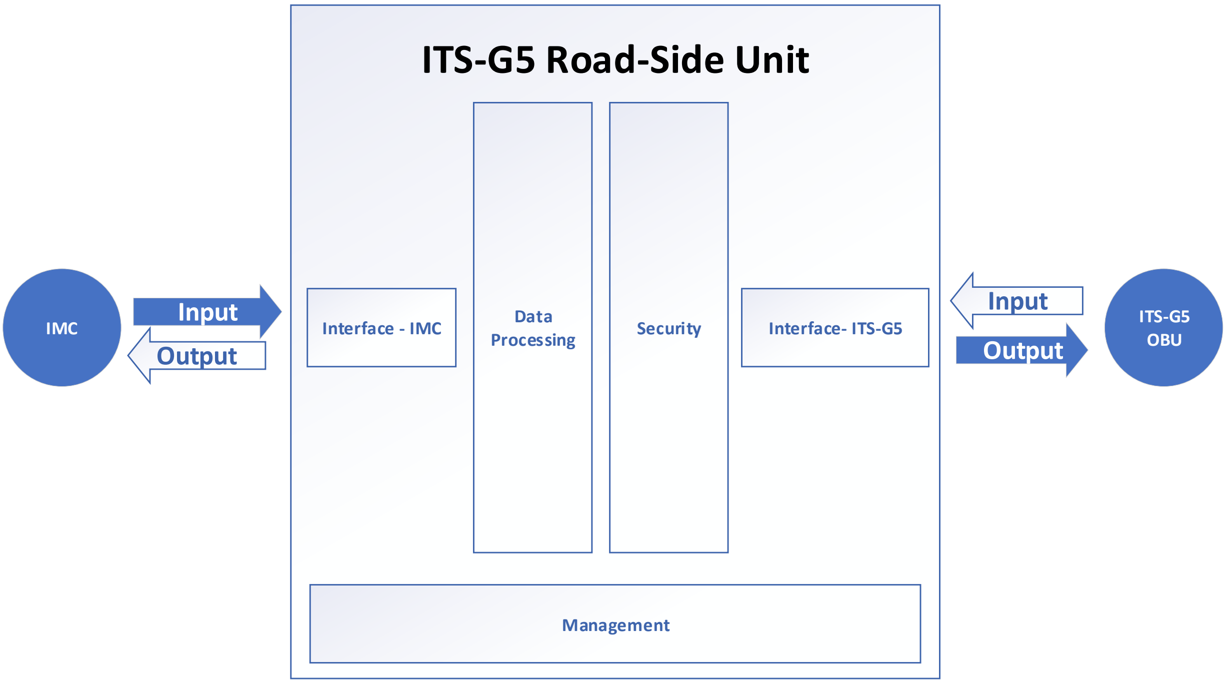

Figure 12 - ITS-G5 Road-Side Unit

The communication interface enables a bidirectional communication-link between the IMC and the RSU. This includes the transmission from C-ITS data payloads and management-settings from the IMC to the RSU, but also the forwarding of messages to the IMC, received by the RSU from passing C-ITS stations (ITS-G5 equipped vehicles).

<u>In overview, the ITS-G5 Road Side Unite enables following two communication links:</u>

- INFRAMIX Management Center ⟷ ITS-G5 Road Side Unit
- ITS-G5 Road Side Unit ⟷ ITS-G5 On-Board Unit

The communication direction from the IMC to the RSU includes the provision of the resulting control-commands, encapsulated in a C-ITS data payload, for the transmission over the air. The IMC further transmits GeoNetwork information to include additional meta-information, like the destination area and the repetition interval, for the ITS-G5 message.

The RSU includes functionalities to de- & encode these received data for the purpose of filling in additional data to the ITS-G5 message (e.g. not known by the IMC). The transmission over the air is executed over the ITS-G5 link by the RSU. The device therefor broadcasts the ITS-G5 message locally to passing vehicles, equipped with ITS-G5 On-Board Units, via the ITS-G5 link. The ITS-G5 message encoding includes the relevant traffic information or dynamic map-information as well as additional a security-layer. This additional layer consists of a digital signature of the C-ITS message, to ensure data integrity, authenticity as well as privacy, by using a C-ITS dedicated Public Key Infrastructure. Receiving C-ITS stations must execute a signature validation of received messages, in order to make sure the validity of the received information.

The bidirectional communication-link further enables a backwards-channel from the RSU to the INFRAMIX Management Center. The RSU receives in its operation-mode also a variety of C-ITS messages within its coverage area from passing vehicles, equipped with a ITS-G5 On-Board Unit.

A major traffic-information can be achieved by the collection of "Cooperative Awareness Messages", which are continuously sent out by C-ITS OBUs. This message-type creates an awareness-information[14] about the vehicle's appearance, including geo-location information, movement-parameter as well as basic attributes and basic sensor information of the OBU. By receiving this information within a predefined detection-zone, Road Side Units can get configured to aggregate these CAM messages during a specified collection interval (short term or long term)[15]. Resulting in aggregated traffic-information, including information about the traffic-volume; average speed as well as minimum and maximum speed during the defined interval. Based on the backwards-channel to the IMC, the RSU can provide this aggregated data as input, to support the IMCs traffic estimation & control strategies with accurate traffic-information.

Table 9 below shows all communication-links as an overview of the OEM Vehicle Services, including its applied communication-protocol, data layer and data-content.

Table 9 - Overview of the ITS-G5 communication-links

System-element	Communication-direction	Communication-protocol	Data-interchange format	Data-content
IMC	Bidirectional	OCIT-C (The ITS-G5 RSU is connected as OCIT-C client to the IMC, acting as OCIT-C server)	XML-encoded	From the IMC: • C-ITS data payload • RSU parameter-configuration data To the IMC: • CAM aggregation
ITS-G5 On-Board Unit	Bidirectional	ITS-G5 air-link	XML-encoded	From the ITS-G5 RSU: • C-ITS messages To the ITS-G5 RSU: • C-ITS messages

[14] https://www.etsi.org/deliver/etsi_ts/102600_102699/10263702/01.02.01_60/ts_10263702v010201p.pdf
[15] A forwarding of single CAMs could also be applied, but is not in scope in INFRAMIX

Both communication interfaces require additional tasks of the RSU for its further processing. This includes the functionalities of the RSU management, the data processing and the security functionalities.

Following overview, Table 10, represents the four major functionalities of the ITS-G5 RSU and its defined tasks for INFRAMIX:

Table 10 - ITS-G5 functionalities

Functionality	Included Tasks
Management	• Device Management • Message Management • Configuration / Parameter configuration ○ e.g. CAM Aggregation • Logging & Monitoring
Data processing	• CAM Aggregation • Filtering of received messages & elimination of duplicated messages, received from passing C-ITS connected vehicles

Interfaces	• Interface: IMC ←→ RSU
	  ○ Reception of C-ITS data payloads from the IMC
	  ○ Reception of Parameter data
	  ○ Forwarding of received single-messages to the IMC
	  ○ Forwarding of aggregated CAM-data to the IMC
	• Interface: ITS-G5 RSU ←→ ITS-G5 OBU
	  ○ Reception of ITS-G5 messages from passing C-ITS connected vehicles
	  ○ Sending of ITS-G5 messages per broadcast to passing C-ITS connected vehicles

Security	• Implemented PKI services, aligned to the European Certificate Policy:
	  ○ Generation of digital signatures for outgoing messages
	  ○ Validation of incoming digital message signatures
	  ○ Updating of cryptographical key-material
	• Enables following ITS-G5 protection goals:
	  ○ Integrity
	  ○ Authenticity
	  ○ Privacy

5.2 Connectivity to end-users

The digital connectivity to end-users in INFRAMIX is based on a hybrid communication-approach. This approach enables a digital end-to-end communication-solution by using two different communication technologies – the ITS-G5 communication as well as the Cellular communication technology. This digital end-to-end communication solution leads to the advantage of having one originating source of traffic control commands and road-related layout data, but different communication-channels to the end-users. The realization of this INFRAMIX system architecture solution enables two independent working communication technologies, communicating the same data-content to the end-devices.

For the reception of the disseminated information, both communication-technologies use different end-devices. Following end-devices assigned to its communication-technology, are part of the INFRAMIX digital system architecture:

- C-ITS ITS-G5 communication
  - ITS-G5 On-Board Units

- Cellular communication
  - OEM vehicle communication-device
  - Cellular end-device

5.2.1 C-ITS (ITS-G5) communication

Cooperative Intelligent Transports Systems (C-ITS) offer a communication between vehicles (“Vehicle-to-Vehicle”) as well as the communication between vehicles and the infrastructure (“Vehicle-to-Infrastructure”). This communication includes applications to increase road safety, to disseminate traffic control-commands, to provide driver assistance and hazard warnings as well as to support emergency services.[16]

The C-ITS communication technology is executed as a short-range direct ad-hoc wireless technology, using the IEEE 802.11p standard. Based on this standard, the European ITS-G5 standard has been developed by ETSI, using the frequency-band of 5.85 to 5.925 GHz. This ad-hoc wireless technology requires no base-station, having each C-ITS station (Road Side Unit at infrastructure; On-Board Unit at vehicles) as a unique network peer, which offers different types of safety services.[17] C-ITS stations execute a real-time broadcast communication, sending out standardized ITS-G5 messages in its locally area to other nearby C-ITS stations. For this dissemination of information, ITS-G5 uses the “GeoNetworking” protocol. This protocol utilizes geographical positions for the dissemination of information and transport of data packets. It offers communication over multiple wireless hops, where nodes in the network forward data packets on behalf of each other to extend the communication range.[18]

The ITS-G5 communication operates by using standardized message types for its broadcasting. To achieve the goals of INFRAMIX, standardized but also new, not yet

[16] https://www.etsi.org/technologies/automotive-intelligent-transport
[17] https://www.car-2-car.org/fileadmin/press/pdf/Press_Information_C2C-CC_Delegated_Act.pdf
[18] https://www.etsi.org/technologies/automotive-intelligent-transport

standardized, message-type extensions are part of the communication. This requires, for the development-process of INFRAMIX, adaption on available C-ITS stations in order to implement these new message-type extensions.

Following overview, Table 11, includes the types of the INFRAMIX C-ITS message-concept:

Table 11 – Types of C-ITS message

Message-Type	Description
Cooperative Awareness Message (CAM)	Continuously broadcasted by vehicle C-ITS stations (OBU), to create and maintain awareness of ITS-Ss and to support cooperative performance of vehicles using the road network.[18] A future extension of this type of message got investigated, including information about the vehicles SAE-level.
Decentralized Environmental Notification Message (DENM)	Broadcasted in INFRAMIX by C-ITS RSUs to inform road users of a detected road-event.
In-Vehicle Information Message (IVIM); [including a new extension to the standard]	Broadcasted in INFRAMIX by C-ITS RSUs to inform road users about traffic regulations and recommendations. This type of message includes a new, not yet standardized, message container, called “Automated Vehicle Container”. This container enables the capabilities to realize specific control commands to CAVs.
MAPEM Message	Broadcasted in INFRAMIX by C- ITS RSUs to inform road users dynamically about new, temporary map-layouts.
Collective Perception Message (CPM)	Broadcasted in INFRAMIX by C-ITS RSUs to inform road users about existence of other vehicles and a collective perception of objects on the road.

ITS-G5 On-Board Unit

An ITS-G5 On-Board Unit is a type of a C-ITS station, which is equipped in connected (automated) ITS-G5 vehicles. ITS-G5 OBUs act as end-user devices, having the functionality to receive & interpret ITS-G5 messages from other C-ITS stations (infrastructure as well as other vehicles), but also to send-out ITS-G5 messages by their own as well.

Vehicles, equipped with an ITS-G5 On-Board-Unit, continuously broadcast CAMs to create and maintain its awareness about their current position and movement. This includes information about their current speed, their heading as well as their position. These continuously broadcasted messages are the basis for the CAM-aggregation, fulfilled by ITS-G5 RSUs. ITS-G5 RSUs collects these received messages and can perform a CAM-aggregation at pre-defined detection-zones.

5.2.2 Cellular network-communication

The Cellular network-communication uses the existing LTE mobile network to transfer the information and recommendations to the individual vehicles. The advantage of this approach is the broadly available mobile network (at least Generation 3 (3G), mostly 4G and occasionally already 5G on some experimental test fields).

An interesting question to be answered here is which would be the minimal generation , related to the transferable data amount, which is needed. Though the INFRAMIX recommendations themselves do not represent large data amounts, the information concerning road layout on HD maps for autonomous driving might be requiring higher technologies like 5G to allow the necessary data transfer. However, it is not in the scope of the project to investigate this question.

Cellular OEM vehicle communication device

The Cellular OEM vehicle communication-device is an INFRAMIX end-user device-solution, integrated in OEM vehicles. This device enables a Cellular connectivity between the vehicle and the Vehicle Service of the OEM. The integrated device offers a functionality to receive, interpret and illustrate received traffic control commands via its backend service, but also to provide information about its movement parameters and geo-location to the backend. As future extension, it also might be connected to an implemented HD-map, to adapt the static map based on received, temporary dynamic map-layouts.

Cellular OEM vehicle communication device is connected in a direct way to its backend-service, which subsequently forwards all received single-vehicle information to the INFRAMIX Management Center. This information is considered as a relevant input data to the INFRAMIX Management Centers' traffic estimation and control strategies, to formulate traffic control-commands.

Cellular end-device

The Cellular end-device is considered as an additional Cellular end-user device-solution in INFRAMIX. For the realization of INFRAMIX, an Android-based application got developed, which is deployable at smartphones as well as tablets. This application establishes a communication-link to the Cellular Service-Providers backend-server, in order to create the capability of receiving digital traffic-control information. This implements the functionality to receive the IMCs control commands via the Cellular Experiments Server. The application interprets and displays this information to the end-user and creates so an additional INFRAMIX Cellular connected vehicle solution.

As future extension, an implementation of a static HD-map can be considered, which is able to get dynamically adapted based on received, temporary map-layouts. Additionally, the application includes also a backward-channel to the Cellular traffic services, to transmit movement-parameters as well as geo-location information for a further data-processing.

5.2.3 **Hybrid-connectivity outlook**

An interoperable, backwards-compatible and secure communication architecture is addressed in the recently published Delegated Act on C-ITS[19]. So far, only ITS-G5 can fulfill the requirements of the DA but in order to establish hybrid connectivity complemented by Cellular communication compliant with the existing regulation, the C-Roads Platform and Car-2-Car Communication Consortium work on a new architecture (illustrated in Figure 13).

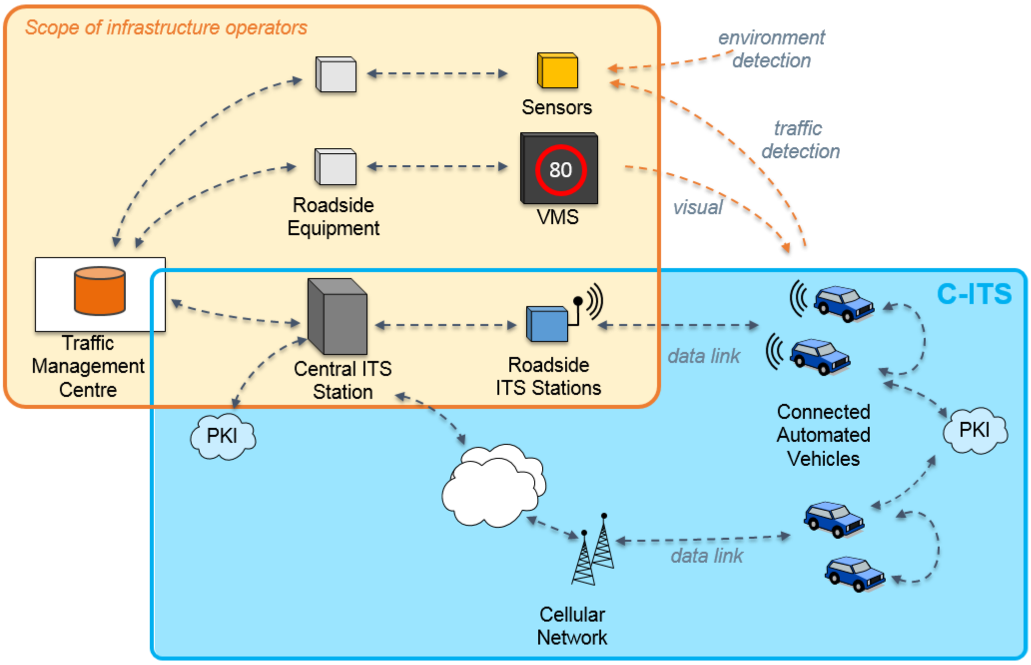

Figure 13 - Hybrid connectivity architecture

<u>This new hybrid connectivity architecture has to underlie the following policies:</u>

- The „European Certificate Policy“ and the related standards „European Certificate Policy“ as of June 2017[20]
- Standard for certificates (ETSI TS 103 097) as of October 2017
- Standard for Trust / Privacy Management (ETSI TS 102 941) as of May 2018
- Service profiles for the C-ITS priority services
- Requirements for C-ITS stations

The task of C-ROADS is to harmonize C-ITS for immediate deployments in all C-ROADS21 member states. Currently, the only available, mature and tested technology for C-ITS is ITS-G5. Although 5GAA states LTE-V2X to be an “available and mature technology” a recent study by the European Commission concluded that they "could not verify any commercial LTE-V2X equipment able to be purchased for operational use in the EU"22. Once it is available, mature and tested, it can be added in the next update of the Delegated Act. Until then, C-ROADS is concentrating on defining a receiver-agnostic, IP-based “hybrid” interface that can be used to send C-ITS services via Cellular / long range communication (3G/4G, in

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[19] https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-2592333/feedback/add_en?p_id=351850

[20] https://ec.europa.eu/transport/sites/transport/files/c-its_certificate_policy_release_1.pdf

[21] https://www.c-roads.eu/platform/activities/tf-hybrid-communication.html

[22] Assessment of the Commercial Availability of LTE-V2X Equipment According to the 5G Automotive Association (5GAA), European Commission, Joint Research Center, 2019

future also 5G), in addition to ITS-G5 / short range transmission. Messages on both communication channels need to be completely identical for the receiving vehicle. This interface needs to ensure that everything that defines C-ITS (services, architecture, standards, message formats AND security model) is part of that interface, otherwise it would not be C-ITS which is considered to be important for safety relevant usage in autonomous vehicles.

Since INFRAMIX is looking for short, middle and long-term strategies, the project implements a test-system for hybrid communication testing. The next step in the evolution of pre-deployment will be provided by the H2020 project ICT4CART23 while task force 4 in C-Roads is going to release a common definition of the hybrid communication interface by mid of 2019.

5.3 Digital messages & information flow

The digital communication within the INFRAMIX system architecture consists of a information flow, which includes an architecture-internal communication between the system elements as well as an information flow to end-devices.

5.3.1 INFRAMIX architecture-internal information flow

The information flow within the INFRAMIX system architecture enables the communication between the single system elements in order to achieve the INFRAMIX end-to-end solution. This includes input provision to the IMC, to run traffic estimation & control strategies, but also output information to end-nodes of the architecture, in order to achieve the dissemination of information to end-user & end-device.

Table 12 lists all INFRAMIX architecture-internal information flow. This table includes the sending-node, the recipient as well as a description of the exchanged data-content.

Table 12 - INFRAMIX architecture-internal information flow

Sender	Recipient	Data-Content
Traffic Management Center	Variable Message Signs	C-ITS Data Payload, including the resulting control commands of the IMC. The Variable Message Sings acts as an INFRAMIX infrastructure end-node, which displays the received information via dynamic visual signs to drivers of conventional vehicles.
Traffic Management Center (Sensors)	INFRAMIX Management Center	Aggregated Traffic-information, as input for running the INFRAMIX traffic estimation & control strategies.
INFRAMIX Management Center	Traffic Management Center	C-ITS Data Payload, including the resulting control-commands. The Traffic Management Center forwards this to its connected the Variable Message Signs.

[23] https://ict4cart.eu/

INFRAMIX Management Center	ITS-G5 Road Side Units	C-ITS Data Payload, including the resulting traffic control commands or dynamic map-layer data. The ITS-G5 RSU acts as an INFRAMIX infrastructure end-node of the ITS-G5 communication. This infrastructure elements broadcasts the data payload via the ITS-G5 air link to vehicles, equipped with ITS-G5 On-Board Units.
INFRAMIX Management Center	Cellular Experiments Server	C-ITS Data Payload, including the resulting control-command or dynamic map-layer data, for the transmission over the Celllar communication link. The Cellular Experiments Server acts as Cellular dissemination hub. This includes the communication link to the OEM Vehicle Services but also being an INFRAMIX infrastructure end-node of the Cellular digital communication. This infrastructure element forwards thereby the information to its connected Cellular end-devices.
ITS-G5 Road Side Units	INFRAMIX Management Center	Aggregated CAM-message data, as input for running the INFRAMIX traffic estimation & control strategies.
Cellular Traffic Services	INFRAMIX Management Center	Aggregated Traffic-information, as input for running the INFRAMIX traffic estimation & control strategies.
OEM Vehicle Services	INFRAMIX Management Center	Single vehicle information, as input for running the INFRAMIX traffic estimation & control strategies.
Cellular Experiments Server	OEM Vehicle Service	Traffic control commands or dynamic map-layer data, processed based on the C-ITS data payload. The Cellular Experiments Server processes the data to the required OEM Vehicle Services data-format. The OEM Vehicle Service acts as INFRAMIX infrastructure end-node of the Cellular digital communication. This infrastructure element forwards the information to its connected vehicle fleet.

Figure 14 illustrates these INFRAMIX architecture-internal communication-flows. This underlines the INFRAMIX Management Center as core-element of the INFRAMIX architecture, acting as recipient for input information as well as sender for the dissemination of the resulting traffic control-commands. The IMC enables a linking to the physical and to digital infrastructure elements, in order to support the transition period and the coexistence of conventional and automated vehicles.

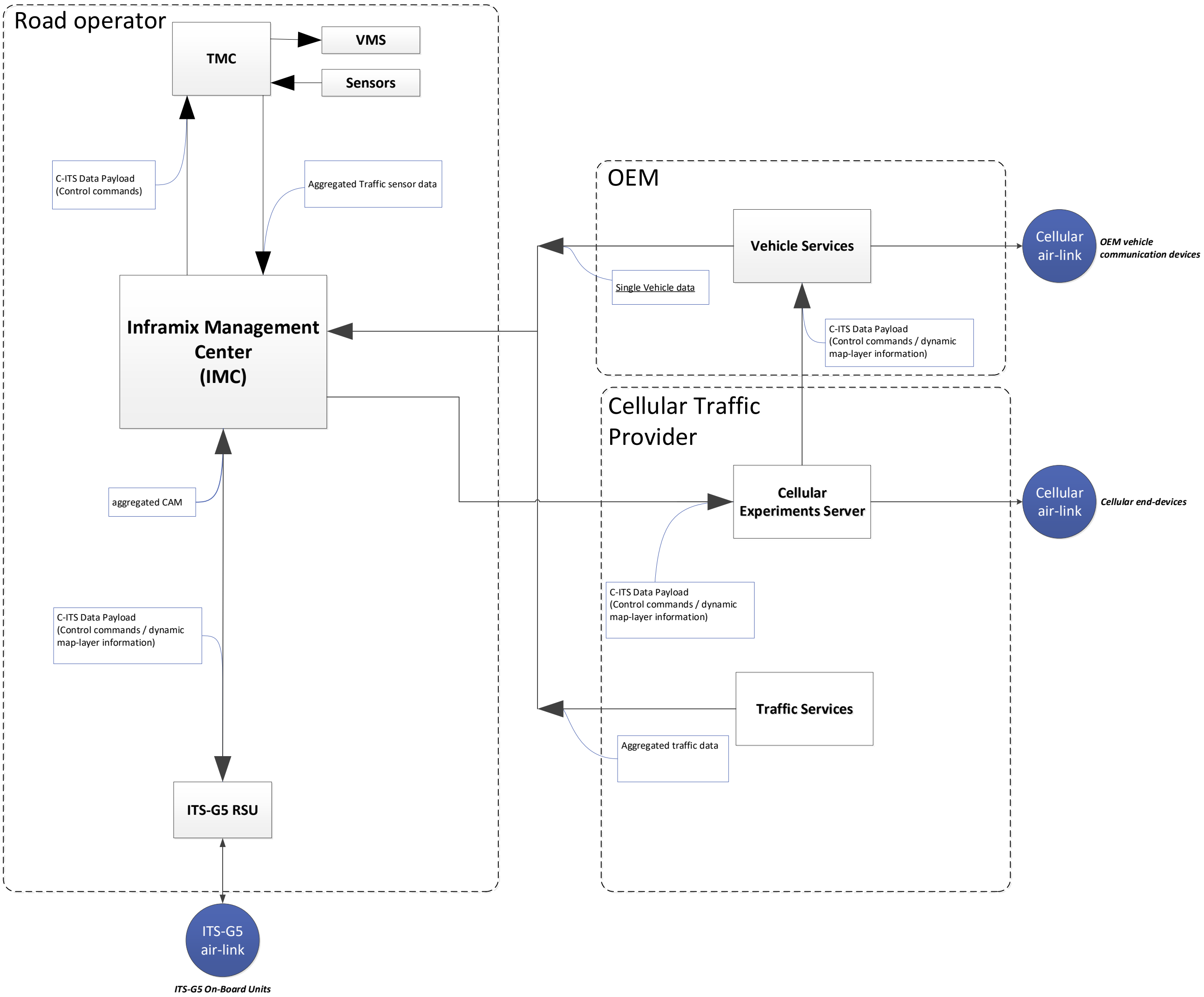

Figure 14 - INFRAMIX system architecture, incl. information-flow

5.3.2 Digital messages to end-devices

To achieve the information flow to end-devices, a common message-set is used, including information about the resulting control commands or the temporary valid map-layout, its related geographic location and its valid time range. The information flow of the traffic information to end-devices origins at the INFRAMIX Management Center and is sent equally to the INFRAMIX infrastructure end-nodes. This includes the C-ITS ITS-G5 communication link (Road Side Units) as well as the Cellular communication link (Cellular Experiments Server & OEM Vehicle Services). The IMC therefore generates C-ITS data-payloads according to its resulting traffic controls or received dynamic road-layouts.

To achieve the digital end-device communication for the three scenarios of INFRAMIX, different C-ITS data-sets are applied, which includes all required information of the resulting control commands or information of new & deviating road-layouts.

Table 13 lists these message sets, allocated by each INFRAMIX scenario and use-case. This table additionally include a description of the messages-content and its applied C-ITS message-type (see also: chapter 5.2.1).

Table 13 - INFRAMIX C-ITS message-sets

		Content of the message	C-ITS Message type
Scenario 1	UC1	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM *(new standard-extension)*
		Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Dedicated Lane Assignment SAE level clearance for automated vehicles, level of automation	IVIM *(new standard-extension)*
	UC2	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM *(new standard-extension)*
		Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Dedicated Lane Assignment SAE level clearance for automated vehicles, level of automation	IVIM *(new standard-extension)*
		Basic Hazardous location warnings (weather conditions, e.g. fog, heavy rain)	DENM
	UC3	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM *(new standard-extension)*
		Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Dedicated Lane Assignment SAE level clearance for automated vehicles, level of automation	IVIM *(new standard-extension)*
		Lane specific time gap advise	IVIM *(new standard-extension)*
		Awareness message about existence of other vehicles/Collective perception of objects on the road	CPM
Scenario 2	UC1	Vehicle type and lane specific speed limit for automated vehicles	IVIM
		Short term road works warning, see Day1 ECo-AT	DENM
		Lane specific time gap advice	IVIM *(new standard-extension)*
		Awareness message about existence of other vehicles/Collective perception of objects on the road	CPM
	UC2	Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Long term road works warning & roadworks layer	MAPEM IVIM *(new standard-extension)*
		Lane specific time gap advise	IVIM
Sc	UC	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM *(new standard-extension)*

		Traffic condition	DENM
		Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Lane specific time gap advise	IVIM *(new standard-extension)*
	UC2	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM *(new standard-extension)*
		Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Lane specific time gap advise	IVIM *(new standard-extension)*
	UC3	Vehicle type and lane specific speed recommendation for automated vehicles	IVIM *(new standard-extension)*
		Vehicle type and lane specific speed limit for automated vehicles	IVIM *(new standard-extension)*
		Lane specific time gap advise	IVIM *(new standard-extension)*

6. Conclusion

In order 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, new designs and developments of road infrastructure elements are required. Therefore, this deliverable contains a full description of required physical and digital infrastructure components, in order to achieve the designated goals of INFRAMIX.

The outcome of D3.1 reveals the necessity of linking physical and digital infrastructure elements to one system architecture, in order to address both types of road users – drivers of conventional vehicles as well as connected (automated) vehicles.
INFRAMIX underlines the importance of controlling the futures arising mixed traffic by the implementation of one reliable central source of traffic regulations and recommendations. This concept achieves a common framework of traffic measures by having the Road Operator as permitted controller of valid traffic regulative.
The resulting INFRAMIX system architecture illustrates the importance in having one reliable central source of traffic regulations and recommendations, which distributes its resulting control commands and traffic behavior-advices to further connected communication channels. This concept realizes the transmission of resulting control commands to all types of road users and, additionally, provides a framework to connected Traffic Service Provider, on which they can realize further individualized controls to its connected (automated vehicles).

The resulting INFRAMIX system architecture also illustrates the advantage of a future hybrid-connectivity, by combining different digital communication channels in order to achieve an interoperability to the real-time traffic. This includes the information flow of the architecture, containing the dissemination process of digital data payloads to connected end-device services. The outcome of the information flow of the INFRAMIX architecture reveals requirements to inform connected (automated) vehicles in an equal way to drivers of conventional vehicles. This includes a variety of different types of digital messages and different message-sets, which need to get disseminated to passing connected (automated) vehicles.
In result of the INFRAMIX's dissemination process, further research needs of these dissemination functionalities get addressed. This illustrates further research goals of a future's digital dissemination process by adapting the required digital messages to a to minimum amount of messages-sets per event, in order to meet all requirements of a real-time transmission rate and to avoid an overload of the given communication channels.

7. Terms and definitions

Terms	Description
Cellular connectivity	LTE mobile network to transfer information and recommendations to individual vehicles
Connected Automated Vehicle (CAV)	A vehicle with SAE level of automation equal to 3, 4 or 5 that communicates (via Cellular or ITS-G5 communication)
Connected conventional vehicle (CCV)	A conventional vehicle that communicates through wireless messages (through Cellular or ITS-G5 communication).
DATEX2	Data exchange standard for exchanging traffic information between traffic management centers, traffic service providers, traffic operators and media partners
Hybrid-connectivity	The coexistence of ITS-G5 & Cellular connectivity.
ITS-G5	A European set of protocols and parameters for V2V and V2I communications based on the IEEE standard 802.11p on wireless access in vehicular environments
OCIT-C	Open Communication Interface for Road Traffic Control Systems – Center to Center
RSU	Road Side Unit necessary for ITS-G5 network coverage
V2I	Vehicle-to-Infrastructure communication (via ITS-G5)
V2V	Vehicle-to-Vehicle communication (via ITS-G5)
V2X	Vehicle-to-X (X represents any entity capable of receiving C-ITS communications)