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Road infrastructure support levels for automated driving

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Abstract
The environmental perception of automated vehicles is limited by the range and capability of on-board sensors. Road infrastructure operators already employ numerous traffic and environmental sensors and provide information that can be perceived by automated vehicles. In order to classify and harmonize the capabilities of a road infrastructure to support and guide automated vehicles, we propose a simple classification scheme, similar to SAE levels for the automated vehicle capabilities. These levels can be assigned to parts of the network in order to give automated vehicles and their operators guidance on the "readiness" of the road network for the coming highway automation era.

Keywords:
Road infrastructure, automated driving, support levels

1. Introduction

By now, most of the research on Automated Driving (AD) has been focused on enriching the Automated Vehicles (AV) capabilities. Indeed, if we think of a future scenario where all the vehicles are fully automated, the role of the infrastructure might seem quite irrelevant. Nevertheless, this fully automated future is still far away [1]. In the meantime, there will be a long transition period when conventional vehicles will coexist with AVs with different (and even variable) levels of automation, referred as mixed traffic. In this scenario, the role of infrastructure and the road operators will be crucial. On the one hand the infrastructure needs to be digitalized to support AD [2], and on the other hand, the Traffic Management Centre (TMC) needs to manage all vehicles (including conventional ones) in order to ensure a secure and smooth travel to all the users.

Even though it is a quite recent topic of research, the role of road operators in AD is already addressed [1, 3, 14]. Indeed, there is a growing interest from both, industry and public administration, to contribute in the development of this "hybrid infrastructure" [12] that will support and manage the mixed traffic of conventional and automated vehicles in the following years. Nevertheless, most of the literature still consists of position papers written more in a "wish-list" mode than focusing on infrastructure elements and capabilities that can be made available using technology of today or of the near future. A lot of research still needs to be conducted to clearly understand what will be required from the road operators (when, where, etc.), and how it will be provided (if possible) to all the users on the road during the transition period from nowadays to full AD. Currently, the EU-funded project INFRAMIX, started in June 2017, is researching in this direction [12].

From a research point of view, it is thus important, to test and evaluate as many different traffic situations as possible in order to answer open questions, in the most possible realistic scenarios. But even more important is to guarantee that these requirements are gathered and further used in a harmonized way worldwide. Indeed, differences between countries are obvious, the total road length and type of roads, their equipment, the traffic regulation, economic wellness, and even the weather conditions (which can be determinant for AD), and it would be impossible to inform an AV about all the functionalities of each road, requiring different actions or behaviours. Furthermore, public administrations cannot create regulation rules in order to guarantee safety for all existing particular real world cases. It is essential to

define a harmonized classification framework similar to the SAE levels for the AV to easily and universally identify the capabilities of the road infrastructure to support AD.
This paper presents, to the best of our knowledge, the first attempt to define a classification scheme to harmonize the capabilities of the infrastructure to support AD. It is based on the idea of gradual steps towards full digitalization of the infrastructure and the information that can be delivered to AVs in order to support driving and effectively performing traffic management tasks for the coming highway automation.
This work is a joint work of ASFINAG and ABERTIS AUTOPISTAS, two European road operators that already maintain a digital infrastructure on which many aspects of AD support can be built on. This work is being conducted in the context of several research projects that will be further detailed in the paper. In Section 3, the role of the road operator to support AD is further analysed, and Section 4 presents the classification of infrastructure capabilities to support AD. Finally Sections 5 exemplifies infrastructure capabilities in two particular cases, Austria and Spain, followed by conclusions and some open issues for future work.

2. Related Work

Smith [5] describes the various means to promote automated driving from a governmental perspective. This includes not only technical elements, but also legal frameworks, societal aspects etc. In this paper we rather focus on technical aspects of the road operator's infrastructure. A recent survey of Farah et al. [3] gives an overview of research related to road infrastructures. They distinguish between digital infrastructure, and physical infrastructure which includes also the design of new road geometries with e.g. dedicated lanes for automated vehicles. Considering the introduction of automated vehicles while conventional vehicles remain part of the road traffic for at least a decade and the even longer terms or road building, we see the digitalization of road infrastructure as a key issue for road operators. Exploiting infrastructure sensors as described by Rebsamen et al. [16] is an important aspect, which we try to describe within the context of road operators and latest state-of-the-art technology. Aspects of connectivity and its importance to advanced driver assistance as highlighted by Sanchez et al. [17] are a further aspect that is linked to the digital infrastructure. As a consequence, digitalization is an important aspect in the categorization of infrastructure support that we propose in this paper. The levels of infrastructure support is clearly inspired by the SAE levels [4] for automated driving, but are not meant to link them together.

3. Road operator requirements to support AD

Automated vehicles are supposed to be independent of road infrastructure elements and to rely solely on its built-in sensors. However this local technology which is used in today's advanced driver assistance systems relies mainly on the quality of infrastructure elements like adequate reflectivity of lane markings or the readability of variable message signs (VMS) and is therefore limited in localization precision. Road operators can support the vehicles' sensor systems by using AD-reflective lane markings and feasible sensor readable extensions of VMS if digital content is not available.
Considering that automated vehicles at a certain SAE level [4] depend on precise localization, GNSS reference points become important elements of the physical infrastructure, especially in areas with missing or bad GNSS coverage such as, e.g., in tunnels.
The physical readable information about lane markings and speed limits can be in some situations replaced or supported by map content based on static information. The latter is typically provided by map providers and road operators. This static information is crucial for managing the self-driving vehicle. It can be further enhanced by additional layers of dynamic content, such as information about temporary changes (e.g., roadwork information, speed limit regulations, and warnings about obstacles on the road). Nevertheless, conventional VMS will remain important due to the long transition phase of estimated several decades between conventional road users and automated road users [2].
In addition to conventional requirements, Car2X communication will be strengthened compared to the European C-ITS roll-out [9]. But the communication between vehicles and infrastructure can be implemented not only by short range communication standard ITS-G5 [16] but also by cloud services based on cellular communication [10]. The advantages of each technology is part of current investigation [5, 10, 12] and completes the picture of hybrid communication. The cooperation and interoperability of

the hybrid communication as well as VMS is part of the INFRAMIX project which focuses on new infrastructure elements, required upgrades of ITS services for automated driving and new traffic management algorithm in order to control mixed traffic [12].
The expectation on automated vehicles is to navigate autonomously through the traffic. In fact, the so-called electronic horizon restricts automated vehicles in mixed environments. While state-of-the-art sensor technologies used in automated vehicles cover only 200-300m along the road and are not distributed equally in all directions, the horizon can be enlarged to 700-800m or a time equivalent of 20 seconds for route planning at critical traffic points using road infrastructure data. The therefore required surrounding traffic data is acquired by radar (see Figure 1), video, lidar and ultrasound sensors which are already installed and used for general traffic management systems.

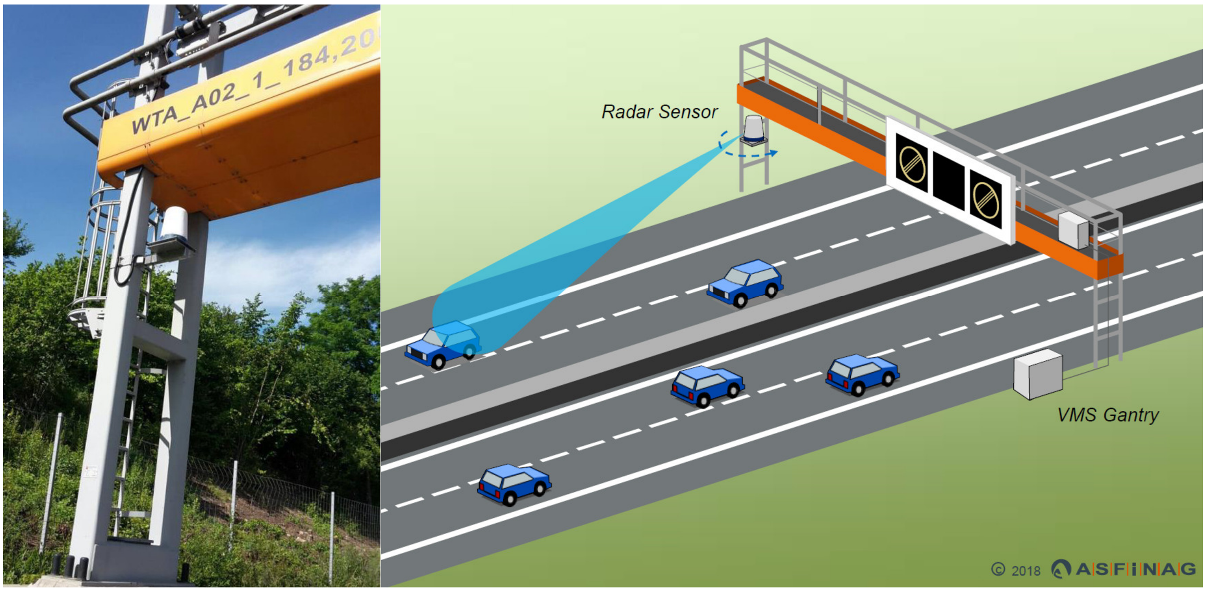

Figure 1 – Fixed infrastructure radar

Considering the comfort of non-degradation and also the safety aspect of a higher perception of the road ahead, the data fusion of vehicle sensor data, required map information and additional road infrastructure data is required for the mixed traffic concept. Different scenarios can be imagined where infrastructure data improves predictive manoeuvres, e.g. by providing warnings of obstacles on the road, of traffic jams or adverse weather conditions like black ice.
Moreover, data of the digital infrastructure, see Figure 2, can be even used to guide the mixed traffic by advising an optimum distance gap between vehicles in order to, e.g., support lane merging or dissolve platoons. The active guidance of automated vehicles is required when aiming at an efficient traffic flow. Latest studies about the capacity impact of mixed traffic in different penetration rates [13] point out that the road capacity will not be increased at all situations without guiding the on-ramp traffic flow.
The multitude of data which is provided and exchanged between the infrastructure and the vehicles poses additional challenges on cyber security for road operators. Guidelines on data security were published recently [11], this is however not considered within the scope of this paper.

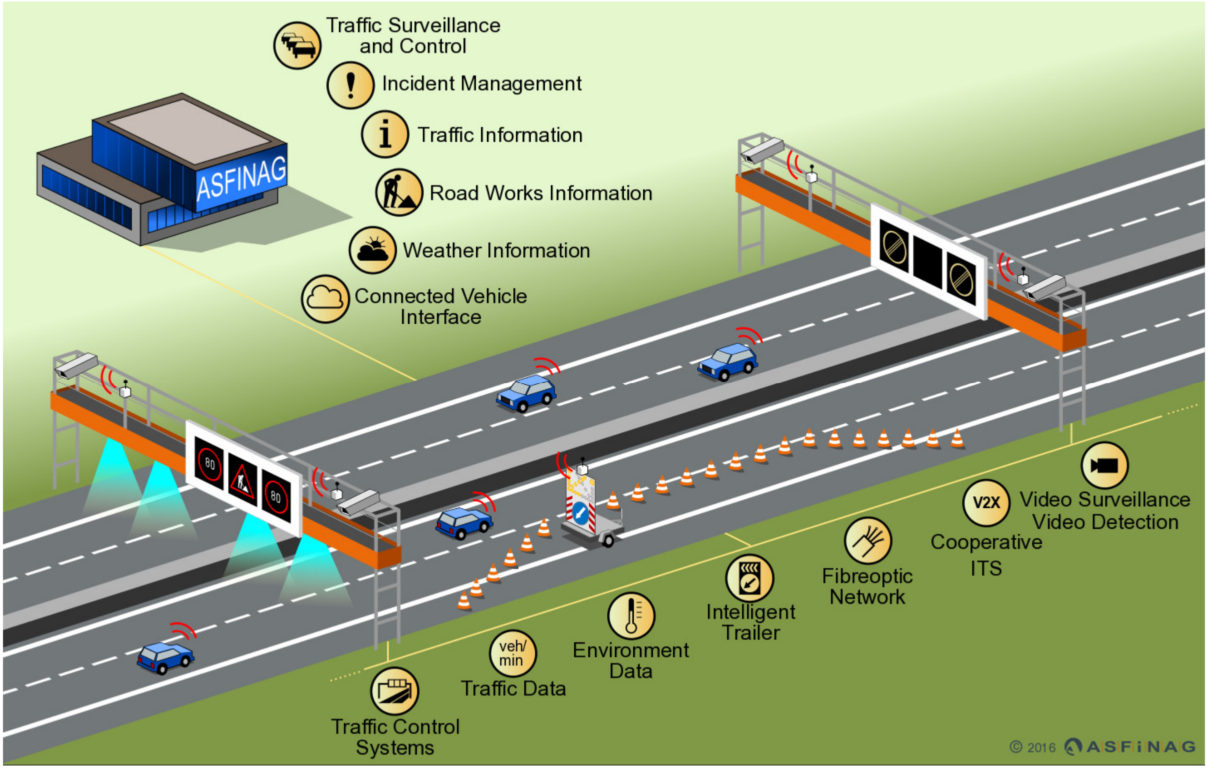

Figure 2 – State-of-the-art elements of the digital infrastructure

4. Infrastructure support automated driving

In order to structure the various means of support that infrastructure can provide towards automated vehicles, we propose 5 levels of infrastructure support for automated driving (ISA). This is based on the idea of the SAE levels for vehicle capabilities. Infrastructure support levels are independent and not linked to SAE levels, i.e. an SAE-Level-3 automated vehicle does not need Infrastructure Support Level B to operate.

Figure 3 shows the description of the 5 ISA levels, along with the information that is provided to automated vehicles. The ISA levels start with the conventional infrastructure without any support for automation (Level E). The availability of a digital map with static regulatory information (e.g. speed limits) is assigned to Level D. At Level C begins the full digitalization of infrastructure elements and thus the availability of all relevant digital information in digital form, esp. VMS, traffic lights, which can be extended by further environment information. Level B describes infrastructures that are able to perceive complete traffic situations on a microscopic basis by specialized sensors (e.g. fixed infrastructure radars). This sensor data could be augmented by data coming from vehicles such as probe vehicle data, and more advanced cooperative perception messages. However, using this data alone does not provide microscopic traffic perception capability as it relies on the equipment of vehicles. At Level A the infrastructure uses its traffic perception capabilities for microscopic traffic management. Microscopic traffic management goes beyond dynamic speed limits (currently displayed on VMS) and provides optimal speed advice, lane usage and lane change recommendations, advice on inter-vehicle gaps etc. to automated and connected vehicles.

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
Digital infrastructure	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

Figure 3 – Levels of the Infrastructure Support for Automated Driving (ISA Levels)

Use of ISA levels

Infrastructure support levels are meant to describe road or highway sections rather than whole road networks. This reflects common practice of infrastructure deployment: Traffic control systems (sensors and VMS) are usually deployed on motorway sections where traffic often reaches the capacity limit (e.g. in metropolitan areas), whereas other motorway sections need no fixed installations of traffic control systems because traffic flow is rarely disrupted. Figure 4 shows an example how ISA levels could describe the changing support along motorway segments. If a complex intersection is covered by dedicated traffic sensors, traffic situation awareness (level B) and even AV guidance (level A) could be provided. Other sections provide only level C support, which includes that VMS data is made available via digital interfaces. Furthermore, in this example the secondary road network is covered partially by map support (Level D), some rural areas have no support. This example illustrates how ISA levels can be used for a simple description of what automated vehicles can expect on specific parts of a road network.

Connectivity requirements

The ISA levels A-D are connected with certain requirements for connectivity. Level D (map support) requires only sporadic connectivity in order to update map data and attached regulatory information. At Level C, where also dynamic information such as speed limits on VMS are provided, the vehicle needs updates on a regular basis (a few seconds) in order to be able to receive changing information in time. At Levels B and A, real time sensor information is exchanged with vehicles, which requires data exchange on a high frequency (milliseconds range).

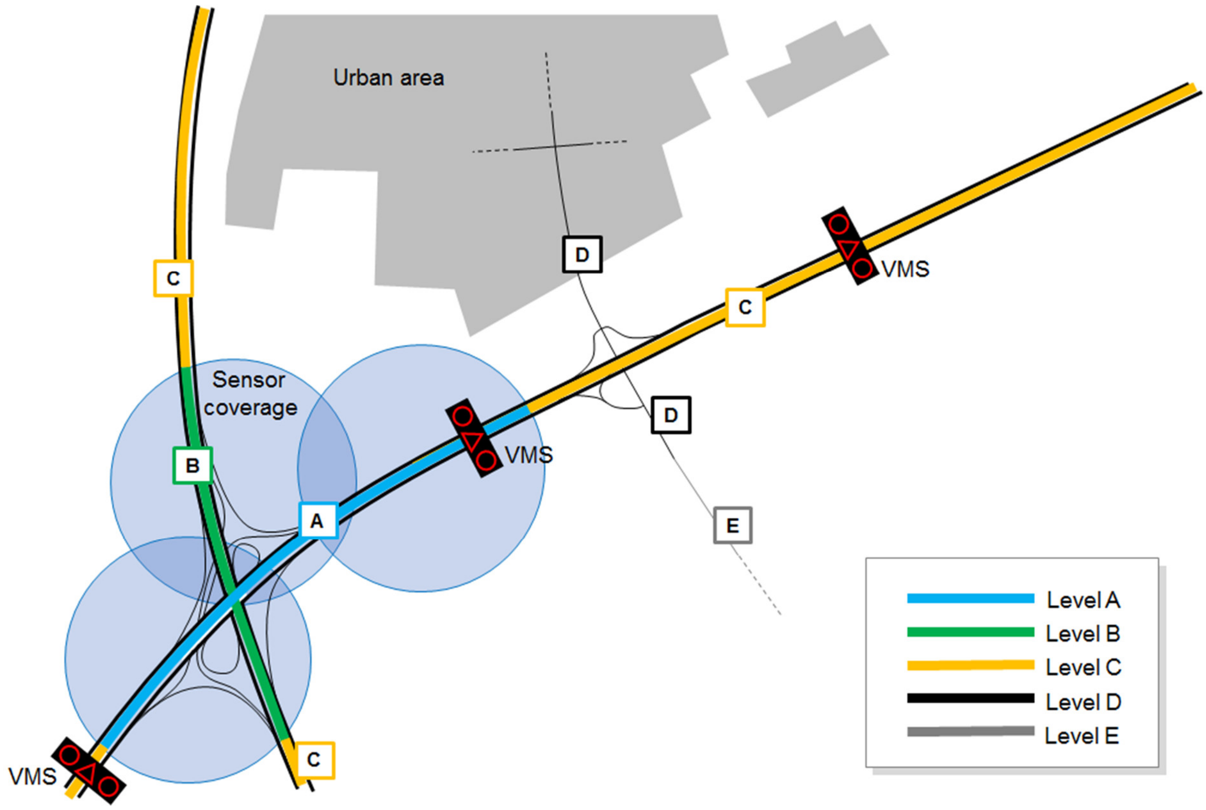

Figure 4 – Examples of ISA Levels assigned to a road network

5. Road equipment for AD

Visible road infrastructure like lane marking and message signs are state of the art elements of every national road operator like video camera surveillance is for live incident management. But manual controlled traffic management centres (TMC) can nowadays also rely on, e.g. radar sensors [6, 7, 8] or traffic counters which provide digital information for rapid alert systems via variable message signs in order to identify quickly vulnerable road users or for controlling the traffic behaviour. However, the road equipment and the control of traffic flow will change. Assuming an automated vehicle is connected via C-ITS and also exchanges probe vehicle data and traffic information with the TMC, C-ITS equipment and standardized traffic message interfaces are part of the digital infrastructure [9]. Besides the passive control of traffic flow and incident management via traffic and infrastructure sensor data, active control via the digital information, e.g. lane suggestions, merge information and roadwork layers, need to be provided for critical points on the road.

Since the detailed requirements on road infrastructure for mixed vehicle traffic flows are under investigation [12], test areas like in Austria and Spain are important to investigate traffic management strategies and new road infrastructure elements for SAE L3/L4 vehicles in a mixed traffic situation.

Status Quo in Austria: ASFINAG

The Austrian road operator ASFINAG operates a 2200 km long road network. Focusing on tackling the challenges of mixed traffic scenarios and the development of automated driving, a twenty kilometre long test site, called “ALP.Lab”, on motorway A2 close to the city of Graz is deployed (see Figure 5). The aim of this test site is to provide a total package of physical and digital infrastructure for validating automated driving functions and test new traffic management strategies for cooperative and connected automated vehicles.

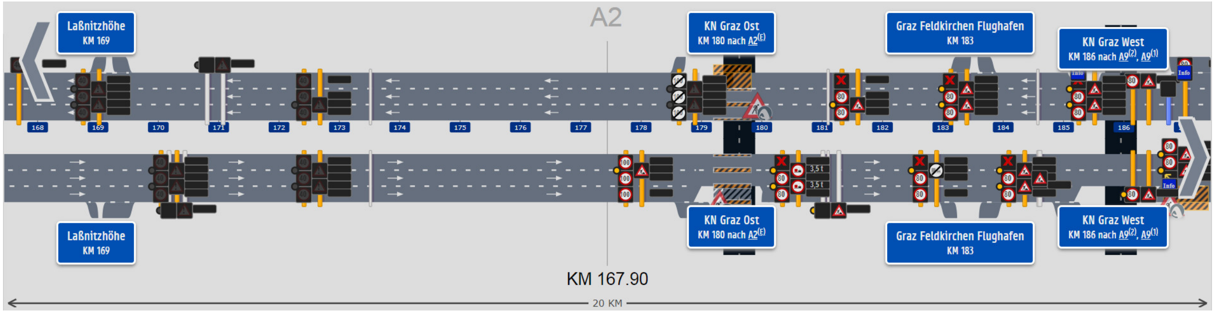

Figure 5 – ASFINAG test site (schematic view)

The infrastructure is based on a fibre-optic network that provides IP-based network connectivity to gantries. HD video based image processing algorithms are used to provide information about the traffic flow and anonymized information about velocity, vehicle type and lane usage. Additional different sensor technologies, such as traffic detectors and infrastructure radar sensor technology [6] are installed to acquire anonymized single vehicle data. By merging the sensor data, traffic information from a bird's eye perspective can be generated. This highly reliable data can not only be used to validate automated vehicle's trajectories and the surrounding traffic but also support automated vehicles in complex traffic situations. The data can be played back via a 3-D simulation tool for visualization. Information about adverse weather conditions can be provided by environmental sensors. This data is used at the TMC to change the 12 VMS accordingly.
Additional to the sensor technology, the test site is equipped with C-ITS road-side units and intelligent, connected, mobile trailers to provide, e.g., C-ITS Day 1 Services like VMS information, road works warnings and additionally first services for automated vehicles. This data can also be provided via a DATEXII interface to cloud services. Consequently, ASFINAG has already the basis to provide ISA Level C support for automated driving on the test site. Infrastructure radars even support the microscopic perception, which is required for ISA Level B.
ASFINAG participates in different activities of harmonization of C-ITS services such as C-Roads [9] and is also part of the R&D project INFRAMIX in order to guarantee safer and more efficient traffic management of mixed traffic.

Status Quo in Spain: AUTOPISTAS

With over 8.300km of highways, Abertis operates in 14 countries. In Spain, Abertis is named Abertis Autopistas España (Autopistas). Autopistas manages over 1.500km of roads, with an Average Daily Traffic (ADT) of 28.191 vehicles. An advanced connectivity consisting on a 10 Gigabit Fibre Optic Ring is available in all the roads, connecting the infrastructure to the corresponding TMC, and the TMCs between them. The Gigabit Ring includes 140 nodes and 5.000 IP devices.
Regarding ITS, the Autopistas total road network includes 500 VMS, a TV closed-circuit including 630 cameras, as well as cameras shipped in vehicles, 350 magnetic loops (with a plan of extending this number to 500 during 2018), 100 weather stations, and 1500 SOS posts (connected to the FO Ring). For traffic management, the infrastructure includes 311 traffic measurement points.
Availability of HD maps is also an important issue for supporting AD as identified previously in this paper. In the case of Autopistas, an Aerophotogrammetric restitution and a Video inventory (Mobile Mapping) are available from all the network.
Furthermore, Autopistas is deploying a 20km test site for C-ITS and AD (see Figure 6) which will be used by the C-Roads Spain project and the INFRAMIX Project from 2018 to 2020. In this section of the AP-7 (Mediterranean Corridor), 100 sensors and at least 10 ITS-G5 Road Side Units are going to be installed, and most of the C-ITS Day 1 Services will be deployed before August 2018 (see Figure 7). These efforts will lead to an ISA Level C support for automated vehicles on the test site.

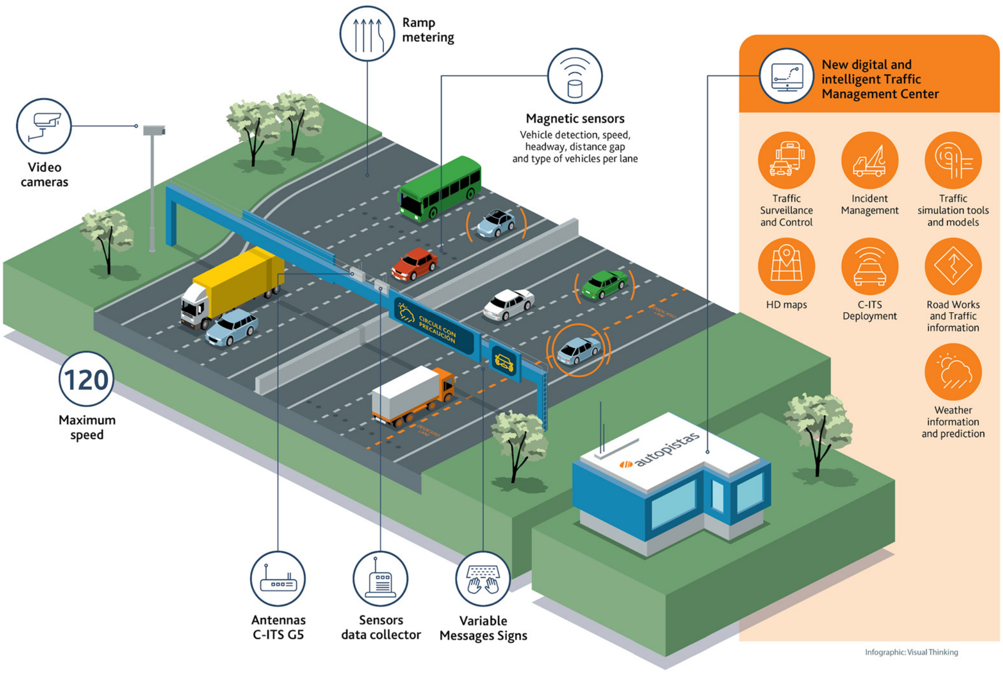

Figure 6 – AUTOPISTAS C-ITS and AD test site (functionalities)

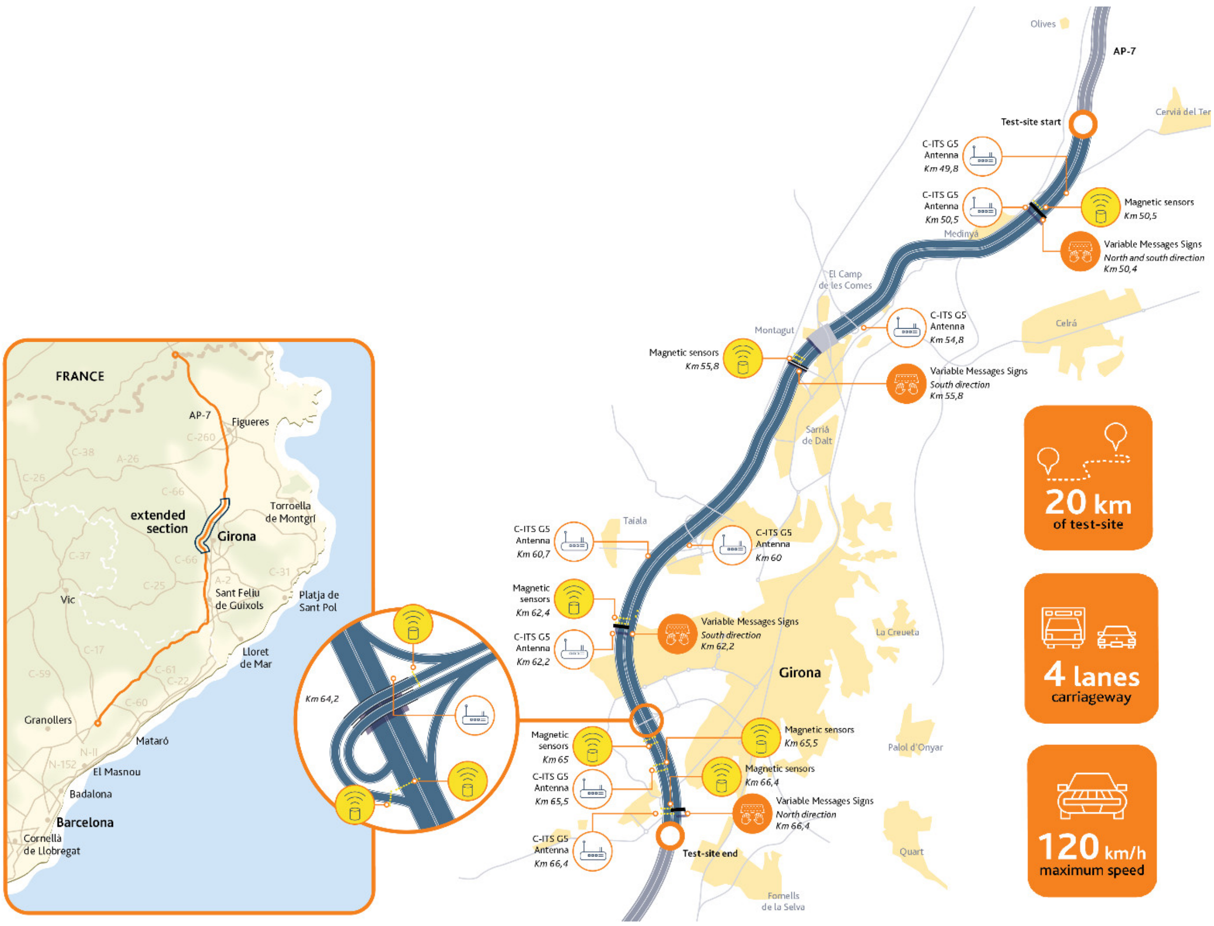

Figure 7 – AUTOPISTAS C-ITS and AD test site (schematic view)

6. Conclusions

The road infrastructure can support and guide automated vehicles by using physical and digital elements. Five levels of infrastructure support for automated driving (ISA Levels) are defined in order to categorize the various means of infrastructure elements and capabilities that support automated vehicles. These levels ISA levels can be used to inform automated vehicles about the road capability on certain road segments. The underlying exchanged information from sporadic connectivity to cooperate guiding support are described. Several research activities are started to develop new infrastructure elements as well as new traffic management strategies for supporting automated vehicles in critical situations. In order to evaluate and test the new infrastructure concepts several AD test sites are deployed whereof the latest status in Austria and Spain is presented.

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