PIARC Special Project
"Smart Roads Classification"

PROPOSAL

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Acronyms and Abbreviations

3GPP – 3rd Generation Partnership Project
ADS – Automated Driving System
AS – Assistedway Smart Level
AT – Automatedway Smart Level
AU – Autonomousway Smart Level
AV – Autonomated Vehicle
AVRI – Autonomous Vehicles Readiness Index
BSI – British Standards Institution
C-ITS – Cooperative Intelligent Transport System
CAV – Connected and Autonomous Vehicle
CRCS – Connected Roadway Classification System
C-V2X – Cellular V2X (Vehicle-to-Everything)
DDT – Dynamic Driving Task
DL – Dedicated Lane
DSRC – Dedicated Short-Range Communication
EAPA – European Asphalt Pavement Association
EU EIP – European ITS Platform
EV – Electric Vehicle
FA – Full Automatedway Smart Level
GNSS – Global Navigation Satellite System
HD – High Definition
HU – Humanway Smart Level
IEEE – Institute of Electrical and Electronics Engineers
INFRAMIX – Road INFRAstructure ready for MIXed vehicle traffic flows
ISAD – Infrastructure Support Levels for Automated Driving
ITS – Intelligent Transport System
ITS-G5 – European implementation of WLANp based on IEEE 802.11p or extended IEEE 802.11bd
KPI – Key Performance Indicator
LMV – Light Mobility Vehicle
LCA – Lane Centering Assist
LKA – Lane Keeping Assist
LOS – Level of Service
LOSAD – Level of Service of Automated Driving
LTE – Long Term Evolution
LTE-V2X – Direct peer to peer short range communication in 5.9 GHz
MRC – Minimal Risk Condition
MRM – Minimal Risk Maneuver
NR – New Radio
NR-V2X – Vehicle- to-Everything (V2X) standard based on the 5G New Radio (NR) air interface
ODD – Operational Design Domain
OEM – Original Equipment Manufacturer
ORS – Operational Road Section
PIARC – World Road Association
PMR – Penetration Market Rate
QoS – Quality of Service
RA –Road Administration
RO – Road Operator
ROD – Restricted Operational Domain
RSU – Roadside Unit
RTK – Real-Time Kinetics
SAE – Society of Automotive Engineers
SRC – Smart Roads Classification
TIER1 – Company that supplies systems directly to OEM
TSR – Traffic Sign Recognition
UPV – Universitat Politècnica de València
V2I – Vehicle-to-Infrastructure
V2N – Vehicle-to-Network
V2P – Vehicle-to-Pedestrian
V2V – Vehicle-to-Vehicle
V2X – Vehicle-to-Everything
VMS – Variable Message Sign
WAVE – Wireless Access in Vehicular Environments
WLAN – Wireless Local Area Network

1. Introduction

1.1. Background

Traditionally, road network classification systems have focused on two fundamental opposite dimensions: mobility and accessibility. Since its inception, these classification systems have evolved with the intention of adapting to the new circumstances of society. This is the case of the Expanded Functional Classification System [1] proposed recently in the United States to integrate the different types of users.

However, none of these classification systems considers the incipient appearance of Connected and Autonomous Vehicles (CAVs) on our roads, so a new Smart Roads Classification system for the road network is therefore required. In this context, two research projects have recently finished integrating the particularities of CAVs in road classification: Connected Roadway Classification System [2] and INFRAMIX [3]. The first one established a road classification based on three approaches: talking (vehicle-infrastructure communication), seeing (infrastructure readability), and simplifying (design and operations for automated vehicles); whereas the second one proposed a road classification focusing mainly on vehicle-infrastructure connectivity.

Existing autonomous vehicles consist of diverse Advanced Driver Assistance Systems (ADAS) that allow an automated driving experience under specific circumstances. Their role in the driving task has become so important that the Society of Automotive Engineers (SAE) proposed a 6-level classification of automation based on how human and vehicle share the driving task [4].

Despite the great effort of the automotive industry during the last decade, the most advanced systems nowadays are level 2 (3 at the most). Such driving automation system is not able to adapt to all circumstances that may arise along a road. An unexpected event triggers the system to transfer control to the driver. These control transfers could become an important safety weakness because of the unexpected event they produce in the driver. This issue increases as control transfers become less frequent, which means that, paradoxically, a system that generates fewer transfers of control might have worse consequences from a road safety perspective. In contrast, in sections with very frequent control transfers, drivers will probably end up switching off the system for their comfort. The frequency of control transfers depends on the system technology as well as the infrastructure and environment. In general, smoother road alignments tend to produce fewer transfers of control [5] [6] [7] [8] [9] [10].

To enable and promote a quick and reliable generalization of autonomous vehicles, users need to trust in their capabilities. A driver should not voluntarily decide whether to connect the assistances, but rather by having objective information about its operation along the segment to be travelled. This information must be provided by combining the characteristics of the infrastructure and the driving automation system.

In addition to the development of automated vehicles, there is also a boost in making use of connectivity and information-sharing to further enhance traffic operation and safety [11]. *Vehicle to X* (V2X) refers to an intelligent transportation environment where all vehicles, users, and infrastructure systems are interconnected. Connecting all elements – vehicles, road users, infrastructure, traffic, and weather data, and so on – will lead to more accurate knowledge of traffic situation across the road network, which in turn will help improve traffic operation, reduce road crashes, and minimize vehicle emissions.

Besides communication between vehicles (V2V), connectivity between vehicles and infrastructure (V2I) comes into play. This protocol will allow vehicles to interpret traffic signals and know who has priority in certain critical situations. Likewise, CAVs will be able to know the ideal route at all times as they will know the status of traffic in real time thanks to Vehicle to Network (V2N) technologies. Furthermore, since they are not on their own, Vehicle to Pedestrian (V2P) communication is also being developed to alert the presence of vulnerable users. Different technologies are being developed and deployed such as Roadside Units (RSUs) equipped with DSRC/WAVE and ITS-G5 or Cellular V2X (C-V2X) solutions based on the last releases of 4G and/or 5G technology at some urban zones and along main highways.

Automated and connected driving goes hand in hand with different political objectives that the European Commission, the United States, United Kingdom, and China has been pursuing for years. For this, the new CAVs must be integrated into the transport system, which requires the joint work of all agents involved. As a result, an adequate legal and political framework is expected that encourages mobility and automated driving.

1.2. Objectives

This Special Project aims at exploring the feasibility of a new framework for the classification of the road infrastructure. This framework is based on the road physical and digital characteristics and the hosting capacity of connected and automated vehicles.

Given that the presence of Connected and Automated Vehicles (CAVs) is on the increase, it is necessary to explore a new Smart Roads Classification (SRC) system that could provide information to users and vehicles on their degree of adaptation to automated and/or connected driving. This information should range from indicating which road sections do not allow any type of autonomous driving, to sections that are ready for any autonomous system, going through various intermediate degrees depending on the technology. Additionally, the system should consider information about the connectivity capabilities.

An integral road classification system would also allow an efficient planning of public investments on physical infrastructure, by enhancing operativity of driving automation, and on digital infrastructure, by increasing the benefits of connectivity between highways and their users (V2X). End users will be informed about the level of automation they can enable through each road segment. Consequently, a safer, more sustainable and comfortable road network is expected.

This system should be based on existing autonomous driving and connectivity technologies and be highly resilient, so it could be quickly adapted to the technology progress, research findings, and best practices. It should also be compatible with existing road classification systems and the coexistence with other human-driven vehicles and users.

The new classification system should be universal – i.e., applicable to roads worldwide –, and agreed upon, to enable a simple-to-use and rapid-to-implement tool. In this way, the SRC would allow road decision makers the planification and prioritization of investment needs in physical and digital infrastructure, including no-regret measures, to progressively expand and encourage an automated and connected driving.

Summarizing, the SRC should fulfill the following objectives:

- Common language, to facilitate communication between all stakeholders;
- Useful, to facilitate the application by Road Administrations or road operators;
- Universal, to be applicable to roads worldwide and to all types of roads;
- Standardized, to ease its development and implementation;
- Interoperable, to facilitate data exchange;
- Robust, to provide an adequate and coherent smart level for every road segment;
- Consistent, to facilitate adequate messages for users;
- Simple, to ensure understanding for users;
- Integrable, to facilitate the necessary transition from the current classification systems;
- Dynamic, to reduce the assigned intelligent level after sudden variations in environmental and operational factors;
- Flexible, to be quickly and easily adaptable to technological advances and sudden variations in technology operation; and,
- No liability for road administrations or road operators.

2. Literature Review

This section contains the main findings and conclusions of the impact of automated driving at the infrastructure level which can be grouped into the following categories: (i) impact of automated driving on road classification systems; (ii) current automated driving limitations; (iii) role of connectivity in automated driving; (iv) definition of key concepts linked to automated driving; and (v) the implications of automated driving on safety.

First approaches on **road classification systems** were focused on motorized vehicles driven by humans. In the last decade, some road administrations have incorporated vulnerable users, such as cyclists and pedestrians, in the classification of the road network [1]. However, this is not enough as automated vehicles already are a reality in our roads.

To address the integration of CAVs in road classification systems, some efforts have been carried out in the last years that include different approaches [2] [12] [13] [14]. The Connected Roadway Classification System (CRCS), based on three main approaches – talking, seeing, and simplifying –, can be very practical for road administrations and operators to allocate investments, but not for road users as the classification system does not stablish clear road levels [2]. To this regard, the proposed classification system defines the attributes or conditions to be gathered in each road level but does not specify the thresholds for these attributes. Therefore, the application of the system requires of further development.

The ISAD levels proposed in the INFRAMIX project [12] add a critical aspect for automation – especially the highest levels –. However, connectivity is not sufficient on its own to define how ready a road section is to host automation. For instance, smooth alignments with weak connectivity are likely to be more drivable by automated vehicles than low-end ones – winding roads – with magnificent connectivity conditions.

Despite the benefits, these levels still require to be completed with additional information to be fully adopted by road administrations and operators. This information includes, but it is not limited to, the accuracy of the maps at the different levels, the update rate of the static information, communication capacity and protocols to/from vehicles, and so on.

The classification system proposed by the EAPA [13] relies on connectivity and vehicle capabilities. In this way, six road classes are defined depending on the ISAD levels [12] and SAE levels of automation [4]. Additionally, the classes are complemented with a number of stars that indicates the integration of electric vehicles (EVs). Despite the inclusion of some key parameters associated with the infrastructure – road marking, signs, and pavement condition –, other important factors – e.g., road geometric design – are not considered. Thus, this classification system underestimates some essential factors that present a great influence on CAVs performance.

Finally, the Autonomous Vehicles Readiness Index (AVRI) includes issues or items not considered by the previous systems such as *Consumer acceptance* and *Policies and regulations* [14]. These items together with *Infrastructure* and *Technology and innovation* are the four pillars that define the level of automation of a country at a macro level. The AVRI cannot properly reflect the degree to which a road network is enabling an automated driving because of its definition. In fact, the infrastructure pillar is mainly based on items related to connectivity, disregarding physical infrastructure features.

In short, the proposed classification systems integrating CAV particularities are based on diverse approaches and, therefore, a harmonization is needed. Although policies and regulations are needed to boost the use of CAVs and consumer acceptance is crucial to increase CAV sales, the level of automation of a road must not depend on these issues. On the other hand, most of criteria included in existing classification systems are not associated with thresholds and key performance indicators, making the implementation of these systems harder. Last but not least, none of existing systems integrate dynamic conditions of the road – e.g., traffic volume or weather conditions – to determine the capability that a road has to enable an automated driving.

Although vehicle technology is constantly enhancing and evolving, the sensors and algorithms included in CAVs cannot cope with specific **challenging situations**. Demanding road geometry – sharp horizontal and vertical curves and narrow lanes – usually leads to vehicle system disengagements. In addition, diverse research found 150 mm width and 150 mcd/m2/lx retroreflectivity road markings ease CAVs operation. In this way, high-capacity roads – freeways, expressways, and motorways – are already ready to integrate CAVs as their features encourage road readability and connectivity. In addition, this road category opens up the creation of dedicated lanes (DLs).

Most Traffic Sign Recognition (TSR) systems recognize only posted speed limits and priority of way signs such as STOP or yield. Nevertheless, the performance of these systems depends on the position – up to transverse distances of 10 m – and orientation – up to 45° perpendicularly to the road – of the traffic signs. Other critical aspects are the maintenance of traffic signs and the environmental lighting as the accuracy of TSR systems decreases with a poor maintenance and in situations of low or altered lightness. Furthermore, Variable Message Signs present additional limitations linked to the intrinsic aspects to this technology: (i) contrast and adaptability to surrounding light; (ii) interpretation of LEDs to form characters and pictogram; and (iii) image flickering.

Despite the few studies quantifying the influence of pavement condition on CAVs performance, it is clear that the state of the pavement surface plays a critical role in automated driving. To this regard, the new road classifications that include the particularities of these type of vehicles agree with a good pavement condition is needed to achieve the highest levels of automation.

The main environmental factors affecting CAVs performance are weather and lighting. Unfavorable weather conditions – heavy rain and fog – makes road marking and traffic sign recognition very difficult as these tasks are carried out by vision cameras that are very sensitive to visibility. Related to this, street lighting and tunnels can also influence the performance of CAVs. An improvement of street lighting, in terms of better illumination or more closely spaced lights, may be required to ensure that the visibility of road markings, signals, and signs is suitable for an effective CAVs performance. Furthermore, tunnels are linked to two important issues: (i) sudden changes in illumination conditions and (ii) low Global Navigation Satellite System (GNNS) signal coverage. Although some innovation solutions have been proposed to deal with both issues, further research is needed to stablish standardized solutions and consistent with automated vehicles' capabilities.

Many car manufacturers are developing safety and communication systems to avoid collisions with non-motorized vehicles, such as pedestrians and cyclists. However, current interaction patterns and strategies cannot be automatically transferred to a situation with automated vehicles or to a situation with vehicles with different levels of automation. Above all, pedestrian and cyclist behavior are often unpredictable.

In addition to above-mentioned shortcomings or limitations, it should be noted that speed is a critical factor in road marking recognition because information processing must be faster as the vehicle speed increases. Related to this phenomenon, the **Automated Speed** was defined as the maximum speed that an automated vehicle can achieved at a specific road geometric element. Furthermore, Advanced Driver Assistance Systems are usually limited to specific range of speeds. Adaptive Cruise Control (ACC) usually works from 30 km/h, while Lane Keeping and Centering Assist (LKA and LCA) work when the vehicle speed is over 60 km/h.

Another of the most important challenges concerning automated driving is **connectivity**. Vehicle to Everything (V2X) is a communication system which interconnects a road vehicle to any entity that may concern it. To this regard, V2X encompasses a range of communications channels, including:

- Vehicle to Vehicle (V2V): Direct communication between two vehicles.
- Vehicle to Infrastructure (V2I): Communication between a vehicle and fixed infrastructure, such as traffic lights, infrastructure monitoring and control devices, parking services, etc.
- Vehicle to Pedestrians (V2P): Communication between vehicles and pedestrian devices, alerting pedestrians of vehicle movements and warnings for vehicles.
- Vehicle to Device (V2D): Communication between vehicles and non-V2V enabled vehicles and cyclists.
- Vehicle to Network (V2N): Communications with the cellular network, either to facilitate other types of V2X communications or to access internet resources.

Currently, there are two V2X communication approaches using different underlying technologies. While the IEEE's approach is Dedicated Short-Range Communications (DSRC), which supports vehicular ad-hoc connectivity WLAN technologies standardized as IEEE 802.11p [15] – known in America as WAVE and in Europe as ITS-G5 –, the 3GPP's approach is based on Long Term Evolution (LTE), which consists of cellular technologies (C-V2X) [16].

Roadside Units (RSUs) are using DSRC communications and need the vehicle speed be relatively low for switching. However, recent C-V2X communications based on 5G New Radio have emerged as a complementary access technology in order to provide sophisticated applications and use cases with more stringent Quality of Service (QoS) requirements – e.g., platooning or advanced driving –.

Highly automated vehicles need to monitor everything taking place on the route ahead, even beyond the range of their sensors. Connected and automated vehicles with their sophisticated sensing systems are also part of the solution, but the quality of traffic information needs to be improved. To this regard, CAVs need basically two types of information systems: (i) real-time information and (ii) rules and regulations of any restrictions ahead. Therefore, a highly versatile framework that supports several wireless technologies is needed, especially to allow high-level automation. For that purpose, a strong cooperation between all stakeholders is mandatory.

Moreover, it is important to distinguish between the **key concepts** of Operational Design Domain (ODD), Operational Road Section (ORS), Level of Service of Automated Driving (LOSAD) [6], and Infrastructure Support Levels for Automated Driving (ISAD) [3].

According to the SAE J3016, an **Operational Design Domain (ODD)** refers to the "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics" [4]. Therefore, an Operational Design Domain can be defined as a road section that meets some characteristics that allow the driving automation system to perform. Many of these characteristics refer to the roadway type, road infrastructure, some others refer to the environment, traffic conditions, maximum speed attainable by the driving automation system, etc. These factors also involve variable – i.e., non-static – parameters. Given the early stage of ODDs awareness and implementation by industry, it might be easier to define them by referring to the limitations, i.e., the conditions that are out the ODD.

To foster the expansion and implementation of ODDs, it is necessary to give a better, more detailed compendium of all parameters and thresholds that might intervene, i.e., a taxonomy. There have been recent efforts in that direction. A first official approach for ODD taxonomy was introduced by the British Standard Institution (BSI), which considered three main attributes: (i) scenery, (ii) environmental conditions, and (iii) dynamic elements [17]. The European ITS Platform (EU EIP) [18] developed another taxonomy, differentiating between (i) physical infrastructure, (ii) digital infrastructure, (iii) communication infrastructure, and (iv) infrastructure operations and maintenance. In 2020, the Society of Automotive Engineers (SAE) released a report with a conceptual framework of ODDs [19]. This framework focuses on the physical road infrastructure including its geometry, the environment, and the behavior of other road users. OEMs are encouraged to explicit and make public the factors supporting/limiting their ODDs. The following factors are proposed: (i) weather- and climate-related environmental conditions, (ii) surface road conditions, (iii) operational restrictions, i.e., other aspects within the operational environment not related to the first category, (iv) road users, (v) non-static obstacles on the road, (vi) connectivity to other road users, infrastructure, and traffic management centers. The most remarkable limitation to ODDs is that these have been defined from the point of view of the vehicle, and every single vehicle (or model) will have its unique – and time varying – ODD. Therefore, a road segment being drivable by an automated vehicle is not a property given or managed by the road administration or operator, but a varying characteristic of every single automated vehicle.

The lack of a standardized definition of ODD hinders OEMs to explicit their ODD constraints. In the end, this makes it more difficult for road administrators to be aware of which road segments are more adequate for automation.

In addition to the elements that an ODD taxonomy should include, thresholds for these elements should be applied too (e.g., minimum radius compatible with automation for a certain speed; minimum road marking width, etc.). These thresholds should be robust, i.e., they should ensure that a vehicle lying within the ODD range would not release control triggered by this factor.

Establishing clear ODDs is especially important for SAE levels 3 and 4. For lower levels, the driver is the one responsible for all the Driving Task, given the relatively frequent disengagements. Level 5 is the top level, a vehicle capable of driving anywhere regardless ODDs.

To facilitate the application and management of ODDs from the road infrastructure side, it is necessary to generalize the concept to a traffic stream with vehicles showing different automation capabilities. Within a certain road segment, the different vehicles will present specific ODD-compliant sections, generated by different factors. The zones that are ODD-compliant to all vehicles are indeed sections that can be driven autonomously by all vehicles. Knowing this information is very important for road administrations and operators, since they could actively work towards increasing their length and adapting new sections.

These sections are proposed to be called **Operational Road Sections (ORS)**. From a practical perspective, an ORS should be established in all zones that match with all vehicles' driving automation systems. It should be noted that these ODDs should be robust enough to prevent disengagements if some of the dynamic factors slightly vary (i.e., ORS should be as static as possible). By making ODDs explicit, ORS would be easier identified, and OEMs could receive feedback from road administrations to improve their systems.

ORSs, like ODDs, will vary in time. At the beginning, only smooth sections at freeways are expected to be supported by all driving automation systems. As the technology evolves, other sections will become compatible with all systems, extending the ORS application. Active adaptation of road sections would accelerate this ORS generalization, but to select the most cost/effective measures, ODDs should be made explicit.

The ODD may terminate at some point, either in a planned way (the vehicle reaches an ODD physical boundary) or abruptly (some factor exits the safe zone and terminates the ODD). In both cases the vehicle might be capable of performing a Dynamic Driving Task (DDT) fallback, which is not a regular DDT but provides some capabilities to take the vehicle to a safe stop. This situation is called a "Restricted Operational Domain" (ROD).

For every single vehicle, the ODD-compliant sections along a road itinerary are expected to be discontinuous. For SAE levels 3 and 4, the driver is expected to be able to shift to a secondary task while the vehicle is in charge of the DDT. A problem may arise under three circumstances: (i) the vehicle experiments a failure that stops automation abruptly, (ii) the Automated Driving System (ADS) fails, and (iii) the ODD approaches to its end, which is already known by the driving automation system. On the contrary to previous situations, the vehicle has more time to plan how to perform and warn the driver.

In all these cases, the Dynamic Driving Task has to be released to the human driver, who might be attentive to a secondary task. Hence, the ideal situation is a planned handover. Nevertheless, if the driver is unable to take over control of the vehicle, Level 4 and level 5 ADSs can take the vehicle to a Minimal Risk Condition (MRC), which is defined as "a condition to which a user or an ADS may bring a vehicle after performing the DDT fallback in order to reduce the risk of a crash when a given trip cannot or should not be completed". This means that these highly automated ADSs can still control the vehicle with restricted conditions, make a decision and take the vehicle to a position that minimizes the risk to itself and the rest of road users.

A MRC is a final state, i.e., the objective to reach by the ADS when needed. From the regular performance to the MRC, a maneuver has to be undertook – Minimal Risk Maneuver (MRM) –, which should also be considered to minimize the risk condition. In fact, the ADS may balance several options with diverse risk conditions, finally performing the one that presents the lowest risk in combination with the maneuvers [20].

Comparing road sections with disengagement patterns is especially relevant in order to verify to what extent the proposed ODDs are robust and match the definitions provided by OEMs. Road administrations and operators could also use this information to determine and check their ORSs; and provide newer ones.

It is important to highlight that the driver – either human or vehicle – is the ultimate responsible for the driving task. Therefore, road administrations and operators should make explicit the available automated vehicle supporting road characteristics for every road segment and the automated vehicle will decide if it can switch on automated driving or not, according to the technologies it is equipped with.

The **Level of Service for Automated Driving (LOSAD)** is a concept recently introduced by García et al. [6] to indicate how ready a road segment is to host automation. Like any other Level of Service (LOS), it ranks the road segment from E – minimal automation support – to A – automation fully supported –. Having such a direct indicator to reflect the automated-readiness level is very important for road administrations and operators. Road networks could be ranked as a function of LOSAD. Traffic volume could also be compared to it. These charts could be used to prioritize actions and/or assess the status of a road network. In fact, the LOSAD A road segments would be those identified above as Operational Road Sections – i.e., road sections that are fully compatible with automation – for a sufficient road segment length (thresholds still to be determined).

LOSAD B to E present different extensions and frequencies of ORSs. For instance, LOSAD B may be a segment that presents relatively long ORSs interrupted with a few non-ODD compliant zones for some of the automated vehicles. LOSAD E may be the case of very short ORSs that almost prevent enabling automation. Thresholds and specific characteristics of every level are still to be determined.

Since LOSAD should be based on Operational Road Sections, a very deep knowledge about factors affecting ODDs is required. Otherwise, ODDs should be evaluated for every single vehicle and finally aggregated for the whole road segment. Figure 1 shows how the LOSAD could be determined for a single vehicle. The lower part of the figure represents the engagement (green) and disengagement zones (red) for a given driving automation system. This could be transformed into a time-space diagram (top), computing how frequent these disengagements are.

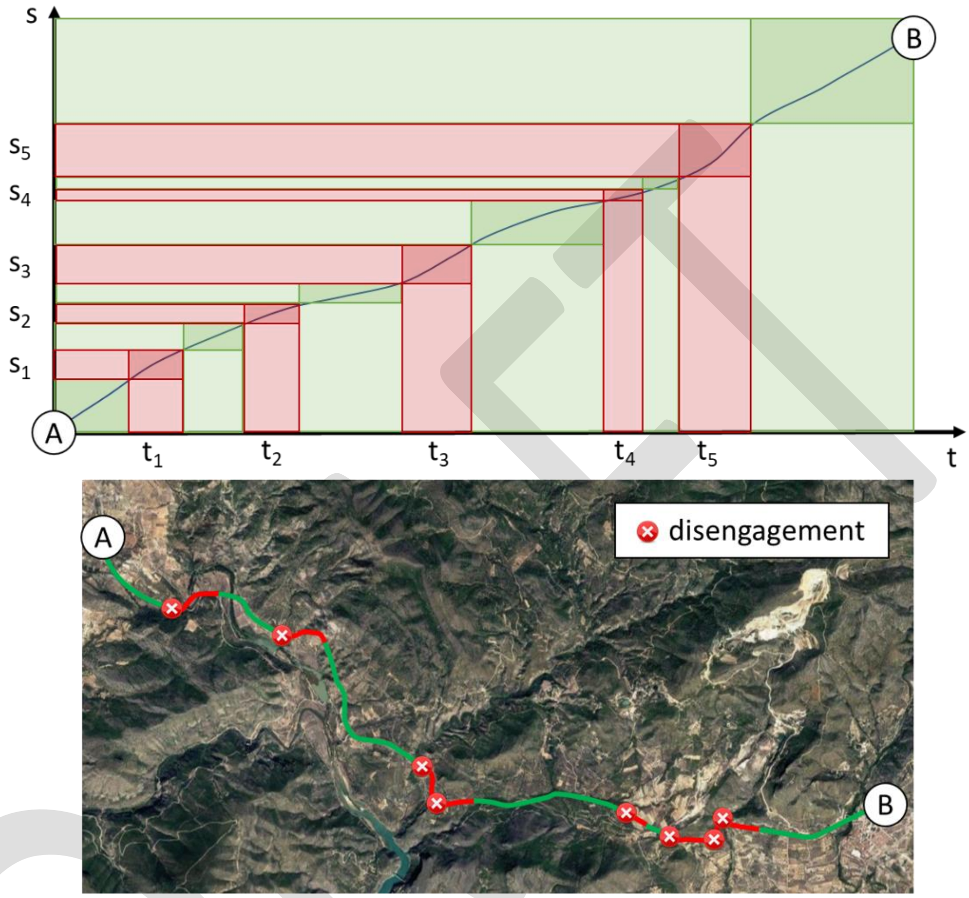

Figure 1. Concepts of ODD and LOSAD.

Another indirect way of determining the LOSAD might be through disengagement reports from marketed vehicles. By geotagging all disengagements – and, if possible, the triggering conditions – HD maps could continuously be updated in order to indicate which road segments are more likely to disengage certain driving automation systems.

The LOSAD concept, despite still requiring further refinements upon the information that finally becomes available, is a complementary parameter to the **Infrastructure Support Levels for Automated Driving (ISAD)** [3]. Like LOSAD, the ISAD is categorized in five levels (A-E), being A the highest connectivity support level, to E (conventional infrastructure). LOSAD describing how vehicles' ODDs interact with the road infrastructure, and ISAD indicating the connectivity capabilities, establish a sound basis to foresee how connected and autonomous vehicles are likely to perform along a road network.

The **implications of automated driving on safety** can be analyzed at diverse levels – (i) vehicle; (ii) transportation system; and (iii) society – and quantified by means of different approaches – (i) target crash population; (ii) road test data analysis; (ii) traffic simulations; (iii) driving simulators; (iv) system failure risk assessment; and (vi) CAV safety effectiveness – [21]. At a vehicle level, CAVs can be examined by means of their contribution to the critical driver-related reasons for crashes, such as distractions, inattention, or performance error. At a transportation system level, a reduction in the number of traffic conflicts and crashes is expected with the integration of CAVs. At a society level, crashes are one of the main health concerns and the health impacts of CAVs can be studied by comparing crash occurrence under different Penetration Market Rates (PMR), including the scenario only with human-driven vehicles. Obviously, these safety implications depend on the automation levels of the CAVs available on the market.

3. SRC Framework

The Smart Road Classification framework aims at providing a powerful but easy-to-use tool to determine the smart level of a road segment, based on the LOSAD and ISAD indicators. Therefore, a Road Administration or Road Operator could use these classifications to rank their road networks, compare regions, plan new actions, and so on. This is called the **main classification system** and will be developed in section 3.1. SRC Proposal.

However, for management purposes, the LOSAD/ISAD-based classification may not be the best option since it requires determining both indicators first. This is why all different, underlying factors related to LOSAD and ISAD have been in-depth developed in section 3.2. Factors. These ones constitute a sort of checklist that could be used by Road Administrators and Operators to determine the smart level of their road segments (see A2. Factors). This has been named as **detailed classification system**.

It is important to highlight that both the main and the detailed classification systems correspond to the same framework, only differing in the way they are applied. Moreover, in the section 3.3. Key Performance Indicators, some KPIs have been proposed to assess the evolution of the SRC application along time.

3.1. SRC Proposal

The smart road classification will be based on two indicators of autonomous performance and connectivity support: LOSAD and ISAD. Both of them are based on explicit indicators that could be retrieved by Road Administrations (RAs). The indicator for the automation level is the **L**evel **O**f **S**ervice for **A**utomated **D**riving (**LOSAD**), proposed by HERG [6], while the indicator for the connectivity level is the **I**nfrastructure **S**upport Levels for **A**utomated **D**riving (ISAD), proposed in the INFRAMIX project [12].

The proposed LOSAD is categorized in five levels, from A to E. It is determined as a function of how ready the road infrastructure is to support automated driving. The most important parameter to define the LOSAD of a road segment is the distribution of their Operational Road Sections. As seen in 2. Literature Review, an Operational Road Section (ORS) can be defined as a section that fully supports automation for all driving automation systems with explicit ODDs. In other words, a section that should be ideally driven by any driving automation system. According to the SAE definition for the different levels of automation, a disengagement-free trip can only be ensured for level 4 (within their ODD sections) and for level 5. Levels 1 to 3 may present disengagements even within their ODDs, so disengagement-free trips can never be ensured.

Before addressing the LOSAD concept, it is necessary to clarify what road segments and sections are in these definitions. A road segment is the road portion delimited by major intersections or an urban environment. Driveways and minor intersections may or may not suppose a road segment change. A road section refers to the minimal portion of the road that presents identical factors, including geometry, cross section, environment, and the like. Every horizontal curve – as well as short tangents – should not be divided into different sections. A long tangent may be divided into different sections, if some important property differs on it.

As the percentage of the road segment that does not belong to an ORS increases, LOSAD will decrease given that high automated vehicles will present lower opportunities to drive autonomously. LOSAD also decreases as ORSs become shorter. The following levels are proposed:

- LOSAD A: The road segment presents a continuous ORS that ensures a safe automated driving for high automated vehicles (levels 4-5). Levels 2 and 3 vehicles should perform with minimum disengagements due to their lower technology, i.e., a disengagement-free driving cannot be ensured from the infrastructure side (although their number would be very low or null).
- LOSAD B: Like for LOSAD A, the road segment is composed of a single ORS that must keep in automation all level 4 and level 5 vehicles. However, dynamic conditions such as weather may temporarily limit the ORS effectiveness. The LOSAD B also appears if the number of disengagements exceeds a given threshold, mostly caused by level 2-3 vehicles.

- LOSAD C-D: These levels are characterized by a non-continuous ORS within the road segment. The final level will depend on the number and length of ORSs along the segment. Most drivers may need to retake manual control of their vehicles at the non-ORSs. A minimum disengagement rate might also be expected within ORS, as for previous levels. In addition, adverse weather conditions might also trigger LOSAD C or LOSAD D conditions. Specific thresholds are still to be researched in the future, depending on how diverse CAVs are, the minimum period of time that would be adequate to be under automatic control, etc.
- LOSAD E: There are no ORSs, or their length is too short to ensure comfortable automated driving. Therefore, most level 3 and 4 drivers might be willing not to activate their systems. Level 2 drivers would not experience any remarkable benefit from lane keeping assistance, given that it would be disengaged most of the time.

The LOSAD classification is dynamic, i.e., a road segment might shift from one level to a lower one depending on dynamic factors such as disengagements and weather conditions. Two examples are given for clarification purposes:

- A LOSAD A road segment might temporarily shift to B if many disengagements are observed within a section, regardless the triggering factor (it may even be unknown). The level of the driving automation systems suffering disengagements is not relevant in this case.
- A LOSAD B road segment might temporarily shift to D if a sudden, violent rainfall takes place. Heavy rain has two effects: (i) creates a layer of water that may affect automation (this also depends on the drainage conditions), and (ii) limits visibility. The limitation of visibility might also be detected using the Visibility factor. These conditions might also trigger a high number of disengagements, which could be detected using the corresponding factor as well.

A new parameter, the disengagement rate, is necessary to apply one of the factors. This can be defined as the number of disengagements within ORSs divided by the volume of automated vehicles. Thus, it is a way of measuring how well the ORSs are performing, and a way to report unexpected or abnormal behavior of the road infrastructure and automated vehicles. If this indicator is finally established, it would be necessary that all automated vehicles reported these events in real time, including position and time. Other data would be helpful in order to identify the triggering cause. Finally, this report should be provided by all vehicles from level 2 to level 5. RAs would then combine data from all vehicles with additional information (e.g., weather, traffic, etc.), obtaining 'disengagement maps' for the road network for a variety of situations.

The information from disengagements is considered to be very important, since it reflects how CAVs are performing along the road segment. Unlike establishing LOSAD based on geometric and environmental factors, this parameter would reflect the consequences of unknown factors affecting CAV performance. Not only would this information be useful to more accurately tag the LOSAD of the road segment, but it would also help research to overcome these limitations, and therefore expand ORSs.

Despite these benefits, all level 2+ vehicles should be legally enforced to provide this information, and RAs should support a detailed, continuously updated road HD map. **This is neither the situation nowadays nor it will be in the short-term**. Once that day comes, a strong effort should be made by Road Administrations to establish an effective way to collect it. If this information is not ever published, alternative protocols should be defined to privately or partially collect this data with the same objective.

From now on, LOSAD, ISAD, and SRC factors will be presented in tables, following the color code in Table 1. Green cells indicate a value proposal. Yellow cells indicate that the value should be defined by the road administrator or operator. Red cells indicate that a value should be provided when its effect on automation is better depicted. However, some values have been provided as a reference (TBD: to be determined).

	Proposed value
	To be researched specific thresholds based upon their effect on Automated Driving.
	To be defined by the Road Operator/Administration

Table 1. Color-code for the values provided in LOSAD, ISAD and SRC tables.

Table 2 shows the static and dynamic factors that should be considered to decide the LOSAD level.

Like LOSAD, the **ISAD is categorized in five levels** (A-E), being A the highest connectivity support level, to E (conventional infrastructure). These are the following:

- ISAD A: Support for cooperative driving, in which the infrastructure is fully capable of perceiving the behavior of all vehicles and guiding the traffic to guarantee efficiency and safety.
- ISAD B: Support for cooperative perception, in which the infrastructure can perceive some microscopic traffic situations and communicate with vehicles. There is some level of cooperation but still not with a full range of situations.
- ISAD C: Dynamic digital information, in which the infrastructure can modify the information of road variable message signs depending on weather or incident warnings.
- ISAD D: Static digital information/map support, which means that in this case the infrastructure provider – the road administration or operator – supplies to the vehicles along the area with digital map data complemented by physical reference points.
- ISAD E: Conventional infrastructure with no digital support, referring to today's roads in which there is not any digital infrastructure data and, therefore, no explicit autonomous vehicle support is provided.

These descriptions were introduced by the InfraMIX project [12]. Most of them refer to the data requirements of the digital infrastructure, with lower attention to the physical part of the infrastructure, or the connectivity requirements.

Table 3 presents a compendium of all properties related to the digital infrastructure, and some requirements on the physical and connectivity parts. Some of these factors have been partially adapted from the originals indicated in the InfraMIX project, for clarification purposes. All factors are just suggested, given that these should be detailed by further research and international agreements about the standards. The same colors than for LOSAD apply (Table 1).

Layer	Factor	Type	Domain	Parameter	Description	E	D	C	B	A
Physical Infrastructure	ORS	Static	Road Segment	Number	Number of ORS that should be within a road segment		<=5 (TBD)	<=2 (TBD)	1	1
			Road Segment	% of total length	Percentage of the total length of the road segment that should correspond to an ORS		75% (TBD)	90% (TBD)	100%	100%
Digital Infrastructure			Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])	Maximum allowable disengagement rate within ORSs, per time and length. All SAE levels are considered. Manual requests are not considered.				5 (TBD)	0 (TBD)
	Weather	Dynamic	Road Segment	Visibility (MOR)	Visibility range from weather stations		200 m	500 m	1000 m	1000 m
		Dynamic	Road Segment	Snow/icy pavement	Ice on the pavement may reduce the skid resistance and therefore prevent adequate automation. Snow on the pavement may prevent to distinguish road markings.		Heavy snow	Moderate snow	Light snow	Light snow
		Dynamic	Road section	Rainfall intensity	Rainfall may limit visibility.		Violent rain (<100 mm/h)	Heavy rain (<50 mm/h)	Moderate rain (<7.5 mm/h)	Light rain (<2.5 mm/h)

Table 2. Factors related to LOSAD.

Layer	Factor		Domain	Parameter	Description	E	D	C	B	A
Digital Infrastructure	Mapping and digital information availability	Static	Road segment	Digital map	Availability of a digital map with static road signs, junctions, etc.		Standard map	HD map	HD map. MRC zones are included	HD map. MRC zones are included
		Static	Road segment	Digital map update frequency	How frequent are maps updated?		Manually	Automatic, not necessarily real-time	Real-time	Real-time
		Static	Road segment	Road traffic and events ahead	Availability of DIGITAL information related to road traffic and events ahead			Y	Y	Y
		Static	Road segment	Weather conditions	Availability of DIGITAL information related to weather conditions			Y	High precission data with forecasting possibilities	High precission data with forecasting possibilities
		Static	Road section	Variable speed limit	Availability of DIGITAL information related to Variable Speed Limit			Variable Speed Limits are transmitted to vehicles	Variable Speed Limits are transmitted to vehicles	Tailored Speed Advice is transmitted to vehicles
		Static	Road section	Traffic lights	Availability of DIGITAL information related to traffic lights			Y	Y	Y
		Static	Road section	Traffic performance information	Availability of traffic data for management, indications, and other purposes			Macroscopic	Microscopic, obtained from vehicle data	Microscopic, obtained by the road infrastructure
		Static	Subject vehicle	Microscopic dynamic driving guidance	Can the Digital Infrastructure provide tailored instructions in a vehicle-basis? (i.e., cooperative driving)				Speed and lane advice might be	Y

Layer	Factor		Domain	Parameter	Description	E	D	C	B	A
									sometimes provided	
	Road equipment	Static	Road Segment	Presence of Roadside Units (RSUs)	Are there RSUs?				Yes, ensuring I2V	Yes, ensuring V2I and I2V
		Static	Road segment	Sensors for trajectories of vehicles and users	Specific road sensors to detect the trajectories of vehicles/users				Y/N	Y
		Static	Road segment	Automatic road data processing	Can the infrastructure automatically process information from multiple sensors (e.g., in-pavement sensors, cameras, ramp metering…)			Y	Y	Y
		Dynamic	Road Segment	Positioning accuracy	How accurate is the position of vehicles, despite the specific equipment used (RTK land stations or reference points)		Accurate	Very accurate	Highest accuracy	Highest accuracy
Connectivity	DSRC/ITS-G5	Static	Road section	Availability	Short range communication			Y/N	Y	Y
	C-V2X (5G)	Static	Road segment	Availability	Cellular V2X (Vehicle-to-Everything) communication			Y/N	Y	Y
	DSRC	Dynamic	Road segment	Range (m)	This range is related to RSUs density			2000	1700	700
	Reliability	Dynamic	Road segment	% Packets received in due time	This is related to signal strength fluctuations			99%	99.90%	100.00%
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)				3	6	30
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?	This is a measure of delay			100	40	5
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (RSRP) (dBm)	The average power received from a single Reference signal			-85	-82	-67

Table 3. Factors related to ISAD.

The different LOSAD and ISAD levels provide road segments with different characteristics related to automated and connected driving. Moreover, some interactions of these levels generate synergies that are especially interesting for road authorities and operators to foster.

As a consequence of the various interactions, **five different types of Smart Road segments can be distinguished with specific characteristics related to CAVs**. Although there are 25 possible combinations of the different LOSAD and ISAD levels, some of them are very similar and can be grouped together. From lower to higher CAV support, these five levels are proposed:

1. **Humanway (HU).** The road is not ready for CAVs. This means that level 2-3 vehicles would experience too many disengagements, prompting their drivers to manually disconnect the system. These segments would not present ORSs, and level 4 vehicles may not find clear ODDs – this would depend on the specific technology of the ADS – and will generally perform in manual mode. A level 5 vehicle would be able to operate along this road – provided that these vehicles are ODD-free – but connectivity to infrastructure is not guaranteed. However, even for these high-end vehicles, performance, operation, and safety might be compromised as well, if they cannot operate at a reasonable speed.
2. **Assistedway (AS).** The road is adequate for level 2+ vehicles, meaning that it would not induce too many disengagements to levels 2-3. This would allow drivers to enable their driving automation systems. Road administrations should put special focus on ORS discontinuities and any other disengagement-prone location, to prevent driver distractions, especially for level 3. While more extensive ODDs can be found compared to HU, the road segment might be divided into many ORSs that do not provide a comfortable and automated driving experience for level 4 vehicles, limited by the physical infrastructure or the connectivity capabilities (the road cannot provide detailed information about the dynamic parameters that should be compared to ODDs).
3. **Automatedway (AT).** The road segment presents better characteristics than AS segments, especially related to connectivity. These road segments present HD maps and can transmit digital information to CAVs, so these can better identify ODD-related factors and ODD terminals. In addition, less and more continuous ORSs can be found within. Level 2 vehicles would experience less disengagements than on AS segments, and level 3 vehicles would be able to use the digital information to foresee oncoming disengagements. The longer ORSs would allow a better, longer performance of level 4 vehicles in automated mode.
4. **Full Automatedway (FA).** The road segment presents a continuous ORS, so all level 4 vehicles should be able to operate autonomously along the entire segment. In addition, these segments present safe harbors – including their junctions to other segments –. While the ORS is not directly related to level 2-3 vehicles – these are not required to explicit their ODDs – a much lower number of disengagements compared to AT is also expected. Connectivity is even better than AT segments, facilitating cooperative perception and including all safe harbors in the HD map. All road users would benefit from better global performance and safety levels.
5. **Autonomousway (AU).** The road segment presents similar physical conditions than the FA segments – i.e., complete ORS along the segment, safe harbors, etc. –, and incorporates exceptional connectivity features that enable cooperative driving. In order to benefit from the best performance and safety levels, only level 4+ should operate along these road facilities or with dedicated lanes. The HD maps will also have very detailed information about the safe harbors – not only their presence but also their capacity and availability of free spaces.

A diamond-shaped chart is proposed to identify the smart level of the road as a function of LOSAD and ISAD (Figure 2). The shape of the diagram has been carefully developed, keeping ISAD and LOSAD separately and showing any improvement in the smart level of a road following a bottom-to-top path. While this chart presents all plausible combinations of LOSAD and ISAD, not all of them seem reasonable, i.e., cooperative driving support should never be provided to a road that cannot be driven by automated vehicles. These inadequate combinations have been cleared with a white pattern and identified with an asterisk.

This proposal establishes a framework that should be adapted to the specific circumstances of every country/region. These circumstances are related to the kind of parameters that could be retrieved from users/vehicles, national laws, enforcement level, characteristics of the road network (total length, type of infrastructure, etc.), existence of technology related to V2X communication, budgetary restrictions, among others. The bottom part of the chart presents two percentage scales for ISAD and LOSAD, corresponding with the cumulative percentage of the road network. This can be used by road administrations and operators to deduct the distribution of the smart levels as a function of the LOSAD/ISAD distribution. More detail about this procedure will be later provided.

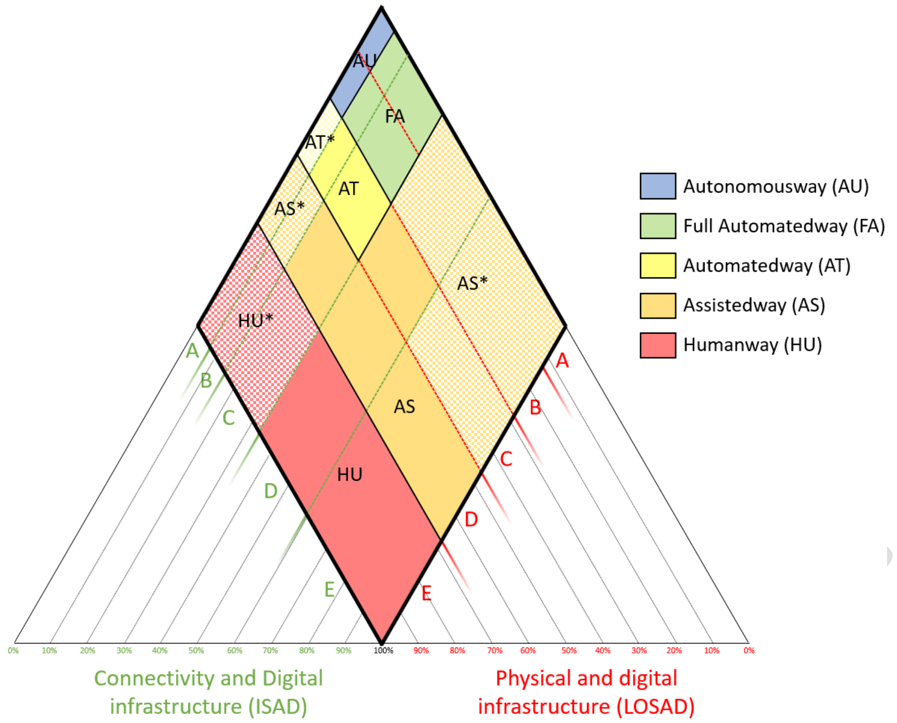

Figure 2. Diamond chart for the Smart Road Classification.

In addition, the smart level can be used in line with the traditional classification system (i.e., in terms of mobility and accessibility), and with the classification systems involving users [1].

Although aggregated, every single zone of the LOSAD/ISAD combination might present some differences compared to the general description of the smart road level. These differences are minimum but can be seen in Figure 3.

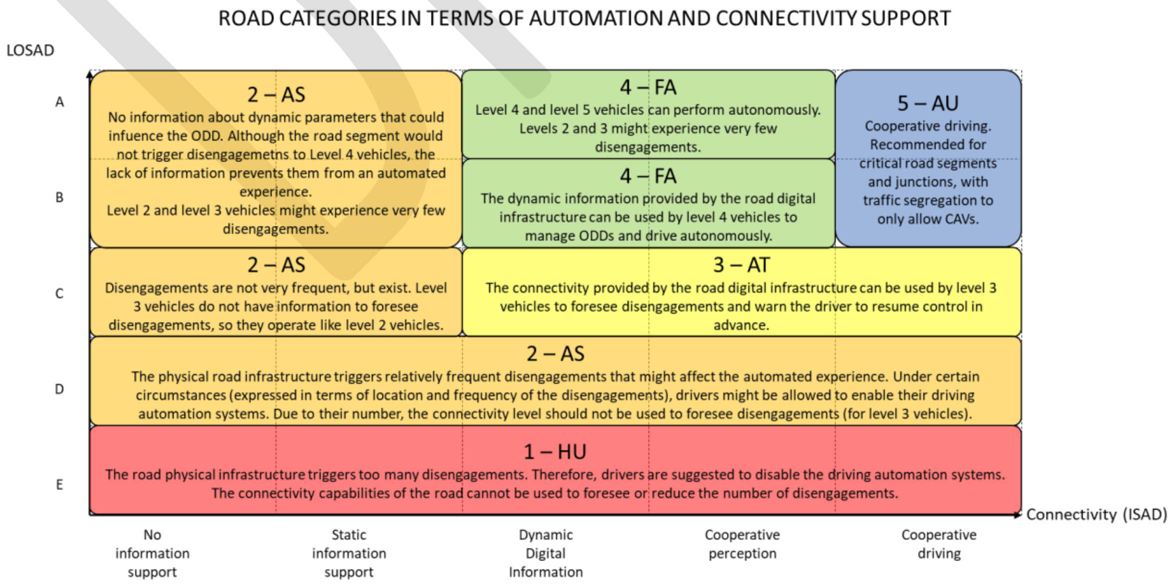

Figure 3. Description of the particularities of any ISAD/LOSAD combination. Minimum differences within the same SRC level can be seen.

Figure 4 represents the concept map of the SRC proposal, indicating the input factors from the different layers and the interaction with other classification systems. As it can be seen, ISAD and LOSAD can be used to determine the smart level, but the underlying factors can be used as well without prior determination of ISAD and LOSAD. In addition, the SRC is also connected to other existing classifications (road typology and the expanded classification including users). In fact, connectivity and/or automation create new kinds of user interactions. Traffic volume and composition are another group of factors that affect the infrastructure management.

Users should be able to perform along every type of road segment, except SRC level 5. This one uses the cooperative driving advantages, which require automation and connectivity. Therefore, these road segments should be restricted to very specific zones – or dedicated lanes – for which cooperative driving supposes a great improvement in terms of safety and/or performance. SRC level 4 road segments may not have any limitation regarding road users, but probably these road segments would apply to freeways and high-end two-lane rural roads. Therefore, road administrations and operators would be likely to prohibit certain users (e.g., pedestrians, bicycles, and LMV) as they do today.

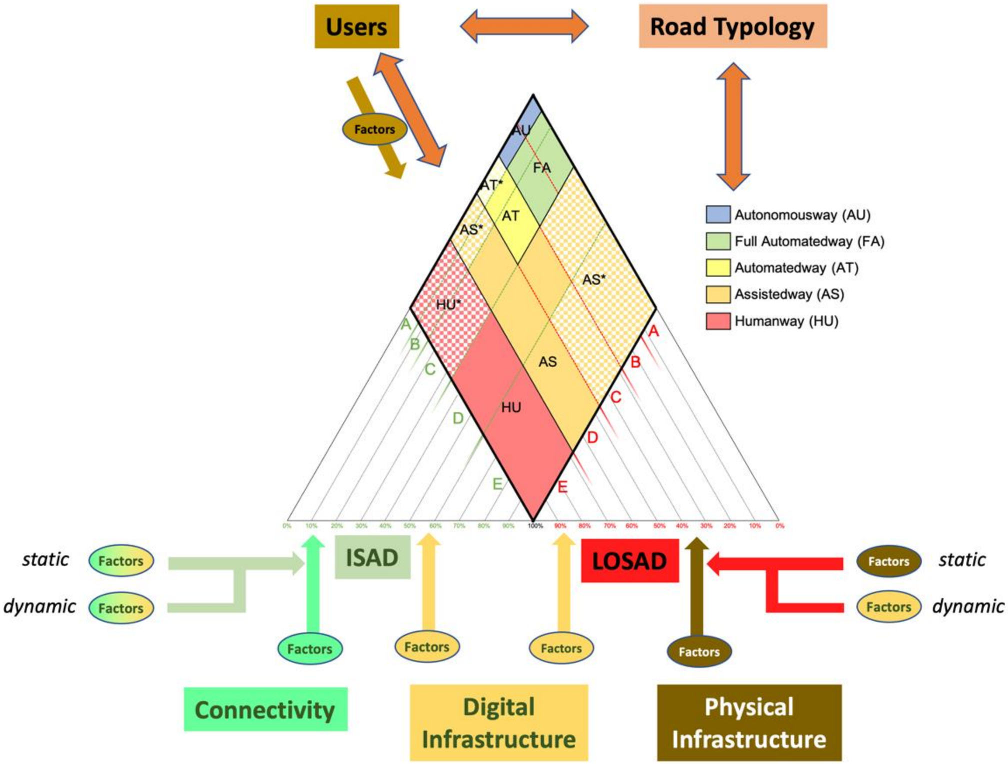

Figure 4. *Smart Road Classification, including source data and interaction with other road classification systems.*

Table 4 shows a detailed compilation of how the different users interact with every smart road classification level. The same color code applies for SRC levels.

C	A	Passenger car						Heavy vehicle						Motorcycle						Bicycle/LMV						Pedestrian					
✗	✗				1	2	X				1	2	X				1	2	X				1	2	X				1	2	X
✓	✗		3	3			X		3	3			X		3	3			X		3	3			X		3	3			X
✗	✓		3	4	4		X		3	4	4		X																		
✓	✓		3	3	4				3	3	4																				

C: connectivity. Does the user/vehicle present connectivity capabilities?

A: automation. Does the vehicle present automation capabilities?

The following codes describe the estimated limitations for the interaction between road segment and road user:

1: The road user cannot benefit from all advantages of the road.

2: The road user cannot benefit from all advantages of the road, but the road can detect it and inform other connected users.

3: The user presents connectivity and/or automation capabilities, but the smart level of the road is not able to provide/receive valuable information, and/or generates too many disengagements.

4: Same as 3, but adequacy depends on the SAE level of the vehicle and the LOSAD level of the road segment.

X: Non-connected and/or non-automated vehicles should not be allowed to perform at AU segments, since these would deprecate the performance of other CAVs.

Table 4. Interaction of the different users with the SRC levels.

It is worth to mention that the benefits for CAVs would also depend on the interaction between the SAE and the SRC level. Table 5 summarizes these interactions, highlighting where CAVs are more adequate, present no advantages, or are not permitted.

		SRC levels				
		1. Humanway	2. Assistedway	3. Automatedway	4. Full automatedway	5. Autonomousway
SAE levels	1					
	2 (with ACC+LKA)					
	3 without MRC					
	3 with MRC					
	4 (MRC included)					
	5 (MRC included)					

Note:	
	Adequate
	Allowed, but not especially benefited compared to lower SRC levels
	Prohibited
	Allowed, but many ODD may not be met and therefore human driving might prevail

Table 5. Particular interactions between the different SAE and SRC levels. SAE level 3 has been divided into two groups, depending on the availability of MRC capabilities.

The implementation of this system, however, should not wait explicit ODD definitions. Instead, road administrations and operators should define the SRC type for their road segments – or at least their best road segments – and let drivers decide whether they activate automation or not. It is important to remind that the ultimate responsibility of the driving task is the driver – either human or vehicle – and road administrations and operators should only provide the road segment characteristics for information purposes. Moreover, vehicles should not ever just rely on data transmitted from the infrastructure side. They should compare this information in a redundant way to what they perceive with their sensors.

3.2. Factors

The direct application of LOSAD and ISAD concepts can be used to determine the SRC of a road segment. As indicated at the introduction of section 3. SRC Framework, a more comprehensive table including specifications for every smart road level is provided. This table summarizes all LOSAD and ISAD factors and provides additional detail related to how ORSs should be materialized. While most ORS factors should be further researched, a few proposed values are given. In addition, the table distinguishes between the aspects that should be provided/ensured by road administrators and operators, and the requirements that every vehicle within the road segment should meet – if automation is activated –. It is important to highlight that the driver – either human or vehicle – is the ultimate responsible for the driving task. Road administrations and operators should make explicit the available automated driving supporting road characteristics for every Smart Road Level and the automated vehicle will decide whether it can switch on automated driving or not, according to the technologies it is equipped with.

Given the size of this table, it has been divided into five different ones, for the different smart road levels (see A2. Factors). In addition, all factors have been grouped into the following categories (these ones can also be found as the first column of the LOSAD and ISAD tables):

- **Physical infrastructure**. This layer includes the road typology, the geometric design of the road, pavement characteristics, road signage, and all other physical aspects related to the road and its environment. Moreover, different speed concepts as performance indicators are included (e.g., speed limit, operating speed, automated speed).
- **Digital infrastructure**. This category summarizes the availability of information for drivers and vehicles, as well as the physical facilities that the road presents to comply with that purpose. It includes aspects such as the presence and typology of Variable Message Signs, existence of maps and inventory, digital signing, and road/data sensors such as weather, safe harbors, and Roadside Units (RSUs).
- **Connectivity**. This group summarizes the connectivity capabilities of the road, including the V2X protocols and possibilities, 5G coverage, capacity of cooperative driving, etc.
- **Users**. This layer is not part of the LOSAD and ISAD tables but has been added to summarize the connectivity and automation implications for the potential users of the road facility.

3.3. Key Performance Indicators

Key Performance Indicators (KPIs) can be used by road administrations and operators to know the performance situation of their road network and make strategic decisions, maximizing the outcome of their investments. There are many possible actions that can be planned to increase road safety and traffic performance, affecting the highest number of people and having a clear picture of the starting situation. Many of these KPIs are alternate and require different sources of data. KPIs can also be used to compare the situation of a road network longitudinally (i.e., in time) and to the road networks of other countries or regions.

Three groups of KPIs are proposed:

- **Automation**. This KPI refers to the distribution of the disengagement rates per every smart road level, for the entire road network.
- **Safety**. This KPI focus on the average crash rate involving only CAVs of the road network.
- **Smart road level**. This final group of KPIs relate to the distribution of the LOSAD, ISAD, and SRC levels across the road network. It is especially interesting to see its current state and evolution in time. Comparisons between different regions of a road administration can be performed with them, as well.

Table 6 details the proposed KPIs for all groups. These primary KPIs could be used in calculations to obtain secondary KPIs that might be preferred by road administrations and operators.

	KPI
Automation	Disengagement rate per road segments of each smart road level, for the entire road network (disengagements/km or mi.)
Safety	Average Crash Rate involving CAVs for the entire road network
Smart road level	Percentage of each smart road level for the entire road network
	Percentage of each smart road level for every road type network
	Percentage of each ISAD level for the entire road network
	Percentage of each ISAD level for every road type network
	Percentage of each LOSAD level for the entire road network
	Percentage of each LOSAD level for every road type network

Table 6. Key Performance Indicators.

Appendices

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A2. Factors

Humanway (HU)

This road segment type supposes no benefits to automation. Therefore, no requirements from the infrastructure side are proposed – just a few recommendations – (Table 7). These roads should be uploaded to digital, conventional maps (like nowadays). This level can be used by all road users regardless their transport mode, connectivity or automation capabilities (although other classification systems may limit specific road segments to some of them, such as freeways).

Layer	Factor	Static/Dynamic	Domain	Parameter	1. Humanway	
					RA/RO	Veh
Physical infrastructure	Roadway type	Static	Road Segment	Type		
		Static	Road Segment	Dedicated lane	No	
	Geometric design	Static	Road Segment - Horizontal curves	Minimum Radius (m)		
		Static	Road Segment - Crest vertical curves	Minimum K (m/%)		
		Static	Road Segment	Lane width (m)		
		Static		Shoulder width (m)		
		Static	Road Section	Available stopping sight distance (m)		
	Speed	Static	Road Segment/Section	Speed limit (km/h): Static; Dynamic		
		Static	Road Section	Minimum operating speed (km/h)		
		Static	Road Section	Automated speed (km/h)		
	Road markings	Static	Road Segment	Line width (mm)		
		Static	Road Segment	Contrast		
		Static	Road Segment	Retroreflectivity		
		Static	Road Section	Edge lines continuity (y/n)		
		Static	Road Section	Prevention of sun glaring		
	Signs	Static	Road Segment	Contrast		
		Static	Road Segment	Retroreflectivity		
		Static	Road Section	Contextual information		
		Static	Road segment	Readability of the VMS		
	Pavement	Static	Road Section	International Roughness Index (IRI) (m/km)		
		Static	Road Section	Longitudinal crack sealing		
		Static	Road Section	Hidden road markings		
	Road works	Static	Road Segment	Compliance of geometry, markings, signs and pavement factors		
	MRCs	Static	Road Segment	Availability of safe harbors		

Layer	Factor	Static/Dynamic	Domain	Parameter	1. Humanway	
Digital infrastructure	Mapping and digital information availability	Static	Road segment	Digital map	Standard map (recommended)	
		Static	Road segment	Digital map update frequency	Manually	
		Static	Road segment	Road traffic and events ahead		
		Static	Road segment	Weather conditions		
		Static	Road section	Variable speed limit		
		Static	Road section	Traffic lights		
		Static	Road section	Traffic performance information		
		Static	Subject vehicle	Microscopic dynamic driving guidance		
		Static	Road Segment	Road works		
	Road equipment	Static	Road Segment	Presence of Roadside Units (RSUs)		
		Static	Road segment	Sensors for trajectories of vehicles and users		
		Static	Road segment	Automatic road data processing		
		Dynamic	Road Segment	Positioning accuracy		
	Disengagements	Dynamic	Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])		
	Weather	Static	Road Segment	Weather stations		
		Dynamic	Road Segment	Visibility (MOR)		
		Dynamic	Road Segment	Snow/icy pavement		
		Dynamic	Road section	Rainfall intensity		
	Sensing and information systems	Static	Road segment	Sensing system		
		Static	Road segment	Availability of Stationary Object Detection system (radar-based side units)		
		Static	Road segment	Information system		
		Static	Road segment	Intelligent Speed Adaptation (ISA)		NA / Open
Connectivity	DSRC/ITS-G5	Static	Road section	Availability		
	C-V2X (5G)	Static	Road segment	Availability		
	DSRC	Dynamic	Road segment	Range (m)		
	Reliability	Dynamic	Road segment	% Packets received in due time		
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)		
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?		
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (RSRP) (dBm)		
Users	User distribution	Static	Road segment	Presence of passenger cars	Y	
		Static	Road segment	Presence of heavy vehicles (y/n)	Y	
		Static	Road segment	Presence of motorcycles (mopeds included) (y/n)	Y	
		Static	Road segment	Presence of bicycles (y/n)	Possible, depending on other classifications	

Layer	Factor	Static/Dynamic	Domain	Parameter	1. Humanway	
		Static	Road segment	Presence of LMV (y/n)	Possible, depending on other classifications	
		Static	Road segment	Presence of pedestrians (y/n)	Possible, depending on other classifications	

Table 7. Factors for Humanway road segments.

Assistedway (AS)

This level includes some advantages, especially focused on lower SAE levels. Some Operational Road Sections (ORSs) may exist. Thus, some restrictions to geometry, environment, data usage, etc. are shown in addition to the basic LOSAD/ISAD factors.

As it can be seen in Table 8, some restrictions to road geometry apply. These restrictions would lead to a higher compatibility with vehicles' ODDs. Probably, the most remarkable restrictions are the minimum radius, minimum *K* for crest vertical curves, and cross-section. The proposed values are just examples and should be updated when ODDs become explicit and the effect of road infrastructure on vehicle disengagements are clearer. Digital maps may be similar than those for HU segments. Some additional information may be provided (e.g., from weather stations).

On the contrary to HU segments, these ones provide some support to automated vehicles. However, it should be stressed that not only should automated vehicles be able to perform along these segments – with more or less disengagements – but they should do it at a reasonable speed. In other words, an automated vehicle operating at 20 km/h would not be a reasonable solution.

This is why a restriction on how automated vehicles should operate must be provided. This does not mean that vehicles that do not meet these conditions are unable to perform along the road segment, but that they should not activate their autonomous systems.

The speed restrictions apply to vehicles – not to the road infrastructure – and are given in a range basis for every single road section. This means that a tangent would presumably require operating at a higher speed than a sharp horizontal curve. The parameter "Automated speed" refers to the minimum speed that an automated vehicle should be kept in automated mode, for a given section. As indicated in the literature review, it basically depends on road geometry and other environmental factors. Different criteria could be provided, most of them as a function of the speed limit for that road section:

- Automated speed should be equal or higher than the speed limit. Moreover, a specific Δv_a could be asked so $v_a \geq v_l + \Delta v_a$, where v_a is the automated speed and v_l is the speed limit.
- Similar to the previous constraint, the minimum automated speed could be asked in terms of a percentage of the speed limit, such as $v_a \geq \alpha_a \cdot v_l$, where $\alpha_a \geq 1$.
- A hard-coded value could be asked, too (e.g., $v_a \geq 100$ km/h), regardless the speed limit.

While not as important as the automated speed, a minimum value of the speed range could also be asked to vehicles. This is called "minimum operating speed". This specification is important because nowadays some driving automation systems change their performance when performing slower than a certain speed. The threshold for this parameter could be indicated in a similar way than for the automated speed:

- Minimum operating speed equal or lower than a certain value, as a function of the speed limit: $v_m \leq v_l - \Delta v_m$, where v_m is the minimum operating speed and Δv_m is a positive speed differential.

- Similarly, another way of indicating the threshold could be: $v_m \leq \alpha_m \cdot v_l$, where $\alpha_m \leq 1$.
- Finally, hard-coded values could also apply.

It is important to mention that these limits are for free-flow conditions.

Layer	**Factor**	**Static/Dynamic**	**Domain**	**Parameter**	**2. Assistedway**	
					RA/RO	**Veh**
Physical infrastructure	Roadway type	Static	Road Segment	Type		
		Static	Road Segment	Dedicated lane	No	
	Geometric design	Static	Road Segment - Horizontal curves	Minimum Radius (m)	>= 250	
		Static	Road Segment - Crest vertical curves	Minimum K (m/%)	>=10	
		Static	Road Segment	Lane width (m)	2.8-4.0	
		Static		Shoulder width (m)		
		Static	Road Section	Available stopping sight distance (m)		
	Speed	Static	Road Segment/Section	Speed limit (km/h): Static; Dynamic		
		Static	Road Section	Minimum operating speed (km/h)		Different options
		Static	Road Section	Automated speed (km/h)		Different options
	Road markings	Static	Road Segment	Line width (mm)	150	
		Static	Road Segment	Contrast	3	
		Static	Road Segment	Retroreflectivity	150	
		Static	Road Section	Edge lines continuity (y/n)	Yes, except on entrance/exit ramps	
		Static	Road Section	Prevention of sun glaring		
	Signs	Static	Road Segment	Contrast		
		Static	Road Segment	Retroreflectivity		
		Static	Road Section	Contextual information		
		Static	Road segment	Readability of the VMS		
	Pavement	Static	Road Section	International Roughness Index (IRI) (m/km)		
		Static	Road Section	Longitudinal crack sealing		
		Static	Road Section	Hidden road markings		
	Road works	Static	Road Segment	Compliance of geometry, markings, signs and pavement factors		
	MRCs	Static	Road Segment	Availability of safe harbors		
Digital infrastructure	Mapping and digital information availability	Static	Road segment	Digital map	Standard map	
		Static	Road segment	Digital map update frequency	Manually	
		Static	Road segment	Road traffic and events ahead		
		Static	Road segment	Weather conditions		
		Static	Road section	Variable speed limit		
		Static	Road section	Traffic lights		

Layer	Factor	Static/Dynamic	Domain	Parameter	2. Assistedway	
		Static	Road section	Traffic performance information		
		Static	Subject vehicle	Microscopic dynamic driving guidance		
		Static	Road Segment	Road works		
	Road equipment	Static	Road Segment	Presence of Roadside Units (RSUs)		
		Static	Road segment	Sensors for trajectories of vehicles and users		
		Static	Road segment	Automatic road data processing		
		Dynamic	Road Segment	Positioning accuracy	Accurate	
	Disengagements	Dynamic	Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])		
	Weather	Static	Road Segment	Weather stations	Information from Weather Stations may be present.	
		Dynamic	Road Segment	Visibility (MOR)	200 m	
		Dynamic	Road Segment	Snow/icy pavement	Heavy snow	
		Dynamic	Road section	Rainfall intensity	Violent rain (<100 mm/h)	
	Sensing and information systems	Static	Road segment	Sensing system	N/Y	
		Static	Road segment	Availability of Stationary Object Detection system (radar-based side units)		
		Static	Road segment	Information system	N	
		Static	Road segment	Intelligent Speed Adaptation (ISA)		Open
Connectivity	DSRC/ITS-G5	Static	Road section	Availability		
	C-V2X (5G)	Static	Road segment	Availability		
	DSRC	Dynamic	Road segment	Range (m)		
	Reliability	Dynamic	Road segment	% Packets received in due time		
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)		
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?		
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (RSRP) (dBm)		
Users	User distribution	Static	Road segment	Presence of passenger cars	Y	
		Static	Road segment	Presence of heavy vehicles (y/n)	Y	
		Static	Road segment	Presence of motorcycles (mopeds included) (y/n)	Y	
		Static	Road segment	Presence of bicycles (y/n)	Possible, depending on other classifications	
		Static	Road segment	Presence of LMV (y/n)	Possible, depending on other classifications	
		Static	Road segment	Presence of pedestrians (y/n)	Possible, depending on other classifications	

Table 8. Factors for Assistedway road segments.

Automatedway (AT)

Automatedway road segments suppose an important step in terms of automation. Connectivity becomes very relevant, and higher SAE levels could benefit of it, especially when retrieving data to determine the ODDs. Some examples are HD maps, information about the minimum available Stopping Sight Distance at a road section basis, information about the roadworks and other dynamic information that corresponds to the ISAD C level.

Road geometry and environment are also better to host automated vehicles. Some additional features may also help vehicles in their Dynamic Driving Task, such as light transition at tunnel exits or the presence of some safe harbors to find Minimal Risk Conditions.

Speed ranges should become wider than for AS segments (at least the upper threshold). All factors are summarized in Table 9.

Layer	Factor	Static/Dynamic	Domain	Parameter	3. Automatedway	
					RA/RO	Veh
Physical infrastructure	Roadway type	Static	Road Segment	Type		
		Static	Road segment	Dedicated lane	No	
	Geometric design	Static	Road Segment - Horizontal curves	Minimum Radius (m)	>=300	
		Static	Road Segment - Crest vertical curves	Minimum K (m/%)	>=15	
		Static	Road Segment	Lane width (m)	3.0-4.0	
		Static		Shoulder width (m)	>=2.5 m	
		Static	Road Section	Available stopping sight distance (m)	ASSD	
	Speed	Static	Road Segment/Section	Speed limit (km/h): Static; Dynamic	Most static. Dynamic at critical locations	
		Static	Road Section	Minimum operating speed (km/h)		Different options
		Static	Road Section	Automated speed (km/h)		Different options
	Road markings	Static	Road Segment	Line width (mm)	150	
		Static	Road Segment	Contrast	3	
		Static	Road Segment	Retroreflectivity	150	
		Static	Road Section	Edge lines continuity (y/n)	Yes, including entrance/exit ramps	
		Static	Road Section	Prevention of sun glaring	Presence of dedicated lights at tunnel exits in order to mitigate sun glaring.	ADSs should have special features to adapt to low-contrast and sun-glared circumstances (e.g., W-E road orientations).
	Signs	Static	Road Segment	Contrast		
		Static	Road Segment	Retroreflectivity		
		Static	Road Section	Contextual information		Yes
		Static	Road segment	Readability of the VMS	Some restrictions apply	

Layer	Factor	Static/Dynamic	Domain	Parameter	3. Automatedway	
	Pavement	Static	Road Section	International Roughness Index (IRI) (m/km)		
		Static	Road Section	Longitudinal crack sealing		
		Static	Road Section	Hidden road markings		
	Road works	Static	Road Segment	Compliance of geometry, markings, signs and pavement factors	If road works take place within an ORS, signage and geometry should meet ORS criteria	
	MRCs	Static	Road Segment	Availability of safe harbors	Some	
Digital infrastructure	Mapping and digital information availability	Static	Road segment	Digital map	HD map	
		Static	Road segment	Digital map update frequency	Automatic, not necessarily real-time	
		Static	Road segment	Road traffic and events ahead	Y	
		Static	Road segment	Weather conditions	Y	
		Static	Road section	Variable speed limit	Variable Speed Limits are transmitted to vehicles	
		Static	Road section	Traffic lights	Y	
		Static	Road section	Traffic performance information	Macroscopic	
		Static	Subject vehicle	Microscopic dynamic driving guidance	Speed and lane advice might be sometimes provided	
		Static	Road Segment	Road works	Road works should be included in the HD maps.	
	Road equipment	Static	Road Segment	Presence of Road Side Units (RSUs)	RSUs are recommended, ensuring I2V	
		Static	Road segment	Sensors for trajectories of vehicles and users		
		Static	Road segment	Automatic road data processing	Y	
		Dynamic	Road Segment	Positioning accuracy	Very accurate	
	Disengagements	Dynamic	Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])		
	Weather	Static	Road Segment	Weather stations	Information from WS is present [low representativity, hourly update]	
		Dynamic	Road Segment	Visibility (MOR)	500 m	
		Dynamic	Road Segment	Snow/icy pavement	Moderate snow	
		Dynamic	Road section	Rainfall intensity	Heavy rain (<50 mm/h)	
	Sensing and information systems	Static	Road segment	Sensing system	N/Y	
		Static	Road segment	Availability of Stationary Object Detection system (radar-based side units)		
		Static	Road segment	Information system	N/Y	
		Static	Road segment	Intelligent Speed Adaptation (ISA)		Closed
Connectivity	DSRC/ITS-G5	Static	Road section	Availability	Y/N	
	C-V2X (5G)	Static	Road segment	Availability	Y/N	

Layer	Factor	Static/Dynamic	Domain	Parameter	3. Automatedway	
	DSRC	Dynamic	Road segment	Range (m)	2000	
	Reliability	Dynamic	Road segment	% Packets received in due time	99%	
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)	3	
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?	100	
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (RSRP) (dBm)	-85	
Users	User distribution	Static	Road segment	Presence of passenger cars	Y	
		Static	Road segment	Presence of heavy vehicles (y/n)	Y	
		Static	Road segment	Presence of motorcycles (mopeds included) (y/n)	Y	
		Static	Road segment	Presence of bicycles (y/n)	Possible, depending on other classifications	
		Static	Road segment	Presence of LMV (y/n)	Possible, depending on other classifications	
		Static	Road segment	Presence of pedestrians (y/n)	Possible, depending on other classifications	

Table 9. Factors for Automatedway road segments.

Full Automatedway (FA)

Full Automatedway road segments present similar connectivity conditions than Automatedway road segments – in fact, they share the same ISAD levels –, but present better geometric and environmental conditions. This implies smoother radii and vertical curves, road markings, lane widths, etc. The most remarkable characteristic is that the whole section becomes an ORS, so all SAE level 4 vehicles should be able to operate driverless.

These road segments could be used at freeways and high-end two-lane rural roads. All users could operate along these road segments, but road administrations might be willing to limit the use to some users (e.g., not bicycles, LMV or pedestrians). This would probably be the case for the first road segments where automation would be fully encouraged. In addition, dedicated lanes could be used within a lower-level road. All factors are summarized in Table 10.

Layer	Factor	Static/Dynamic	Domain	Parameter	4. Full automatedway	
					RA/RO	Veh
Physical infrastructure	Roadway type	Static	Road Segment	Type	Freeways and high-end two-lane rural roads	
		Static	Road segment	Dedicated lane	Optional	
	Geometric design	Static	Road Segment - Horizontal curves	Minimum Radius (m)	>=400	

Layer	Factor	Static/Dynamic	Domain	Parameter	4. Full automatedway	
		Static	Road Segment - Crest vertical curves	Minimum K (m/%)	>=25	
		Static	Road Segment	Lane width (m)	3.25-3.8	
		Static	Road Segment	Shoulder width (m)	>=2.5 m	
		Static	Road Section	Available stopping sight distance (m)	ASSD	
	Speed	Static	Road Segment/Section	Speed limit (km/h): Static; Dynamic	Dynamic	
	Speed	Static	Road Section	Minimum operating speed (km/h)		Different options
	Speed	Static	Road Section	Automated speed (km/h)		Different options
	Road markings	Static	Road Segment	Line width (mm)	150	
	Road markings	Static	Road Segment	Contrast	3	
	Road markings	Static	Road Segment	Retroreflectivity	150	
	Road markings	Static	Road Section	Edge lines continuity (y/n)	Always	
	Road markings	Static	Road Section	Prevention of sun glaring	Presence of dedicated lights at tunnel exits in order to mitigate sun glaring.	ADSs should have special features to adapt to low-contrast and sun-glared circumstances (e.g., W-E road orientations).
	Signs	Static	Road Segment	Contrast		
	Signs	Static	Road Segment	Retroreflectivity		
	Signs	Static	Road Section	Contextual information		Yes
	Signs	Static	Road segment	Readability of the VMS	High visibility/readability standards	
	Pavement	Static	Road Section	International Roughness Index (IRI) (m/km)	<=TBD	
	Pavement	Static	Road Section	Longitudinal crack sealing	N	
	Pavement	Static	Road Section	Hidden road markings	N	
	Road works	Static	Road Segment	Compliance of geometry, markings, signs and pavement factors	If road works take place within an ORS, signalization and geometry should meet ORS criteria	
	MRCs	Static	Road Segment	Availability of safe harbors	Yes [shoulders and medium-spaced harbours at junctions]	
Digital infrastructure	Mapping and digital information availability	Static	Road segment	Digital map	HD map	
		Static	Road segment	Digital map update frequency	Automatic, not necessarily real-time	
		Static	Road segment	Road traffic and events ahead	Y	
		Static	Road segment	Weather conditions	Y	
		Static	Road section	Variable speed limit	Variable Speed Limits are transmitted to vehicles	
		Static	Road section	Traffic lights	Y	
		Static	Road section	Traffic performance information	Macroscopic	

Layer	Factor	Static/Dynamic	Domain	Parameter	4. Full automatedway	
		Static	Subject vehicle	Microscopic dynamic driving guidance	Speed and lane advice might be sometimes provided	
		Static	Road Segment	Road works	Road works should be included in the HD maps.	
	Road equipment	Static	Road Segment	Presence of Roadside Units (RSUs)	RSUs are recommended, ensuring I2V	
		Static	Road segment	Sensors for trajectories of vehicles and users		
		Static	Road segment	Automatic road data processing	Y	
		Dynamic	Road Segment	Positioning accuracy	Very accurate	
	Disengagements	Dynamic	Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])	5 (TBD)	
	Weather	Static	Road Segment	Weather stations	Information from WS is present [high representativity, constantly updated]	
		Dynamic	Road Segment	Visibility (MOR)	1000 m	
		Dynamic	Road Segment	Snow/icy pavement	Light snow	
		Dynamic	Road section	Rainfall intensity	Moderate rain (<7.5 mm/h)	
	Sensing and information systems	Static	Road segment	Sensing system	Y	
		Static	Road segment	Availability of Stationary Object Detection system (radar-based side units)		
		Static	Road segment	Information system	N/Y	
		Static	Road segment	Intelligent Speed Adaptation (ISA)		Dynamic Closed
Connectivity	DSRC/ITS-G5	Static	Road section	Availability	Y/N	
	C-V2X (5G)	Static	Road segment	Availability	Y/N	
	DSRC	Dynamic	Road segment	Range (m)	2000	
	Reliability	Dynamic	Road segment	% Packets received in due time	99%	
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)	3	
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?	100	
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (RSRP) (dBm)	-85	
Users	User distribution	Static	Road segment	Presence of passenger cars	Y	
		Static	Road segment	Presence of heavy vehicles (y/n)	Y	
		Static	Road segment	Presence of motorcycles (mopeds included) (y/n)	Y	
		Static	Road segment	Presence of bicycles (y/n)	Possible, depending on other classifications	
		Static	Road segment	Presence of LMV (y/n)	N	

Layer	Factor	Static/Dynamic	Domain	Parameter	4. Full automatedway	
		Static	Road segment	Presence of pedestrians (y/n)	Possible, depending on other classifications	

Table 10. Factors for Full Automatedway road segments.

Autonomousway (AU)

Finally, Autonomousway road segments represent the best option for automation. Like FA road segments, a single ORS appears throughout all their length. Additional facilities are also present, such as a high-density distribution of safe harbors which are also included in the HD maps. The most remarkable difference is that the connectivity support is remarkably better than for FA segments, enabling cooperative driving. Thus, these road segments are recommended for all zones with a high volume of vehicles, where dynamic traffic parameters could be used for managing purposes. Since non-connected vehicles cannot participate in the cooperative driving, these road segments would exclusive apply to freeways and only to connected and automated vehicles. These road segments should therefore be in exclusive road facilities, where needed and when the percentage of CAVs becomes important. To make their implementation cheaper, these could be placed as dedicated lanes in a lower-level road facility (SRC 4). Table 11 summarizes all factors.

Layer	Factor	Static/Dynamic	Domain	Parameter	5. Autonomousway	
					RA/RO	**Veh**
Physical infrastructure	Roadway type	Static	Road Segment	Type	Freeways	
		Static	Road segment	Dedicated lane	Optional	
	Geometric design	Static	Road Segment - Horizontal curves	Minimum Radius (m)	>=500	
		Static	Road Segment - Crest vertical curves	Minimum K (m/%)	>=30	
		Static	Road Segment	Lane width (m)	3.5-3.6	
		Static		Shoulder width (m)	>=2.5 m	
		Static	Road Section	Available stopping sight distance (m)	ASSD	
	Speed	Static	Road Segment/Section	Speed limit (km/h): Static; Dynamic	Dynamic	
		Static	Road Section	Minimum operating speed (km/h)		Different options.
		Static	Road Section	Automated speed (km/h)		Different options.
	Road markings	Static	Road Segment	Line width (mm)	150	
		Static	Road Segment	Contrast	3	
		Static	Road Segment	Retroreflectivity	150	
		Static	Road Section	Edge lines continuity (y/n)	Always	
		Static	Road Section	Prevention of sun glaring	Presence of dedicated lights at tunnel exits in order to mitigate sun glaring.	ADSs should have special features to adapt to low-contrast and sun-glared

Layer	Factor	Static/Dynamic	Domain	Parameter	5. Autonomousway	
						circumstances (e.g., W-E road orientations).
	Signs	Static	Road Segment	Contrast		
		Static	Road Segment	Retroreflectivity		
		Static	Road Section	Contextual information		Yes
		Static	Road segment	Readability of the VMS	No restrictions (all vehicles and all information would be digital, too).	
	Pavement	Static	Road Section	International Roughness Index (IRI) (m/km)	<=TBD (comfort)	
		Static	Road Section	Longitudinal crack sealing	N	
		Static	Road Section	Hidden road markings	N	
	Road works	Static	Road Segment	Compliance of geometry, markings, signs and pavement factors	If road works take place within an ORS, signalization and geometry should meet ORS criteria	
	MRCs	Static	Road Segment	Availability of safe harbors	Yes [High frequency]	
Digital infrastructure	Mapping and digital information availability	Static	Road segment	Digital map	HD map. MRC zones are included	
		Static	Road segment	Digital map update frequency	Real-time	
		Static	Road segment	Road traffic and events ahead	Y	
		Static	Road segment	Weather conditions	High precision data with forecasting possibilities	
		Static	Road section	Variable speed limit	Tailored Speed Advice is transmitted to vehicles	
		Static	Road section	Traffic lights	Y	
		Static	Road section	Traffic performance information	Microscopic, obtained by the road infrastructure	
		Static	Subject vehicle	Microscopic dynamic driving guidance	Y	
		Static	Road Segment	Road works	Road works should be included in the HD maps.	
	Road equipment	Static	Road Segment	Presence of Road Side Units (RSUs)	Yes, ensuring V2I and I2V	
		Static	Road segment	Sensors for trajectories of vehicles and users	Y	
		Static	Road segment	Automatic road data processing	Y	
		Dynamic	Road Segment	Positioning accuracy	Highest accuracy	
	Disengagements	Dynamic	Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])	0 (TBD)	
	Weather	Static	Road Segment	Weather stations	Information from WS is present [high representativity, constantly updated]	
		Dynamic	Road Segment	Visibility (MOR)	1000 m	
		Dynamic	Road Segment	Snow/icy pavement	Light snow	

Layer	Factor	Static/Dynamic	Domain	Parameter	5. Autonomousway	
		Dynamic	Road section	Rainfall intensity	Moderate rain (<7.5 mm/h)	
	Sensing and information systems	Static	Road segment	Sensing system	Y	
		Static	Road segment	Availability of Stationary Object Detection system (radar-based side units)	Y	
		Static	Road segment	Information system	Y	
		Static	Road segment	Intelligent Speed Adaptation (ISA)		Dynamic Closed
Connectivity	DSRC/ITS-G5	Static	Road section	Availability	Y	
	C-V2X (5G)	Static	Road segment	Availability	Y	
	DSRC	Dynamic	Road segment	Range (m)	700	
	Reliability	Dynamic	Road segment	% Packets received in due time	100.00%	
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)	30	
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?	5	
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (RSRP) (dBm)	-67	
Users	User distribution	Static	Road segment	Presence of passenger cars	Yes, only CAVs	
		Static	Road segment	Presence of heavy vehicles (y/n)	Yes, only CAVs	
		Static	Road segment	Presence of motorcycles (mopeds included) (y/n)	N	
		Static	Road segment	Presence of bicycles (y/n)	N	
		Static	Road segment	Presence of LMV (y/n)	N	
		Static	Road segment	Presence of pedestrians (y/n)	N	

Table 11. Factors for Autonomousway road segments.