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D.5.4

Infrastructure Classification Scheme

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Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
AD	Automated Driving
ADAS	Advanced driver-assistance systems
AV	Automated Vehicle
CAM	Cooperative Awareness Message
CCTV	Closed Circuit Television
CCV	Connected Conventional Vehicles
DENM	Decentralized Environmental Notification Message
GDPR	General Data Protection Regulation
HD	High Definition
I2V	Infrastructure to Vehicle
ISA	Intelligent Speed Adaptation
ISAD	Infrastructure Support for Automated Driving
iTMC	Intelligent Traffic Management Centre
ITS	Intelligent Transportation System
MaaS	Mobility as a Service
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
RSU	Road Side Unit
SAE	Society of Automobile Engineers
TMC	Traffic Management Centre
V2I	Vehicle to Infrastructure
V2X	Communication from Vehicle to Everything
VMS	Variable Message Signs

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Executive Summary

The coexistence of different levels of automated and conventional vehicles can result, among other things, in confusing and potentially unsafe situations due to the way humans are driving and the lack of communication of the automated vehicle's intentions to other traffic participants. Until now, most of ITS literature focuses on the capabilities of automated vehicles rather than on those of the infrastructure.

Road infrastructure will play a major role in managing this transition period to make heterogeneous traffic faster, smoother, safer, acceptable and socially beneficial for all traffic participants. The more “intelligent” the infrastructure will be, the more efficient and safe will the traffic network be. The infrastructure classification Scheme for Automated Driving (ISAD) will allow to distinguish the amount of support for automated driving that different classes of infrastructure can offer. This could allow automated vehicles to keep up ODDs for longer stretches of time and space and will therefore lead to a decreased number of handovers of the driving function to the human driver. ISAD will support the timely deployment of automation-appropriate infrastructure networks. However, critical aspects should be considered, regarding legal framework, governance model, introduction of new automated functions in a transport network, possible legal and financial concerns of stakeholders, possible conflicts of interest between stakeholders etc.

In this deliverable, all the prescribed issues are analysed focusing on highways. In Chapter 2, road operator requirements towards automation are defined. An initial approach to ISAD classes is made. In Chapter 3, physical and digital infrastructure elements are merged into one system as an effective way of implementing and understanding the automated network on a high level.

In Chapter 4, the infrastructure classification Scheme is enhanced through a specific methodology and interviews with the Advisory Group. Furthermore, this chapter includes a preliminary classification of the ASFINAG and AAE highways, the first step for a concept expansion to urban roads and the relation to SAE Levels of vehicles and ODD.

In Chapter 5, two important aspects of infrastructure and their relation to infrastructure classification are considered: the regulatory framework and the public acceptance of Intelligent Transport and automated functions. In Chapters 6 and 7, potential benefits and major challenges in implementing such a classification scheme are analysed. In Chapter 8, the way how the various infrastructure classes can contribute to implementing and improving Mobility as a Service is analysed. Finally in Chapter 9, a roadmap to automated mobility based on ASFINAG example is provided.

1 Introduction

1.1 Purpose of Document

Road infrastructure plays a crucial role in the increased percentage of automated and connected vehicles into real traffic. Apart from the typical road infrastructure quality standards (e.g. clear lane markings, visibility and accuracy of signs), automated functions will be supported or even enhanced by more advanced and digital infrastructure elements: highly accurate and dynamic maps, infrastructure-to-vehicle messages, weather information, and recommendations for the optimum route.

The enhanced capabilities of the road infrastructure will enable the coexistence of vehicles with different automation levels and will not only improve traffic flow and efficiency, but also minimise the incidents of misuse of the automated functions, improving safety as well. The Intelligent Transportation Systems in the future will be based on the cooperation of road infrastructure and all the connected vehicles.

Since INFRAMIX's main target is to design, upgrade and test both physical and digital elements of the road infrastructure, in which the TMC will be the central player, the taxonomy of road infrastructure into different automation support classes will allow the effective deployment of future infrastructure networks. The purpose of this deliverable is to create an infrastructure classification Scheme, categorising different road types according to their automated capabilities and mapping these categories to specific and detailed automated functions. As an input, results of the INFRAMIX deliverable D3.1 (Design and Development of infrastructure Elements) were used. This classification gives a guideline on what support the infrastructure can offer an automated vehicle on entering and passing a certain road section. As road operation is highly dependent on the surrounding areas of the landscape, such support can always only be offered by the infrastructure on a voluntary basis. The deliverable covers mostly highways, but will also make the initial steps for the expansion of the classification to urban roads, as well.

The ultimate purpose of this work is to provide a guide for incremental physical and digital improvements of the road infrastructure.

2 Road operator requirements to support AD

2.1 Terminology

Many domains influence automated driving; see Figure 12. ISAD classes embedded in other domains [6]. For some of these domains, taxonomies have been established. E.g., traffic regulations consist of binding laws and non-obligatory recommendations; the taxonomy of automated driving by the SAE is the SAE levels [1] that are regularly adapted to current needs in their publications; the ODDs are determined separately by each member of the automotive industry; the ISAD classification is currently under constant discussion by stakeholders from all areas, and first proposals have already been published [4],[5],[6].

To avoid confusion between the categorisation of the SAE levels and the classification of ISAD, it is recommended to use the term "class" for the ISAD classification, i.e. "The motorway section between kilometre 174 and kilometre 179 on the Austrian motorway A2 is equipped with specific functionalities of class ISAD B."

2.2 Requirements

Generally, there are several perspectives on the topic of road infrastructure; inter alia, the academic one and the one of the road operator.

The road operator acts within the bounds of the applicable regulations such as national or international laws. Therefore, the most basic point from which any classification of infra-structure must start is a road with no additional equipment whatsoever other than the one required by the applicable laws and regulations.

Any change of this status is connected with costs, with road closings for installations of new equipment, but also with often time-consuming approval processes for the installation of such equipment. As, on the part of the automotive industry, automated driving functions such as lane-keeping assist or traffic jam assistant have already been introduced, it is a realistic scenario that a vehicle with several automated driving functions is operated on a road with the very basic equipment. This means that the car might receive no support from the infrastructure whatsoever and still be able to keep their ODD and stay in the current SAE level. This status needs to be reflected in a taxonomy of ISAD (see Table 1). Therefore, the lowest class E of the ISAD classification as proposed by the road operator ASFINAG in [6] consists of a road that complies with the legal framework but has no additional equipment whatsoever.

Table 1. The ISAD classification 6[5]

	ISAD	Name	Infrastructure side	AV side	Digtial information provided to AVs			
					Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional Infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (inlcuding static road signs) complemented by physical reference points	Traffic lights, short term road works and VMS have to be recognized by AVs on their own				
Digital Infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of percieving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of percieving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimize traffic flow (C-ITS Day 2+)				

From the point of view of the infrastructure provider, the classification needs to be made along the functionalities offered to the AV on a road section of a certain class. Examples for the different technical realisations of these functionalities are exemplified in [4] and are under constant change due to technical development and different solutions for the same functionality, e.g. vehicle counts can be carried out by using magnetic coils or by optical and acoustic measurements . There are different possible technologies that can be used for lane markings such as paint or foil coatings, with different specifications regarding visibility under different conditions, stability etc. Weather conditions such as snow make good lane markings invisible but are out of the sphere of influence of the road operator until snow removal has been completed (and snowfall has stopped). Of course, the lane markings need to comply with the regulations and applicable laws.

2.2.1 ISAD E

For most of today's "conventional" infrastructure, in general, no digital infrastructure data is available, and therefore, no explicit AV support can be provided. The vehicle has to rely on the on-board sensor system exclusively and has no redundant second source of information. Additionally, road geometry and road signs have to be recognised by automated vehicles on their own. This is denoted as ISAD E in the ISAD classification.

2.2.2 ISAD D

If a road is classified as ISAD D within the ISAD classification, static digital information in the form of a map support of this road section is available. Map support means that the infrastructure provider, the road authority or another relevant body offers digital map data (including static road signs). However, automated vehicles will still have to recognise traffic lights, short-term road works and variable message signs (VMS) on their own. The provided data needs to be requested and downloaded by the respective map service provider in advance.

2.2.3 ISAD C

To be classified as ISAD C, "dynamic digital information" has to be available on the network in question. This means that information of dynamic road signs (e.g. variable speed limits) and dynamic information about warnings, incidents and weather warnings is available. A very relevant data exchange standard, which is wide-spread in Europe, for such dynamic information is DATEXII [7].

2.2.4 ISAD B

The classification ISAD B requires the capability of "cooperative perception", which means that the infrastructure is capable of perceiving microscopic traffic situations and also of communicating to vehicles. Microscopic traffic data can be acquired by various sensor types. The infrastructure can react in real time and inform vehicles about traffic situations, e.g. via I2V communication using C-ITS messages as defined in [8].

2.2.5 ISAD A

For the highest classification ISAD A, the infrastructure has to be capable of perceiving vehicle trajectories and of guiding single AVs or AV groups. When driving on a road classified ISAD A, automated vehicles can be guided and orchestrated by the infrastructure to optimise traffic flow. The corresponding messages sent out by the infrastructure comprise, e.g., gap and lane change advice to control automated traffic. These advanced messages are referred to as C-ITS Day 2 for automated driving [10].

2.2.6 Dynamic down- and upgrade of a road section

The ISAD classification of a given road stretch is not regarded as constant and static. In case of an exceptional situation such as a roadworks zone, it can, depending on the specific situation, be downgraded to a lower, or even upgraded to a higher ISAD class. In the following, this is described for the Use Case 2 Roadworks zone.

2.2.6.1 Situation: INFRAMIX Use Case 2: Roadworks zone

Due to construction works, one lane of a road section cannot be used by traffic.

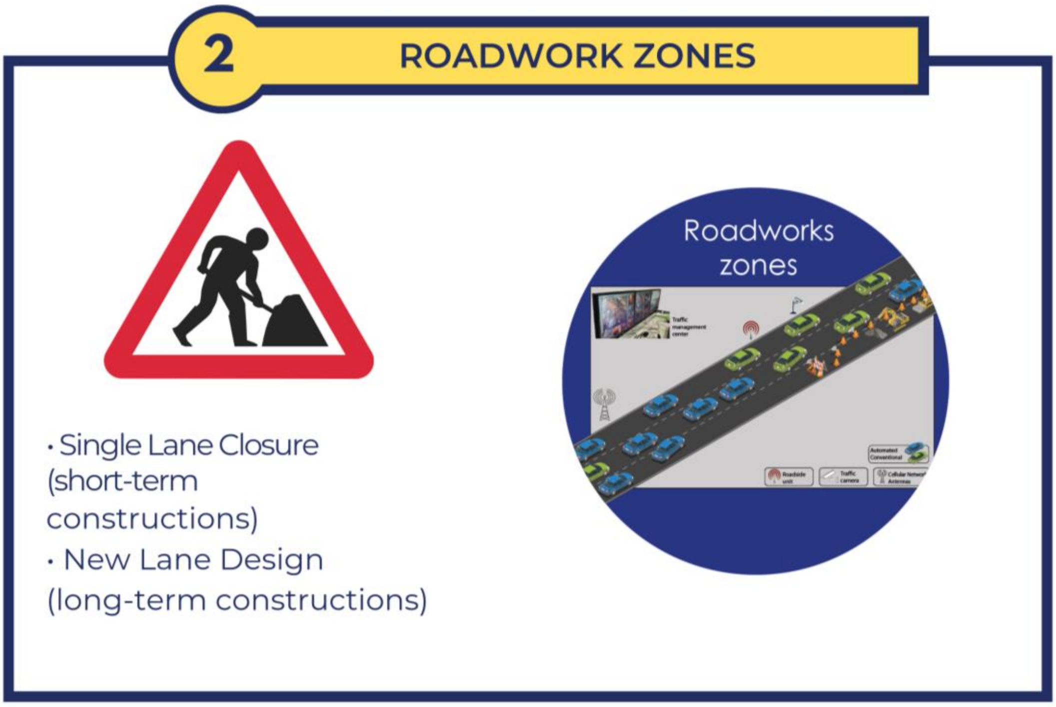

Figure 1. Roadworks zone – INFRAMIX Use Case 2

	ISAD	Name	Infrastructure side	AV side	Digital information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situations	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own				
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

Figure 2. The ISAD classification 6[5]

One lane of a road section is closed. Traffic is diverted to the other lanes. The exact lane topology is different than usual.

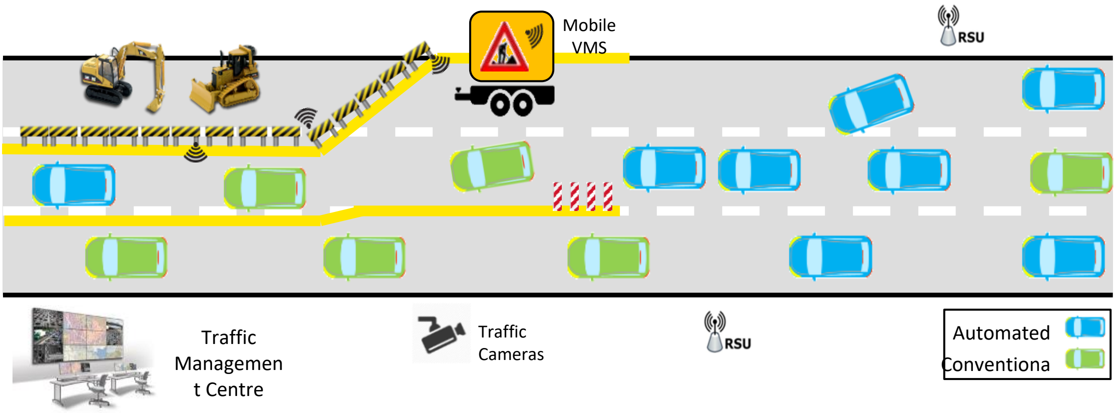

Figure 3. Road section with roadworks zone

2.2.6.2 Classification of a road section with a roadworks zone

2.2.6.2.1 Situation 1

- The roadworks zone is on a road strip that is classified ISAD E (no infrastructureinfrastructure support).

➔ This results in the road section being still classified as ISAD E:

■ Why **ISAD E**? There are no digital map data, the road section is originally ISAD E.

	ISAD	Name	Infrastructure side	AV side	Digital information provided to AVs: Digital map with road signs	Digital information provided to AVs: VMS warnings, incidents, weather	Digital information provided to AVs: Microscopic traffic situations	Digital information provided to AVs: Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own				
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

2.2.6.2.2 Situation 2

- The roadworks zone is on a road strip that is classified minimum ISAD D or higher (e.g. a digital map exists for the usual road section.)
- Traditional traffic signs are used.
- There is no additional digital information about the existence, location or extent.

➔ This results in the road section being classified as **ISAD D**:

➔ Infrastructure side: Digital map data (including static road signs)

➔ AV side: Traffic lights, short-term road works and VMS have to be recognized by AVs on their own

■ Why ISAD D? No dynamic digital information (including the roadworks zone) available.

	ISAD	Name	Infrastructure side	AV side	Digital information provided to AVs: Digital map with road signs	Digital information provided to AVs: VMS warnings, incidents, weather	Digital information provided to AVs: Microscopic traffic situations	Digital information provided to AVs: Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own	✓			
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

2.2.6.2.3 Situation 3

- The roadworks zone is on a road strip that is classified minimum ISAD D or higher (e.g. a digital map exists for the usual road section.)
- There is additional digital information about the existence and localization of the roadworks zone. This also includes the approximate localization on a specific road section (for example in case of a moving road works)

➔ This results in the road section being classified as **ISAD C**:

■ All static and dynamic information can be provided to the AVs in digital form

■ Why ISAD C? AVs perceive infrastructure support data

	ISAD	Name	Infrastructure side	AV side	Digital information provided to AVs: Digital map with road signs	Digital information provided to AVs: VMS warnings, incidents, weather	Digital information provided to AVs: Microscopic traffic situations	Digital information provided to AVs: Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own				
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data	✓	✓		
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)				
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

2.2.6.2.4 Situation 4

- A mobile VMS trailer is used. The roadworks warning message (**DENM/IVI**) is sent out locally (short-range).

➔ This results in the road section being classified as **ISAD B**:

➔ Infrastructure side: Infrastructure is capable of perceiving microscopic traffic situations

➔ AV side: AVs perceive infrastructure support data in real time (C-ITS Day 1)

■ Why ISAD B? The infrastructure support data are sent out locally in real time. The VMS trailer includes a radar sensor and is therefore capable of perceiving microscopic traffic situations.

	ISAD	Name	Infrastructure side	AV side	Digital information provided to AVs: Digital map with road signs	VMS warnings, incidents, weather	Microscopic traffic situations	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support		Road geometry and road signs have to be recognized by AVs on their own				
	D	Static digital information / map support	Digital map data (including static road signs) complemented by physical reference points	Traffic lights, short-term road works and VMS have to be recognized by AVs on their own				
Digital infrastructure	C	Dynamic digital information	All static and dynamic information can be provided to the AVs in digital form	AVs perceive infrastructure support data				
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations	AVs perceive infrastructure support data in real time (C-ITS Day 1)	✓	✓	✓	
	A	Cooperative driving	Infrastructure is capable of perceiving vehicle trajectories and guide single AVs (or AV groups)	AVs are guided by the infrastructure in order to optimise traffic flow (C-ITS Day 2+)				

2.2.6.3 *Perspective of an vehicle manufacturer*

From the perspective of the vehicle, once the infrastructure offers information as to the existence of a roadworks zone in a certain road section, this is enough digital information to help the automated vehicle.

Therefore, the moment the infrastructure offers this information, from the point of view of the vehicle, this road section counts as ISAD class C.

3 Hybrid road infrastructure support for AD

The road infrastructure is considered as a system that provides advanced services to the road users to support the coexistence of conventional, connected conventional and automated vehicles. In [4], the concept of "hybrid" road infrastructure is introduced. This concept merges the physical and digital infrastructure elements into one system to address the introduction of automated vehicles in a flexible, fast and cost-effective way while being understood by all traffic participants, automated or not.

The so-called "hybrid" road infrastructure (see Figure 4. High-level architecture (source: H2020 INFRAMIX project 2018) consists of the traffic signage (digital wireless messages, smart applications and conventional traffic signs, gantries or trolleys digital signage etc.), the road sensors system (which could take measures of road surface status or traffic flow states), the antennas and Road Side Units ensuring the connectivity of V2X communication, and the Traffic Management Centre (incl. data handling, traffic management strategies, interactions with cloud services).

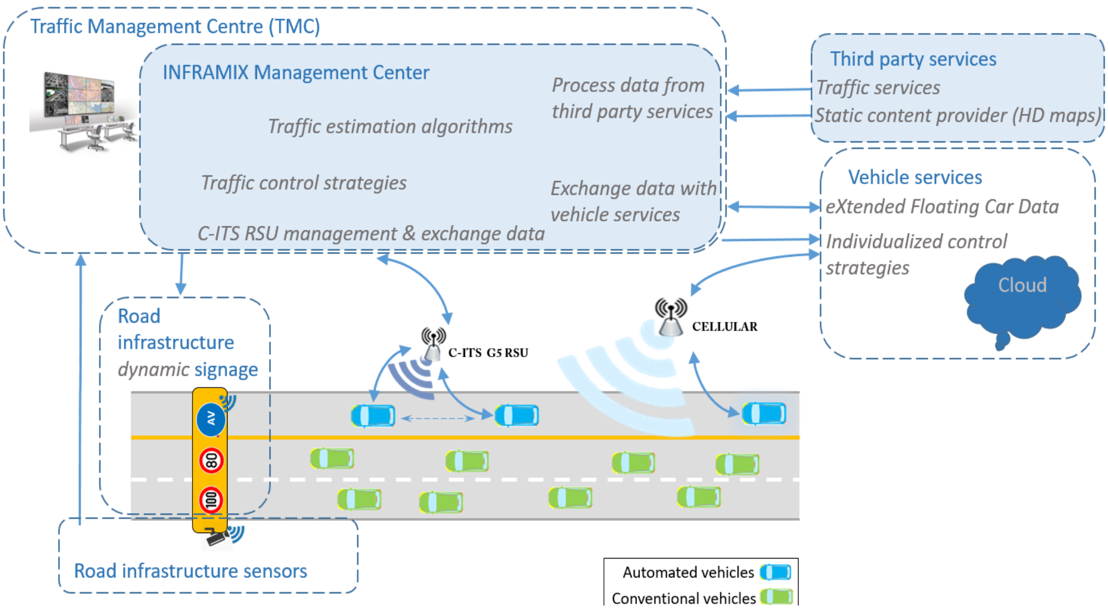

Figure 4. High-level architecture (source: H2020 INFRAMIX project 2018)

3.1 Dynamic Signage

As the road infrastructure nowadays is built to accommodate conventional vehicles, the visual signs provide mainly static information (e.g. speed limits). Modern highways also include dynamic signage (e.g. traffic congestion information, incident information, weather conditions warnings etc.) through Variable Message Signs (VMS). Nevertheless, this still is only to be recognised by human drivers. For mixed traffic flow, new visual and electronic signals that communicate information, issue warnings or guide all highway users (conventional, conventional connected and automated vehicles) might have to be implemented.

Novel signalling content related to innovative traffic management, like the lane assignment to AVs, needs to be investigated. The human drivers' appreciation of new content of signalling plays an important role in the acceptance of novel traffic management functionalities. A challenge, related to the development of the infrastructure, is the automatic and real-time communication between the road infrastructure elements and the traffic management centre (TMC). Currently, even in modern highways, any changes in the dynamic signalling are made manually by the road operator located at the TMC. This causes a delay which might be a limiting factor for dynamic traffic control.

Related to the in-vehicle signalling and guidance of the AVs or CCVs, different alternatives will be investigated, such as nomadic and cooperative systems. To enable such systems, road infrastructure should not only be equipped with Road Side Units (RSUs) (e.g. for the ITS-G5 network), but also should handle the challenges of sending at the same time a specific message to all users through different networks (e.g. LTE-V and ITS G5).

Considering a wireless bi-directional communication with the AVs, further ITS-specific wireless message enhancements might be required, like the enhanced IVIM (based on the "C-ITS for Automated Driving - SWP1.2 - Functional Specification v01.00" of the ECo-AT project) which has been applied within the scope of INFRAMIX. In this situation, the assessment in matters of both users' appreciation and technical feasibility is necessary regarding the new wireless messages extensions. The evaluation outcome would be critical for the standardisation of the wireless messages (e.g. in relevant standardisation bodies such as ETSI, ISO-CEN and SAE).

3.2 Sensors

Road infrastructure sensors are currently used to collect traffic data (such as inductive loop detectors, radar, ultrasound sensors and LiDAR) or record traffic incidents (cameras). The installation and maintenance costs are high, but the data from infrastructure sensors are valuable for their reliability. However, in the future, a critical set of data obtained from connected vehicles is expected. The connected vehicle will be able to send (and receive) real-time information to (and from) a local or central monitoring (and control) centre. Connected vehicles may communicate their position, speed and other important information, acting as mobile sensors. This might allow for a sensible reduction, and probably in the future possible elimination, of the spot sensors, which would lead to a remarkable reduction of the purchase, installation and operation cost for traffic monitoring; while, at the same time, improving the traffic estimation quality. However, as the sensor horizon of an infrastructure sensor system is considerably wider than that of a vehicle's on-board sensors, this may be a very long-term goal.

3.3 TMC/iTMC

Safety is nowadays the main focus of traffic management advice to vehicles. The trend is the move to a future where the driving style will be controlled, and the traffic mobility will be fully cooperative [3]. So, new and smart traffic control strategies should be implemented in the TMCs functionalities. Road infrastructure will not just a supporting asset for automated driving. Vehicles and road infrastructure will be cooperating components. In the project of

INFRAMIX,,first steps have already been achieved by developing a first version of the iTMC (called “INFRAMIX Management Center”; see D3.1).

The efficiency of traffic management highly depends on traffic flow estimation methods for mixed traffic, comprising conventional and connected vehicles at any (even low) penetration rates. The penetration rate of the connected vehicles is a dynamic factor and difficult to predict. However, it influences the traffic estimation. This is because the estimation tools will collect information provided by all the connected vehicles and will fuse them with measurements stemming from an adequate minimum number of spot sensor measurements in order to deliver reliable real-time estimates of traffic density and traffic flow even by lane in combination with travel times and incident detection.

Towards that direction, the research report which has been created in the frame of the platform TM2.0 detects the currently most critical road infrastructure requirements and functionalities in matters of physical and digital infrastructure, organisational, localisation and connectivity needs. It focuses on a list of traffic management functions necessary for each class of automation. The report proposes an intelligent local Traffic Management Centre (iTMC), which can be implemented either at a roadside station, a traffic light controller or in the cloud. The iTMC could for instance maintain a dynamic registry of all connected vehicles in its control area, including the level of automation of each vehicle.

Critical challenges have to be faced concerning TMC/iTMC, for instance, the decision on the level of TMC coordination across different functionalities and ISAD classes, the requirements definition for the transition from manual to control mode (e.g. minimum risk manoeuvre by TMC after the failure of manual take-over of control) and the TMC decision on formation or break-up of platooning.

3.4 Third Party Services

Two of the basic aspects in this area are the High Definition (HD) maps and the accuracy at a lane level. Different companies provide various solutions that are not mature yet. More advanced concepts of the digital infrastructure integrate aspects of low latency communication and cloud computing; however, these are at an early stage.[4]

The exchange of data between an enhanced TMC as described above and traffic party services (e.g. HD map providers) will be the basis for the extraction of the in-vehicle electronic horizon and will help both automated and conventional vehicles to perform challenging manoeuvres with increased safety and comfort. Nowadays, the electronic horizon is static and based on the on-board vehicle sensors and the digital map of the road. When learning fleet data quickly, based on a combination of data from vehicles and the infrastructure, the electronic horizon could contain dynamic information about traffic flow (e.g. velocity and density of vehicles, even separately for different car types) as a basis for individualised speed, gap and lane recommendations. Such recommendations, considering traffic control strategies, will enable smoother and safer operation in dense mixed traffic, allowing for a reduction of both traffic jams and dangerous manoeuvres.

4 Infrastructure Classification Scheme

The baseline in our approach is to register the different types of information that the infrastructure can provide to the vehicles and in the second phase to define the possible means to communicate that. Having defined the system elements, the process to classify them in a certain category is a difficult task. Some indicative examples of the multiple potential dimensions, used to classify the road infrastructure are following:

- Grade of involvement of TMC/iTMC in automated functions control
- Readiness for specific levels of vehicle automation
- Physical infrastructure adherence to specific technical standards or condition of repair
- Availability of additional physical infrastructure support elements (e.g. special markers)
- Wireless communication infrastructure capabilities (V2I & I2V)
- Digital infrastructure (Local Dynamic Map Layers)
- Back-office information support functionality

Following this approach, five infrastructure (ISAD) classes were designed and are highlighted in Table 1. The step forward from the conventional infrastructure is the digitalisation of the information managed. This gives further capabilities, such as the real-time data exchange, but increases the requirements both in physical equipment as well as in data handling.

4.1 Methodology

The creation of a high-level system architecture was the initial step for the definition of the classification. So, the system was defined with an emphasis on its main components, and associated challenges for further deployment were clarified. Then state-of-the-art infrastructure was grouped into physical-digital-operational layers. The next step was to classify the different types of information that the infrastructure can provide to the vehicles and to identify the possible means by which the above information can be communicated (as depicted in Table 1). This process created a gradually enhanced classification scheme where each class includes the capabilities of the previous one plus additional features. The outcome is described in detail in Section 4.4.

After that, possible extensions of the ISAD classification had to be investigated with the target to end up in a roadmap for incremental updates in the infrastructure to accommodate the expected mixed traffic flows safely and efficiently. Continuous improvement through workshops with experts and an Advisory Group (interviews, questionnaires, etc.) was achieved.

4.1.1 Advisory Group

To enhance and develop the above classification, an updated Advisory Group was formed by ITS experts. Our target, as INFRAMIX project, is to define an infrastructure classification Scheme which will be a benchmark for the future development of ITS Industry, and one of the ways to achieve this is conducting interviews with experienced professionals, who provided their expertise on the topic.

The experts firstly were asked for their permission with an official invitation to join the Advisory Group of INFRAMIX. Since the task of classifying the infrastructure into different categories of automated capabilities was a rather new effort in ITS industry, with [5] and [4] as probably the first concrete results, it was not very easy to find many experts having been involved in the topic. On the other hand, the ones that were finally contacted and accepted, were of high expertise, assuring that their suggestions will be of high importance.

Before the interviews, the experts received emails informing them about the INFRAMIX Project, about [5] and [the work done in [4], and the topics/functionalities they would discuss during the interviews.

These functionalities are shown in Table 2.

Table 2. Functionalities considered for mapping to ISAD classes

ISAD Functionalities / Infrastructure Elements under evaluation
Traffic signs automatic recognition by vehicles, through the wireless information exchange with the TMC (V2I).
Road markings
I2V communication
Spot traffic detectors
Traffic trajectory sensors
High definition maps
Automated vehicle localisation enhancement through the fusion of data from various sources (on-board sensors, from other vehicles and roadside units)
I2V special road information about road friction, pothole identification
ISAD upgrade/downgrade under specific conditions (e.g. weather, traffic incidents, road conditions, technical failures)
TMC to Control or Management Centres of Third Parties (e.g. OEM) communication, in case of an incident
Driving style monitoring for the TMC speed, gap and lane change advice
RSUs or TMC to vehicle communication if they find a technical problem in a connected vehicle
TMC to vehicles communication for the existence of aggressive or dangerous drivers in their surrounding
V2V communication
I2V Highway Merge Assistance
I2V advice on changing driving style
I2V truck parking advice, including availability and occupancy
Automatic snow removal and disposal decision support system
Platooning formation and break up of
Information drivers would like to get from TMC to make driving safer and more comfortable
TMC inspection or enforcement of traffic regulation compliance to vehicles
Route recommendations alternatives with the time of arrival and distance for each of them
TMC to vehicle priorities according to their types (different SAE levels, trucks etc.), as far as dedicated lane assignment and V2I messages are concerned
Pay-as-You-Go Insurance support
Pay-as-You-Go Toll support

V2X communication with speech and screen interaction
Liability for an accident: Car manufacturer or Driver/Car owner or the Infrastructure/authority or the third-party service providers

After this first contact, the experts were contacted through interviews which explored either the importance of existing functionalities for each of the ISAD classes or the importance of new or developing TMC / iTMC / infrastructure functionalities. Experts were also encouraged to highlight any other issue they considered of great importance concerning the infrastructure classification Scheme.

Functionalities regarded as crucial for the majority of existing or future highways were included in infrastructure class C and up, provided that they apply to the basic functionalities of the class, as described in Table 1. Functionalities that were regarded as good to have were included in infrastructure classes B and up. Functionalities that were regarded as optional were included in infrastructure class A. It is to be noted that the majority of current highways are classes E, with the most modern ones belonging to class D.

4.2 Simulations

4.2.1 Simulation

According to the simulation methodology, the setup developed in WP2 includes the components as depicted in the following picture. More details could be found in D2.4.

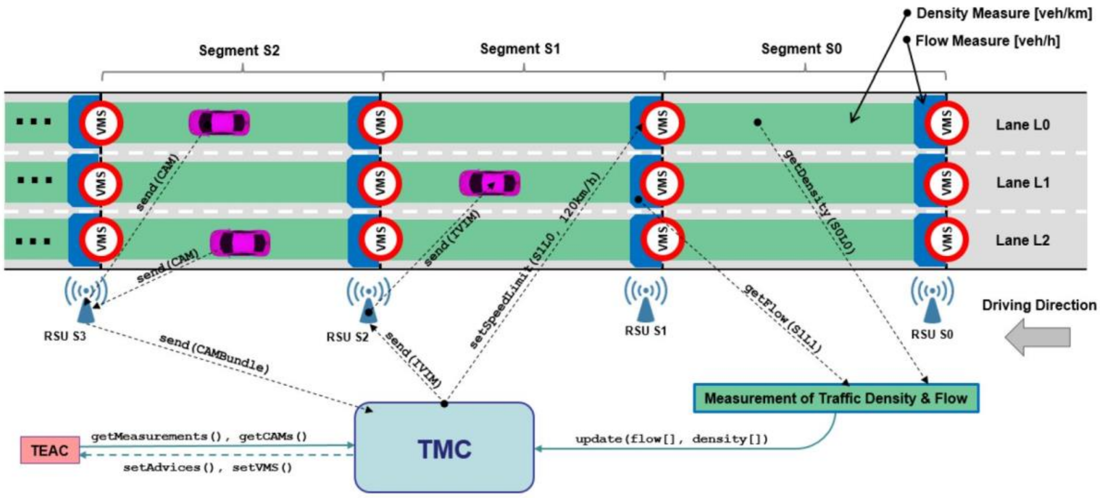

Figure 5. Infrastructure components (incl. sensors, VMS, communication, estimation/ control algorithms)

First of all, the road network is modelled with its layout, the number of lanes, geometry etc. With the employment of real map data, not only abstract road layouts, but also the road layouts from the real INFRAMIX test site of AP7 Girona could be simulated. In contrast to the real world, where traffic signs give notice of static traffic rule information such as general speed limits, in simulation, the employed maps already include those attributes, and the behaviour of the vehicle complies to these rules. With the use of the newly developed

TrafficSignAmbassador, VMS interaction with vehicles could be realised. For INFRAMIX, the displayed information allows speed limits and AV lane assignments.

Second, the developed Traffic Estimation and Control algorithms could be put in the loop. The estimation algorithms could rely either 1) only on sensor data or 2) on sensor data and communication (i.e. CAM information by vehicles). The sensor models deliver the important measurements of several vehicles and their speeds and derived measures such as traffic flows and densities. However, the models abstract from the kind of real sensor hardware, such as cameras, in-pavement loops etc. For the direction of controlling/advising vehicles, also two options exist, 1) informing vehicles by VMS (speed, lane assignments) as well as 2) C-ITS messages, e.g. IVIMs (speed, lane change, gap and acceleration).

The communication could be realised by the two links of 1) ad-hoc communication employing ITS-G5 RSUs or 2) cellular link employing a mobile network with specs of different generations of LTE or even 5G. Accordingly, the communication could be configured as uni/bi-directional communication between the road/vehicles and the TMC. Moreover, the communication allows the modes unicast or broadcast dissemination.

With the named design principles, the simulation setup for the evaluation of the Bottleneck Scenarios allows to investigate the ISAD classification as follows:

Table 3. Simulation setup of the bottleneck scenario

ISAD class	Included simulation components of variation
E	Baseline scenario Note: The microscopic simulation models for vehicle behaviour consider static traffic signs and static information on VMS equally (as attributes in the underlying maps)
D	
C	Scenario • Without real-time communication (no CAMs from vehicles to TMC, no IVIMs from TMC to vehicles) • With traffic estimation based on sensor data only • With traffic information via VMS
B	Scenario • With uni-directional communication from TMC to vehicles (only IVIMs, no CAMs)
A	Scenario • With additional measures for adverse weather conditions

To conclude, the presented simulation variations are part of the evaluation plan for simulation series of Task 5.3 and the according results will be presented in Deliverable 5.3. As could be seen, the main focus of evaluations will aim at the highest classes A and B and how the introduction of new technologies (sensors, communication) in real-time connection with advanced algorithms could improve traffic efficiency.

4.2.2 Submicroscopic Simulation

For the baseline-scenario where no infrastructure support was used, the simulation was realised using a co-simulation framework utilising SUMO instead of the VSimRTi traffic simulator. The reason for this is the fact that the same framework is utilized in the real-time hybrid testing of the scenarios. The allowed maximum speed and other traffic rules are, similar to the Microscopic simulation, already part of the simulation framework and are incorporated in the map information. For the sub-microscopic simulation of ISAD classification classes E and D, the co-simulation framework including SUMO, was decided to be sufficient.

For the simulation of the measure scenarios “Roadwork-Zone” and “Vehicle on On-Ramp”, the sub-microscopic simulation uses all of the above-described design principles (messaging via TMS/RSU, various message types etc.). For the sub-microscopic simulation of ISAD class A, a potential approach is described below. For the infrastructure measures, the sub-microscopic simulation uses design principles, implemented in VSimRTI. The corresponding link and information flow are shown below.

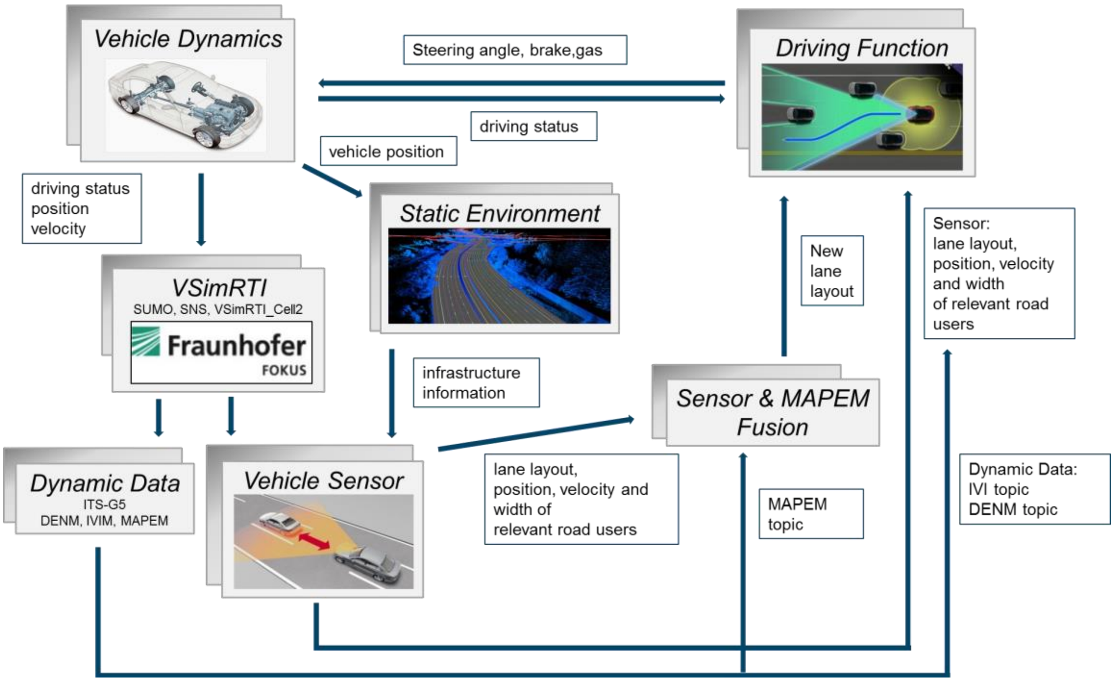

Figure 6. Coupling VSimRTI and ICOS

A non-implemented extension to the sub-microscopic co-simulation framework in the scope of ISAD class A requires physics-based simulation of the environment as well as the adverse weather conditions including lighting and atmospheric effects such as rain, fog and snow. Such an environment model simulation architecture could be based on the CARLA simulator, which is an open-source software developed for autonomous driving research. Depending on the investigated sensor type in the sub-microscopic simulation, the relevant sensor models are affected by the physics-based environment simulation. These models are specific to the sensor type and can include various combinations of camera, Lidar and radar models with possible implementations as Python codes based on the CARLA simulator. The CARLA simulator already includes a point cloud generator that mimics Lidar; however it needs to be parametrised to match the specific Lidar sensor output (range, number of lines etc.). An innovative idea for further research in this field could address the inclusion of the environmental simulation into the co-simulation framework, thereby making it possible to analyse the effect of the adverse weather conditions on the behaviour of the autonomous driving functions of the vehicle under test. It is also possible to extend the behaviour of the simulated end-effect from sub-microscopic simulation to study the effect of the adverse weather on the microscopic behaviour of the whole traffic using VSimRTI in the co-simulation framework. While theoretically possible, the specific implementation and study of such a physics-based simulation are outside the scope of the INFRAMIX project. It is obvious that many aspects can be tested in the future to improve the ISAD specification

Using the simulation framework, the ISAD classes can be:

Table 4. ISAD classification in the simulation framework

<table>
<tr><th>ISAD class</th><th>Included simulation components of variation</th></tr>
<tr><td>E</td><td rowspan="2">Baseline scenario
Note: The sub-microscopic simulation models for the static environment and the SUMO traffic simulation consider static traffic signs and static information on VMS equally (as attributes in the underlying maps)</td></tr>
<tr><td>D</td></tr>
<tr><td>C</td><td>Not considered in Sub-microscopic Simulation, optional by VMS speed advice in SUMO.</td></tr>
<tr><td>B</td><td>Scenario RoadWorkZone
• With uni-directional communication from TMC to vehicles (only MAPEM, no CAMs)
Scenario Vehicle on On-Ramp
• With uni-directional communication from TMC to vehicles (only IVIM, no CAMs</td></tr>
<tr><td>A</td><td>All Scenarios
• With additional measures for adverse weather conditions</td></tr>
</table>

4.3 ISAD classification

4.3.1 ISAD E

ISAD class E represents the conventional road infrastructure nowadays. Table 5 analyses the components on which AVs focus to recognise road geometry and signs. Class E includes only physical elements. Maintenance is the most critical aspect of this type of infrastructure. For ISAD E, traffic signs need to comply with the regulations of the law in the given country. The OEMs have to develop technical strategies as to how they can detect those traffic signs and make the vehicles react to them. Currently, there are no norms or standards referring to traffic sign machine readability. The functions may be carried out through the use of existing or future technologies.

Table 5. ISAD class E

Class	Components	Justification
E / Conventional infrastructure	AVs need to recognize road traffic signs; colours, position	Information about the accurate road characteristics could prevent ADAS misuse
	Signs with speed limits, road curvature and inclination	Accurate speed limit recognition facilitates the AV operational domain perception (and is necessary for ISA function)
	Lane markings complied to regulations and standards on both sides	Safety-related automated functionalities need proper lane condition and recognition (supporting accurate localization, e.g. automated lane positioning, automated lane change)
	Lane width based on standards	Change on lane width could pose safety related challenges even in conventional traffic
	Working zone signalization	Working zone signalization could prevent the misuse of automated functions in the specific road segment, and the human driver could timely take over
	Partial CCTV coverage for real-time vehicle detection	Traffic detection through camera could reduce the concerns related to the safety of mixed traffic flows in the near future

4.3.2 ISAD D

ISAD class D represents the state-of-the-art in most present highways. The infrastructure classified to this class includes all the elements of class ISAD E plus the ones listed in

Table 6. This ensures the capability of this infrastructure to provide static digital information to the vehicles on a road segment. This information is collected by road sensors' data, processed by the management centre, and normally visualised on gantries which are nowadays updated remotely, but in most of the cases manually. The digital map of the road segment also includes speed limits and sign location static information.

The dynamic update of static information in a digital map, e.g. change of speed limits due to long term roadworks, is important. This could be done with the cooperation of the authority which handles this information (e.g. road operator, national/local authority) and the map providers. Map providers can update their maps with the help of satellites, crowdsourcing etc. The capability to provide updated static information through VMS to all vehicles and drivers ensures redundancy, especially for critical information related to safety, such as roadworks and speed limits.

The functions may be carried out through the use of the following technologies or through the use of other equivalent or future technologies.

Table 6. ISAD class D

Class	Components	Justification
D / Static digital information	Digital map with static road signs (incl. accurate position of traffic signs)	The accurate position of the speed limit signs is necessary, e.g. for ISA function. This information being integrated into the digital map could complement the on-board vehicle sensors

	Variable Message Signs	Visualise information related to warning, incidents, and weather.

4.3.3 ISAD C

ISAD class C provides dynamic digital information to connected vehicles through the timely processing of data and the automated update of VMS content. These functionalities require a considerable upgrade of the technological class of a typical TMC nowadays. In general, the more advanced the automated functionalities, the more increased the role of TMC/iTMC.

This class also supports the accurate localisation necessary for the SAE Levels 3-5. This may include physical elements serving as reference points for automated vehicles as well as high definition digital maps.

Many advanced automated functionalities have been added to the basic version of ISAD class C, as published in [4].

The functions may be carried out through the use of the following technologies or through the use of other equivalent or future technologies.

Table 7. Enhanced ISAD class C

Class	**Components**	**Justification**
C / Dynamic Digital information	HD maps (incl. accurate position of signs, dynamic update of lane topology)	Precise vehicle localisation is of high importance in hands-off automated functionalities, e.g. reference points can support localisation (also applicable in urban areas), dynamic update of lane topology through the HD map could support automated vehicles passing through a roadworks zone with new lane markings, automated lane change requires accurate lane recognition
	Dense location referencing points	
	Data fusion from on-board sensors, other vehicles and RSUs	Automated vehicle localisation
	Advanced TMC/iTMC software	Prioritisation, Class upgrade/downgrade only to specific vehicle types (of different SAE Level, different size etc.)
		Vehicle technical problem identification and vehicle/ driver warning, I2V warnings for the existence of aggressive, dangerous drivers.
		I2V truck parking advice, road condition (road friction, potholes) information (not always in real-time)
		I2V traffic regulation compliance
		Pay-as-You Go Toll service (optional)
	Advanced Infrastructure to Vehicle / V2X communication	Vehicles recognition of traffic signs through TMC – Third Party Services
		Speech and screen V2I interaction (optional and provided mainly by OEM and third parties)
	Automatic data processing	Provision of digital information from multiple sensors and/or sources requires automatic data processing (e.g. from in-pavement sensors, camera for detection of stopped vehicles, ramp metering)
	Automated update of digital infrastructure	Provision of timely dynamic information (e.g. roadworks warnings, weather conditions, traffic information) requires an automatic update of the traffic signs (not always in real-time)

4.3.4 ISAD B

Infrastructure classified as class ISAD B (Table 8) facilitates the use of more complex digital functionalities. Vehicles acquire a broader perception of their surroundings, thus enabling higher levels of automated driving. Road sensors, the communication with third parties and cloud services are the data sources of the infrastructure. The functions may be carried out through the use of the following technologies or through the use of other equivalent or future technologies.

Table 8. Enhanced ISAD class B

Class	Components	Justification
B/ Cooperative perception	HD maps (cloud based digital maps incl. the accurate position of signs, dynamic update of lane topology, location of emergency stop zones) Weather (High precision meteorological stations, in-pavement sensors to detect moisture, temperature, strain)	Cloud based digital maps could enhance traffic perception, supporting traffic flow optimisation. The frequency of the emergency stops and their accurate positioning in the HD maps could support the transitions to minimal risk condition if a human driver does not take over Info about weather conditions relevant to road status (e.g. slippery road, strong side wind, heavy rain, snow, reduced visibility) could support the automated vehicle in perceiving its operational domain, thus preventing incidents of automated functions misuse.
	Advanced TMC/iTMC software	I2V Highway Merge Assistance
	Data exchange with cloud services	Data exchange with service providers supports services such as the provision of travel and route recommendations, with alternatives depending on time arrivals and distance.
	Elements to ensure continuous connectivity (enabling I2V) along the segment (e.g. RSUs) Microscopic traffic situation (in some cases speed and gap advice)	I2V connectivity should be ensured to enable the communication of advanced perception info to vehicles and related recommendations
		Driving style monitored and taken into consideration for route recommendations and traffic advices (speed, gap, change of driving style)

4.3.5 ISAD A

A cooperative road transportation future, as it has been envisaged by many researchers and vehicle manufacturers, entails an active role of the infrastructure in the traffic flow management [2, 4]. ISAD class A (Table 9) is referring to an infrastructure able to dynamically guide automated and connected vehicles based on traffic control strategies managing mixed traffic in a road segment. Data handling and fusion from various sources, advanced software management tools, smart traffic estimation algorithms, demanding wireless communication capabilities and information security effective management are required.

The penetration rate of automated and connected vehicles is a critical factor because they can act as sensors and actuators from the traffic management perspective. Consequently, it is important to support automated vehicles to maintain their automation level while being supported by the TMC. For example, due to safety aspects, AVs may degrade their automation level during adverse weather conditions, by complying to thresholds which are initially chosen rather conservatively. With more accurate information gathered from infrastructure sensors, these thresholds can be set higher. In this frame, it is possible to define the circumstances under which the infrastructure class should be downgraded or upgraded.

The functions may be carried out through the use of the following technologies or through the use of other equivalent or future technologies.

Table 9. Enhanced ISAD class A

Class	Components	Justification
A / Cooperative driving	Advanced TMC/iTMC software Sensors for trajectories of the vehicles Dynamic Guidance: speed, gap, lane advice	The capability to provide dynamic guidance towards the time-gap, lane and speed a vehicle should drive results in higher traffic efficiency accompanied by an increase in safety. To perform such recommendations, the TMC requiresdetailed traffic data, such as the automation level of the vehicles and the traffic flow per lane.
	Elements to ensure continuous connectivity (enabling I2V) along the segment (e.g. RSUs)	I2V and V2I are necessary to enable traffic tracking and monitoring. The automation level of each vehicle is critical information in that direction.

4.4 Mapping of ISAD classification to infrastructure and operational elements

Table 10 includes all the relevant elements for each ISAD class, divided into digital, physical and operational infrastructure/ functionalities.

The table is a result of the analysis of existing infrastructure capabilities, existing AV capabilities, future assumptions for the progress of ITS industry, safety and traffic efficiency today challenges, road user convenience and acceptance. The interviews with the Advisory Group, as described in Chapter 4.1.1, contributed to the mapping of different and advanced functionalities to the ISAD classification. It should be noted that in comparison with ISAD classification of [4], class A+ has been merged with class A since the emphasis is given to the automated functionalities irrespective of the connectivity capabilities or the type of communication.

Table 10. Enhanced ISAD classification mapped to digital, physical and operational elements

Class / Name	Digital infrastructure	Physical infrastructure	Operational infrastructure/Functionalities
A / Cooperative driving	Advanced TMC/iTMC software	Elements to ensure continuous connectivity (enabling V2X) along the segment (e.g. RSUs) Sensors for trajectories of the vehicles	Dynamic Guidance: speed, gap, lane advice based also on driving style monitoring (unicast communication to individual vehicles) I2V traffic regulation compliance I2V warnings for the existence of aggressive, dangerous drivers. Detailed weather info + class B
B / Cooperative perception	Advanced TMC/iTMC software HD maps (cloud based digital maps incl. the accurate position of signs, dynamic update of lane topology, location of emergency stop zones) Weather (High precision meteorological stations, in-pavement sensors to detect moisture, temperature, strain)	Elements to ensure continuous connectivity (enabling V2X) along the segment (e.g. RSUs)	Microscopic traffic situation Vehicles' recognition of traffic signs through TMC – Third Party Services I2V Highway Merge Assistance I2V truck parking advice, road condition (road friction, potholes) information Pay-as-You Go Toll service Guidance: Travel route recommendations and in some cases speed, gap advice based on driving style monitoring Data exchange with cloud services Info about weather conditions relevant to road status (e.g. slippery Road, strong side wind, heavy rain, snow, reduced visibility) could support the automated vehicle in perceiving its operational domain, thus preventing incidents of automated functions misuse. Infrastructure state of repair assessment + class C
C / Dynamic Digital information	HD maps (incl. accurate position of signs,		Automated data processing

	dynamic update of lane topology)		
	Advanced TMC/iTMC software		Prioritisation, Class upgrade / downgrade only to specific vehicle types (of different SAE Level, different size etc.) Vehicle technical problem identification and vehicle/ driver warning, I2V truck parking advice, road condition (road friction, potholes) information (not always in real-time) (optional) Speech and screen V2I interaction (Provided mainly by OEM and third parties)
Data fusion from on-board sensors, other vehicles and RSUs	Advanced Infrastructure to Vehicle (X2V/V2X) communication	Dense location referencing points	Automated vehicle localization Provision of timely dynamic information (e.g. roadworks warnings, weather conditions, traffic information) requires an automatic update of the traffic signs (not always in real time) + class D
D / Static digital information	Digital map with static road signs (incl. accurate position of signs)	VMS Gantries	Handling information related to: Roadwork Warnings, Incidents, weather +Class E
E / Conventional infrastructure	-	AVs need to recognise road traffic signs; colours, position Signs with speed limits, road curvature and inclination	Information about the accurate road characteristics could prevent ADAS misuse Accurate speed limits recognition facilitates the AV operational domain perception (and is necessary for ISA function)
		Lane markings complied to regulations and standards on both sides Lane width based on standards	Safety-related automated functionalities need proper lane condition and recognition (supporting accurate localisation, e.g. automated lane positioning, automated lane change) Change on lane width could pose safety-related

			challenges even in conventional traffic
		Working zone signalization	Working zone signalisation could prevent the misuse of automated functions in the specific road segment, and the human driver could timely take over
		Partial CCTV Coverage for real-time vehicle detection	Traffic detection through camera could reduce the concerns related to the safety of mixed traffic flows in the near future

4.5 ASFINAG roads classification

The Austrian road network consists of 2,200 km of motorways. The network is equipped with traffic signs and with lane markings complying with the respective regulations. For the entire network, digital map material has already been prepared and is in use (see the brown markings). Variable message signs are installed and connected to the ASFINAG traffic management centres via a fibre-optic network along the roads. Of these, 23 km on the motorway A2 are equipped with most modern sensory equipment in high density; this is the ALP.Lab proving ground to test C-ITS messages. The data from the sensory equipment are fused by a complex algorithm called sensor fusion to provide the exact trajectories of single vehicles on this road stretch. This motorway stretch can be classified as ISAD class B (see the green marking in the south-east).

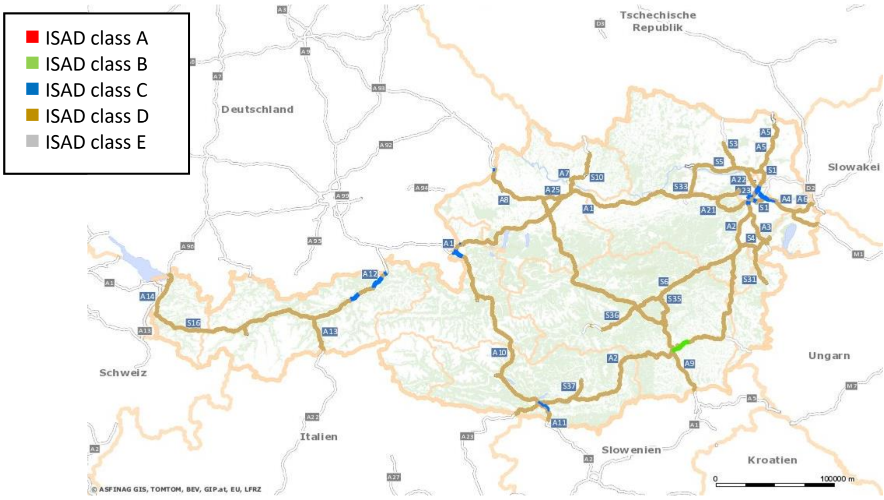

Figure 7. A preliminary road classification of the Austrian highway network [6]

The ISAD classification is implemented as an automated service in the ASFINAG database, which in the future could also be used for dynamic up- and downgrade of the classes on several segments. The algorithm thereby takes into account requirements similar as those defined in Table 1 of Section 2.2.

The difference whether a section is classified as D or C, for example, is often related to the availability of real-time weather data.

It is clearly visible that the vast majority of the ASFINAG network is categorised as class D. Since there is no road strip which does not hold digital map info (including info about the traffic signs), in this classification there is actually no class E on the ASFINAG network. An example for possible class E sections would be roadwork zones with missing digital map info. The interface to the roadworks database in order to get this information automatically and dynamically into the ISAD classification is, however, not yet implemented.

4.6 AUTOPISTAS roads classification

Abertis Autopistas España (AAE) is the Spanish leader in toll roads management. It directly manages more than 1,500 kilometers, which accounts for 59% of the country's toll roads. It also has a non-majority stake in other toll roads and tunnel concessions. The overall network is equipped with traffic signs and lane marking complying the current regulations. Moreover, AAE is constantly extending and updating its infrastructure, incorporating the latest innovations in terms of free-flow, signaling, real-time services and reliable connectivity. Nowadays, the network counts with more than 500 VMS, 630 CCTVs cameras, 350 traffic sensors and 100 weather stations, among other IT equipment, connected to the 4 AEE Traffic Management Centres by a 10 Gigabit fibreoptic ring. A complete digital map with all this equipment and road signs accurately positioned is available.

Therefore, according to the aforementioned criteria and infrastructure capabilities, the whole network can be classified as ISAD class D.

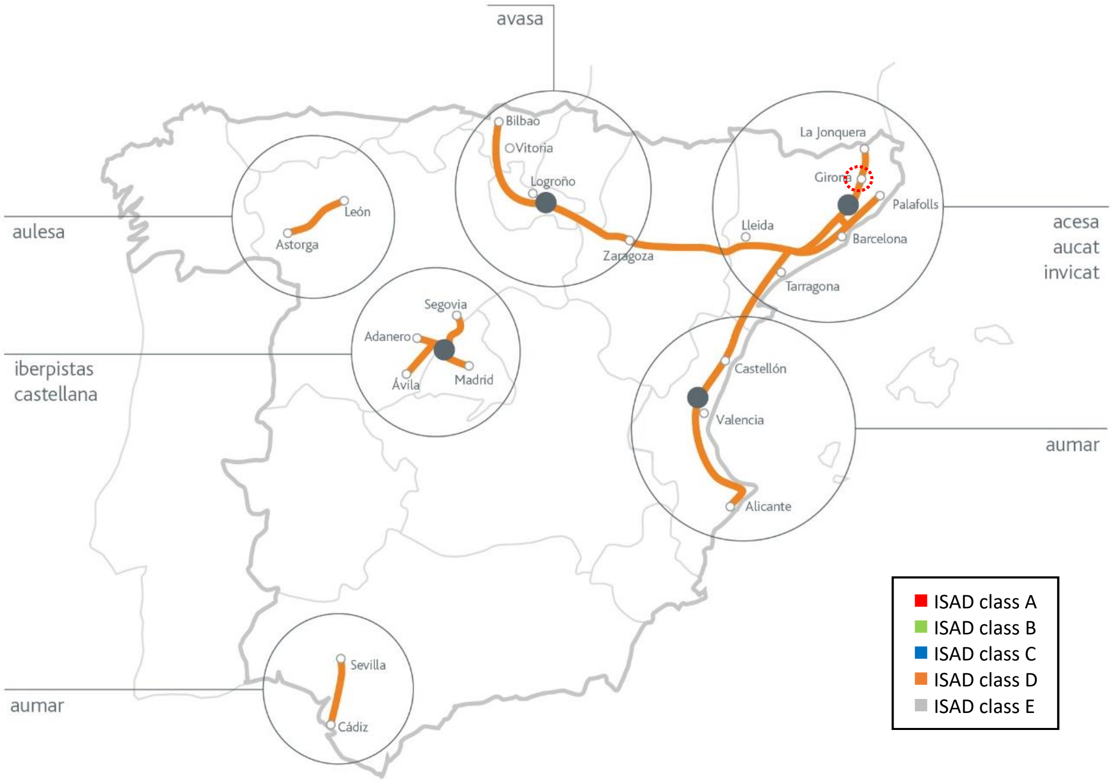

Figure 8. A preliminary road classification of the Spanish highway network

In the context of the INFRAMIX and C-Roads projects, AAE has densely equipped a 20 km section of the AP-7 motorway with additional traffic sensors, VMS and C-ITS RSUs that allow V2X communication between the AVs and the AAE Autopistas-Hub. Thus, if this hub is provided with traffic strategies, such as during the Spanish INFRAMIX demonstrator, this section could be classified as ISAD class B.

Figure 9. Girona AAE test-site AP-7 – ISAD class B

4.7 Expansion beyond highways (urban streets etc.)

In principle, the definition of the several ISAD classes is designed in a way so that it can easily be expanded also to the urban area. The origin of ISAD lies in the highway area due to lower complexity of the possible traffic situations. This is illustrated in Figure 10:

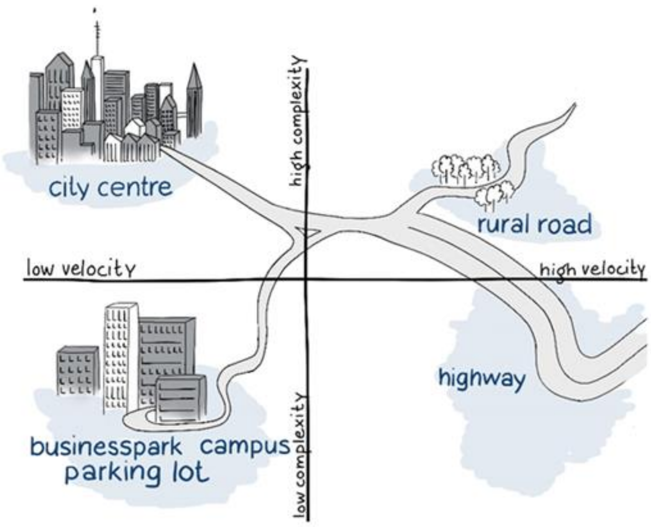

Figure 10. Complexity / velocity diagramme for different fields for AD (c) Tom Alkim

Although the typical driving velocity is very high, the low complexity on highways can be attributed to the absence of crossings, pedestrians, bicycles and inbound traffic, all of which are present in the urban area. Therefore, strategies and infrastructure support addressing these road users and topics have to be defined, invented and described.

Therefore, it is natural that ISAD classes for the urban area need refinement and also extension. However, the high complexity of the topic also reflects the opinions of the stakeholder group present at the Graz workshop. The Joint Stakeholder Workshop took place on Wednesday, 9th October 2019, on the premises of VIF. The workshop was a cooperation of the INFRAMIX and the TransAID project. 39 persons, project members from both projects as well as other interested persons from several stakeholder groups, participated in keynote presentations and discussion sessions and created an intensive discussion on the topics of both INFRAMIX and TransAID. The conclusion is that there is a large group of experts who believes that AD in cities still is decades away (see Figure 11).

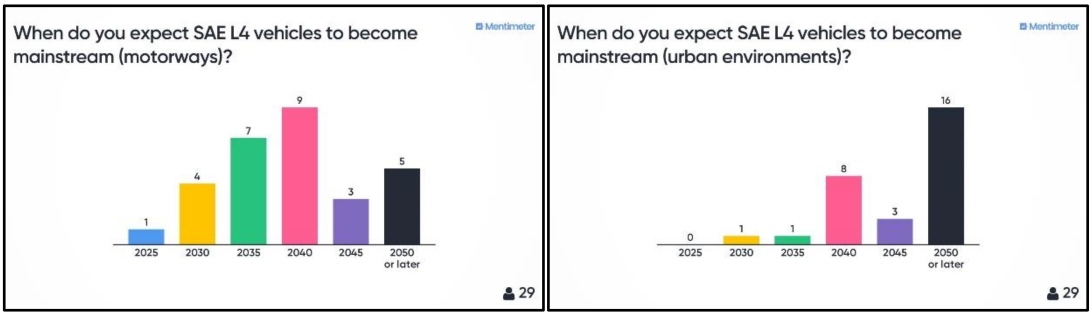

Figure 11. Mentimeter plots from the joint stakeholder workshop of INFRAMIX and TransAID on the potential spread of highly automated driving on motorways and urban environments.

A functional example for high infrastructure support and low velocities is the automated valet parking [11] recently introduced. This is already a real-world working example with low complexity and low velocities, but sensor equipment comparable to ISAD A.

On the verge of the joint stakeholder Workshop with the project TransAID, the concept of ISAD was also discussed with the sister project focussing more on urban areas than the INFRAMIX project. TransAID develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, especially at Transition Areas.

Further, there are intensive efforts to extend ISAD to the urban area within Measure 6.6. Automated mobility action package [12] of the Austrian Federal Ministry of transport, innovation and technology. A review board of experts (including also INFRAMIX project partners from ATE) was formed and will address this issue in the following months.

4.8 Relation with other ITS elements (SAE Levels, ODD)

The aim of automated driving draws on the participation of several stakeholders and their domains: car manufacturers, legal requirements and regulations, external conditions such as the weather, infrastructure conditions such as speed recommendations or limits. A vehicle that drives automatically is, therefore embedded in a plethora of different restrictions from different domains, which is shown in Figure 12.

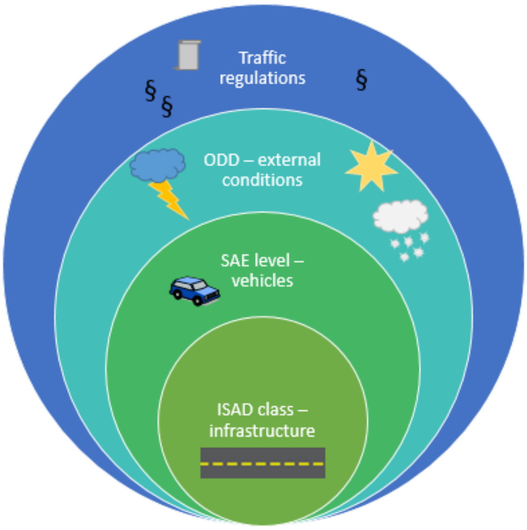

Figure 12. ISAD classes embedded in other domains [6]

This highlights once more the support character of ISAD since ISAD can never alone be the deciding factor, e.g. for an ODD breakdown. However, it illustrates that the ISAD concept can help to extend several ODDs in such a way that ODD breakdowns become much less frequent. Since typically, an ODD breakdown is related to a handover manoeuvre (machine to human), this is not only a matter of convenience but also highly important for future traffic safety.

5 Important Factors / Critical Requirements

5.1 Regulatory Framework

Many legal aspects are involved in infrastructure deployment and classification. In case of an incident, the liability is a complex issue. For instance, in case of an accident, the involved parties are road operators, Third Parties operating TMC or providing services, car manufacturers, drivers. The future ITS will be so dependent on technology that an incident will require a combination of technical assessment, special conditions investigation, possible human fault etc. Many subsequent questions arise: Should the same rules of liability apply to all the different ISAD classes? It might be possible that incidents of the same conditions will be judged differently, according to the ISAD class. As road infrastructure transfers from lower to higher ISAD classes, the responsibility needs to be reevaluated. Participants are the driver, the vehicle, the automated functions, and the information which the infrastructure supports. But even then, it could be a different liability if the management control command was given manually or automatically by the TMC software platform (ISAD Class A). These are challenges that should be taken into consideration, to have an effective ITS, accepted by all the stakeholders and especially the users.

This topic is also related to the regulations for specific functions of the infrastructure and linked to users acceptance as well: If, e.g. the regulative requirements for a specific function of the infrastructure were very high (and the road operator would be regarded as fully liable for wrong information), the road operator might not be able or willing to cover large areas of infrastructure with the available budget. On the other side, the vehicles may need in some cases a very high quality of service that they can rely on.

Additionally, some advanced services imply legal and commercial aspects (e.g. the platooning service provider); is the TMC the ideal candidate manager for forming and deforming the platoon? Also this question only arises for ISAD A, since for lower classes the formation and dissolution process of platoons needs to be organized by the trucks themselves. Up to and including ISAD B, the road operator will only provide and send out a platooning clearance. For a fully infrastructure driven platooning service, a road operator would need a legal framework firstly to decide a platooning formation (ISAD Class A). Then, within this framework, he needs to be able to permit or decline permission for platooning depending on the concrete road and traffic situation. It will depend on which concrete infrastructure functions (which can be located in different ISAD classes) will be used by, e.g. the platooning operator. And then, once again, what if the decision is made manually, automatically or semi-automatically? For some services, it will be no problem if the quality standard is not that high, others will require a high support class.

In case an incident occurs and the user/driver has not followed the TMC commands, the situation becomes complex: if the driver claims that he adhered strictly to the instructions by the TMC? Such problems may prevent new advanced Pay-as-you-go services.

A governance model should probably be investigated when defining a taxonomy for infrastructures because of several legal and commercial aspects in order to deal also with potential conflicts. There are strategic topics that imply a conflict of interest: would any message favour specific classes of vehicles?

A governance model also should be a global one, a continental one, a national or even different per local / infrastructure operator? Do the existing national or European regulations permit such governance? Are there any other conflicts?

A national regulatory frame probably would not be sufficient, since a vehicle manufacturer will not implement several different solutions for Europe. Also for the advanced automated capabilities and the higher ISAD classes, worldwide governance might be preferable.

5.2 Public acceptance

User's appreciation is one important strategic target of INFRAMIX. It is very important for such an ambitious and challenging effort to receive broad acceptance, especially in its beginning, and public acceptance in general, not only among users/drivers, but also among all the stakeholders and the whole society as well. Acceptance of ISAD classes by the different stakeholder groups will highly depend on what will be the benefits of using the ISAD classes.

One of the benefits is the availability of a categorisation scheme for infrastructure equipment based on different properties (e.g. static, dynamic, level of cooperation). Additionally, the components listed in the single classes give a good overview of which functions can be supported by the infrastructure. This is a potential common benefit for the road / infrastructure operators, vehicle manufacturers and service providers as well. The road / infrastructure operators can define a strategy where to implement which class. The vehicle manufacturer / provider knows where support from the infrastructure is available.

Last but not least, service providers, e.g. goods transport could see on which routes infrastructure support is available and take this into account by deciding on a specific route (e.g. choose a route where the vehicle can drive the most time in automated mode).

Having more details on the requirements (e.g. data quality) would allow the road operators to assess in detail what costs are linked to the implementation and maintenance of these elements and also to have a clearer view which detailed services / use cases are supported. The automotive industry will also have a better view, on what they can expect from infrastructure sections and therefore also allow to decide for which functions it is useful / realistic to consider the support of the infrastructure or to even rely on infrastructure support in future.

When considering potential services for TMC or infrastructure management, it is relevant to understand which possible business models could be developed: Are the key players' strategies clear? Are the existing business models sufficient to cover the future ITS needs? What are the required conditions for establishing effective business models?

Road operators, also depend on public concessions (or are public), and of course also have financial goals and limits. This could affect development strategies and also the development and implementation of different ISAD classes.They won't adopt any business or business model if the Return of Investment (RoI) is not guaranteed. Note however, that this return of investment does not necessarily be financially, but also could mean lower congestions and accidents or even lower emissions, for instance. Additionally, not only road operators but also other industries related to the transport sector, like vehicle manufacturers, might be afraid of the competition. Some sectors may fear that other companies will gain market share. But this is a rather short-sighted approach. On the contrary: developments in ITS create opportunities for new products, services and applications, and cross-sector collaborations such as insurance companies, motorway managers, third-party service providers, vehicle manufacturers etc.

Therefore public acceptance (especially during the first phases of deployment) should be the key concern of all involved in the ITS development, in order to avoid scepticism from the user side.

There are also other stakeholders' strategic decisions that imply conflicts of interest. What will happen if a vehicle manufacturer will blame a third-party service provider or a road operator that, using traffic management functionalities, operates in favour of a specific class of vehicles? This is an issue with legal aspects too.

Sensitive data transferred over the loop and exchanged messages may cause social reactions. New advanced services like pay-as-you-go toll, or pay-as-you-go insurance are not covered by the current law and rules, and this might cause problems in ITS and ISAD development.

Another important issue is public acceptance in case, especially during the first period of ITS developments if the number of incidents due to the coexistence of conventional and autonomous vehicles is high. A clear and well-defined infrastructure classification is a critical prerequisite to reduce the number of incidents or accidents.

6 Potential Benefits

Why is the ISAD classification needed? What will it offer? Why not concentrate on the field of ITS, to be just intensively improving and developing road infrastructure or AV capabilities in particular, without any infrastructure classes? What are the benefits?

To answer these questions firstly we have to understand a basic principle: The future of ITS, especially distant future, is not based on, as some might assume, that of vehicle autonomy over road infrastructure. On the contrary, vehicles and road infrastructure will be equal players in the ITS industry, and the more the automated capabilities are improved and enhanced, the more the role of road infrastructure will increase, mainly through TMC / iTMC. However, it should be noted that despite the coordinating role of the TMC, the role of in-vehicle sensors in a bottom-up approach will still be important and increasing. It is not only the traffic data that are gathered and accumulated. Traffic infrastructure through but not only TMC can also use bottom-up communication messages to increase safety. Sensors or traffic lights with digital collision avoidance systems would help them recognise when a crash between two vehicles was about to happen, based on their trajectories, and warn the drivers / users. The same approach can be taken to speed limits. Intelligent speed adaptation (ISA) helps a driver be compliant with the limit by correlating information about his/her vehicle's positions over time with an HD map to determine his/her speed. The TMC/iTMC might one day be able to warn an aggressive driver using special signals, or even slow him down automatically.

The necessity of cooperation between road infrastructure and automated vehicles can be even more comprehensible if we consider the relationship between smartphones and Telecom Network Management Centre. Irrespective of how "smart" the smartphones are, regardless of their type, it is inconceivable that they could operate without the coordination of a telecom centre, or at least for some functions, without the support of third parties services. In the same way, we cannot imagine the future of the ITS Industry, with autonomous vehicles, without the support of TMC/iTMC. Of course, there are also discrete and important differences between these two industries.

Keeping in mind the necessity of the increased role of road infrastructure through traffic management activities, but not limited to them, the benefits are multiple. The modular approach offers the opportunity for a smooth, incremental and efficient upgrade of infrastructure with new functionalities.

Since safety, as expressed through the reduction of accidents and incidents, is a key objective of both the ITS Industry and the INFRAMIX project, the coexistence of conventional and automated or connected vehicles largely depends on the classification of the infrastructure, according to the functionalities they provide to every type of vehicle. If the capabilities of both vehicles through SAE levels and road infrastructure through classification scheme are not always fully elaborated in their cooperation, the coexistence of conventional and automated or connected vehicles instead of increasing safety could have the reverse effect. So, a precise, detailed, smart and modular infrastructure classification is a prerequisite for the safe coexistence of all vehicle types.

The same objectives are served by the standardisation of road infrastructure achieved through classification. At the same time, this standardisation will achieve other objectives such as road operators' compliance with safety rules and criteria. This will ensure the harmonious co-operation of vehicles and road infrastructure, a prerequisite for future ITS. A classification scheme will help the development of AVs by improving existing ones and developing new functionalities. Some of the functionalities now implemented by the vehicles themselves may be supported or even managed by the road infrastructure via TMC/iTMC.

Apart from the safety aspect, the enhanced traffic management functionalities and the dynamic upgrade or downgrade of infrastructure class due to special conditions, incidents or extreme weather can improve traffic efficiency. This will be supported by advanced traffic management software in TMC/iTMC, but also by on-board sensors that will replace to a great extent the physical road side sensors.

Another benefit from such infrastructure classification is the resolution of new legal cases that will arise from both the coexistence conventional and connected vehicles and complicated legal liability issues with many involved parties: Third parties, car manufacturers, car owners/drivers, road operators, national authorities.

New or existing services will be developed or enhanced with the help of advanced traffic management functionalities, for instance, pay-as-you-go toll service. Special aspects and new marketing opportunities, such as different charging in different infrastructure classes, need to be explored.

A type of structural waste in the transport infrastructure system is the disruption caused by unplanned corrective maintenance. Road infrastructureRoad infrastructure of top ISAD classes (e.g. A and B) with the aid of smart sensors might one day assess the state of repair of roads, communicate that to their manufacturers, and thereby facilitate the on-demand planning of maintenance activities. This avoids infrastructure going to a bad condition. Such an approach increases the feasibility of product-as-a-service type business models and the ability to increase profitability. Incidents are also likely to decrease.

Using digital technologies supported by infrastructure classified into ISAD classes to efficiently decrease congestion and enhance safety – and reduce the negative effects on public health and the world climate due to the CO_2 emission – has a great economic benefit. In the USA, it is estimated that traffic jams cost approximately USD 10 billion a year and waste more than 10 billion litres of fuel.

There is a potential need and opportunity also for new roles in the value chain: some services could be proposed by the infrastructure operators in cooperation with others, e.g. telematics service providers, acting in more extended areas.

Finally, Mobility as a Service (MaaS) is the future of ITS Industry. Enabler for the transition to the concept of mobility as a pure service is undoubtedly TMC/iTMC functionalities and capabilities. In this frame, it is obvious that a classification of road infrastructure according to these capabilities, is a prerequisite.

7 Future Challenges

Despite the undoubted benefits of infrastructure classification, there will be challenges that need to be addressed, such as the transition to an ITS industry where the percentage of automated or connected vehicles will be increasing gradually. Especially in the early stages of this transition, the coexistence of conventional and automated or connected vehicles will be a high-risk factor. Therefore, all necessary measures must be taken to avoid incidents or reduce the consequences if they occur.

One of the challenges, not only the future but also nowadays, is the lack of data from semi- or fully-automated vehicles in real driving circumstances. Despite the fact that there are numerous automated functions with different ODDs even for the same driving task (in the sense that there might be differences in the way that a vehicle perceives its surrounding environment or in the way that the automated system interacts with the driver), the kind of information which can support a driving task to be performed automatically is similar for the different functions. For example, a lane change driving task can be supported with information regarding accurate localisation. So, this does not seem to be a big issue. However, it could prove useful in the future to define an ODD classification Scheme.

Another issue is that of the degree of TMC/iTMC involvement in automated functions and the requirements definition for the transition from manual to control mode (e.g. minimum risk manoeuver by TMC after the failure of manual take over control). Also, the TMC itself has special characteristics. I2V communication is not point to point and is influenced by many factors such as ODD or vehicle interaction.

Downgrade or upgrade of the ISAD class under specific conditions (e.g. weather, traffic incidents, road conditions, and technical failures) is also a complicated topic. Will, for instance, the ISAD class transition be relevant to all the SAE levels and vehicle types? Will be the same criteria for all the infrastructure of the same class, or they will be affected by local characteristics and specific features (weather, road conditions etc.) related to ODD also? Who will decide such a downgrade/upgrade? How the users/drivers will be informed? What about the legal responsibilities in case of incidents during the upgrade/downgrade?

The definition of quality in more detail is a challenging task. There is a difference in the requirements towards data quality. if the detailed map of the changed lane layout in a road work zone is used by a vehicle either to start an early handover procedure – since the vehicle is not able to navigate itself through the changed layout of the roadwork zone – with emphasis on timely communication or to navigate through the road work zone – with emphasis both on timely communication and digital map information accuracy.

Concerning individual driving monitoring, this is another challenge with many different aspects. Profiling of different driving styles is difficult to define. Defining objective criteria for driving style in certain conditions is also difficult. Then, implementation and communication of customised messages is also a complicated task. Last but not least, cybersecurity aspects are also involved.

New legal issues are going to come up. Liability for an accident will become more complicated than nowadays. Who will be responsible for an accident: driver, car manufacturer, the infrastructure authority or the third-party service provider? GDPR and cybersecurity issues will also be difficult to face. Big data fusion and process, data storage, transfer of personal or even sensitive data, access to these data by TMC/iTMC personnel are subject to cybersecurity incidents and careless or bad human handling. Harmonisation of legislation between different roads and different countries is also an issue that should also be considered in detail. Is this harmonisation desired or local rules should prevail?

All the ITS stakeholders, including users / drivers, should be trained in new technologies and functionalities, supported or controlled by TMC/iTMC. Even driving license exams might be affected.

A platooning service provider is a new service dealing with operational (pairing / unpairing), strategic (itinerary planning) and economic factors. These aspects go beyond the geographical scope of a TMC and therefore limit the potential effectiveness. An enhanced TMC/iTMC could play this role, but it might require agreement with other elements in the value chain (logistics operators) and definition of the commercial role of a public or private TMC/iTMC. Anyway, criteria for platooning are widely discussed in the literature, and the main barriers seem to be commercial as clear governance in the multi-operator management of the platooning should be defined.

From the analysis above, it is clear that defining an ISAD classification scheme should take into consideration many interacting aspects. When considering potential services for TMC or infrastructure management, it is essential to understand which possible business models could be developed, what are the strategies of key stakeholders, as the automotive industry and the infrastructure industry. The return of investment in technologies is not clearly defined. This could affect development strategies.

It has already been mentioned that some services imply legal and commercial aspects (e.g. the platooning service provider): is TMC the ideal “manager” for this? A governance model should probably be investigated when defining a taxonomy for infrastructures because of several legal and commercial aspects.

8 Mobility as a Service

Digital technologies not only are transforming vehicles and how we interact with them, but they are also redefining transport infrastructure. Smart infrastructure technologies are going to be embedded in road infrastructure through TMC/iTMC capabilities, described in previous sections. Vehicle to Vehicle and Vehicle to infrastructure communications as ISAD class functionalities are key players to achieve the full potential of automated driving. Together, these innovations provide the opportunity for a transport infrastructure system that suffers less traffic jams, is safer, and can be maintained effectively. But mostly they build a future with incredible services, in which vehicles will speak to vehicles, drivers will pay their bills or prepare their presentations for their job while driving, vehicles will use smart priorities, transfer goods from supermarkets and park without a driver.

How can effective principles be applied to take full advantage of such intelligent assets and help them contribute to Mobility as a Service? The answer lies in letting a highly networked transport system, detailed and precisely described and categorised in classes, behave as a holistic system, relying on an environment with rich interaction between vehicles and the infrastructure by which they are supported or even controlled.

9 A roadmap to automated mobility – the ASFINAG example

One of INFRAMIX's objectives is to "Provide a roadmap and guidelines both for short and for the long term (towards automated transport systems) to support infrastructure owners, road operators and relevant authorities.". This chapter gives an overview on how ASFINAG as a road operator was and is dealing with the challenges.

9.1 Traffic management

One of the topics that will gain more and more focus as automated mobility becomes more frequent is the role of traffic management centres. ASFINAG has a centralized database for all their roadwork information and several interfaces via which different stakeholders can collect the up-to date information. Roadworks and traffic information are available in 14 languages. Currently, ASFINAG is working on providing this information also specifically for each lane. The information is transmitted to the VMS via the already operational fibre-optic network along the entire ASFINAG road network. In the future, it will be additionally transmitted by wireless technologies.

Traffic management will also be improved by route recommendations, which are published in MaaS applications such as the *Kompagnon* function of the ASFINAG mobile phone app *Unterwegs*.

9.2 Communication technologies

The data that is collected and prepared by the traffic management centre needs to be transferred reliably and in time to the automated vehicles. The road network of ASFINAG is supplied with a fibre-optic cable network which connects the VMS and various sensors to the traffic management centres. As for wireless communication, ASFINAG plans to use a hybrid approach to cover both long-range and short-range needs. The long-range communication will be covered via the cellular network (at least LTE is needed, maybe even 5G dependent on the payload of the network; however, 5G is not yet operable). The short-range communication is covered via a WiFi technology specific to traffic messages, ITS-G5, also called pWLAN, which has been standardized (IEEE 802.11p) and has already been tested successfully multiple times, including the ASFINAG test track on the motorway A2 near Graz.

ASFINAG has started a tender for C-ITS rollout in 2018 as specified by C-ROADS, using the standards of the ECo-AT system specification. This involves a long-term contract for a central station and several hundreds (500+) of roadside stations. The rollout will start in 2020 and cover in a first step the Vienna region and extensions to Linz and Salzburg with around 170 C-ITS roadside units. In a second step starting in 2022, it is planned to install 350 further roadside units on almost the entire ASFINAG road network.

9.3 Ultra-high definition maps

For the entire ASFINAG road network, traditional standard digitial map material on different quality levels exists. For sections that have recently been measured for road construction, high definition map material already exists with a variance of 10 to 15 cm. The most recent effort is the preparation of ultra-high definition (UHD) map material. ASFINAG cooperates with external partners from the automotive sector (industry, academia). The test track on the A2 near Graz has already been recorded with an accuracy of (+/-2 cm). The resulting point cloud has been analysed and transformed with complex algorithms into a reference map to create a “Dynamic Ground Truth” which is ten times more accurate than the already existing high definition maps. In order to standardise this highly exact localisation within the coordinate system, passmarks have been installed on the ASFINAG test track. The prepared UHD map data can be provided via interfaces to simulation programmes such as IPG-Carmaker or Visim and imported for specifically programmed visualisations of the road, the ego car, or car trajectories.

Further UHD mapping of road sections is in progress and will be expanded continuously, e.g. on part of the motorway A9 in the direction from Graz towards Slovenia.

9.4 Weather stations

The test track of ASFINAG between Lassnitzhoehe and Graz West is equipped with 29 sensor stations for weather and environmental data.

In 2017, ASFINAG has implemented a new weather forecast system to create detailed forecasts for 240 microclimate weather sections. This programme uses input from public weather data providers plus the sensory data from the weather stations. It calculates prognoses for temperatures, rainfall, snowfall, snowline, wind speed, clouds etc. It also provides a detailed forecast of 10 days for these small road sections and has a detailed depiction of rain- and snowfall of the last hours plus a prognosis for the next hours. This information is used by the motorway maintenance personnel to schedule or initiate gritting, preventative salting and snow removal.

9.5 Mobile roadworks trailers

ASFINAG has been working on the development and testing of intelligent mobile roadworks trailers with VMS, CB radio transmission and C-ITS communication equipment using WLAN technology. These trailers can be used for traffic management and broadcasting C-ITS messages regarding roadworks warnings in road sections without existing cable connection to the traffic management centre or cellular connection. A first deployment of these trailers is in progress and will take place in 2020.

10 Conclusions

The following conclusions can be drawn:

- The infrastructure classification Scheme can facilitate the transition period to higher levels of automation, indicate modularity and scalability in functionalities and services, help ensuring safety and security, and handle different system lifecycle integrations. However, there are several challenges to face: the connection between the ISAD classes, the SAE Levels and the ODD concept, liability issues, the lack of real data from CAVs, governance and regulation, conflict of stakeholders' interests, and others. Also, the expansion to national and urban roads is required, since the current classification refers to highways only.
- Road infrastructure will not only be a valuable asset for automated driving, in the future there will be a partnership (teamwork) between vehicles and road infrastructure. Quickly learning fleet data, based on a combination of vehicle data and infrastructure, can contain complex traffic flow information as guidelines for individualized speed, distance, and path. These guidelines, taking into account traffic control measures, would allow for smoother and healthier activity in heavy mixed traffic, allowing both traffic jams and risky movements to be minimized.
- Functionalities that may, from today's point of view, be supporting automated driving in the future are listed in the descriptions of the different ISAD classes as described in Table 1. We also gave examples for possible implementations of these functionalities. The classification starts with class E which most current highways can be categorised as, fulfilling all legal requirements, but providing no additional data.
- The ISAD Scheme would probably not be sufficient for a national regulatory framework as a vehicle manufacturer is not going to implement several different solutions across Europe. Therefore, global governance may also be preferable for advanced automated capabilities and higher ISAD classes.
- The improved traffic management capability and the complex enhancement or deterioration of the infrastructure class due to special conditions, accidents or extreme weather could improve traffic productivity in addition to the safety aspect. This will be enabled by advanced traffic management technology in TMC / iTMC as well as on-board sensors. Because of the different viewpoints of on-board sensors and infrastructure sensors, cooperation and merging of their data is a key factor.
- Given ISAD's undoubted advantages, there will be problems that need to be tackled, such as the transition to an ITS industry where the percentage of automated and connected vehicles will gradually increase. The coexistence of conventional and automated or connected vehicles could potentially be a high-risk factor, particularly in the early stages of this transition. This is one of the reasons why the issue of mixed traffic is the main focus of the INFRAMIX project.
- In the direction of simulation and demonstration of the "automation-appropriate levels", a proof-of-concept demonstration was made with hybrid testing in the scope of Task 4.4. In this demonstration, IVIM messages sent from an RSU were used to initiate speed recommendation to the connected automated vehicle, thereby showing how connected

vehicles can react to such recommendations in the scope hybrid testing framework. This also demonstrated the virtual implementation of closed-loop ISAD class B system evaluation with virtual static and dynamic traffic components and real AV vehicle with real ADAS functions. The results of the Hybrid testing implementation is reported in deliverable D4.2. Further analysis will be made using the same framework in the scope of sub-microscopic simulation analysis and to be reported in the scope of deliverable D5.3.

Moreover, microscopic simulation in INFRAMIX allows drawing conclusions regarding the highest classes A and B and how the introduction of new technologies (sensors, communication) in real-time connection with advanced algorithms could improve traffic efficiency. Therefore, different simulation series are planned with the focus on

1) Control Algorithm Evolution (Speed Advice, Lane Change Advice etc.),

2) Control Segment Virtualization (number of VMS per segments up to purely virtual control via ITS-G5 or Cellular Link), and

3) AV Lane Localization (dedicated lane for AVs).

According to the main objective of INFRAMIX, these simulation series always regard for the penetration rate of equipped vehicle with communication technologies or even automated vehicles to analyse mixed traffic situations. The results will be reported in deliverable D5.3.

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