SMART INFRASTRUCTURE INDEX REPORT. SECOND RELEASE

D6.6

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Authors	Ana V. Silva (A-to-Be) Nuno Vidal (A-to-Be) Tiago Dias (A-to-Be)
Internal reviewers	Lakshya Pandit (RUPPRECHT) Lucie Tristant (ID4MOBILITY)
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Executive summary

The shift towards Connected, Cooperative, and Automated Mobility (CCAM) represents a significant paradigm shift in mobility. To navigate this transition effectively, the establishment of standardized procedures for evaluating infrastructure capabilities is crucial. One of these procedures is the definition of classifications schemes to evaluate the maturity, readiness or support infrastructures can provide for CCAM. These classifications serve a multifaceted purpose, including informing end-users, assisting operators, and aiding authorities and policymakers in planning the evolution of CCAM. Furthermore, as smart infrastructures become more prevalent, these standardized approaches play a pivotal role in infrastructure management, by guiding planning future infrastructure improvements and investments to support higher levels of automation and advanced use cases.

This document is the final release of a set of two, delivered at the end of the project, when the implementation of TANGENT's classification system was already performed and tested. It starts by introducing the relevancy of smart infrastructure classifications accompanied by describing known best practices and followed by identifying the requirements deemed more relevant from expert stakeholders. A literature review on the main existing smart infrastructure classification schemes was performed, tackling six indexes: ISAD, CRCS, EAPA index, LOSAD and SRC and was further extended in this final version to include two other indexes for MTM Cluster TANGENT sister projects FRONTIER and DIT4TRAM with the SRICI and SIRI indexes respectively. The initial literature review supported the identification of the most relevant infrastructure characteristics, alongside pinpointing the limitations of the existing classifications, allowing the consortium to evolve the existing work to an urban and peri-urban context and to expand it to include multimodal transport. The consultation of TANGENT's Advisory Board aided the consortium to swiftly adapt to urban multimodal scenarios, while avoiding some pitfalls from the previous indexes.

Next, the deliverable introduces TANGENT's own smart infrastructure classification, the Smart Infrastructure Classification Index (SICI), laying out the TANGENT classification categories, its evaluation criteria, and its integration into the TANGENT platform. The six categories considered for SICI are: Physical Elements, Infrastructure Perception, Reference Information, Dynamic Information, Information Channels and Active Traffic Management. The first category focuses on physical infrastructure elements like road marks and signs that are crucial for the perception of human drivers as well as autonomous vehicles. The second category is comprised of the several different types of sensors that allow characterization and monitoring of the infrastructure. The third one evaluates the availability of reference information on the infrastructure side, namely from road and transport operators, while the fourth refers to (quasi) real-time information on the transport network state. The fifth category addresses how the information reaches vehicles and users, while the last one evaluates the existing of both classic and cooperative active traffic managements functions. An individual scoring of each SICI category is considered. This is a fundamental concept behind SICI, as the different categories focus on different dimensions of maturity of a smart infrastructure, which correlate but do not imply each other. This document presents the evaluation process of each SICI category, by providing a detailed list of evaluation criteria for each of the items in each of the categories. Finally, this deliverable introduces how the consortium implemented SICI in TANGENT's integrated platform and does a summary comparison between the most relevant indexes mentioned and SICI.

Key words

Smart Infrastructure, Infrastructure Classification, Levels of Service, Infrastructure Support, Infrastructure Digitalisation and Connectivity, Automated Driving, Traffic and Public Transport, Physical Infrastructure, Digital Infrastructure, Operational Infrastructure

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List of abbreviations and acronyms

Acronym	Meaning
AASHTO	American Association of Highway and Transportation Officials
AB	Advisory Board
ACC	Adaptative Cruise Control
ACEA	Association des Constructeurs Européens d'Automobiles (European Automobile Manufacturers' Association)
AD	Automated Driving
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
AS	Assistedway
ASAP	As Soon As Possible
ASSAD	Available Stopping Sight Distance
AT	Automatedway
AU	Autonomousway
AV	Autonomous Vehicle
AVRI	Autonomous Vehicles Readiness Index
AWS	Amazon Web Services
BRT	Bus Rapid Transit
B2B	Business-to-business
B2C	Business-to-Consumer
CACC	Cooperative Adaptive Cruise Control
CAD	Connected and Automated Driving
CADS	Collaborative Automated Driving System
CAH	Connected Automated Highway

CAV	Connected Automated Vehicle
CAVH	Connected Automated Vehicle Highway
CCAM	Cooperative Connected and Automated Mobility
CIM	Cooperative Incident Management
C-ITS	Cooperative Intelligent Transport System
COP	Common Operational Picture
CRCS	Connected Roadway Classification System (CRCS)
CV	Connected Vehicle
C-V2X	Cellular-V2X
DoS	Denial of Service
DMS	Dynamic Message Signs
DRT	Demand Responsive Transportation
DSRC	Direct Short Range Communication
ERS	Electric Road Systems
EAPA	European Asphalt Pavement Association
ERTRAC	European Road Transport Research Advisory Council
EC	European Commission
EU	European Union
EV	Electrical Vehicle
FA	Full Autonomousway
FR	Functional Requirement
GA	Grant Agreement
GRVA	Working Party on Automated/Autonomous and Connected Vehicles
GPS	Global Positioning System
HE	Horizon Europe
HU	Humanway

HTTPS	Hyper Text Transfer Protocol Secure
H2020	Horizon 2020
IAM	Identity and Access Management
IMD	Institute for Management Development
IOO	Infrastructure Owners and/or Operators
ISAD	Infrastructure Support for Automated Driving
ISA	Intelligent Speed Adaptation
IRF	International Road Federation
IRI	International Roughness Index
iTMC	intelligent TMC
ITS	Intelligent Transport System
I2V	Infrastructure to Vehicle
JSON	JavaScript Object Notation
JSON-LD	JSON for Linking Data
KoM	Kick-off Meeting
KPI	Key Performance Indicator
LaaS	Logistics as a Service
LKA	Lane Keeping Assist
LMV	Light Mobility Vehicle
LoS	Level of Service
LOSAD	Level of Service of Automated Driving
MaaS	Mobility as a Service
mLoS	Minimum Level of Service
MOR	Meteorological Optical Range
MRC	Minimum Risk Condition
MUTCD	Manual of Uniform Traffic Control Devices

NA	Not Applicable
NAP	National Access Point
NFR	Non-Functional Requirement
NTM	Network Transport Management
OBU	On Board Unit
OD	Origin-Destination
ODD	Operational Design Domains
OEM	Original Equipment Manufacturer
ORS	Operational Road Section
PDI	Physical and Digital Infrastructure
PIARC	Permanent International Association of Road Congresses (World Road Association)
PT	Public Transport
RDF	Resource Description Framework
RDS-TMC	Radio Data System - Traffic Message Channel
RPP	Response Plan Package
REST	Representational State Transfer
R&I	Research and Innovation
RQI	Road Quality Indicator
RSRP	Reference Signal Received Power
SICI	Smart Infrastructure Classification Index
SCI	Smart City Index
SNLB	Smart Network Load Balancing
SPaT	Signal Phase and Timing
SRC	Smart Road Classification
TBD	To Be Determined

TCD	Traffic Control Device
TMC	Traffic Management Centre
TMS	Traffic Management System
TSP	Transit Signal Priority
UNECE	United Nations Economic Commission for Europe
UI	User Interface
UITP	International Association of Public Transport
URL	Uniform Resource Locator
UX	User Experience
VM	Virtual Machine
VMS	Variable Message Signs
VRU	Vulnerable Road Users
V2I	Vehicle to Infrastructure
V2X	Vehicle to Everything
WP	Work Package
WS	Weather Station
XML	Extensible Markup Language

1 Purpose of the deliverable

1.1 Attainment of the objectives and explanation of deviations

The main purpose of this deliverable is to introduce the Smart Infrastructure Classification Index created in the scope of TANGENT, a classification metrics integrated into the project's transport network management system, that allows different stakeholders, namely transport authorities and policymakers, to assess the level of support different sections of the network have during the transition to Cooperative Connected and Automated Mobility (CCAM).
This deliverable is an output of Task 6.5 – *"Smart infrastructure classification index definition"* [M6-M36] from work package (WP) 6 – *"Integrated support tool for cooperative traffic management"*. This report is the final release of a set of two, introducing the relevancy of such smart infrastructure classifications, describing best practices, exploring the state-of-the-art, identifying the requirements deemed relevant by expert stakeholders and laying out the TANGENT classification categories, its evaluation criteria and its implementation into the TANGENT's integrated tool, further specifying the classification metrics and detailing its deployment.

The objectives of this release are considered achieved as it updates the main infrastructure characteristics the classification scheme should have (considering expert advice inputs), describes the TANGENT classification solution and provides an eagle-eye comparison between SICI and the several of the other index schemes described.

1.2 Intended audience

This deliverable is intended for the project partners, project officers, and the public interested in Smart Infrastructures Classifications and the solution under implementation in TANGENT.

1.3 Structure of the deliverable and links with other work packages/deliverables

- Section 2 of this deliverable describes the background and motivation of the deliverable's thematic, starting from the road infrastructure adaptation to vehicles' automation, the need for classification schemes as a tool to support CCAM and the methodology followed by the project consortium to create TANGENT's Smart Infrastructure Classification Index (SICI).
- Section 3 presents the main Smart Infrastructure characteristics that should be considered for the design and implementation of TANGENT's classification. It's starts by performing a State-of-the-Art analysis of the existing Smart Infrastructure classifications, followed by an overview of the perspectives of different experts on the subject, from TANGENT's own Advisory Board and from other selected initiatives.
- In section 0, the Smart Infrastructure Classification Index (SICI) is introduced. After contextualizing the particularity of the TANGENT scheme and presenting the shortcomings of Smart Infrastructure classifications that were previously described, SICI's different classification categories are presented, followed by the description of the evaluation criteria considered. Next, the way TANGENT's SICI was implemented is described, namely how the data to calculate the evaluation parameters is collected and how the classification results are displayed the TANGENT integrated tool.
- Section 5 provides a short but relevant comparison between most of the different classification indexes covered in this work, including SICI, providing a good way to put SICI under context next to other indexes.
- Finally, in section 6, the concluding remarks of this deliverable are presented.

The proposed classification system incorporates advice from expert stakeholders and thus a close collaboration with WP1 – *“Multi-actor cooperation models and policies”*, under Task 1.3 – *“Stakeholder engagement and consultation”* [M6-M36] was established. This collaboration produced the organization of a technical meeting with the TANGENT Advisory Board in June 2023. The session - “Unlocking Data Collaboration and Assessing Smart Infrastructure Indexes” - was centred around smart infrastructures and automation and promoted an open discussion on classification schemes, present and future technologies, and the transition to CCAM. This fruitful engagement continued with external expert stakeholders in the TANGENT Forum, an online discussion forum at the Mobility Academy[1] where, starting from September 2023, further in-depth discussions were promoted and where first the way for presenting SICI results as a combination of a color-coded table and radar plots per category was presented.

The devised classification scheme was implemented in the TANGENT integrated tool in Task 6.4 – *“Integration and development of TANGENT decision-making support tool for coordinated traffic and transport management”*.

For the collection of classification parameters, WP6 benefited from the work developed in WP2, WP4 and WP5. Data automatically collected from TANGENT’s Data Catalogues, WP2 – *“Data Gathering, Harmonization and Fusion”*, described in deliverable D2.1 – *“Data requirements and available data sources”* [M12] and materialized by D2.3 – “TANGENT API for harmonisation and fusion”. In addition, the automatic collection of parameters from the pilot cities’ transport models and geographical information systems for SICI, was considered by the accesses created to these sources under Task 4.5 – *“Developing a framework for real-time traffic monitoring and forecasting”* and Task 5.5 – *“Development of the transport network optimization module*”.

TANGENT’s classification index was made available as specific functionality in the TANGENT Dashboard, presented visually at the TANGENT Dashboard for the corresponding city. Under the activities of WP7 – *“Future Case Studies”*, the ease of using this information by the TANGENT tool users was evaluated in Task 7.3 – *“Upscaling and full operation: testing of the overall system”* and the relevancy of this index for transport authorities and policymakers assessed in Task 7.4 – *“Results & Impact Assessment”*.

[1] https://www.mobility-academy.eu/course/index.php?categoryid=57

2 Introduction

As the introduction of connected and automated vehicles becomes feasible, public authorities, mobility planners and transport managers need to prepare for the revolution that Connected and Automated Driving (CAD) brings to the transportation sector.

Understanding the challenges of traffic safety, efficiency and sustainability that the Connected Cooperative and Automated Mobility brings is fundamental to plan, design and implement this new transportation ecosystem. While most early debates were centred on vehicles, it became evident that the infrastructure will have a paramount role.

The future transport ecosystem, especially in the urban and peri-urban context, will become a vehicle-infrastructure collaborative smart system, where information of most elements will be available: vehicles, users, infrastructure, weather conditions, traffic conditions and events, etc.

2.1 Background

During the transition to CCAM, there will be simultaneous operation of conventional vehicles, connected vehicles and vehicles with different levels of automation, all sharing the same infrastructures and with evolving penetration rates. Several institutions, such as the *European Road Transport Research Advisory Council* (ERTRAC)[2] or the *European Automobile Manufacturers Association* (ACEA)[3] have proposed roadmaps for the deployment of automated driving in the European Union (EU) [1][2], contemplating amongst a myriad of aspects the necessary infrastructure rollouts. In 2021, the *International Road Federation* (IRF)[4] published a manifesto stating there is a lack of clear system design and classification of CAD systems, which is hindering the industrialization and usage of CCAM technologies. They consider it is essential to assess the level of infrastructure support and that it is urgent to develop a uniform classification index harmonized worldwide [3].

Several projects have been evaluating the road infrastructure and vehicle readiness for CCAM. The European *Connected and Automated Driving*[5] initiative provides a complete and up-to-date list of all CAD projects funded by the EU[6], from which ERTRAC created a summary of the main 2015-2023 initiatives, gathering them into four research fields: Networking, Coordination & Support; Infrastructure, Connectivity and Cooperative Systems; Driver Assistance Systems and Partial Automation; and Highly Automated Road Transport. In Figure 1 the most relevant EU funded projects about Smart Infrastructures are highlighted for easy identification. In 2022, the *CCAM Partnership*[7], a public-private initiative co-funded under the Horizon Europe (HE) programme published the final version of its 2021-2027 strategic agenda, which aggregates Research and Innovation (R&I) actions into seven operational clusters. Cluster 4 – "Integrating the vehicle in the transport system" dwells into the Physical and Digital Infrastructure. And one of its expected outcomes is the classification of infrastructure support levels and the contribution for an EU-wide/global infrastructure classification harmonization [4]. Several CCAM R&I initiatives with a focus on infrastructure support have already been funded by the HEU programme

[2] https://www.ertrac.org/
[3] https://www.acea.auto/
[4] https://www.irfofficial.org/
[5] https://www.connectedautomateddriving.eu/
[6] https://www.connectedautomateddriving.eu/projects/findproject/
[7] https://www.ccam.eu/

Europe: AUGMENTED CCAM (2022-2025)[8], CONDUCTOR (2022-2025)[9], IN2CCAM (2022-2025)[10], PoDIUM (2022-2025), MODI (2022-2026)[11] and ROADVIEW (2022-2026)[12].

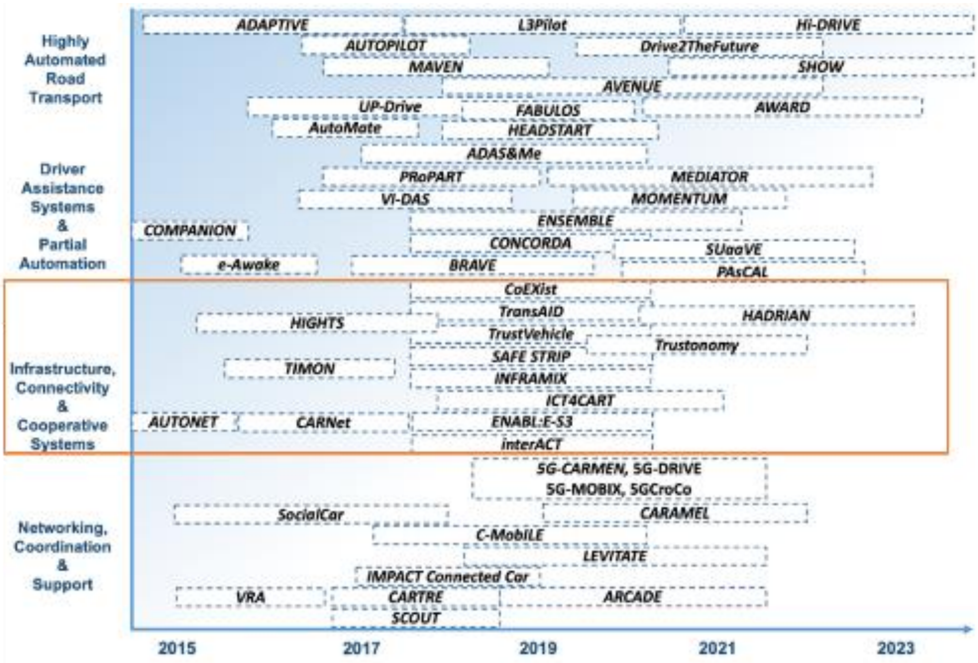

Figure 1: Summary of the main EU Horizon 2020 (H2020) projects on CAD, highlighting (orange box) the ones focusing on Infrastructure Connectivity & Cooperative Systems. Adapted from [2].

2.2 Road Infrastructure and Automation

Traditionally, the road was considered to be an asphalt transportation corridor, composed of roadways and lanes space, its pavement, and the physical elements that regulated its usage (*e.g.*, road signs, road markings). With the massification of electronics, the physical elements list kept being extended to include a myriad of sensors, variable road signs, and all the equipment that comprises the road communication infrastructure. These elements produce digital information that supports digital representations of the road environment which can benefit Connected Vehicles (CVs), Connected and Automated Vehicles (CAVs) and advanced Traffic Management Systems (TMS) [5]. These two dimensions of the road infrastructure are designated the Physical and Digital Infrastructure (PDI). Advanced traffic management functions, such as the ones providing active guidance and traffic control, highly depend on the PDI, but also require the continuous interaction with external stakeholders (*e.g.*, Transport Authorities, Original Equipment Manufacturers (OEMs), mobility cloud service providers) and constitute what has been defined as the Operational Road Infrastructure [6]. To be able to support connectivity and automation one should consider the road infrastructure in three dimensions:

- **Physical road infrastructure** – integration of all the physical elements present where vehicles circulate, namely:

[8] https://augmentedccam.com/
[9] https://conductor-project.eu/
[10] https://in2ccam.eu/
[11] https://modiproject.eu/
[12] https://roadview-project.eu/

- Roadways, and other lanes
- Bridges, tunnels, etc.
- Pavement
- Lighting
- Safety barriers
- Landmarks
- Pavement markings
- Road signs (static and variable, *e.g.*, Dynamic Message Signs (DMS), Variable Message Signs (VMS))
- Traffic Control Devices (TCD)
- Traffic sensors (*e.g.*, radar, lidar, vision systems, loop detectors, ultrasonic, treadles and other counters)
- Environmental sensors (*e.g.*, weather, air quality)
- Communication infrastructure (*e.g.*, Cooperative Intelligent Transport System (C-ITS)) Roadside Units (RSUs), cellular equipment, fibre back-bone)
- Power infrastructure

- **Digital road infrastructure** – integration of multiple geo-located information layers containing:
  - Static data: Base Maps (*e.g.*, digital cartographic data, topological data, road facilities and technical characteristics, High Definition (HD) maps)
  - Semi-static data: Planned activities and Forecasts (*e.g.*, traffic regulations, road works)
  - Semi-dynamic data: Incidents Information (*e.g.*, accidents, congestion, localized weather events)
  - Dynamic data: Microscopic Traffic Information (*e.g.*, C-ITS data, surrounding vehicles, average speeds, presence of Vulnerable Road Users (VRUs))

- **Operational road infrastructure** – advanced traffic management functions which facilitate the traffic flow by providing guidance and/or control and that require integration with external stakeholders' cloud services for added information, such as other modes of transport real-time data (*e.g.*, navigation systems, real-time traffic, incidents reporting, road weather services, tolling systems). Examples of these advanced traffic management functions include:
  - Incident management
  - Ramp metering
  - Traffic-responsive or traffic-adaptive traffic signal operations
  - Active traffic management (*e.g.*, lane merging or overtaking support)
  - Managed lanes
  - Integrated corridor management

Only by simultaneously considering and improving these three infrastructure dimensions, connected and automated mobility can be taken to higher levels of automation. Together they can support a broad variety of use cases, either by direct infrastructure-vehicle interaction (*e.g.*, lane merging, overtaking), by advanced traffic management measures (*e.g.*, vehicle platooning) or by the support of maintenance activities (*e.g.*, HD maps update). To support advanced CCAM use cases, one needs to adapt the physical infrastructure; to sensorize it, in order to have the correct digital representation; to implement suitable communications channels, to provide quality data; and to setup advanced TMS functions. Since the road infrastructure requirements are strongly use case specific, a harmonized approach on how to describe them is highly beneficial. A common understanding of the physical, digital, and operational infrastructures, their specifications, its interfaces, alongside extensive piloting is essential to fulfil the requirements of future CCAM.

2.3 Automated Driving Classification

In Automated Driving (AD), road perception and vehicle control gradually move from the human to computer systems. AD requires certain prerequisites, which can be grouped into different context domains (refer to Figure 2):

- the **domain of law and regulation**
- the **domain of the driver-machine interaction and of the surrounding environment**, where the driving happens. This domain is normally described in by the Operational Design Domains (ODDs) which describe the conditions (geographical, environmental, etc) where the system can perform (and stay performing) in an automated way.
- the **domain of the vehicle automation capability**. This domain is commonly described by the US standards SAE International (SAE)[13] levels of Driving Automation – SAE J3016™, introduced in 2014 – the main reference worldwide to describe the automation levels of on-road motor vehicles. An updated version was delivered in 2021 [7].
- the **domain of the road infrastructure**

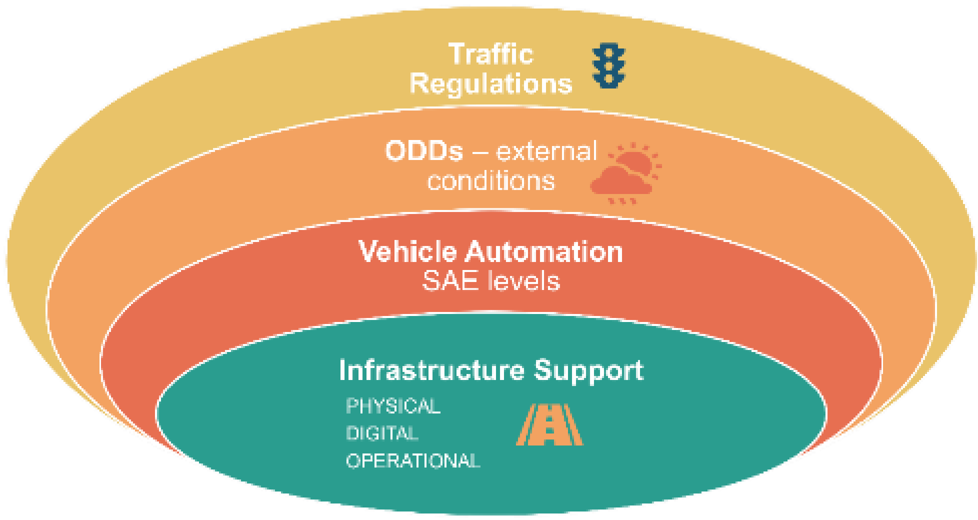

Figure 2: Automated Driving Context Domains. Adapted from [12].

Figure 3 presents a digest of the SAE J3016™, published by the European Commission [8], when defining the roadmap for automated mobility in 2018 and reviewed in this deliverable to match the latest SAE J3016 version (J3016_202104) [7]. This classification has 6 levels, where 0 represents vehicles without any kind of automation implementation (where the driver is solely responsible for all perception and car control) up to level 5, which represents fully automated vehicles, where there is no need for a driver. The most recent AD vehicle models accessible to the regular citizens are between level 3 for private cars (where the driver does not have to monitor the system at all time, as the car has control in specific use cases and when recognizing its performance limits requests the driver to resume control) and level 4 (for some shuttle-like vehicles operating in specific controlled urban environments where the system operates automatically in restrict use cases).

[13] https://www.sae.org/

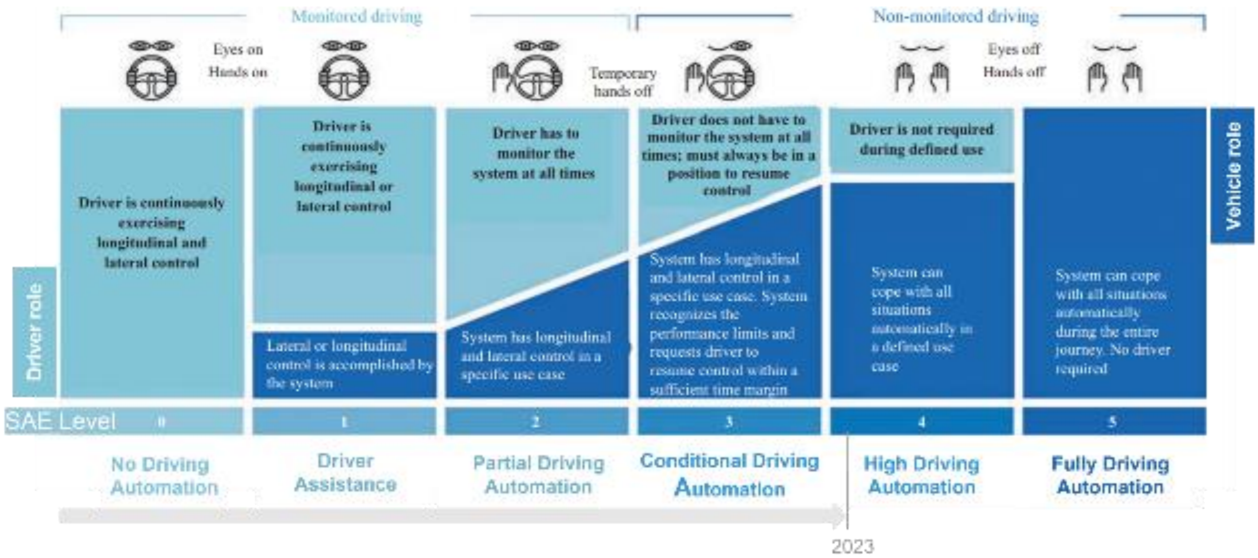

Figure 3: SAE J3016TM Levels of Driving Automation. Adapted from [7] and [8].

2.4 Smart Infrastructure Classification Schemes

To cope with the transition periods of CCAM, an effective network traffic management system needs to assess the level of infrastructure preparation towards road automation. For that, a myriad of different physical and digital characteristics require evaluation, assessing the quality and completeness of the information being provided to users and vehicles at each road segment, and their degree of adaptation (or potential) towards automated and/or connected driving.

Classification schemes organize information categorizing it into abstract groups (*e.g.*, categories, classes, types) based on common characteristics. Since there is limited standardization of the intelligence levels of road infrastructures [3], it became imperative to create smart infrastructure classification systems. These schemes create a framework for assessing the infrastructure, while developing a common language for the infrastructure role in CCAM and the incorporation of the technological progress, thus facilitating the exchange of information between the different stakeholders (road users, automotive industry, infrastructure owners/operators, etc.) [9]. Furthermore, these classifications can assist transition periods to higher levels of automation, identify modularity and scalability in functionalities and facilitate the handling of different system lifecycle integrations [10].

To address the need for smart road transport categorization, several research projects have started defining classification schemes for road infrastructure and vehicle readiness to CCAM. The two seminal works were delivered by the EU H2020 funded project INFRAMIX (2017-2020)[14] and by the US NCHRP 20-24 funded project CRCS (2017-2020)[15]. In 2018, INFRAMIX presented the *Infrastructure Support for Automated Driving* (ISAD) classification scheme, which characterized the digital and connectivity readiness of the infrastructure, by mapping the digital information that it provided to road users [10][11][12]. In 2019, the CRCS project delivered the *Connected Roadway Classification System* (CRCS) that characterized the infrastructure in three axes: vehicle-infrastructure communication, infrastructure readability and infrastructure design and operation for AD [9].

[14] https://www.inframix.eu/
[15] https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4224

In 2020, the *European Asphalt Pavement Association* (EAPA)[16] proposed a classification of the *Road Readiness for adopting Connected and Automated Vehicles*, which results mostly from the combination of the ISAD and SAE automation levels but also includes some parameters characterizing the physical road infrastructure (*e.g.*, road marking, signs, pavement conditions) [13]. However, this classification does not consider the quality of the geometric design of the road segments for its automatic recognition, essential for automated driving. To address this, the *Highway Engineering Research Group* (HERG)[17], from the Universitat Politecnica de Valencia, proposed the concept of *Level of Service of Automated Driving* (LOSAD), which summarizes the physical roadway readiness for Automated Driving [14]. This group was recruited by the *World Road Association* (PIARC)[18] to devise a more complete classification system and in 2021 they presented the *Smart Road Classification* (SRC) that combines the automation readiness classification provided by LOSAD and the infrastructure support classification provided by ISAD into a single classification system [15].

TANGENT belongs to the 4FRONT cluster of projects funded under H2020, in the topic “Network and Traffic management for Future Mobility” from the program “Smart Green and Integrated Transport”. Two of the cluster projects aim at providing smart infrastructure classifications: TANGENT and FRONTIER (2021-2024)[19]. FRONTIER aims at presenting a new road infrastructure classification based on the World Road Statistics[20] from IRF, one of its consortium partners[21]. In addition, the EU HE funded project AUGMENTED CCAM (2022-2025)[22] plans to extend and harmonize PDI classifications and support schemes.

Benefiting from the previous works, TANGENT will develop its own **Smart Infrastructure Classification Index** (SICI). This will assess the Connectivity and Digital Support infrastructures can provide for CCAM (CAVs, connected vehicles, conventional vehicles, and connected users), adapted to the urban and peri-urban multimodal contexts it focuses on (aligned with its pilot case studies). The devised SICI will be integrated into the TANGENT Framework and may be accessible to the Case Study pilots' stakeholders.

2.5 Methodology for TANGENT’s SICI definition

TANGENT’s SICI is being developed in WP6 under Task 6.5 - “Smart infrastructure classification index definition”. The methodology for its development is illustrated in Figure 4 and consists of a three-step process.

Step 1: **Characteristics elicitation**

The project consortium will assess the main transport infrastructure characteristics that support connected and automated mobility. First, it will review the existing infrastructure classification indexes and engage with expert stakeholders, through the consultation mechanisms organized by WP1, to evolve that elicitation, namely for the urban and peri-urban scenarios. This will allow to identify the most relevant requirements for the penetration of CCAM and from it extract the properties of the physical and digital infrastructures that can constitute objective and meaningful classification parameters. In addition, WP6 will assess the feasibility of deriving these parameters directly from transport models, geographic

16 https://eapa.org/
17 https://www.researchgate.net/lab/Highway-Engineering-Research-Group-Alfredo-Garcia
18 https://www.piarc.org/
19 http://www.frontier-project.eu/
20 https://datawarehouse.worldroadstatistics.org/
21 https://www.linkedin.com/feed/update/FRONTIER_SRICI
22 https://augmentedccam.com/

information systems and infrastructure's datasets, in order to implement an automatic classification process.

Step 2: **Classification index creation**

With the parameters identified in the previous step, WP6 will design a classification index (defining ranges, thresholds, weights, etc), applicable to urban and peri-urban multimodal contexts, that can consider the infrastructure at a micro level, based on locally supported use cases, and at a meso level considering overall connections and restrictions.

Step 3: **Integration of SICI in the TANGENT Framework**

Finally, the classification index will be integrated into the TANGENT framework, providing the ability to different mobility stakeholders (*e.g.*, policymakers, transport authorities, infrastructure owners, operators) of identifying what level of support each infrastructure has.

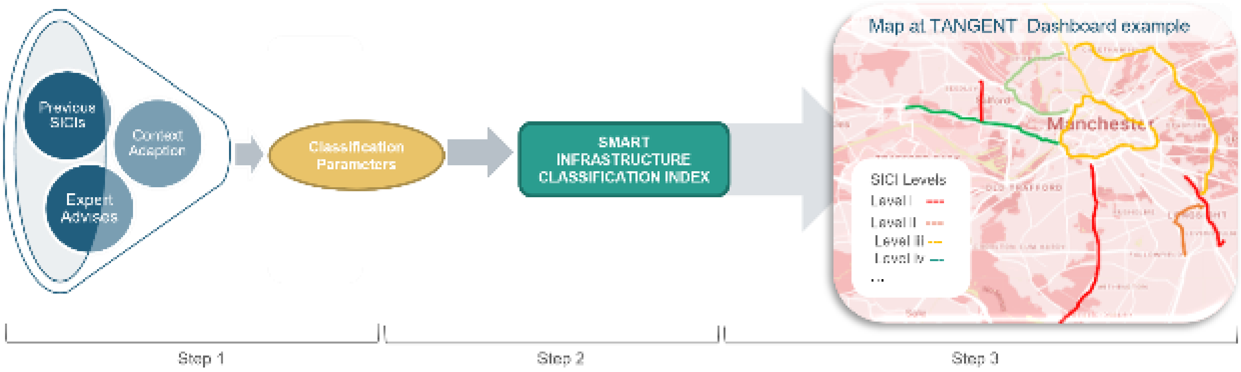

Figure 4: Methodology followed by TANGENT for the implementation of the Smart Infrastructure Index Classification.

3 Smart Infrastructure characteristics elicitation

3.1 Smart Infrastructure Classification State-of-the-Art

Initial approaches to road classification systems were focused on motorized vehicles driven by humans, mainly communicating the character of service, by describing the road's context (*e.g.*, rural, suburban, urban) and functional type (*e.g.*, motorway, arterial, local). More recently these systems started including the type of road users and the priority they give to each type however they are still insufficient in the context of CCAM [15]. To overcome this limitation, in the last 5 years, several new road classification schemes have been proposed and an overview of the main ones is presented in the next sections.

3.1.1 ISAD: Infrastructure Support for Automated Driving - Classification Scheme from INFRAMIX

The first known classification index proposed was the ISAD - ***Infrastructure Support for Automated Driving*** - developed under the INFRAMIX EU project[14] which assesses the digital and connectivity readiness of the infrastructure to support automated driving. The ISAD index has five levels according to the digital information the infrastructure provides to its users (relevant for AD) and depending on the connectivity of the infrastructure [10**¡Error! No se encuentra el origen de la referencia.**][12]. A summary of the ISAD classification is presented at Table 1 The first version of ISAD was presented in 2018 [11].

	LEVEL	Name	Description	Digital Information Provided			
				Digital map with static	VMS, warnings,	Microscopic traffic	Guidance: speed, gap,
Conventional Infrastructure	E	**Conventional infrastructure / No AV support**	Conventional infrastructure without digital information. Autonomous Vehicles (Avs) need to recognize road geometry and road signs				
	D	**Static digital information / Map support**	Digital map available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short-term road works and VMS need to be recognized by AVs				
Digital Infrastr	C	**Dynamic digital information**	All dynamic and static infrastructure information is available in digital form and can be provided to AVs				

	B	**Cooperative perception**	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time					
	A	**Cooperative driving**	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups or single vehicles) in order to optimize the overall traffic flow					

Table 1: Infrastructure Support for Automated Driving (ISAD) Classification Scheme [10].

The ISAD classification scheme is to be applied at the road stretch level, creating ISAD levels maps, as illustrated in Figure 5. The full ASFINAG (Austrian concessionaire) road network (2200 km) was evaluated under this classification scheme, based on its GIS database. All ASFINAG network fulfilled a minimum level D, with 23km long ALP.Lab corridor near Graz achieving a maximum of level B [10][11][12]. In addition, the full 1500 km tolled motorway network operated by AAE in Spain was also evaluated, also achieving a minimum level D in all network and a maximum level B at the 20 km Girona AAE test-site AP.7 [10][11].

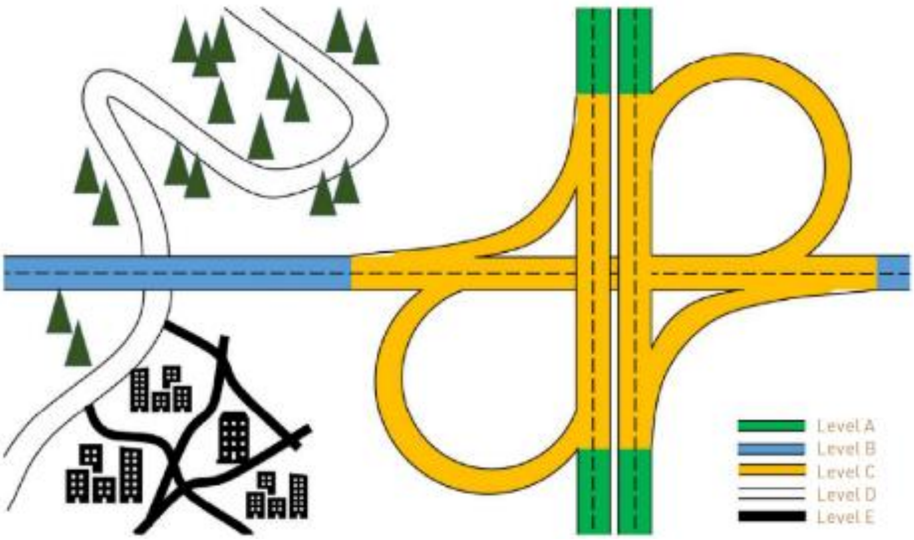

Figure 5: Example of the application of the ISAD index on a transport network area, from [**¡Error! No se encuentra el origen de la referencia.**][23].

Throughout the execution of INFRAMIX, its consortium further developed the ISAD classification, by specifying a more extensive set of information components, use cases and equipment covering each category. All the infrastructure components considered by the INFRAMIX project, for each ISAD level, are listed in Table 2.

ISAD Level	Infrastructure Support Components
E / Conventional Infrastructure	Vehicle recognizable road traffic signs and position
	Signs with speed limits, road curvature and inclination
	Regulations compliable lane markings on both sides

[23] Under creative commons CC-BY-NC-ND.

	Lane width based on standards
	Working zone signalization
	Video cameras for real-time vehicle detection
D / Static digital Information	Digital map with static road signs (including accurate position of traffic signs)
	Variable message signs
C / Dynamic digital Information	HD maps (including accurate position of signs, dynamic update of lane topology)
	Dense location referencing points
	Automatic data Processing from multiple sources (*e.g.*, in-pavement sensors, camera for stopped vehicles detection, ramp metering)
	Automatic update of digital Infrastructure (*e.g.*, roadworks warnings, weather warnings, traffic information)
B / Cooperative perception	HD maps (cloud based digital maps incl. accurate position of signs, dynamic update of lane topology, location of emergency stop zones)
	Weather (High precision meteorological stations, in-pavement sensors to detect moisture, temperature, strain)
	Advanced Traffic Management Centre (TMC) / intelligent TMC (iTMC) software (with *e.g.*, Highway Merge Assistance)
	Data exchange with cloud services (*e.g.*, OEMs, route recommendation services)
	Elements to ensure continuous connectivity (enabling Infrastructure to Vehicle (I2V)) along the segment (*e.g.*, RSUs, 4G antennas)
	Microscopic traffic situation (in some cases speed and gap advice)
A / Cooperative driving	Advanced TMC/iTMC software (with information on automation level of the individual vehicles and the traffic flow per lane)
	Sensors for trajectories of the vehicles
	Dynamic Guidance: speed, gap, lane advice
	Unicast communication (iTMC communicates with vehicles in its control area or service providers or any other relevant control centres)

Table 2: ISAD Level components, from [10].

Section 0 of Annex I maps the main physical, digital and operational elements to each ISAD level. This is the result from INFRAMIX's analysis of existing infrastructure capabilities, existing AD functions and assumptions of the probable evolution of ITS technology, safety challenges, traffic efficiency and road usage.

The ISAD classification scheme was the basis for several posterior classification schemes, like the ones presented in sections 3.1.2, 3.1.3 and 3.1.5. In some of the latter classification schemes, ISAD evolutions and refinements were made, namely in the PIARC's classification system (summarized in section 3.1.5), where specifications of the digital infrastructure and connectivity factors were proposed, (refer to section 0 of Annex II).

3.1.2 CRCS: Connected Roads Classification System - Classification Scheme from AASHTO

The US NCHRP funded project CRCS[15], conducted by the Texas A&M Transportation Institute[24], proposed in 2019 the CRCS - ***Connected Roads Classification System*** - for the *American Association of State Highway and Transportation Officials* (AASHTO)[25] Committee on Agency Administration [9]. This classification scheme is based in three infrastructure dimensions to support CCAM: (1) ***talking to the road*** (ability to support vehicles to connect to the infrastructure and other vehicles), (2) ***seeing the road*** (ability to support operation of Automated Driving Systems (ADS) / AVs by providing good physical markings/signage and digital descriptions of the road), and (3) ***simplifying the road*** (ability to support safety automation and operation by providing suitable ODDs).
The CRCS levels assess the maturity of the infrastructure and its need to incorporate new knowledge to meet present and future CCAM requirements. Infrastructure Owners and/or Operators (IOOs), by describing their infrastructure elements (listed in Table 3), can characterize their capabilities on the three infrastructure dimensions. By matching them with the *Tx*, *Sx* and *Mx* criteria of the CRCS levels (refer to Table 4), one is able to classify the infrastructure readiness to support CV and AVs. The CRCS framework is flexible to allow an IOO to assess its readiness in a way that is consistent with an agency's goals.

Infrastr. Appro-ach	Infra-structure Element	CRCS Assessment Levels			
		Needs Upgrade & Maintenance	**Meets Current Best Practices**	**Meets Emerging Market (1–5 years)**	**Meets Next Decade Market (10 years)**
TALKING TO THE ROAD Electronic communications between vehicles & roadway	**Roadway**	• No wireline or wireless communication to TMC ability (*i.e.*, limited or no backbone fibre installed or limited or no cellular coverage to connect)	• Fibre along roadway with access points • Good cellular coverage in corridor	• Direct Short Range Communication (DSRC) or celluler V2X (C-V2X) nodes tied into fibre backbone	• Small cells deployed along roadway right-of-way with good 5G coverage and connection to fibre backbone
	Traffic Signals	• Temporary TCD deployed with no communication • Signals equipment outdated with no connections	• Signal has updated controller meeting the current technology standards and is connected as part of system • Infrastructure has no I2V capability	• TCDs are equipped with I2V communication Capability (either DSRC or cellular)	• Signal transmits SPaT messages
	Roadside Devices (ITS equipment, DMS,	• Limited or no roadside devices with communication capability	• ITS Equipment (DMS, sensors, ITS cabinets) are tied to fibre backbone or have cellular	• Infrastructure element is equipped with capability to communicate over	• Infrastructure element transmits information on conditions with local processing

[24] https://tti.tamu.edu/
[25] https://transportation.org/

	Sensors, etc.)		capability to communicate to TMC	DSRC or C-V2X (has I2V Capability)	capability
	Temporary traffic control devices (Cones, barricades, portable DMS)	• Traffic control devices are deployed with no communication capacity	• Temporary traffic control devices are equipped with cellular communication capability	• Portable infrastructure element is equipped with technology that has the capability to communicate	• Portable infrastructure element communicates information on conditions and performance
SEEING THE ROAD Infrastructure (*e.g.*, signs, markings) readable by vehicle sensors	**Roadway**	• Roadway assets are not recorded in digital form	• Digital inventory of roadway assets exist	• Major corridors or areas have digital maps	• All roadways are digitally mapped
	Signs	• Signs either not present and/or lack of desired visibility based on retro-reflectivity guidance	• Signs are present and meet the retro-reflectivity guidance	• Signs provide visibility needed for CV/AV recognition	• Signs include technology that provides for future machine visibility and processing
	Marking	• Markings either not present and/or lack of desired visibility based on retro-reflectivity guidance	• Markings are present and meet the retro-reflectivity guidance	• Markings are consistent (both lane and edge lines) and provide visibility needed for CV/AV recognition in terms of reflectivity and contrast	• Markings include technology that provides for future machine visibility and processing
	Traffic Signals	• Traffic signals in need of upgrade or maintenance	• Traffic signal equipment meets official requirements	• Signals heads are consistent in design and use of technology and use glare reduction backplates • Removal of all visual obstructions	RESEARCH IS NEEDED
SIMPLIFYING THE ROAD Design & Operations for AV vehicles and their uses	**Roadway**	• Infrastructure geometry, temporary and permanent TCDs may not recommended guidelines • Pavement in poor Condition	• Infrastructure geometry meets recommended guidelines, with at least one full shoulder • Pavement free of defects • Temporary and permanent TCDs meet recommended guidelines	• Infrastructure geometry is designed to facilitate navigation by CVs/AVs	• Infrastructure geometry is specifically designed to accommodate navigation and operation of CV/AVs

	Temporary Roadway Geometry (*e.g.*, work zones, utility zones)	• Minimal navigational aids (cones, barricades, etc.) are available to define temporary geometry	• Navigational aids (cones, barricades, etc.) for temporary geometry follow recommended guidelines	• Navigational aids (cones, barricades, etc.) for temporary geometry follow recommended guidelines, are equipped with communication technology for V2I and are designed to be visible for CAVs	• Navigational aids (cones, barricades, etc.) for temporary geometric changes communicate with vehicles and are designed to be support CAV navigation and operations
	Low-speed Environments	• No designation of zone or district for CAVs	• Infrastructure geometry design and traffic control devices meet recommended guidelines	RESEARCH IS NEEDED	RESEARCH IS NEEDED
	Dedicated Facilities	• No designation for a dedicated CAV facility	• Managed lanes that have user requirements for access	RESEARCH IS NEEDED	RESEARCH IS NEEDED

Table 3: Infrastructure elements for CRCS Assessment[26] [9**¡Error! No se encuentra el origen de la referencia.**].

[26] Original classification scheme reference to MUTCD (Manual of Uniform Traffic Control Devices) and /or AASHTO guidelines was substituted by “recommended guidelines” to generalize this classification scheme to all geographies.

CRCS Levels		INFRASTRUCTURE APPROACH		
		TALKING TO THE ROAD Electronic communications between vehicles & roadway	**SEEING THE ROAD** Infrastructure (*e.g.*, signs, markings) readable by vehicle sensors	**SIMPLIFYING THE ROAD** Design & Operations for AV vehicles and their uses
CRCS Levels	**Needs Upgrade and Maintenance** Design or functionality that falls short of meeting existing guidance or recommendations for future technology accommodation	*T1*	*S1*	*M1*
CRCS Levels	**Meets Current Best Practices** Design or functionality that meets existing guidance or recommendations for future technology accommodation	*T2*	*S2*	*M2*
CRCS Levels	**Meets Emerging Market (1–5 years)** Design or functionality that supports early adoption of CV and AV applications or positions the roadway elements for communication/ interaction with vehicles	*T3*	*S3*	*M3*
CRCS Levels	**Meets Next Decade Market (10 years)** Design or functionality that supports operation of most CV and AV applications and/or communicates/interacts with vehicles proactively	*T4*	*S4*	*M4*

Table 4: Connected Roads Classification System (CRCS) Assessment Framework [9**¡Error! No se encuentra el origen de la referencia.**].

3.1.3 Classification of Road Readiness for Electric, Connected and Automated Vehicles – Classification Scheme from EAPA

The EAPA[16] proposed in 2020 a classification of the ***Road Readiness for adopting Connected and Automated Vehicles***, which results mostly from the combination of the ISAD and SAE automation levels (refer to Table 5) but also including some parameters characterizing the physical road infrastructure. This classification framework is intended to classify road stretches, aiming at providing the road user with information about the available technologies supporting automated and electrified driving [13**¡Error! No se encuentra el origen de la referencia.**]. The key parameters considered for each EAPA road class in terms of readiness for CCAM are listed in Table 6.

ISAD Levels (Infrastructure Support for Automated Driving)	SAE Levels (Driving Automation): 0 / No Automation	1 / Driver Assistance	2 / Partial Automation	3 / Conditional Automation	4 / High Automation	5 / Full Automation
E / Conventional Infrastructure	F	E	E	E	E	E
D / Static digital information	F	E	D	D	D	D
C / Dynamic digital information	F	E	D	C	C	C
B / Cooperative Perception	F	E	D	C	B	B
A / Cooperative Driving	F	E	D	C	B	A

Table 5: EAPA's Classification of Road Readiness for Connected and Automated Vehicles [**¡Error! No se encuentra el origen de la referencia.**].

CLASS	Description	Key Parameters
F	**ISAD Level E – SAE Level 0:** • Deficient pavement, no markings.	• Optical visibility is not clear in at least 100 m • Deficient or non-existing markings, signs and traffic lights • State of pavement:[27] INADEQUATE
E	**ISAD Level E – SAE Level 1:** • Pavement in acceptable conditions. Physical markings and signs visible and in good conditions • No digital information. Autonomous vehicles need to recognise road geometry and physical road signs • To be implemented in restricted and well-controlled areas, such as parking or service areas.	• Optical visibility clear in 50 m • Existence of markings, signs and traffic lights in good condition and clearly visible • State of pavement[27]: ADEQUATE
D	**ISAD Level D – SAE Level 2:** • Pavement in good conditions.	• Optical visibility clear in 100m • Existence of markings, signs and traffic lights in good condition and clearly visible

[27] EAPA proposed the following reference parameters for State of Pavement: International Roughness Index (IRI), Rutting, Macrotexture; Crack percentage.

	• Digital map data is available with static road signs. • Map data could be complemented by physical reference points (landmarks signs). • Traffic lights or short-term road works need to be recognised by the vehicle.	• Digital information about road geometry and static signs available • State of pavement[27]: SATISFACTORY
C	**ISAD Level C – SAE Level 3:** • Pavement condition is excellent. • Digital map data available. • Radio transmitters and sensors replacing traffic lights, signs and markings, higher-capacity mobile and wireless data networks handling both V2V and V2I communication. • Common protocols and communications standards will have to be devised and negotiated, as it was done with internet protocols or GSM for mobile phones. • Vehicle receives information about weather and pavement conditions, disruptions and any other incident that might affect the circulation and these are all correct.	• All static and dynamic infrastructure information available in digital form • Assisted visibility systems (radio transmitters, sensors…) • State of pavement[27]: EXCELLENT • Vehicle-infrastructure communication systems • Emergency parking lane • Construction/maintenance works updated in geophysical system (this condition could change temporally the class) • Real-time data detection systems (weather, disruptions, etc.)
B	**ISAD Level B – SAE Level 4-5:** • The infrastructure is capable of perceiving microscopic traffic situations (for example due to the presence of an animal / person on the road) and providing this data to the vehicles in real-time.	*Key parameters for Class C* • Real-time microscopic traffic situations detection systems (unexpected obstacles)
A	**ISAD Level A – SAE Level 5:** • Guiding roads. When each vehicle accesses the road, it transfers control to the road, which synchronises all the vehicles present along. • Roads equipped with vehicle-infrastructure communication systems and integral management centre. • Microscopic traffic measurements. Road contents monitoring systems operating in real time along the whole distance of the road. • The control centre calculates a path for each vehicle and the target platoon size and speed and communicates them to the vehicle. • If there is an incident, all the cars modify speed and direction to by-pass the problem in safety conditions	*Key parameters for Class C* • Integral vehicles management system

Table 6: Key parameters proposed by EAPA for each road class of Table 5 [13].

To characterize the available technologies supporting electrified driving, EAPA resorted to the description of Electric Road Systems (ERS) presented by PIARC[18] in 2018 [16], creating four classes of roads, with the increase in electrification readiness being represented by increase in the number of attributed stars (refer to Table 7).

CLASS	Description
-	No EV charging equipment
★	Charging systems only for certain conditioned vehicles
★★	Static systems to charge any vehicle while stopped in specific areas
★★★	Dynamic systems to supply energy to any vehicle circulating along the road

Table 7: EAPA Road Classification according to its readiness level for electrified driving [13].

Based on these two approaches (Table 6 and Table 7) the EAPA defined six classes of roads - from A to E - for adopting connected and automated vehicles, followed by a number of stars - from 0 to 3 stars – indicating the availability of ERS.

3.1.4 LOSAD: Level of Service for Automated Driving – Classification Scheme from HERG

The HERG[17] group proposed the concept of LOSAD - ***Level of Service of Automated Driving*** - which summarizes the physical roadway readiness for automated driving [14]. This group was recruited by PIARC[18] to devise a complete classification system (the SRC, that is presented in the next section, 3.1.5). A published report about the SRC also thoroughly details the LOSAD classification scheme [15].

To properly characterize how the quality of the roads' geometric design affects roadway automatic recognition, essential for automated driving, the HERG researchers devised the concept of *Operational Road Section* (ORS) [15][17] as illustrated in Figure 6.

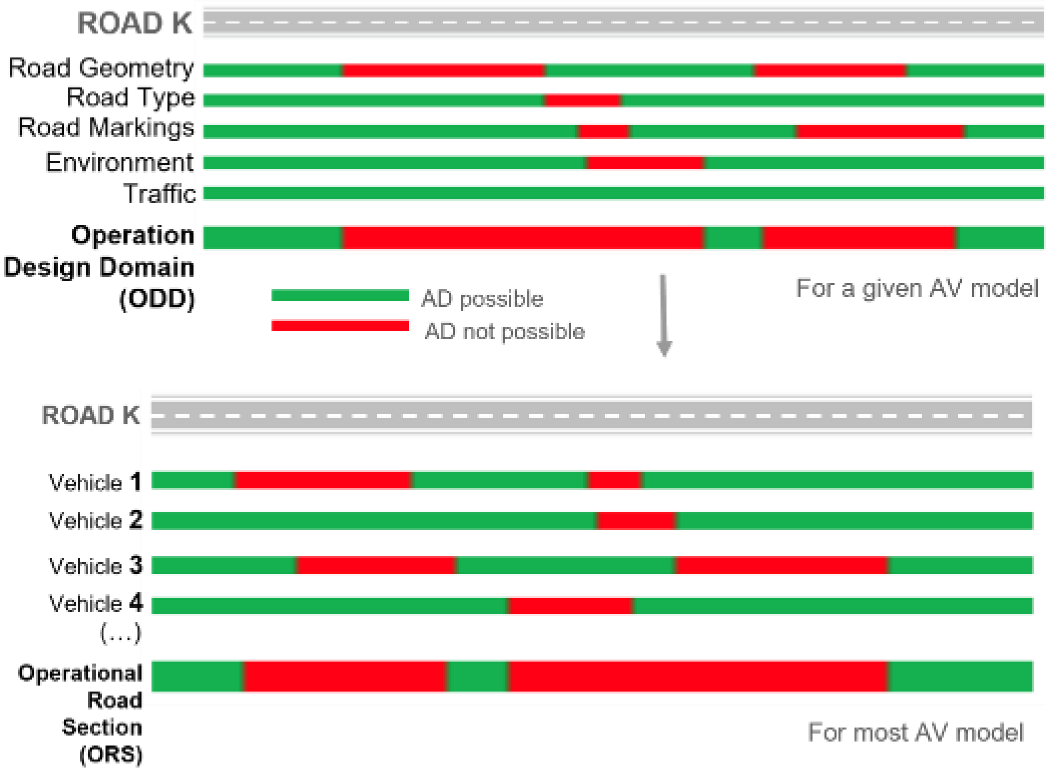

Figure 6: Operational Road Section (ORS) mapping [15].

Given road K and analysing the different physical characteristics that influence the readiness for automated driving (like road geometry, road markings, etc,) for each vehicle model, one can define the road segments where that model's ODDs prevail. Taking all automated vehicles models that will use road K and overlapping all those road segments, one reaches a map of the ORSs for that road K where Automated Driving is possible.

The LOSAD classification scheme, has 5 levels, where A – the highest corresponds to ORS continuity to ensure automation for SAE level 4-5 and minimum automation disengagements for levels 2-4 - up to level E, where the amount of road sections where automation is possible is so small (or even non-existent) that automation is not recommended. For a description of the LOSAD levels refer to Table 8.

LEVEL	ORS status	Description
E	**None or very short ORSs**	**SAE levels 4:** Most vehicles may have to drive in manual mode **SAE levels < 4:** Vehicles present massive disengagements and therefore automation is not recommended
D	**Short ORSs**	**SAE levels 4:** Most vehicles may have to drive in manual mode **SAE levels < 4:** Vehicles experience high number of disengagements *Weather conditions and disengagements may activate this level from higher readiness ones*

C	**Non- continuous ORS within the segment**	**SAE levels 4:** Vehicles may have to drive in manual mode **SAE levels 2-3:** Vehicles experience relevant number of disengagements
B	**Mostly Continuous ORS**	**SAE levels 4-5:** ORS continuity that ensure automation for vehicles in these levels **SAE levels 2-3:** Very low number of disengagements *Dynamic conditions may limit ORSs. Abnormal presence of disengagements may also reduce level A to B*
A	**Continuous ORS**	**SAE levels 4-5:** ORS continuity that ensure automation **SAE levels 2-3:** Very low number of disengagements

Table 8: LOSAD: Levels of Service of Automated Driving (LOSAD) [15]

In section 0 of Annex II is presented a proposal for specifications of the PDI factors that support the LOSAD classification.

3.1.5 SRC: Smart Road Classification – Classification Scheme from PIARC

In 2021, PIARC presented the outcomes of its special project “Smart Roads Classification” [15] which combines the PDI automation readiness classification provided by LOSAD, and the infrastructure support in terms of connectivity and digital information provided by ISAD, into a 2D road classification scheme – the *Smart Road Classification* - composed of five Smart Road Levels:

- **Humanway (HU)** road sections that do not support Automated Driving
- **Assistedway (AS)** road sections where there is partial support for automation, with remarkably less disengagements than on Humanway sections
- **Automatedway (AT)** road sections which present similar physical characteristics of Assistedway sections, but also present connectivity capabilities that could help connected vehicles prevent and avoid disengagements
- **Full Automatedway (FA)** road sections which present full support for SAE level 4 vehicles, alongside with good connectivity capabilities
- **Autonomousway (AU)** road sections which present full support for SAE level 4 vehicles and exceptional connectivity capabilities. They can only be used by SAE level 4 and 5 vehicles.

The direct combination of the ISAD and LOSAD classifications would yield an infrastructure description as presented in Table 9. The PIARC team considered that not all combinations are plausible (*e.g.*, cooperative driving support should never be allowed on a road not ready for automation) and thus the Smart Road Classification they propose is as presented in Figure 7 and Table 10, where the inadequate combinations have been identified with a white pattern and an asterisk (*) in Figure 7 and grey pattern in Table 10.

<table>
<tr><th colspan="2"></th><th colspan="5">PDI levels of service for Automation (LOSAD)</th></tr>
<tr><th colspan="2"></th><th>LOSAD E</th><th>LOSAD D</th><th>LOSAD C</th><th>LOSAD B</th><th>LOSAD A</th></tr>
<tr><td rowspan="5">Connectivity & Digital support (ISAD)</td><td>ISAD E / Conventional Infrastructure</td><td rowspan="5">The road physical infrastructure triggers too many disengagements. Drivers are suggested to disable DAS. Connectivity capabilities of the road cannot be used to foresee or reduce the number of disengagements</td><td rowspan="5">The physical road infrastructure triggers relatively frequent disengagements that might affect the automated experience. Under certain circumstances (expressed in terms of location and frequency of the disengagements), drivers might be allowed to enable their driving automation systems. Due to their number, the connectivity level should not be used to foresee disengagements (for level 3 vehicles)</td><td rowspan="2">Disengagements are not very frequent but exist. Level 3 vehicles do not have information to foresee disengagements, so they operate like level 2 ones.</td><td rowspan="2" colspan="2">No information about dynamic parameters that could influence the ODD. Although the road segment would not trigger disengagements to Level 4 vehicles, the lack of information prevents them from an automated experience. Level 2 and 3 vehicles might experience very few disengagements.</td></tr>
<tr><td>ISAD D / Static digital information</td></tr>
<tr><td>ISAD C / Dynamic digital information</td><td rowspan="3">The connectivity provided by the road digital infrastructure can be used by level 3 vehicles to foresee disengagements and warn the driver to resume control in advance</td><td rowspan="2">The dynamic information provided by the road digital infrastructure can be used by level 4 vehicles to manage ODDs and drive autonomously</td><td rowspan="2">Level 4 and 5 vehicles can perform autonomously. Levels 2 and 3 might experience very few disengagements.</td></tr>
<tr><td>ISAD B / Cooperative Perception</td></tr>
<tr><td>ISAD A / Cooperative Driving</td><td colspan="2">Cooperative Driving. Recommended for critical road segments and junctions, with traffic segregation to only allow CAVs</td></tr>
</table>

Table 9: Particularities of the ISAD and LOSAD classifications combinations [**¡Error! No se encuentra el origen de la referencia.**].

The SRC framework aims at delivering a powerful, but easy-to-use tool to rank road facilities. It is intended to be applied by the IOOs and its information is to be disseminated by the different road stakeholders (Road Users, OEM's, Transport Authorities, etc.). Users will be the immediate SRC beneficiaries. The end goal of this classification scheme is that they receive clear and precise information to help them decide on when or if to activate and which AD functions. Nowadays the digital infrastructure and connectivity factors are still at an early stage and information on explicit ODDs or disengagement is lacking from OEMs. This is supposed to dramatically change in the upcoming years, so how road stakeholders use SRC will evolve in time. There are many future applications to SRC, namely with (i) aiding infrastructure management (*e.g.*, monitoring how vehicles perform through the road networks); (ii) support planning future infrastructure improvements and investments (iii) leverage higher SAE levels of automation, by providing information that can expand the vehicles' ODDs.

Several key characteristics of LOSAD, ISAD and SRC should be highlighted:

- **Road stretch granularity:** Since both LOSAD and ISAD provide road characterization at the road section/segment level, the SRC is intended to have similar granularity;

- **Temporal evolution:** LOSAD, ISAD and SRC will evolve with the progress of automation, digital information and connectivity technologies;

- **Temporary Downgrade/Upgrade:** All 3 classifications consider temporary downgrade and upgrades of road section classification under transitory situations due to road incidents, extreme weather, technology failure, etc.;

- **Regional adaptability:** All classifications schemes should be adapted to country/regions specificities, such as legislation and regulations or road facilities characteristics.

Connectivity & Digital support (ISAD)	Physical and Digital Infrastructure levels of service for Automation (LOSAD): LOSAD E	LOSAD D	LOSAD C	LOSAD B	LOSAD A
ISAD E / Conventional Infrastructure	**Humanway (HU)** The road is not ready for CAVs. This means that SAE level 2 and 3 vehicles would experience too many disengagements, prompting their drivers to manually disconnect the system. These segments would not present ORSs, and SAE 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 SAE level 5 vehicle would be able to operate along this road - given 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		AS	AS	AS
ISAD D / Static digital information		**Assistedway (AS)** The road is adequate for SAE 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 SAE 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 SAE 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)			AS
ISAD C / Dynamic digital information	HU		**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. SAE level 2 vehicles would experience less disengagements than on AS segments, and SAE 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 SAE level 4 vehicles in automated mode	**Full Automatedway (FA)** The road segment presents a continuous ORS, so all SAE level 4 vehicles should be able to operate autonomously along the entire segment. In addition, these segments present safe harbours - including their junctions to other segments. While the ORS is not directly related to SAE level 2 and 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 harbours in the HD map. All road users would benefit from better global performance and safety levels	
ISAD B / Cooperative Perception	HU	AS			
ISAD A / Cooperative Driving	HU	AS	AT	**Autonomousway (AU)** Autonomousway (AU). The road segment presents similar physical conditions than the FA segments i.e., complete ORS along the segment, safe harbours, etc., and incorporates exceptional connectivity features that enable cooperative driving. In order to benefit from the best performance and safety levels, only SAE level 4+ should operate along these road facilities or with dedicated lanes. The HD maps will also have very detailed information about the safe harbours - not only their presence but also their capacity and availability of free spaces	

Table 10: Smart Roads Classification (SRC) scheme, with Smart Road Levels description [15].

PIARC's recommends that the **AU** road segments be restricted to very specific zones (*e.g.*, dedicated lanes) where cooperative driving can safely occur. In addition, **FA** segments may not have any limitation regarding road users, but probably will only correspond to motorways, freeways and high-end two-lane rural roads, where certain users (*e.g.*, pedestrians, bicycles) are not allowed. In all others SRC levels, **AT**, **AS** and **HU** all types of road users can co-exist. At section 0 of Annex II, a more comprehensive proposal of how the different road users could interact with the different SRC levels is presented.

The benefit for CAVs will also depend on the interaction between SAE and SRC levels. Nowadays there are no SAE level 5 vehicles, level 4 only has marginal existence and level 3 are at their early stages, therefore **AU, FA** and **AT** do not have much impact and IOOs should focus on characterizing **AS** segments so that they can provide recommendations to SAE level 2 and 3 users. IOOs should make available to users all the detailed information on the SRC road segment characteristics to drivers but it is the latter who are responsible for deciding on how to maintain driving. At section 0 of Annex II, PIARC's analysis and recommendation on the interaction between different SAE level vehicles and SRC levels is presented, highlighting where CAVs circulation is more adequate, present no advantages or should not be permitted.

The diamond chart representation of the SRC (Figure 7) provides a tool to easily follow the evolution of the road. The smart road levels improvement is represented in a bottom-to-top approach. Its horizontal axes have percentage scales for the ISAD and LOSAD levels, corresponding to the cumulative percentage each level as of the road facility (*e.g.*, ISAD A ~0%, (…), ISAD E ~80%, LOSAD A ~ 5%, (…), LOSAD E ~30%). These percentages will dramatically evolve over time, changing the diamond shapes and sizes of each SRC level, creating an impactful visualization of the smart levels' distribution.

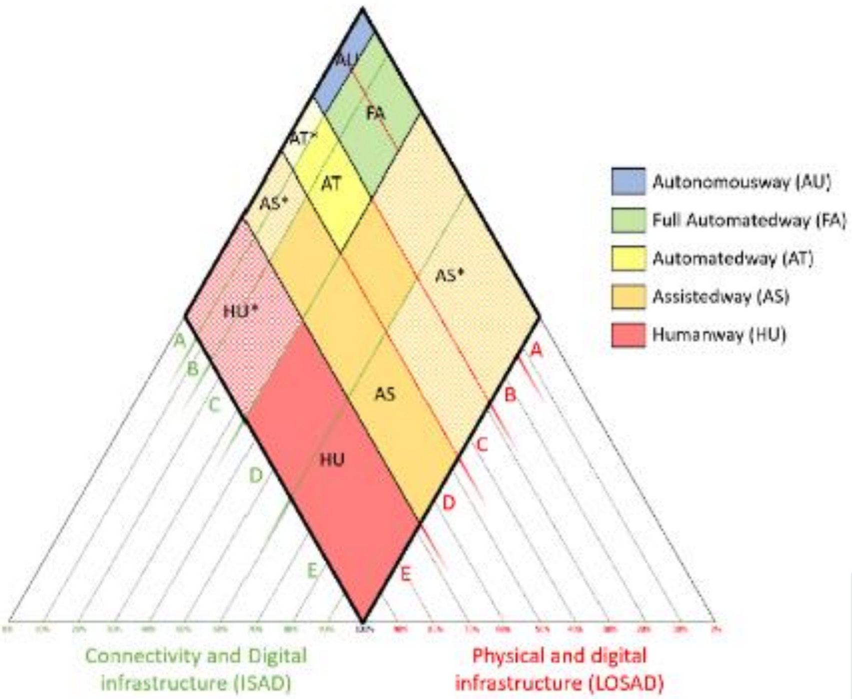

Figure 7: Smart Roads Classification (SRC) scheme – Diamond chart representation, from [15].

The PIARC's team proposes two methods (called classification systems) of applying the SRC:

a. ***Main classification system:*** Obtaining the ISAD and LOSAD levels independently and with them, determining the SRC levels. The specific factors proposed by PIARC to determine the ISAD and LOSAD levels are presented in **¡Error! No se encuentra el origen de la referencia.** and Table 14 of Annex II. The presence of these factors or its threshold values will determine which ISAD/LOSAD levels the road segment corresponds to, allowing to determine the SRC level either using Table 10 or Figure 7.

b. ***Detailed classification system:*** Obtaining the SRC levels directly from the checklist of road factors specifications for every smart road level created by PIARC, presented at Table 15 of Annex II. This table summarizes all LOSAD and ISAD factors, additionally providing details related to how Operational Road Sections should materialized. The factors contemplated by the detailed classification system are organized in the following categories:
   - Physical infrastructure: Category including road typology, road geometric design, pavement characteristics, road signage, and all other physical aspects related to the road and its environment. Different speed concepts as performance indicators are also included (*e.g.*, speed limit, operating speed, automated speed)
   - Digital infrastructure: Category summarizing the availability of information for road users, as well as the physical facilities that the road presents to comply with that purpose (*e.g.*, presence and typology of VMS, maps inventory, digital signing, and road/data sensors, communication infrastructure).
   - Connectivity: Category summarizing the connectivity capabilities of the road, including V2X protocols, cellular coverage, capacity of cooperative driving, etc.
   - Users: Category summarizing the connectivity and automation implications for the potential users of the road facility.

Most threshold values for these road factors are initial suggestions that require either further research or definition by the main involved stakeholders (*e.g.*, IOOs, transport authorities).

To assess the status of a road facility, analyse its evolution over time and compare it to other road facilities, PIARC's report suggests some Key Performance Indicators (KPIs) on (i) Automation, (ii) Safety, (iii) Operation and (iv) Road Smartness. They are summarized at section 0 of Annex II. At this stage of the SRC maturity, this KPI proposal should be considered tentative and be further developed.

3.1.6 Other initiatives

The main existing smart transport infrastructure classifications were presented in the previous sections. However, for the sake of completeness, some other relevant initiatives should also be referenced.

Recently in 2023, the *Connected Automated Vehicle Highway* (CAVH) research group[28] from the University of Wisconsin-Madison, published the work "**Classification of Roadway Infrastructure and Collaborative Automated Driving System**" in the Journal of Connected and Automated Vehicles of SAE International. The authors propose that the intelligence levels of the highway infrastructure should be defined from the perspective of collaborative automated driving, instead of the vehicle perspective alone. They introduced the concept of Collaborative Automated Driving System (CADS) where the system's intelligence and driving tasks are dynamically distributed between the Connected Automated Highway (CAH) and CAVs and state that the CADS architecture realizes reliable automated driving and transportation management through the optimal cooperation of CAH and CAVs [18].

In 2022, ITS researchers from the University of Zilina[29], published the article "**Physical and Digital Infrastructure Readiness Index for Connected and Automated Vehicles**" where they propose microscopic five-fold classification of road-segments on: connectivity, precise location, machine-readable signage, automatic object detection and digital maps. Each infrastructure dimension has some indicators associated. These indicators are scored from 0 to 1 (0 meaning not ready for CAVs and 1 meaning fully ready) or its source valuers are displayed in geolocated heat maps [19]. Although with a limited number of indicators and with only a microscopic description of the road infrastructure, no meso

[28] https://cavh.cee.wisc.edu/
[29] https://feit.uniza.sk/en/home-page/

or macro level evaluation of the road facilities, this classification strategy has the benefit of directly pinpointing the location of the segments less ready for CCAM.

The **Autonomous Vehicles Readiness Index (AVRI)**, proposed by *KPMG International*[30] (2018-2020), ranked the preparedness of 30 countries (in 2020) and jurisdictions for automated driving [20]. The AVRI uses 28 different variables, organized into four pillars: policy and legislation, technology and innovation, infrastructure, and consumer acceptance. This is a macro level (country wise) approach not reflecting the degree to which a road network is enabling AD and thus, cannot be considered an infrastructure classification system. Nevertheless, it uses some interesting parameters that could be considered for smart infrastructure classifications (*e.g.*, data-sharing environment, EV charging coverage, individual readiness, online ride-hailing market penetration).

The **Smart City Index (SCI)** proposed by the *World Competitiveness Center (Institute for Management Development)*[31] ranks >140 cities (2018-2023) according to technological, economic, and human criteria (*e.g.*, quality of life, mobility, environment, inclusiveness) [21]. The SCI assesses the smartness of a city through a mixture of hard data and surveys to residents in two pillar dimensions: (i) the cities' infrastructures and (ii) the technological provisions and services available to inhabitants. These pillars are evaluated over five areas, with one of them being the cities' mobility. SCI is also a macro level (city wise) approach, not reflecting the degree to which the infrastructure network is enabling CCAM and thus cannot also be considered an infrastructure classification system. Nevertheless, it focuses on an extremely relevant factor to the CCAM transition: user acceptance, evaluating the inhabitants' perception on Public Transportation (PT), congestion, micro and shared mobility, and other online services (*e.g.*, mobility Apps with parking suggestions, real-time journey information, or PT ticketing).

The **Automated Mobility Working Group** projects from the *International Association of Public Transport* (UITP)[32] are another set of relevant initiatives to consider. Although none directly proposes smart infrastructure classifications, they focus on CCAM in public transportation, a sector not considered in the existing schemes and one of the dimensions TANGENT's wants to bring to its classification index (refer to section 4.1). In 2018, UITP launched its flagship SPACE project (2018-2021)[33], which proposed a high-level reference architecture for the integration of automated driving into PT in a combined transport ecosystem, guiding the industry towards standardisation [22]. Since 2020, UITP is participating in the EU H2020 funded project SHOW (2020-2023) (refer to Figure 1) for real-life urban demonstrations of the integration of AV fleets in PT, Demand-Responsive Transport (DRT), Mobility as a Service (MaaS) and Logistics as a Service (LaaS) schemes. In 2021, UITP launched its Working Group on Automated Mobility, for knowledge exchange and roadmaps definitions. In addition, UITP is part of the *CCAM.Partnership*[7] (see section 2.1) co-leading its Cluster 1 – "Large-scale Demonstration". Furthermore, since 2022, UITP is part of the HE EU funded initiatives FAME (2022-2026)[34], that supports the *Connected and Automated Driving*[5] initiative (see section 2.1) for knowledge exchange along the complex cross-sectorial value chain existing in large-scale CCAM demonstrations and ULTIMO (2022-2026)[35], which aims at deploying the very first economically viable large scale, on-demand and user-oriented AV public transportation service.

3.1.7 SRICI: Smart Road Infrastructure Classification Index from FRONTIER

The Smart Road Infrastructure Classification Index (SRICI), developed by the International Road Federation (IRF) within the FRONTIER project, aims to evaluate the readiness of road networks for Connected and Autonomous Vehicles (CAVs). This index is crucial as it helps in understanding the

30 https://kpmg.com/
31 https://www.imd.org/centers/wcc/world-competitiveness-center/
32 https://www.uitp.org/topics/automated-mobility/
33 https://www.uitp.org/projects/space/
34 https://www.uitp.org/projects/fame/
35 https://ultimo-he.eu/

potential requirements that CAVs demand from road infrastructure and their actual availability. Introduced by IRF, a global, independent, not-for-profit organization, SRICI assesses the infrastructure's capability to support CAV operations effectively.

SRICI considers various parameters aligned specifically with CAV requirements, acknowledging that CAV performance relies heavily on components such as connectivity networks, signaling systems, precise localization services, machine-readable road signage, and CAV-friendly road geometries. The classification index is designed to accommodate the complex and dynamic nature of smart road infrastructure, providing a structured methodology for assessing road networks.

SRICI needs to consider various parameters specifically aligned with CAV requirements. Parameter selection is a crucial and complex process within SRICI. SRICI parameter evaluation levels range from 1 to 10, each describing the suitability of road segments for different SAE levels of vehicle automation. The lower levels (1-2) indicate roads unsuitable for CAVs due to connectivity issues, requiring human intervention, similar to SAE level 0-1. The mid-levels (2-4) are better suited for assisted driving, though occasional disengagements may occur. Higher levels (4-6) have fewer disengagements and support longer operational road segments for SAE level 4 vehicles. The top levels (6-10) represent fully automated road segments with high connectivity, ensuring safety through cooperative driving for SAE levels 4 and 5 vehicles.

A case study conducted on the Attiki Odos freeway in Athens demonstrated SRICI's practical application, highlighting its usefulness and identifying areas for future improvement. The study emphasized the importance of continuous updates and real-world testing to keep pace with technological advancements and evolving CAV capabilities. The findings underscored the need for a dynamic, collaborative approach involving international partnerships with researchers, industry stakeholders, road operators, and authorities.

The SRICI framework includes over 50 parameters grouped into physical infrastructure, digital infrastructure, and connectivity, which are essential for efficient CAV operation. These parameters provide a comprehensive evaluation of the road infrastructure's readiness to support smart environments. By setting a global standard, SRICI aims to guide infrastructure improvements and ensure the seamless integration of CAVs into existing transportation networks.

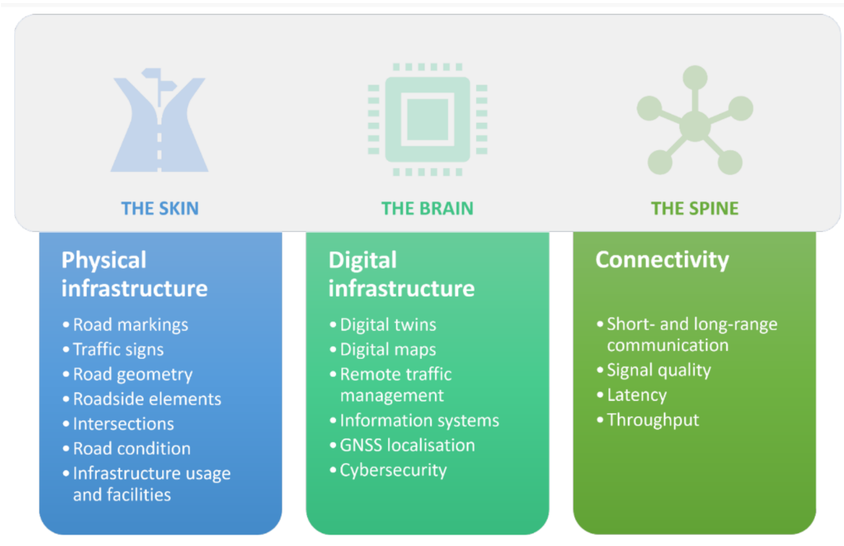

Figure 8: The three SRICI parameter groups, from [25**¡Error! No se encuentra el origen de la referencia.**].

SRICI is a significant step towards enhancing infrastructure readiness for CAVs but it requires ongoing refinement to stay relevant with technological advancements and regulatory changes. The IRF's collaborative efforts with international bodies and stakeholders are vital for SRICI's global relevance, laying the groundwork for safer and more efficient transportation systems in the future.

3.1.8 SIRI: Smart Infrastructure Readiness Index from DIT4TraM

The DIT4TraM (Distributed Intelligence & Technology for Traffic & Mobility Management) project has developed the Smart Infrastructure Readiness Index (SIRI) [26] to assess cities' readiness for implementing intelligent transportation systems (ITS). The index aims to help city authorities and policymakers evaluate their progress, prioritize investments, and stay at the forefront of innovation in urban mobility.

Unlike most of the previous indexes analysed, which focus on the existing physical and/or digital infrastructure, the DIT4TraM SIRI focuses on a higher-level strategic perspective that spans mobility related aspects such as the mobility vision of the entire city, innovation and R&D or public support and collaborations. The development of SIRI involved a comprehensive literature review, identifying key performance indicators (KPIs) crucial for assessing smart infrastructure readiness, found, namely, in several high-level qualitative / KPI-based indexes such as Smart Cities Connected and Autonomous Vehicles Readiness Index (Khan et al., 2019), Autonomous Vehicles Readiness Index (AVRI) (KPMG Global, 2020), Deloitte's City Mobility Index (Dixon et al., 2019) and Global Cities AI Readiness Index (Oliver Wyman Forum, 2019).

SIRI's KPIs were categorized into four main criteria to evaluate a city's smart infrastructure readiness comprehensively:

- Vision, Priorities, and Mindset: Strategic planning, funding, and knowledge sharing.
- Activation: Stakeholders' involvement, collaborations, public support, and flexibility of governance.
- Asset Base: Workforce - human capital, private sector maturity, quality of digital and physical infrastructure.
- Trajectory and Development: Innovation, investments in R&D, penetration of intelligent vehicles and novel mobility services, trends in car ownership, traffic mix, and multimodality.

The Analytic Hierarchy Process (AHP) methodology was employed, utilizing expert opinions from 11 European countries and Israel to prioritize SIRI's KPIs. This allowed for the assignment of appropriate weights, ensuring a robust assessment framework.

Two questionnaires were utilized: one to prioritize the KPIs and another to derive the final scores for each pilot city. The scoring was based on qualitative assessments by pilot leaders and local experts within the cities, ensuring that the index reflected the unique characteristics and priorities of each urban context.

SIRI evaluation within DIT4TraM provided a hierarchical ranking of the project's pilot cities, with Utrecht emerging as the top performer, indicating its leadership in smart infrastructure readiness. Nonetheless, all cities demonstrated relatively good scores, showcasing comparable efforts across the EU in adopting advanced mobility technologies.

The SIRI framework empowers cities to strategically plan their investments and unlock the potential of advanced technologies for efficient and sustainable urban transportation. By prioritizing readiness for smart infrastructure, cities can adapt to changing demands and pave the way for smarter, greener, and more liveable urban environments.

3.2 Expert Advice

Consultation of expert advice is of paramount importance when evolving existing solutions and TANGENT intends to benefit from expert consultation and incorporate their relevant inputs in its own classification index. In the next sections, the expert consultation results of two past initiatives are presented, followed by the introduction of the ongoing expert stakeholders' engagement and consultation procedures organized by TANGENT's WP1 directly benefiting the SICI development, followed by a summary of their already provided inputs.

3.2.1 TRANSAID project – Stakeholder consultation

The EU H2020 funded project TransAID (2017-2021)[36] - Transition Areas for Infrastructure-Assisted Driving is aimed at developing and demonstrating traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, especially in transition areas. For that, it invested in performing extensive stakeholder consultation, which resulted in the organization of nine events (3 main stakeholders' workshops, 2 international liaison activities and 4 dedicated sessions in workshops at conferences). These activities are summarized in deliverable D8.1 – "*Stakeholder consultation report*" [23]. The main outcomes from these consultation activities, that can benefit the identification of the road infrastructure characteristics to support CCAM and the definition of TANGENT's classification scheme are summarized next:

- There is an overall evolving perception on the growing need to develop comprehensive standards or taxonomies for classifying automated vehicle systems and infrastructure support levels.

- Connectivity emerges as consensual for supporting automated driving to extend the vehicles ODDs. In addition, it enables cooperation between connected vehicles and infrastructure, boosting safety, efficiency, and comfort. Experts anticipate a hybrid solution involving both ITS-G5 and cellular connectivity.

- Digitalisation of infrastructure through enhanced roadside equipment, improved road sensors, and communication capabilities is considered a 'no regret' investment However, efforts to digitize road infrastructure and dynamic traffic management can be substantial and thus implementing these services is more feasible in the short-term on motorways before urban roads.

- Stakeholder consultations, though with deficient insights from vehicle manufacturers, show a growing collective understanding of the link between vehicle automation and infrastructure.

- OEMs express hesitancy in sharing data on vehicle capabilities due to competition and potential liability concerns, particularly regarding the disclosure of its ODD. If communication with the infrastructure fails and an accident happens, determining responsibility becomes a complex legal issue.

- Infrastructure authorization by road authorities to provide real-time advice to vehicles or actively control automated driving underscored the need for new regulations, without them the development of such functionalities is unfruitful. Worldwide differences in legal frameworks and legislation, hinders a harmonized evolution of such technologies.

[36] https://www.transaid.eu/

- Road authorities face a dilemma: prioritize digital infrastructure for private automated cars or enhance public transport with automated shuttles. Despite a shared greener vision, including reduced parking, environmental zones, car-sharing and MaaS, uncertainty surrounds the path to realizing it. The challenge lies in how vehicle automation aligns with sustainability goals and when it becomes viable. Currently, authorities are not favouring a specific mode, instead monitoring for reactive policies as automated driving matures. Decisions between managing private CAVs and promoting public automated shuttles will depend on adoption rates.

3.2.2 CRCS project – Experts recommendations

The researchers from the CRCS project (refer to section 3.1.2) conducted several expert stakeholders consultation actions which culminated in a list of best practice recommendations for their classification system that can benefit other smart infrastructures classifications:

- Keep the classification index straightforward, simple to use and easy to implement, so that it can be employed by a wide variety of users.
- Regularly update the classification index to keep up with all the research and technological developments (a five-year frequency was suggested).
- IOOs need a foundational situational awareness of their roadway. Thus, the classification should highlight the available sensorization technology and telecommunications infrastructure, as well as accommodate the emerging digital infrastructure.
- Separate roadway infrastructure from operational scenarios and applications. The classification systems should focus on classifying roads by where and what infrastructure is deployed to support CCAM, and not focus on classifying roads by which applications and operational functions are deployed.

3.2.3 TANGENT Advisory Board

Task 1.3 – *"Stakeholder engagement and consultation"* from WP1 is focused on coordinating several initiatives with external stakeholders and experts (*e.g.*, researchers, transport authorities, IOOs, city representatives and users in general). For that, it has setup a diversified consulting body – TANGENT's Advisory Board (AB) - composed of 11 members from different professional backgrounds in the field of transport. Several technical discussions between the consortium and the AB members have been and will be organized, on several topics relevant to the project execution. Furthermore, WP1 is organizing the TANGENT Forum, a wider consulting community, and is setting up an online portal for documenting the project's outputs and case studies and for provisioning online forum discussions.

In June 2023, a technical session on "Unlocking Data Collaboration and Assessing Smart Infrastructure Indexes" was organized with some Advisory Board members. The attendees included representatives from municipalities (Helmond – The Netherlands[37] and Braga – Portugal[38]), a PT operator (Transdev Group[39]), a ITS research centre (SINTEF[40]), a ITS association (ITS Norway[41]) and a 4FRONT cluster

[37] https://www.helmond.nl/
[38] https://www.cm-braga.pt/
[39] https://www.transdev.com/en/our-group/
[40] https://www.sintef.no/en/expertise/digital/ict-general/intelligence-for-transport/
[41] https://its-norway.no/

EU funded project (ORCHESTRA (2021-2024)[42]). Part of the session was centred around smart infrastructures and automation. The following questions were launched to the discussion panel, as a brainstorm guide:

1. **Classification Schemes**
   a) Considering the relevancy of the existing classification systems, should TANGENT focus on **Classification of Infrastructures** alone? Either when considering Automated Driving in particular, or when focusing in a Connected and Digitally monitored Mobility.
   b) Or should TANGENT focus on the **Classification of Roads as Systems**, combining Infrastructure characterization, Vehicles automation levels, Levels of Service for AD, etc)?
   c) Is the ISAD **index adequate for urban/peri-urban roads**, either in its original formulation or in the evolutions that followed? Which characteristics are missing for that context adaptation?
2. **Smart Infrastructure Technology:**
   a) What are the main priorities for **Smart Roads investment**? Is it the quality of pavement and horizontal & vertical signage (for automated detection)? Or equipping the roadway with communication technology? Or is it equipping the roadway with a wide variety of sensors?
   b) What are the most **relevant communication characteristics** relevant for a smart road infrastructure? Is it the end-to-end latency time, independently of technology used (DSRC, direct PC5, Uu, ...)? The installed network coverage? The range of each individual equipment? The communication technology bandwidth?
3. **Automated Driving Transition:**
   a) Should it be mandatory for AVs to be connected (SAE level >=3)?
   b) Should it be **mandatory for CAVs to broadcast** (for network efficiency): (i) their optimized route to non-automated vehicles? (ii) their extended traffic information to all connected vehicles? (iii) their AD disengagements to traffic managers?
   c) Will we reach **full Autonomous Driving**? Should it require backend support? Who would control it?
   d) Should the infrastructure provider limit the automation level it allows?
   e) Should motorways have dedicated AV lanes, whilst in a transition period?
   f) Should parts of the urban road network not allow AVs of SAE level >=3?

With these questions in the background, an open discussion on the transition to CCAM, classification schemes and present and future technologies occurred. The main input from the AB members were:

- **Classification of Automation Levels**

One expert expressed scepticism about the practicality of a detailed classification of vehicle automation. The expert considers these classifications to be more for the public's understanding than for technical experts or the planning of systems, since for every SAE level, tens of sub-levels exist (in order to properly define an automated system).

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[42] https://orchestra2020.eu/

In addition, creating automation classes for the infrastructure does not ensure that the vehicle's OEMs consider using the infrastructure as defined by the classification scheme. The expert argued that this type of categorization can create the perception that a certain level of infrastructure ensures safety and security to automated driving when that responsibility belongs to the vehicles and how they use the infrastructure.

This expert participated in the *Working Party on Automated/Autonomous and Connected Vehicles* (GRVA) from UNECE[43], where they have decided not to officially name levels of automation, due to differing perspectives from companies like Waymo, Tesla, and Uber and speak only of systems controlled by the vehicles. Unlike the rail, where there is a railway community and every operator uses the infrastructure in the same way, different autonomous vehicles players use the road infrastructure in rather distinct ways. So, it was decided in GRVA not to categorize AVs and not to make the infrastructure restrict vehicle movement based on automation levels. One might even consider having the vehicle OEMs classifying the roads.

- **Infrastructure and Services**

One should shift to the idea of infrastructure providing added services for automated and connected vehicles, instead of focusing on its automation classification.

Although, today, CAVs do not interact with the infrastructure and traffic management in general, if we are going to have an optimal traffic system, in the future, traffic management also must influence how these vehicles operate in the network. And then, there will exist services provided by the infrastructure and by traffic management, with certain service levels at the different road segments, that should be communicated to the vehicles so that they can adapt. So, in conclusion, there is immense potential importance of infrastructure services for optimizing traffic systems, even if the current vehicle systems still do not directly interact with traffic management.

- **Smart Infrastructure Indicators**

Another relevant topic is to classify not the quality of the infrastructure levels of service, but the quality of the infrastructure itself. There is an obvious need to classify the quality of the roadway, including road marks, signage, and pavement for automated driving functions.

Furthermore, one should focus on classifying connectivity levels and classifying information provided to describe traffic states rather than directly supporting automated driving.

Regarding which investments should be prioritized: roadway conditions, road sensorization or connectivity, an expert from ITS Norway[41] introduced the challenge of snowy environments and the importance of communication technology. For vehicles under harsh environmental conditions, where sensors might stop functioning, road markings and signs might no longer be visible, connectivity is the type of road factor that can increase road safety and efficiency.

- **Urban Focus and Priorities**:

The need for practical indicators or KPIs for measuring urban mobility quality was emphasized. Adapting smart infrastructure classifications to the urban context can help determine priorities for road improvement and understand the relevance of technology in smart infrastructure. But one should highlight that governance and political willingness are the key factors in any paradigm shift and that the devised KPIs should be easy to be applied and interpreted by transport authorities and legislators.

This thematic and the remaining undiscussed topics are being transferred to the TANGENT Forum online platform, where the consultation of TANGENT's external stakeholders on SICI and its ability to aid the CCAM transition will be further brainstormed by the community.

[43] https://unece.org/working-party-automatedautonomous-and-connected-vehicles-grva

4 TANGENT Smart Infrastructure Classification Index v1.0

This section presents the TANGENT Smart Infrastructure Classification Index (SICI) in its first version (v1.0). We devised SICI to be an evolving Classification Index for which future versions can be produced.

Our focus is on the Smart Infrastructure and the Digital information it can provide to vehicles (common, connected, automated), drivers and passengers. It is true that even for the multimodal perspective of the TANGENT project, roads are still a very relevant part of the infrastructure because of their usage by many Public Transport (PT) and Demand Responsive Transportation (DRT) vehicles, not only by private cars. SICI intends to extend coverage from the road into rail stations and other infrastructure elements in a multimodal network, covering both autonomous vehicles and connected users in these networks.

This section starts by exploring the shortcomings of the existing classification systems and providing a context adaption for SICI in the line of the previous paragraph. It then presents the six SICI categories and the evaluation items in each category, going on to detailing the evaluation criteria of each item, providing the basic guidelines for an adequate implementation of the index.

4.1 Shortcomings of the existing classifications and Context Adaptation

Existing smart infrastructure classifications were presented in section 3.1 with a good amount of detail. An evolution of these classifications is visible there and it seems to be guided by an iterative process of development, trial usage followed by evaluation, allowing future indexes to overcome limitations of prior ones. This motivated us to create the SICI clearly as a work in progress asset and specifically led us to introduce the version number after its name.

Taking into consideration some of the broader needs in smart infrastructure classification brought about by the TANGENT project and from our own experience, we identified a set of limitations with the existing indexes and tried to overcome the most relevant ones in SICI.

None of the smart infrastructure classification indexes analysed in section 3.1 (except for SIRI, only introduced in the final version of this document) addressed multimodality. This oversight is notable given promising developments of AVs, which are applied in Public and Demand Responsive Transport solutions and the automation efforts are not limited to vehicles traveling on roads but also apply to rail, water and airways. Additionally, many of the existing classifications do not cover urban environments adequately and can be biased towards higher-speed roads. A more holistic approach is thus necessary.

Some of the indexes analysed in section 3.1 consider only local V2X communications for infrastructure to vehicle interaction whereas many other scenarios for V2X communication also exist, some of which even seem more likely than V2X communication at this point, in particular the telematics platforms from vehicle brands / OEMs. Another aspect related with communication is that most classifications consider higher levels of AV autonomy to only be possible with real-time cooperation. This view might not align with the view of AV manufacturers who are focusing on making vehicles fully autonomous even in the absence of connectivity. As stated in [15], a physical infrastructure that is optimal for AVs but lacks connectivity will provide a better autonomous experience to AVs than one that physically is not adequate for AVs (for *e.g.*, with bad road markings and no traffic signals) but has fantastic connectivity. Through a harmonized and more comprehensive classification, SICI can support alignment between public authorities and AV manufacturers. Even if connectivity is not deemed important to OEMs, it is key for aspects like safety, traffic management, multimodality, etc. Through SICI, public authorities can be more proactive and assertive in defining the road environment for AVs, providing clear conditions for the manufacturers to adapt their technology. In addition, a less partial vision would evaluate aspects of the physical infrastructure (like LOSAD and SRC do) to cover the scenarios of fully autonomous driving but welcome cooperation and connectivity as promoters of a safer transport environment. As will be seen, SICI tries to do this by evaluating the infrastructure, the information it collects, shares and the channels used for it, and, finally, the level of adoption of active traffic management use cases, including cooperative ones. Considering not only the enabler technology for cooperative systems but also the availability of actual use cases is also a differentiator of more complete classifications.

Another aspect of existing classifications is their adequacy to be applied to small network sections or entire cities or networks. Most classifications are applied to road segments and a map is produced conveying these partial results for the entire network or study area. We consider that such classifications should be able to scale the scope they can be applied to. Ideally it should be possible to evaluate sections of roads, streets, or PT lines but also it should be possible to provide a cumulative summary evaluation for an entire network. We tried to achieve this with SICI, so it is possible to provide an evaluation for an entire city and then drill-down into a more detailed evaluation for specific locations, categories or infrastructure element types.

Some of the presented classifications define SAE automation levels regarding infrastructure characteristics. This is not the correct approach because different AVs will deal differently with the same infrastructure characteristics, meaning the SAE level should differ between AVs for the same infrastructure. This approach has been acknowledged by the more recent classifications and is part of SICI also. SICI categories provide detailed evaluation for a series of parameters that can be considered by AV ODD systems to determine the adequate SAE level based on the data available from the SICI.

Consumer acceptance of the technologies available, traffic/passenger volume and other real-time conditions, can also influence the adequacy of the networks for AVs and are aspects not usually covered by classifications.

Another important aspect that was not covered by some of the previous classifications is the existence of parameter evaluation mechanisms that are viable to implement and for which information is available. In SICI we tried to define clear and feasible evaluation parameters.

SICI has been created to focus on **Connectivity and Digital Infrastructure Support for CCAM,** spanning CAVs, connected and even legacy vehicles in **Urban and Peri-urban** Contexts, fitting the TANGENT integrated Tool.

4.2 SICI Categories

Existing classifications, like ISAD, define levels of automation and connectivity capability for roads. Lower levels typically apply to conventional roads while higher levels apply to increasingly connected roads and ones supporting automated vehicles. In reality, this is not aligned with the current perspective from autonomous vehicle makers and operators as has been highlighted in section 3.2.3. The autonomous vehicle industry is still pursuing autonomy as a vehicle centred capability, gathering needed information mostly from the vehicle’s own sensors. This is justified by the need for full local decision-making abilities, especially considering the absolute time-sensitivity involved. Adding to this capability, extended connected services optimise the experience with extended knowledge about the surroundings. But from the perspective of AV makers and operators this is primarily supported services controlled by AV makers and operators. Our perspective with SICI is thus that a key category for the support of AVs focuses the physical aspects of the infrastructure such as signage and lighting. On top of this key category, other categories add knowledge, safety, and efficiency in a cooperative fashion. Thus, enhancing the AV, CV and legacy vehicles experience and providing an optimisation level that goes way beyond what AV makers and operators can provide and is totally impossible without cooperation.

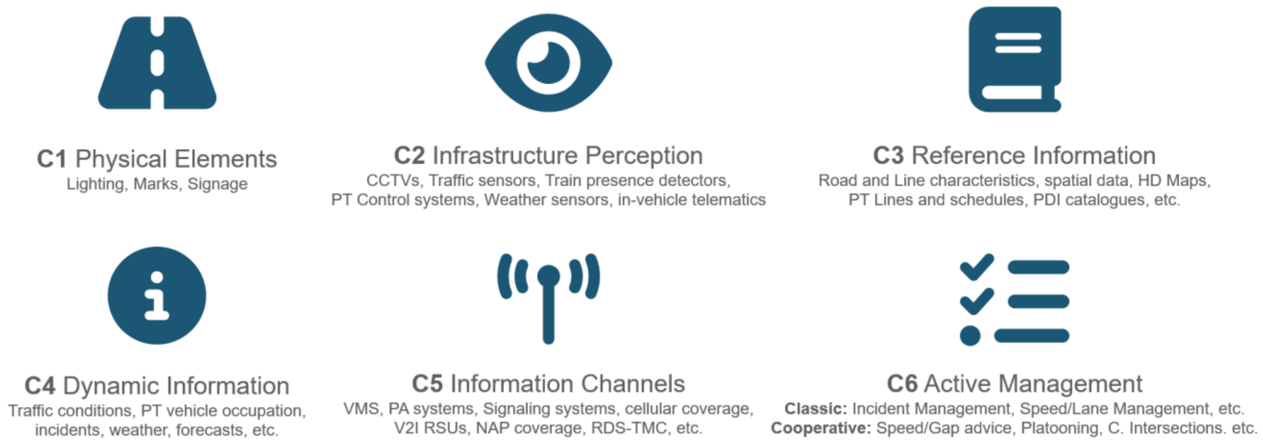

Figure 9: The six SICI categories.

4.2.1 SICI category 1 – Physical Elements

SICI's 1st category focuses on the physical infrastructure elements like road marks and signs. These elements are crucial for the perception of human drivers as well by sensors in autonomous vehicles. This category is similar to ISAD Level E. It is important to note that autonomous vehicles may operate correctly relying only on elements from this category and this is what is currently happening on motorways around the world.

This category evaluates a set of physical element control indexes that are relevant for automated driving, such as:

- Artificial lighting quality
- Road marks
- Vertical signage

4.2.2 SICI category 2 – Infrastructure Perception

The first layer of a smart system is usually perception. In the case of smart road and rail infrastructure this is true. The infrastructure perception layer is comprised of several different types of sensors that allow monitoring and capturing different aspects such as flow (of vehicles, fleets and passengers) and safety (detecting incidents, monitoring the weather, etc.).

This category evaluates a set of equipment types such as:

- Video cameras
- In Vehicle Telematics (OBUs, other sensors, also in PT and DRT fleets)
    - Through communication, vehicle sensor data can be shared with the infrastructure in real-time, so we consider this a means for infrastructure perception too.
- Traffic Sensors (loops, Bluetooth sensors, etc.)
- Traffic Radars
- 3D LiDARs
- Train Presence detectors
- Ticketing, validation, and passenger control systems in PT (in stations and in vehicles)
- Weather/Environmental Stations
- Specialized Sensors with Relevance for Traffic Safety (in tunnels, bridges, etc.)

The mere existence of perception elements does not make infrastructures smart but is an important step towards intelligence. That is why we introduced this category and followed it with categories where perception is transformed into knowledge and then into management actions.

4.2.3 SICI category 3 - Reference Information

Accurate and detailed reference information about infrastructures is essential for connected and automated vehicles to extend their electronic horizon, to provide details beyond what their sensors can measure, as well as provide information otherwise not available to human drivers.

This category evaluates the availability of reference information on the infrastructure side, namely from road and transport operators. It can also consider such information from third parties, not affiliated with the infrastructure itself, but this should be explicitly mentioned in the SICI report justifying a SICI score. Reference information should not only exist but be disseminated through at least one channel from SICI category 5.

This category evaluates a set of reference information types such as:

- Road lanes technical characteristics (geometry - segments, width, etc., speed limits, road marks, road signs, navigational constraints – one-way streets, turn restrictions, etc., interconnections)
- Road spatial data (including elevation data)
- HD Maps of the infrastructure
- Train lines technical characteristics (types of line, power availability, etc.)
- Public Transport lines and schedules
- Demand Responsive Transport providers, coverage and schedules
- Road markings and road sign catalogues
- Speed limits on road segments
- Navigational constraints (one-way streets, etc.)
- Communications infrastructure coverage (cellular, Vehicle to Infrastructure (V2I), etc.)
- Sensor Calibration Data (for cameras, LiDAR and radar)

4.2.4 SICI category 4 – Dynamic Information

The previous category focused on reference information. Reference information is usually produced during planning stages and updated, not so frequently, along the operation timespan of infrastructure. Dynamic information, on the other hand, changes quickly and is usually produced by perception elements such as those listed in SICI category 2. Knowledge is either extracted directly by the perception sensors (such as in traffic counters), computed (such as passenger control systems), or results from human or artificial intelligence analysis of the sensor data collected (such as in video cameras or 3D LiDAR). Furthermore, elements of this dynamic information can also be used for further analysis, to produce even more relevant dynamic information (such as incident detection or traffic and weather forecasts), namely through forecasting. We consider the resulting information itself, dynamic information also.

This category evaluates a set of dynamic information types such as:

- Traffic conditions (for *e.g.*, from traffic counters, Floating Car Data, fused from different sources)
- Public Transport line/vehicle occupation
- Microscopic traffic information (*e.g.*, vehicle positions and speed vectors from traffic radars)
- Weather Data
- Traffic and Public Transport Incidents

- Lane availability information (*e.g.*, lane closures, HD geometry of temporarily obstructed lanes)
- Passenger demand for specific routes
- Traffic forecasts
- Weather forecasts
- Passenger demand forecasts

4.2.5 SICI category 5 – Information Channels

Information needs to reach vehicles, drivers and passengers, to become valuable. This motivates our 5th category. The availability of different communication channels defines the ability of smart infrastructure to share information.

This category evaluates a set of information channels such as:

- Variable Message Signs (in roads, city streets, public transport stations and vehicles)
- Public Announcement Systems (in stations, inside vehicles, in road tunnels)
- Signalling systems (for trains)
- Cellular coverage (including underground coverage in metro lines)
- V2I Road-Side Units
- National Access Point (NAP) coverage (availability of data for the infrastructure through NAP)
- RDS-TMC Traffic Message Channel (availability of data for the infrastructure through RDS-TMC at the infrastructure location)
- Service Providers / Integrated Cloud Services (availability of data for the infrastructure through these services)
- Vehicle Navigation Platforms with online information (availability of data for the infrastructure through these platforms)
- Coverage in HD Map Services

4.2.6 SICI category 6 – Active Traffic Management

Since SICI category 1, we've covered mechanisms that convey information from the infrastructure to the vehicle, driver and/or passenger, with the exception of category 2, which actually collects information from the vehicles, drivers and/or passengers. There is no actual interactivity and bidirectionality in these categories. They actually build on top of each other a system that is able to perceive, communicate, know and share its knowledge. What is lacking here is the ability for this system to adapt and optimise itself through the bidirectionality between the smart infrastructure and the (smart) vehicles, drivers and/or passengers.

This category evaluates a set of classic active traffic management use cases such as:

- Incident Detection and Management
- Variable Speed Limits (not as a communication mechanism to the driver/vehicle, but as a system which can optimise vehicle speed for maximized flow)
- Lane Management Systems (as a mean to optimise flow and maximize safety)
- Dynamic Traffic Lights (as a mean to optimise flow)
- Congestion Pricing Systems
- Adaptive Ramp Metering
- Smart Parking Systems (providing parking availability information to drivers)
- Train Control and Signalling Systems
- Transit Signal Priority (TSP)
- Bus Rapid Transit (BRT) Systems
- Dynamic Scheduling and Dispatching for Public Transport

- Automated Fare Collection Systems
- Integrated Fare and Routing Systems

But also evaluates a set of cooperative active traffic management use cases such as:

- Speed and Gap Advice
- Assisted Lane Merge and Lane Change
- Emergency Vehicle Priority
- Cooperative Intersection Management
- Collision Avoidance
- Platooning
- V2X-based Traffic Management
- Collaborative Parking Assistance
- Cooperative Adaptive Cruise Control (CACC)
- Infrastructure-Guided Automated Driving - where the infrastructure optimises traffic flow globally and provides specific guidance to individual automated vehicles
- Cooperative Automated Driving - Automated Driving fully performed by the infrastructure

4.3 SICI Evaluation Criteria

The elements in the categories laid out in the previous section can be evaluated in very different ways, resulting in totally different classification indexes. It is thus important to define the evaluation criteria that should be applied with SICI to achieve a uniform classification index. While it would be helpful to evaluate the elements with a good amount of detail, this is often not possible due to the lack of available data and because this would render the index too complex for real-life implementation.

One such example is category 5 where the mere existence of the communications channels is not enough, and we should evaluate what kinds of information and to what level of detail the channel is used for. This would not be practical to achieve and would make the index implementation too complex to be feasible, thus we opted for a simpler approach as will be seen.

Each element in the evaluation criteria of each category will produce a unique index for each infrastructure being evaluated (*e.g.*, a section of a motorway, an urban road or even an entire city). Each category will then produce a respective index built from each of the elemental indexes. This is done simply by calculating the arithmetic average from each of the category individual criteria:

$$C_n = \frac{\sum_{i=1}^{m} C_{n,i}}{m}$$

Where n is the category number from 1 to 6, m is the number of individual criteria in the category, C_n is the category index value for category n, and $C_{n,i}$ is the individual criteria value i for category n.

In case values are not available for one of the individual criteria the index C_i should still be calculated but using 0% as value for the individual indexes that are absent. A note mentioning the absence of data should always accompany the resulting index C_1 and the index should be listed as $C_{i\ (partial:\, a,b,c)}$, where a, b, c are the indexes of the individual criteria that were not absent. In case no individual index is available, the category index value shall be 0% and it shall be listed as $C_{i\ (N/A)}$.

4.3.1 SICI category 1 – Physical Elements

Category 1 selects aspects from Quality Control Plans that are especially relevant for Autonomous Vehicles. The evaluation of these aspects has also been tailored for what is considered more relevant for the scenario at hand.

The evaluation criteria for this category should be as follows:

- $C_{1,1}$ - **Artificial lighting quality**
  - Index value should be the % of the infrastructure / network with illumination indexes within the following values:
    - Illumination value (lux)
      - Open road
        - Intersections in residential area - Night-time - between 20 and 200 lx
        - Intersections in high-speed areas – Night-time – between 100 and 200 lx
        - Section outside intersections (if illuminated) - Night-time - between 20 and 200 lx
      - Tunnel or road not on the exterior
        - Night-time – Between 100 and 200 lx
        - Daytime – Above 300 lx
- $C_{1,2}$ - **Road marks**
  - Index value should be the % of the infrastructure / network with road marks indexes within the following values:
    - Road marks present on the road and following local standards
    - Absence of any visible secondary road marks (*e.g.*, during or after road works)
    - Retroreflection index – between 100 and 300 $mcd/m^2/lx$
- $C_{1,3}$ - **Vertical signage**
  - Index value should be the % of the infrastructure / network with vertical sign indexes within the following values:
    - Signs according to local standards should be installed
    - Signs should be easily readable and well oriented towards the road (in the future an automated test could be developed for this)
    - Retroreflection index – between 100 and 600 $mcd/m^2/lx$

Again, we emphasize the importance of evaluating the physical elements of this category as they are currently the most relevant aspects when considering Autonomous Vehicles driving on road trials or real roads nowadays. It is also important to note that fulfilment of these criteria will also guarantee the achievement of a high level of visual safety for human drivers.

4.3.2 SICI category 2 – Infrastructure Perception

Category 2 focuses on the existence of perception elements on the infrastructure. It could also go into evaluating characteristics of these elements and the usage that is done with their data, namely whether video cameras are monitored by humans and/or AI and what is done with them, yet these aspects are too detailed for the current analysis. Meanwhile the following categories cover some of the functional results from the perception activity, thus covering partially the effectiveness of these perception elements. For the sake of this category, the existence of the perception elements should be enough.

The evaluation criteria for this category should be as follows:

- $C_{2,1}$ – **Video Cameras**

    - Index value should be the % of the infrastructure / network covered with video cameras, considering a 200 m radius for the coverage of each camera.
- $C_{2,2}$ – **In Vehicle Telematics**
    - Index value should be the % of vehicles using OBUs for the infrastructure / network (average value from samples from the entire network).
- $C_{2,3}$ – **Traffic Sensors**
    - Independently of the technology used, the index value should be the % of the infrastructure / network covered with traffic sensors. We consider a 500 m radius for the coverage of each sensor, although they may be collecting point data only or may be collecting average speeds along road stretches with different lengths.
- $C_{2,4}$ – **Train Presence Detectors**
    - The index value should be the % of the infrastructure / network covered with train presence detectors, assuming a 5 km maximum distance between detectors for full coverage.
- $C_{2,5}$ – **Ticketing, validation and passenger control systems in PT**
    - The index value should be the % of the PT operators in the infrastructure / network covered that have digital ticketing, validation and passenger control systems that can control the movement of passengers online.
- $C_{2,6}$ – **Weather/Environmental Stations**
    - Index value should be the % of the infrastructure / network covered with weather/environmental stations, considering a 5 km m radius for the coverage of each station.
- $C_{2,7}$ – **Radar**
    - Index value should be the % of the infrastructure / network covered with Radars, considering a 500 m radius for the coverage of each radar.
- $C_{2,8}$ – **3D LiDAR**
    - Index value should be the % of the infrastructure / network covered with 3D LiDAR, considering a 200 m radius for the coverage of each LiDAR.

Specialized Sensors with Relevance for Road Traffic Safety (road tunnels, bridges, etc.) are not considered as they are very heterogeneous and present only in specific locations.

Different sensors have different impacts on different forms of mobility and impact differently autonomous vehicles. It is an intended simplification to weight the different sensors in the same way for this index.

4.3.3 SICI category 3 - Reference Information

Category 3 focuses on reference information about the infrastructure. Aspects such as accuracy, density of data and frequency of update are not considered for this index, although these aspects are also relevant for this category. Only the existence of specific types of reference information about the infrastructure is considered. Recall from section 4.2.3 what is considered as existent information for the evaluation criteria below.

The evaluation criteria for this category should be as follows:

- $C_{3,1}$ – **Road lanes technical characteristics**
    - Index value should be the % of the infrastructure / network with road lanes technical information existent.
- $C_{3,2}$ – **Road spatial data**
    - Index value should be the % of the infrastructure / network with road spatial data information existent.
- $C_{3,3}$ – **HD Maps of the infrastructure**
    - Index value should be the % of the infrastructure / network with HD Maps information existent.

- $C_{3,4}$ – **Train lines technical characteristics**
  - Index value should be the % of the infrastructure / network with train lines technical information existent.
- $C_{3,5}$ – **Public Transport lines and schedules**
  - Index value should be the % of the infrastructure / network with public transport lines and schedules information existent, only applicable where public transport lines exist.
- $C_{3,6}$ – **Demand Responsive Transport providers, coverage and schedules**
  - Index value should be the % of the infrastructure / network with DRT information existent, information on no DRT coverage counts as valid information for the applicable portion of the network.
- $C_{3,7}$ – **Road markings and road sign catalogues**
  - Index value should be the % of the infrastructure / network with road markings and road signs information existent.
- $C_{3,8}$ – **Speed limits and road segments**
  - Index value should be the % of the infrastructure / network with speed limit and road segments information existent.
- $C_{3,9}$ – **Navigational Constraints**
  - Index value should be the % of the infrastructure / network with navigational constraints information existent.
- $C_{3,10}$ – **Communications infrastructure coverage**
  - Index value should be the % of the infrastructure / network with information about the coverage of the communications infrastructure.
- $C_{3,11}$ – **Sensor Calibration Data**
  - Index value should be the % of the infrastructure / network with sensor calibration information existent.

4.3.4 SICI category 4 – Dynamic Information

Category 4 evaluates the existence of dynamic information. It could address the richness and adequacy of the information, but our current focus is solely on the existence of the information near real time (except for forecasts). The criteria for what is considered existent information from section 4.2.3 also applies to this category. Additionally, if the information is not available near real time it shall not be considered (except for forecasts).

The evaluation criteria for this category should be as follows:

- $C_{4,1}$ – **Traffic conditions**
  - Index value should be the % of the infrastructure / network with traffic conditions information existent.
- $C_{4,2}$ – **Public Transport line/vehicle status and occupation**
  - Index value should be the % of the infrastructure / network with public transport line/vehicle occupation information existent.
- $C_{4,3}$ – **Microscopic traffic information**
  - Index value should be the % of the infrastructure / network with microscopic traffic information existent.
- $C_{4,4}$ – **Weather Data**
  - Index value should be the % of the infrastructure / network with weather information existent.
- $C_{4,5}$ – **Traffic and Public Transport incidents**
  - Index value should be the % of the infrastructure / network with traffic and public transport incident information existent.
- $C_{4,6}$ – **Lane availability information**

    - Index value should be the % of the infrastructure / network with lane availability information existent.
- $C_{4,7}$ – **Passenger demand for specific routes**
    - Index value should be the % of the public transport network with passenger demand for specific routes information existent.
- $C_{4,8}$ – **Traffic forecasts**
    - Index value should be the % of the infrastructure / network with traffic forecast information existent.
- $C_{4,9}$ – **Weather forecasts**
    - Index value should be the % of the infrastructure / network with weather forecast information existent.
- $C_{4,10}$ – **Passenger demand forecasts**
    - Index value should be the % of the public transport network with passenger demand forecast information existent.
- $C_{4,11}$ – **HD Map updates for dynamic situations**
    - Index value should be the % of the infrastructure / network with HD Map updates for dynamic situations existent.

4.3.5 SICI category 5 – Information Channels

Information is nothing if not disseminated and exchanged. This is achieved by a myriad of information channels that can be available within infrastructures. To keep the evaluation criteria within the boundaries of practicality we opted to consider only the geographic coverage of the information channels for SICI evaluation.

The evaluation criteria for this category should be as follows:

- $C_{5,1}$ – **Variable Message Signs**
    - Index value should be the % of the infrastructure / network covered by variable message signs assuming a coverage radius of 5km on roads, station coverage in metro and train and line coverage in either stops or in-vehicle.
- $C_{5,2}$ – **Public Announcement Systems**
    - Index value should be the % of the public transport network covered by public announcement systems with station coverage in metro and train and line coverage in-vehicle. Tunnel and other road public announcement systems are not covered.
- $C_{5,3}$ – **Signalling systems**
    - Index value should be the % of the rail network covered by signalling systems.
- $C_{5,4}$ – **Cellular coverage**
    - Index value should be the % of the infrastructure / network with cellular coverage. Coverage is considered if at least one operator supports a specific location. No minimum bandwidth criteria defined to consider a coverage. Underground coverage is considered in another specific index.
- $C_{5,5}$ – **Underground cellular coverage**
    - Index value should be the % of the underground metro network with cellular coverage. Coverage is considered if at least one operator supports a specific location. No minimum bandwidth criteria defined to consider a coverage.
- $C_{5,6}$ – **V2I Road-Side Units**
    - Index value should be the % of the infrastructure / network with RSU coverage, assuming a 2km radius for the coverage of each RSU. DSRC and C-V2X Road Safety RSUs are considered.
- $C_{5,7}$ – **National Access Point coverage**

    - Index value should be the % of the infrastructure / network with data available in a National Access Point (Datex II hub) independently of the type of data or level of detail made available.
- $C_{5,8}$ – **RDS-TMC Traffic Message Channel**
    - Index value should be the % of the infrastructure / network both with data available on RDS-TMC and covered by RDS-TMC.
- $C_{5,9}$ – **Service Providers / Integrated Cloud Services and Vehicle Navigation Platforms**
    - Index value should be the % of the infrastructure / network with flow information available through Service Providers / Integrated Cloud Services / Vehicle Navigation Platforms. This includes services such as Google Maps and Waze.
- $C_{5,10}$ – **Coverage in HD Map Services**
    - Index value should be the % of the infrastructure / network with detailed HD Map geometry information available through an HD Map provider (such as TomTom or HERE).

The information channels in SICI category 5 will be used to exchange information from categories 3 and 4. A future version of SICI should evaluate how the information in categories 3 and 4 is disseminated through each channel in category 5. For now, we only evaluate the existence of the information and the dissemination channels, independently of the information circulated by each channel.

A future version should also evaluate the level of adoption of different technologies from the end-user side to evaluate if the channel is reaching its targets or not.

4.3.6 SICI category 6 – Active Traffic Management

Category 6 evaluates the adoption of Active Traffic Management use cases. It's divided between two Active Traffic Management groups, the first one is comprised of classic Traffic Management use cases which do not rely on V2X/cooperation.

The evaluation criteria for the first group of Classic Active Traffic Management use cases should be as follows:

- $C_{6,1}$ – **Incident Detection and Management**
    - Index value should be the % of the infrastructure / network covered by active incident detection and management systems. This should cover both road and public transport operations.
- $C_{6,2}$ – **Variable Speed Limits**
    - Index value should be the % of the infrastructure / network covered by variable speed limits. Only applicable to roads with a fixed speed limit above 90 km/h, as with lower speed limits, the advantages of varying speed limits are more restricted. Used to optimise traffic.
- $C_{6,3}$ – **Lane Management Systems**
    - Index value should be the % of the infrastructure / network covered by lane management systems use to optimise traffic.
- $C_{6,4}$ – **Dynamic Traffic Lights**
    - Index value should be the % of the infrastructure / network covered by dynamic traffic lights. Only applicable to locations covered by traffic lights.
- $C_{6,5}$ – **Congestion Pricing Systems**
    - Index value should be the % of the infrastructure / network covered by congestion pricing. Only applicable to locations where traffic occurs recurrently.
- $C_{6,6}$ – **Adaptive Ramp Metering**
    - Index value should be the % of the motorway ramps in the infrastructure / network covered by adaptive ramp metering.

- $C_{6,7}$ – **Smart Parking Systems**
  - Index value should be the % of public parking in the infrastructure / network announcing availability publicly (usually through message signs on the road at strategic points like roundabouts).
- $C_{6,8}$ – **Train Control and Signalling Systems**
  - Index value should be the % of rail network supported by train control and signalling systems.
- $C_{6,9}$ – **Transit Signal Priority**
  - Index value should be the % of traffic lights in the infrastructure / network supporting Transit Signal Priority for at least one kind of transit type.
- $C_{6,10}$ – **Bus Rapid Transit (BRT) Systems**
  - Index value should be the % of the bus network equipped with dedicated bus lanes.
- $C_{6,11}$ – **Dynamic Scheduling and Dispatching for Public Transport**
  - Index value should be the % of the public transport network where dynamic scheduling and dispatching is applied.
- $C_{6,12}$ – **Automated Fare Collection Systems**
  - Index value should be the % of the public transport network adopting automated fare collection.
- $C_{6,13}$ – **Integrated Fare and Routing Systems**
  - Index value should be the % of the public transport network adopting integrated fares and routing between modes.

The second group of Traffic Management use cases is composed by Cooperative use cases based on communication. Our criteria are to consider that locations are enabled if they allow the use case, independently of how it is supported technically or the percentage of vehicles that can use it.

The evaluation criteria for the second group of Cooperative Traffic Management use cases should be as follows:

- $C_{6,14}$ – **Speed and Gap Advice**
  - Index value should be the % of the infrastructure / network covered by Speed and/or Gap Advice systems.
- $C_{6,15}$ – **Assisted Lane Merge and Lane Change**
  - Index value should be the % of the infrastructure / network where Assisted Lane Merge and/or Lane Change services are offered.
- $C_{6,16}$ – **Emergency Vehicle Priority**
  - Index value should be the % of the infrastructure / network where Emergency Vehicles can be prioritized. This can either be through traffic signals and/or lane control systems give priority to emergency vehicles but also if emergency vehicles are announced through V2X or other technologies where drivers are alerted to their presence and how they should proceed to give way.
- $C_{6,17}$ – **Cooperative Intersection Management**
  - Index value should be the % of the infrastructure / network where Emergency Vehicles can be prioritized.
- $C_{6,18}$ – **Collision Avoidance**
  - Index value should be the % of the infrastructure / network where Emergency Vehicles can be prioritized.
- $C_{6,19}$ – **Platooning and Cooperative Adaptive Cruise Control (CACC)**
  - Index value should be the % of the infrastructure / network which support platooning and/or CACC (typically motorways) where platooning and/or CACC is technically possible.

- $C_{6,20}$ – **Automated Public Transports**
  - Index value should be the % of the infrastructure / network where automated public transport can operate.
- $C_{6,21}$ – **V2X-based Traffic Management**
  - Index value should be the % of the infrastructure / network where real-time vehicle information is collected and used to optimise the traffic management approaches for the network.
- $C_{6,22}$ – **Collaborative Parking Assistance**
  - Index value should be the % of public parking in the infrastructure / network where parking availability is digitally available in real time and/or dynamic guidance to available spots is provided.
- $C_{6,23}$ – **Infrastructure-Guided Automated Driving**
  - Index value should be the % of the infrastructure / network where there is a traffic optimisation process that provides individual guidance that can be sent individually to autonomous vehicles.
- $C_{6,24}$ – **Cooperative Automated Driving**
  - Index value should be the % of the infrastructure / network where automated driving can be fully supported by the infrastructure.

At the time of writing of SICI version 1.0 it is not expected that any infrastructures will achieve high scores in the second group of this last category as most of the cooperative use cases are experimental and limited in space and time. Still, as time goes by, it's expected that some of these use cases gain traction and become more widely adopted, causing an increase of the resulting index value for this category.

It is important to note that autonomous vehicles are expected to be able to operate autonomously even without these use cases in place. The larger advantage of these use cases is augmented safety and a potentially large optimisation of the traffic and passenger flows, thus achieving an actual Smart Infrastructure.

4.4 SICI Application

This section starts by describing generically how SICI v1.0 can be applied and its results presented, then we show how it was applied to three physical case-studies of the TANGENT project (Rennes, Greater Manchester and Lisbon), its results presented inside the TANGENT Dashboard, provide the detailed results obtained and finally present some considerations on data availability for this kind of indexes.

4.4.1 SICI results presentation – an example dataset

SICI is broken down into six distinct categories. It was our option to keep results from the six different categories separate instead of combining them together for a final ultimate result. We also sought for a way to present specific results within each category and this was successfully achieved using a radar plot for each.

Below is such a presentation of a SICI evaluation for a city segment using a dummy example data set. It features on the left a graphical table summary of the six categories with the overall result in percentage and a colour coded circle. On the right it then provides a radar chart for each category with a single point entry with a plot of each individual evaluation criteria in the category. All the evaluation criteria are represented by a 0-100% value as defined in the previous section thus they can be compared graphically on this radar plot, making it easy to understand the points where each category is stronger at and quickly understand the justification for the overall category values on the left.

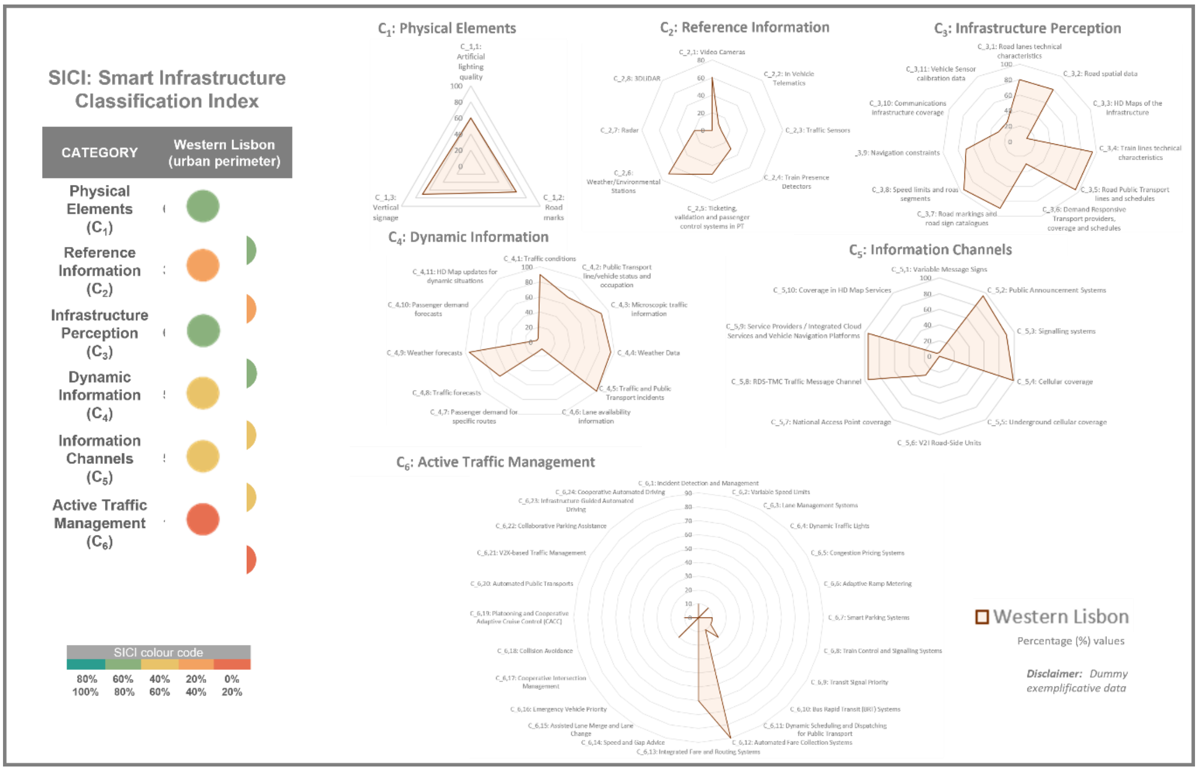

Figure 10: SICI results for dummy data in a city segment.

This presentation approach is also prone to be used for direct comparison between two distinct infrastructures.

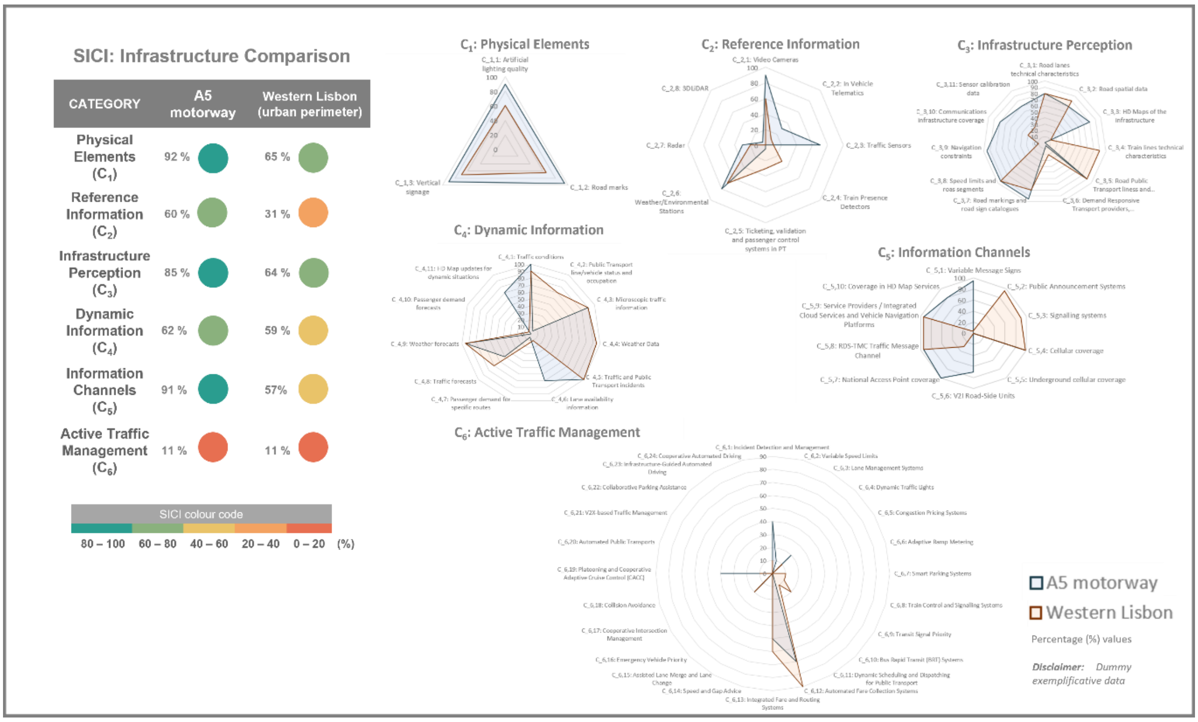

Figure 11: SICI results comparison for a city segment and a motorway, both using dummy data.

For further details, optionally, each evaluation criteria can be listed in a table and provide the input data and algorithm used to calculate its final value. This may help understand the rationale behind each individual evaluation criteria and provides traceability in the produced index scoring.

4.4.2 SICI's spatial distribution

In the previous sub-section the example results were presented for an entire infrastructure with results for the entire infrastructure in regards to each evaluation element. SICI can be evaluated for datasets for the entire infrastructure to achieve these results, but it can also be evaluated for geographically filtered datasets to provide segmented data for different regions of the entire infrastructure. This last approach can be taken to different levels of aggregation from city neighbourhoods down to 10x10 meter square cells when more granularity is necessary.

In our TANGENT Tool implementation of SICI we opted for a simpler city-wide approach but it would have been possible to explore more granular approaches, displaying value distributions geographically on map displays or calculating values using the Dashboard Indicator feature and filtering it for specific geographic locations (such as neighbourhoods).

It is a clear objective of SICI to be able to provide data at different granularities when it is necessary. It is also important to notice that, unlike other indexes which opt for a linear infrastructure model, adequate for highways, in SICI we opted for a fully 2D geographic infrastructure model which is adequate for urban transport roads and lines and can cope with multi-level layered infrastructure such as sub-way lines, tunnels and multi-level roads.

4.4.3 SICI integrated in the TANGENT Dashboard

Some of the data collected for the TANGENT project could be used to calculate some of SICI's evaluation criteria. It was not our ambition to collect data specifically because it was needed for SICI, but only to use existing data in the best way possible.

Next, we present which data was available for each city and how it was represented in the TANGENT Tool.

4.4.3.1 Rennes

For Rennes data was only available for the following evaluation criteria (with respective city-wide values):

- C2.3 Traffic Sensors (23.639%)
- C4.1 Traffic Conditions (4.59%)
- C4.2 Public Transport line/vehicle status and occupation (3.419%)
- C4.5 Traffic and Public Transport Incidents (50%)
- C4.8 Traffic Forecasts (0.092%)

The results are presented on the User Dashboard through a Specific SICI functionality on the left menu bar that is available to all the users in the platform (although this can be controlled and limited if necessary).

For a description of how the data was calculated see the next main section in this Chapter.

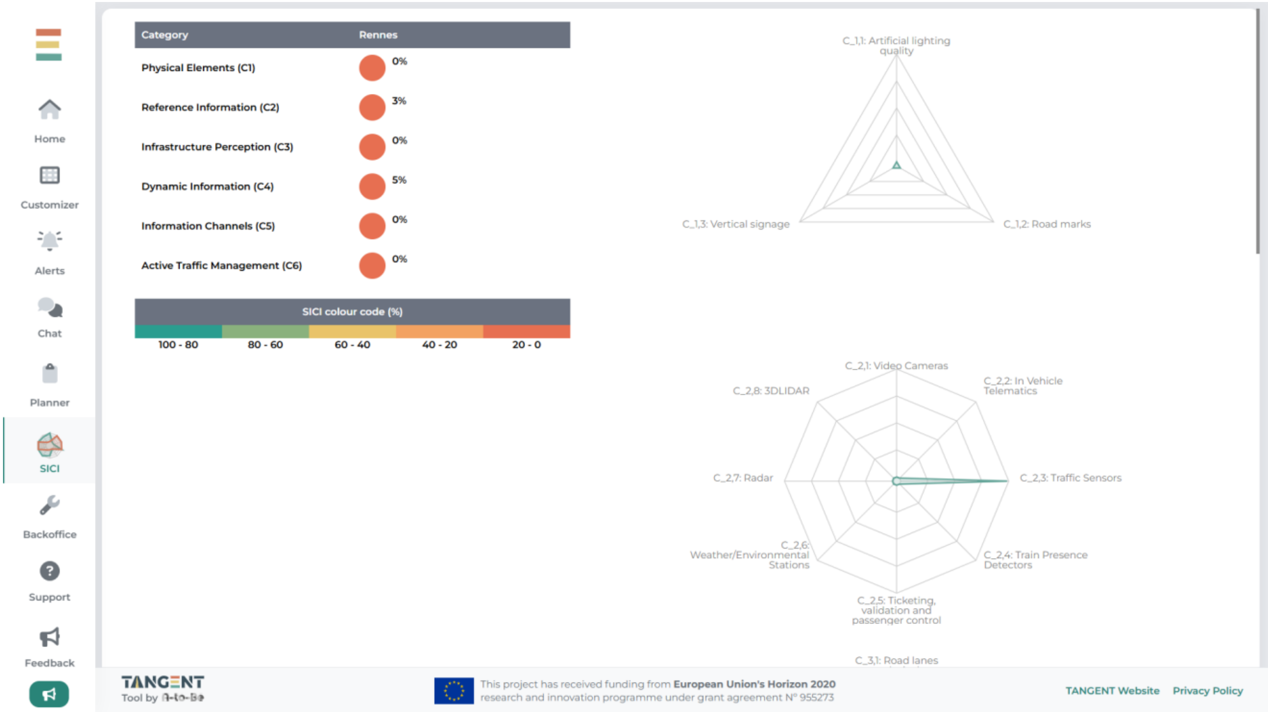

Figure 12: Dashboard view of the SICI results for the city of Rennes using the real data.

Category	Rennes
Physical Elements (C1)	0%
Reference Information (C2)	3%
Infrastructure Perception (C3)	0%
Dynamic Information (C4)	5%
Information Channels (C5)	0%
Active Traffic Management (C6)	0%

SICI colour code (%)				
100 - 80	80 - 60	60 - 40	40 - 20	20 - 0

Figure 13: Graphical SICI table summary for the city of Rennes.

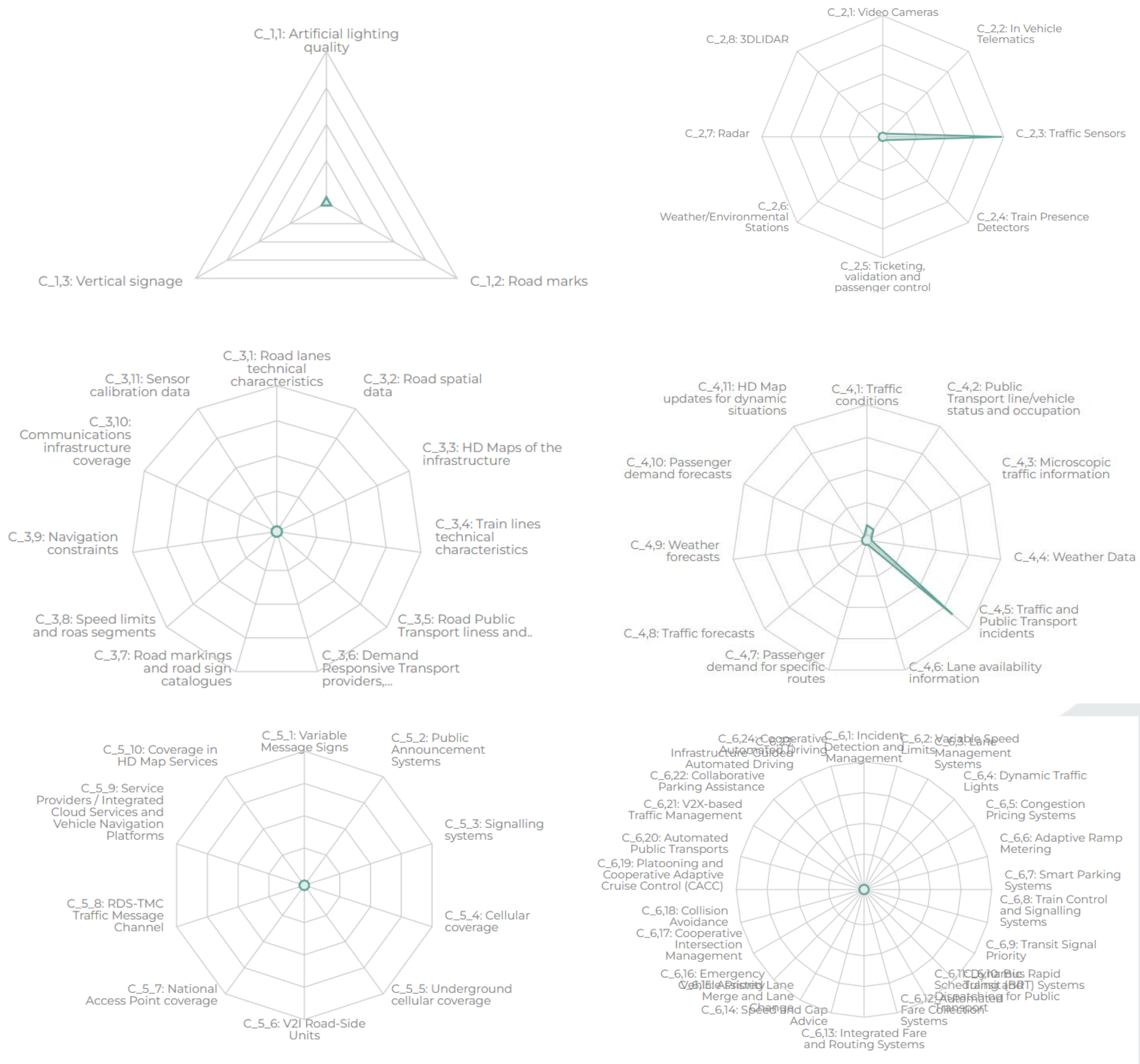

Figure 14: Radar plots for the six SICI categories for the city of Rennes.

4.4.3.2 Manchester

For Manchester data was only available for the following evaluation criteria (with respective city-wide values):

- C2.1 Video Cameras (0.142%)
- C2.3 Traffic Sensors (0.83%)
- C4.1 Traffic Conditions (37.8%)
- C4.2 Public Transport line/vehicle status and occupation (61.11%)
- C4.5 Traffic and Public Transport Incidents (25%)
- C4.8 Traffic Forecasts (0.396%)

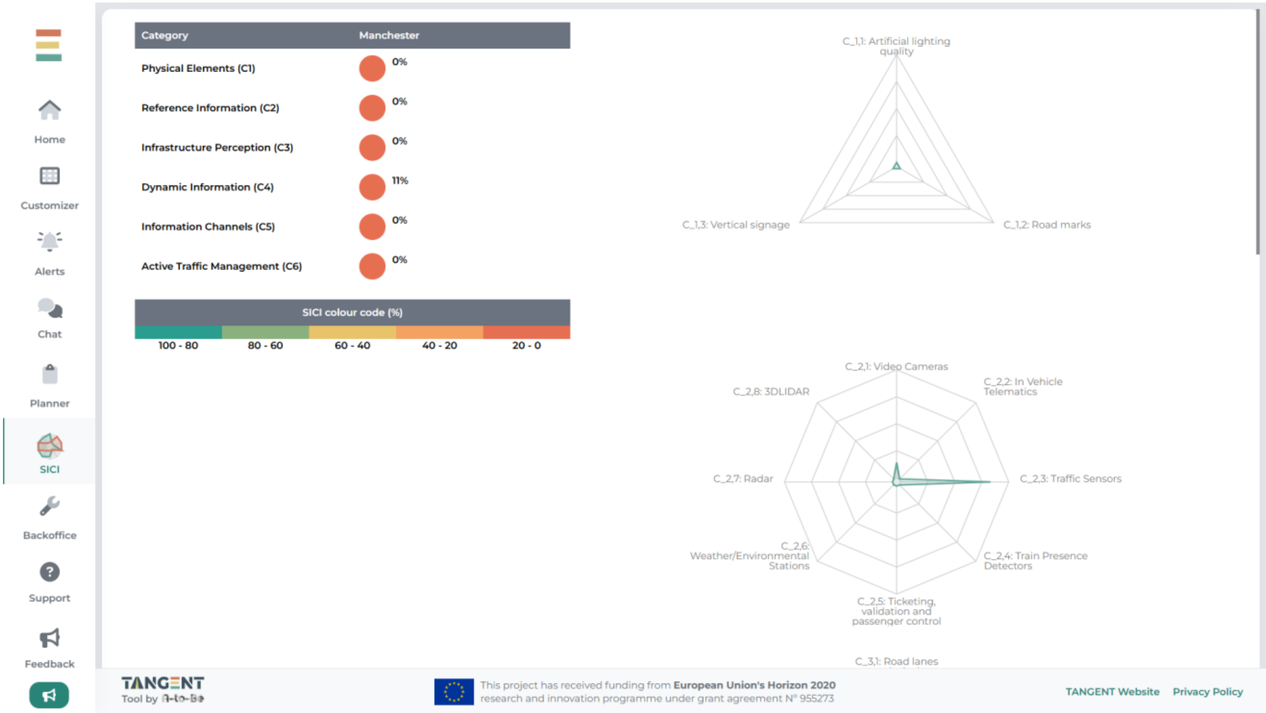

Figure 15: Dashboard view of the SICI results for the city of Manchester using the real data.

Category	Manchester
Physical Elements (C1)	0%
Reference Information (C2)	0%
Infrastructure Perception (C3)	0%
Dynamic Information (C4)	11%
Information Channels (C5)	0%
Active Traffic Management (C6)	0%

SICI colour code (%)				
100 - 80	80 - 60	60 - 40	40 - 20	20 - 0

Figure 16: Graphical SICI table summary for the city of Manchester.

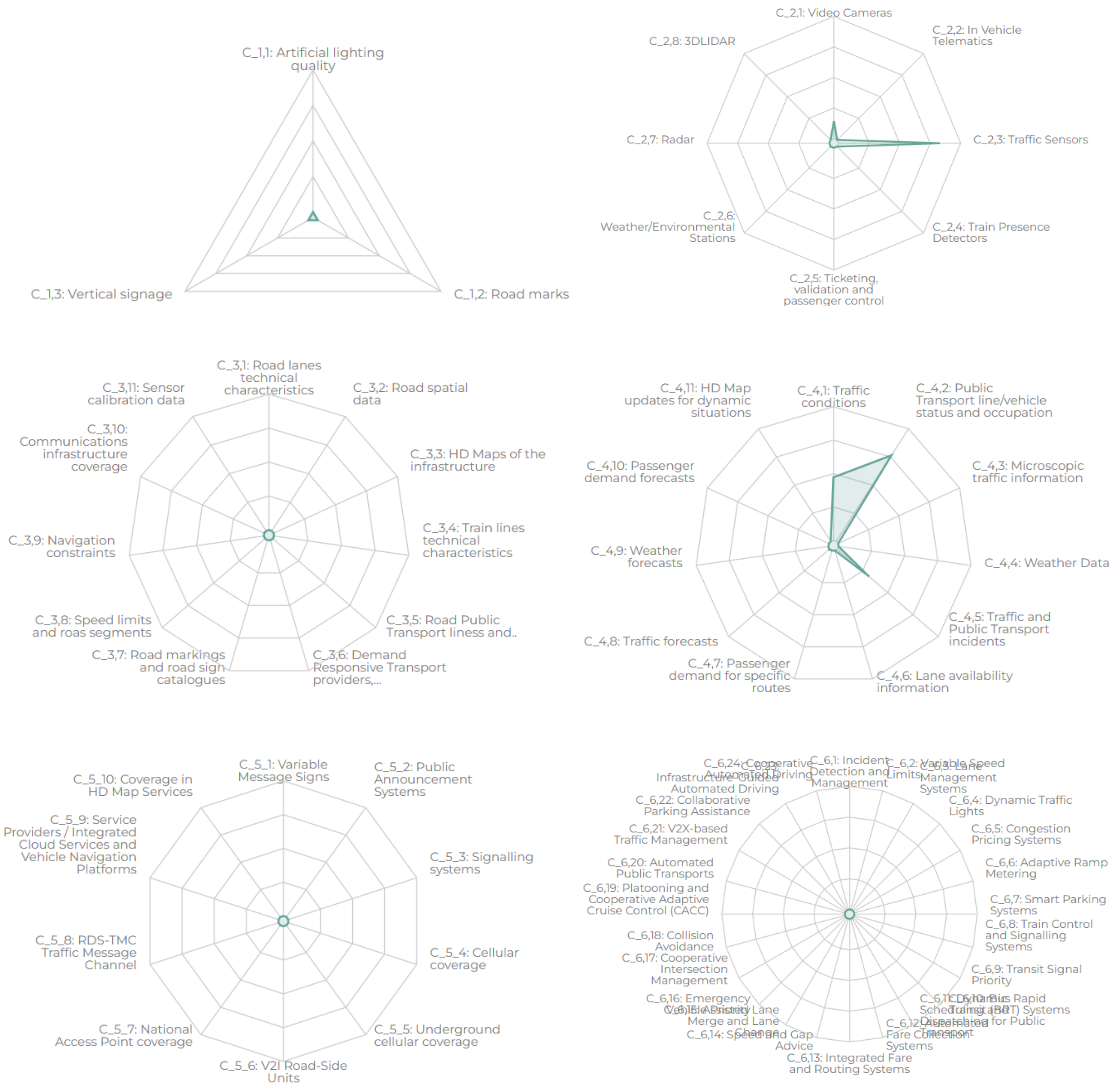

Figure 17: Radar plots for the six SICI categories for the city of Manchester.

4.4.3.3 Lisbon

For Lisbon data was only available for the following evaluation criteria (with respective city-wide values):

- C2.1 Video Cameras (0.08%)
- C4.1 Traffic Conditions (15.743%)
- C4.2 Public Transport line/vehicle status and occupation (100%)
- C4.5 Traffic and Public Transport Incidents (50%)
- C5.1 Variable Message Signs (0.446%)
- C5.6 V2I Road-Side Units (0.178%)

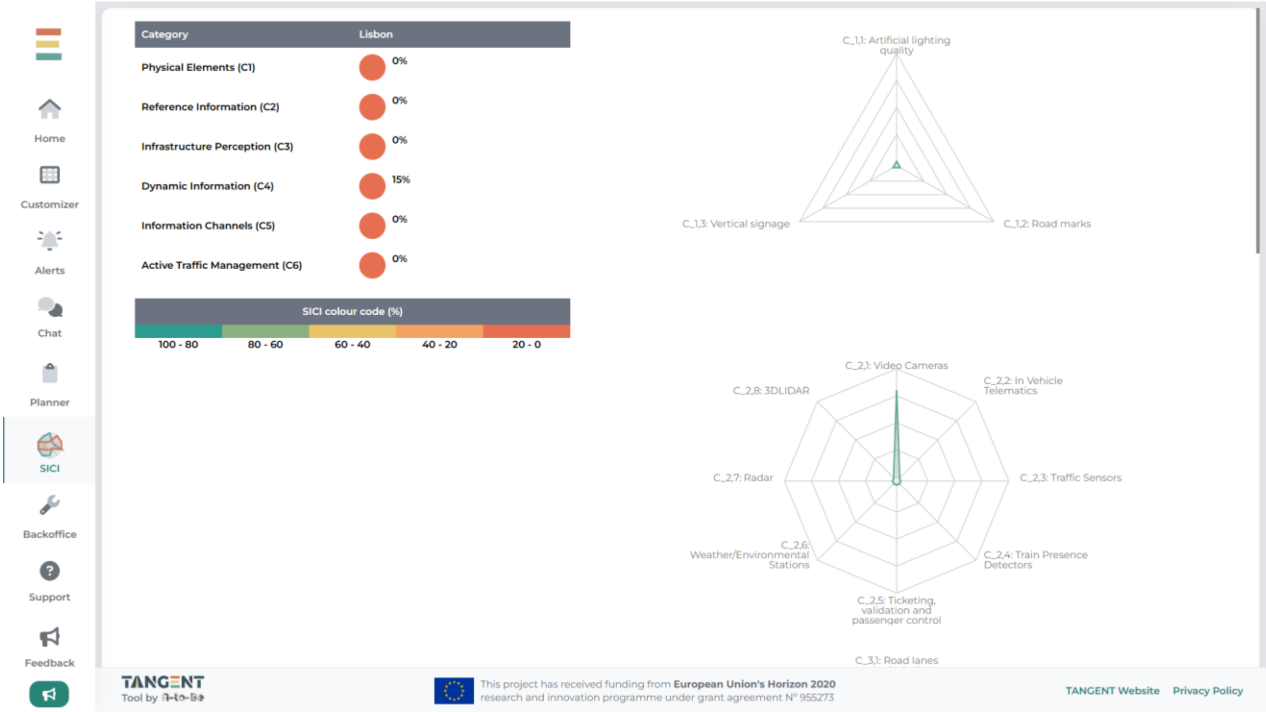

Figure 18: Dashboard view of the SICI results for the city of Lisbon using the real data.

Category	Lisbon
Physical Elements (C1)	0%
Reference Information (C2)	0%
Infrastructure Perception (C3)	0%
Dynamic Information (C4)	15%
Information Channels (C5)	0%
Active Traffic Management (C6)	0%

SICI colour code (%)				
100 - 80	80 - 60	60 - 40	40 - 20	20 - 0

Figure 19: Graphical SICI table summary for the city of Lisbon.

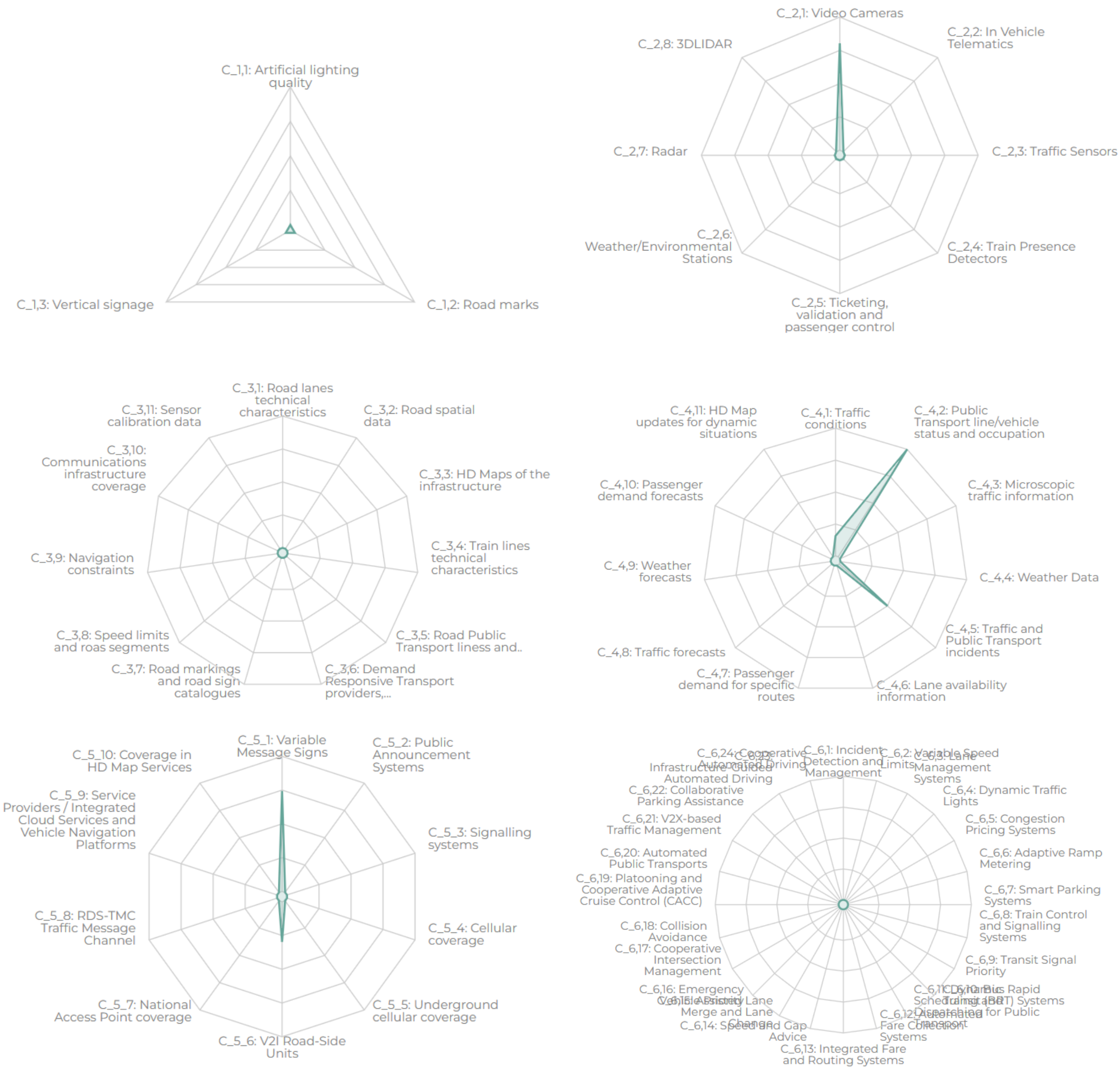

Figure 20: Radar plots for the six SICI categories for the city of Lisbon.

4.4.3.4 Side-by-side comparison

The data available is not relevant to evaluate the cities entirely because it lacks too many elements at this point. But it is still an interesting exercise to do a side-by-side comparison of the category results between the three different case study cities as follows.

The most relevant aspect of this implementation of SICI was showing how it was possible, and simple, to do the calculations necessary for a set of SICI evaluation criteria and how the proposed visualisation is intuitive and prone to direct comparison between different infrastructure elements.

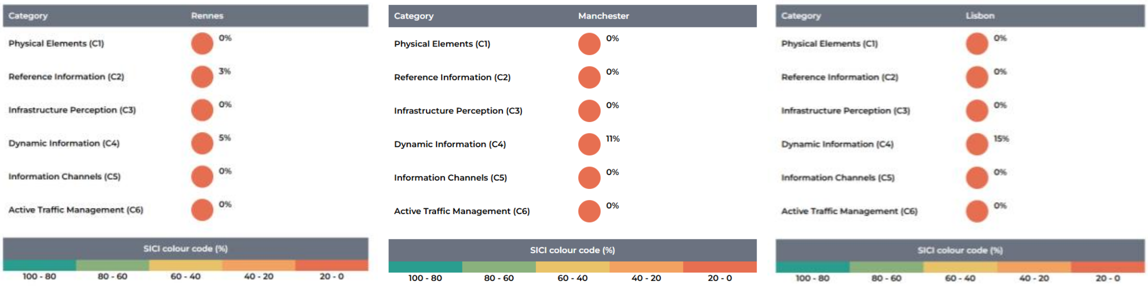

Figure 21: Graphical SICI table summary side-by-side comparison between the case studies.

While the current datasets utilized in SICI implementation, limited to reference and dynamic data from roads and public transport networks already collected by the project for operational reasons, offer significant insights, they fall short in providing a comprehensive evaluation due to the absence of several crucial elements.

The available data primarily focuses on traffic and public transport incidents, variable message signs, and V2I road-side units. However, other critical infrastructure factors, such as the physical infrastructure and active traffic management approaches adopted, are not adequately represented.

To bridge these gaps in future iterations, we propose to establish partnerships with local governments, transport authorities, and private sector stakeholders to access a broader range of data sources. We can also leverage machine learning and big data analytics to integrate disparate data sources seamlessly. This would involve the use of data fusion techniques to combine GIS data, transport models, and socio-economic datasets into a unified analytical framework. It would also be desirable to create extensive data catalogues that encompass not only traffic and public transport data but also infrastructural datasets. These catalogues should be regularly updated and maintained to ensure data accuracy and relevance. It should also be considered engaging with the community through participatory data collection initiatives, such as crowd-sourced data and citizen science projects. Vehicle-mounted camera data could be processed with AI to evaluate physical road parameters, mobile phone apps and in-car integrated apps could provide data about the existence and quality of, for instance, SICI's Category 5 Information Channels. This approach would supplement traditional data sources and provide more granular insights into local infrastructure needs and issues but is not viable for all SICI's categories.

Incorporating these strategies would significantly enhance the robustness and comprehensiveness of the SICI evaluations, enabling more informed decision-making and planning.

4.5 SICI Implementation

TANGENT implemented SICI v1.0 for the different Case Studies following the same approach and using the same data and tools already used for the other functionality provided by the TANGENT Tool. This not only simplifies the implementation but delivers SICI as a fully integrated element in the TANGENT Tool for the different users that access it.

4.5.1 Collection of parameters used by evaluation criteria

4.5.1.1 Collection from Data Catalogues

When data needed by the evaluation criteria was available from data sources already available in the TANGENT API these were used. Data aggregations and transformation were performed to calculate the new evaluated criteria data source. This data transformation was implemented using MongoDB views, which is the same process used to calculate KPIs and other calculated / aggregated values in the TANGENT Dashboard.

4.5.1.2 Collection from Transport Models

Data was not used from the Transport Models.

4.5.1.3 Collection from Geographical Information Systems

In some calculations, namely where it was necessary to account for the total number of road lengths within a geographic region, GIS APIs were used to fetch this data and persist it in TANGENT.

4.5.2 Integration in the TANGENT Framework

In TANGENT, SICI v1.0 was implemented not as a data source available in the TANGENT Dashboard but as a specialized functionality using a MongoDB view per each case study. This was necessary as we opted to have a specialized visualization using radar plots and color-coded tables that existed nowhere else in the TANGENT Dashboard.

The initial plan of adopting SICI v1.0 as native TANGENT API data sources within the TANGENT Dashboard is still possible and would allow, in the future, displaying evaluation criteria values on a map interface and filtering these values using TANGENT’s geographic region filters, for instance.

5 Comparison

In the ever-evolving landscape of intelligent transportation and infrastructure systems, the evaluation and classification of infrastructure capabilities have become paramount. This section aims to provide a comparative analysis of some of the infrastructure evaluation indexes analysed in this document, focusing on their methodologies, strengths, and shortcomings. We will delve into the evolution from ISAD to LOSAD, and subsequently to SRC, along with a detailed comparison of CRCS, SIRI, and SICI.

The following table compares these selected indexes on several different aspects:

- Index - names of the various smart infrastructure indexes that are compared.
- Creation - the year or period when each index was created.
- Author - individuals or organizations responsible for developing each index.
- Infrastructure - type of infrastructure that each index evaluates. It defines the specific focus of each index, whether it is focused on physical, digital, operational or even higher-level concerns.
- Scope - the extent or range of the infrastructure covered by each index. Either it covers only roads or highways, or if it also includes other modes of transportation and, finally, if it has a radically non-systemic city-wide approach.
- Evaluation Type - the kind of evaluation each index performs. It could include qualitative assessments, quantitative measurements, or hybrid approaches combining different evaluation methods.
- Evaluation Dimensions - the various dimensions or criteria considered in the evaluation process of each index. Typically, more of a way of organizing several criteria or KPIs within the index.
- Space Type - the type of spatial environment each index is designed to assess. The typical approach is linear and does not scale very well to city streets for e.g., but a 2D approach is better suited.
- Granularity - the level of detail or resolution at which each index operates. It can range from very detailed, fine-grained assessments to broader, city-wide evaluations.

Index	Creation	Author	Infrastructure	Scope	Evaluation Type	Evaluation Dimensions	Space type	Granularity
ISAD	2018	INFRAMIX (EU)	Digital	Road	Binary Quantitative	1	Linear	Adjustable
CRCS	2019	AASHTO (US)	Physical + Digital	Road	Qualitative	4 (Talking, Seeing, Simplifying, Time)	-	-
LOSAD	2020	HERG (EU)	Physical + Digital	Road	Quantitative	Multiple (layered)	Linear	Adjustable
SRC	2021	PIARC (EU)	Physical + Digital	Road	Quantitative	2 (Physical, Digital)	Linear	Adjustable
SICI	2023	TANGENT (EU)	Physical + Digital + Operations	Multimodal Transport	Quantitative	6 (Physical, Perception, Reference, Dynamic, Channels, Management)	2D	Adjustable by geo regions
SCRICI	2024?	FRONTIER (EU)	Physical + Digital	Road	Quantitative	3 (Physical, Digital, Connectivity)	Linear	Adjustable, typically 100 m sections
SIRI	2023	DIT4TRAM (EU)	Higher-level KPIs	Entire City	Qualitative	4 (Vision, Activation, Asset Base, Trajectory)	N/A	City-wide

Table 11: Comparison of the most relevant Smart Infrastructure Indexes covered in this document.

The journey of smart infrastructure evaluation began with the ISAD index, which laid the groundwork for subsequent methodologies. LOSAD built upon ISAD's framework by incorporating more detailed parameters and a broader scope, particularly suited for urban and peri-urban environments. The SRC index further extended this approach, providing a robust catalogue of parameters with clearly defined evaluation criteria, making it a more holistic tool for assessing infrastructure maturity.

CRCS stands out for its comprehensive, multi-dimensional perspective that addresses both physical and digital elements of infrastructure. This index recognizes the integration of technology and infrastructure at an early stage, combining a future-oriented approach with current capabilities. CRCS aligns with the strategic outlook seen in indexes like SIRI, which evaluates infrastructure from a visionary standpoint by considering potential and research aspects.

The SRICI index enhances the multi-dimensional approach of SRC and brings a powerful catalogue of parameters with very well-defined evaluation criteria. However, it lacks an operational scope with active traffic management support for instance. SRICI's detailed evaluation criteria make it a more mature and exhaustive tool compared to other indexes.

SIRI diverges from other indexes by focusing on a strategic perspective rather than measurable infrastructure capabilities. It evaluates different stakeholders' roles and their strategic actions, providing a broader view of infrastructure readiness that goes beyond physical and digital measures. This strategic approach is crucial for long-term planning and aligns with CRCS's inclusion of the time dimension.

SICI introduces several novel aspects that set it apart from other indexes:

- Operational Focus: It emphasizes active traffic management approaches, which are essential for real-time infrastructure management.
- Multi-modality: SICI includes multi-modality considerations, addressing the diverse transportation needs in urban environments.
- Geographic Perspective: The index offers a 2D, non-linear adjustable geographic perspective, enhancing its applicability to various scenarios.

Despite its innovative features, SICI has some limitations:

- Limited Multimodality: Its treatment of multimodality is still somewhat limited compared to other indexes like SIRI, which offer more extensive evaluation elements in this field.
- Evaluation Criteria: The criteria defined by SICI, while straightforward, may lack the depth and completeness found in SRICI, which presents a more mature and exhaustive set of criteria.
- Evaluation: SICI primarily assesses the existence of systems and data, whereas SRICI evaluates the quality and effectiveness of these elements in technical detail.
- Complexity for End-users: The separation of evaluation into six dimensions in SICI, while conceptually sound, may be too complex for end-users. Promoting an average score in future iterations could simplify the perception and usability of the index for various stakeholders.

The paradigm shift towards Connected, Cooperative, and Automated Mobility (CCAM) is underway, necessitating standardized procedures to evaluate the capabilities of infrastructures in supporting this transition. These standardized taxonomies and classifications can aid in infrastructure management, guide future planning, and leverage higher levels of automation. The consultation of TANGENT's Advisory Board is allowing the consortium to swiftly adapt to the urban context while avoiding pitfalls from previous indexes, ensuring a comprehensive and effective evaluation framework for smart infrastructures.

6 Conclusions

The mobility paradigm shift to CCAM is underway. To cope with the multi-stage transition it represents, it is beneficial to have standardized procedures to evaluate the capabilities of infrastructures in supporting this shift, by conveying what is available for end-users (including AVs), helping operators identify network sections that do not effectively support CCAM, and provide a tool for authorities and policymakers to plan the evolution in CCAM. In addition, when smart infrastructures are a consolidated reality, these standardized taxonomies and classifications can aid in infrastructure management, guide planning future infrastructure improvements and investments and leverage higher SAE levels of automation.

To address this challenge, a literature review on the main existing smart infrastructure classification schemes was performed, identifying six indexes: ISAD, CRCS, EAPA index, LOSAD and SRC. This allowed us to identify the most relevant infrastructure characteristics alongside understanding the shortcomings of these solutions, namely in their application to multimodal, urban and peri-urban scenarios.

This literature review was extended in this version to include also two Infrastructure Classification indexes also born within Multimodal Traffic Management (MTM) Cluster projects like TANGENT'S SICI. DIR5TRAM's SIRI and FRONTIER's SRICI were also reviewed as part of our literature review.

The consultation of TANGENT's Advisory Board allowed the consortium to swiftly adapt to the urban context while avoiding pitfalls from the previous indexes. This deliverable introduces and describes TANGENT's Smart Infrastructure Classification Index and further explores its applicability and how it was implemented within the TANGENT Tool.

The SICI v1.0 positions itself as a more holistic smart infrastructure classification index relatively to existing classifications, while trying to keep the evaluation process quantitative, simple, clear and easily reproduceable. This document presented the overall rationale of SICI and how it tries to address some of the shortcomings of existing classifications while creating an adequate classification for the multimodal scope of the TANGENT project.

This report introduces the six categories of evaluation items that makeup the SICI, contextualizing each and justifying the separation of the index in these six categories. The considered categories are: Physical Elements, Infrastructure Perception, Reference Information, Dynamic Information, Information Channels and Active Traffic Management.

The separate evaluation and scoring of these categories are fundamental to the concept behind SICI, as the different categories focus on different dimensions of maturity of a smart infrastructure, which correlate but do not cancel each other out. *E.g.*, evaluating the physical infrastructure aspects alone would be a too narrow approach but considering only connectivity or information availability aspects would also be inadequate. Additionally, this addresses the fact that different stakeholders have different views on how CCAM should evolve, allowing to evaluate the transport network from different perspectives. Through a harmonized and more comprehensive classification, SICI can better support the future alignment between different stakeholders.

The evaluation process was presented, and a detailed list of the evaluation criteria for each of the items in each SICI category is proposed. Both the process and criteria were designed in a simple way to aid in the ease of implementing SICI for a specific infrastructure / network.

In addition, this document lays out how TANGENT adopted SICI v1.0 inside the TANGENT integrated tool and how it achieved high-level category scores for each Case Study as a whole, while allowing the analysis of the more detailed scoring at different levels of detail. It also explains how only very specific SICI v1.0 evaluation criteria had data available within the TANGENT Tool and how our focus was not to achieve completeness of the index but to trial its usage.

There were several simplifications involved in our formulation of SICI that can pose as shortcoming in the future and will need to be addressed. The implementation itself imports data from sources that are not updated frequently and thus will not create an automated import process for these items. At the same time, we are aware that many items do not have evaluation information in each of the Case Studies and also we did not adopt a multi-granularity geospatial approach for SICI's implementation within the TANGENT Tool but have proposed how that could be achieved. In the future, SICI, and its implementation inside TANGENT, could be a real-time Road Quality Indicator (RQI) as proposed in [24] and provide multi-granularity visualisation from the top-city level perspective down to a very detailed geographic view in maps and geographically filtered indicators with SICI data.

SICI introduces unique features including a focus on active traffic management, multi-modality, and an adjustable geographic perspective. However, it has limitations such as limited multimodality compared to other more holistic indexes like SIRI, a less exhaustive set of evaluation criteria when compared to SRICI, and eventually some potential complexity for end-users by not providing a single final value, but instead six. Future iterations might simplify this by promoting an average score.

By including the MTM Cluster indexes, doing an overall comparison and describing SICI's implementation in TANGENT, the revised document provided a thorough and up-to-date overview of SICI's role within the TANGENT project, reinforcing its capacity to support the transition towards Connected, Cooperative, and Automated Mobility (CCAM) effectively.

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Annex I INFRAMIX's ISAD Classification details

I.1 Mapping of ISAD classification to infrastructure and operational elements

ISAD	Digital Infrastructure	Physical Infrastructure	Operational Infrastructure / Functionalities
E	-	AVs need to recognise road traffic signs; colours, position	Information about the accurate road characteristics could prevent ADAS misuse
	-	Signs with speed limits, road curvature and inclination	Accurate speed limits recognition facilitates the AV operational domain perception (and is necessary for ISA function)
	-	Lane markings complied to regulations and standards on both sides	Safety-related automated functionalities need proper lane condition and recognition (supporting accurate localisation, *e.g.*, automated lane positioning, automated lane change)
	-	Lane width based on standards	Change on lane width could pose safety-related challenges even in conventional traffic
	-	Working zone signalization	Working zone signalisation could prevent the misuse of automated functions in the specific road segment, and the human driver could timely take over
	-	Partial CCTV Coverage for real-time vehicle detection	Traffic detection through camera could reduce the concerns related to the safety of mixed traffic flows in the near future
D	Digital map with static road signs	VMS Gantries	Handling information related to: Roadwork Warnings, Incidents, weather
	-		**+ Level E functionalities**
C	HD maps (including accurate position of signs, dynamic update of lane topology)		Automated data processing
	Advanced TMC/iTMC software		Prioritisation, Class upgrade / downgrade only to specific vehicle types (of different SAE Level, different size etc.) Vehicle technical problem

			identification and vehicle/ driver warning, I2V truck parking advice, road condition (road friction, potholes) information (not always in real-time) (optional) Speech and screen V2I interaction (Provided mainly by OEM and third parties)
	Data fusion from on-board sensors, other vehicles and RSUs	Advanced Infrastructure V2X communication	Dense location referencing points Automated vehicle localization
			Provision of timely dynamic information (*e.g.*, roadworks warnings, weather conditions, traffic information) requires an automatic update of the traffic signs (not always in real time)
			+ Level D functionalities
B	Advanced TMC/iTMC software		Microscopic traffic situation Vehicles' recognition of traffic signs through TMC – Third Party Services I2V Highway Merge Assistance I2V truck parking advice, road condition (road friction, potholes) information Pay-as-You Go Toll service Guidance: Travel route recommendations and in some cases speed, gap advice based on driving style monitoring
B	HD maps (cloud based digital maps incl. the accurate position of signs, dynamic update of lane topology, location of emergency stop zones, etc.)		Data exchange with cloud services
B	Weather (High precision meteorological stations, in-pavement sensors to detect moisture, temperature, strain)		Info about weather conditions relevant to road status (*e.g.*, slippery road, strong side wind, heavy rain, snow, reduced visibility) could support the automated vehicle in perceiving its operational domain, thus preventing incidents of automated functions misuse. Infrastructure state of repair assessment
B			**+ Level C functionalities**

A	Advanced TMC/iTMC software	Elements to ensure continuous connectivity (enabling V2X) along the segment (*e.g.*, RSUs)	Dynamic Guidance: speed, gap, lane advice based also on driving style monitoring (unicast communication to individual vehicles)
		Sensors for trajectories of the vehicles	I2V traffic regulation compliance and I2V warnings for the existence of aggressive, dangerous drivers
			Detailed weather info
			+ Level B functionalities

Table 12: ISAD Classification mapped to PDI and operational elements

Annex II PIARC's "Smart Roads Classification" details

II.1 Detailed road characterization Factors proposed by PIARC[44]

II.1.1 Physical and Digital Infrastructure Factors for LOSAD classification

						LOSAD LEVELS				
Layer	Factor	Type	Domain	Parameter	Description	A	B	C	D	E
Physical Infrastr.	ORS	Static	Road Segment	Number	Number of ORS that should be within a road segment	1	1	<=2 (TBD)	<=5 (TBD)	
			Road Segment	% of total length	Percentage of the total length of the road segment that should correspond to an ORS	100%	100%	75% (TBD)	75% (TBD)	
Digital Infrastructure	ORS	Static	Road Section	Maximum disengagement density & 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	0 (TBD)	5 (TBD)			
	Weather	Dynamic	Road Segment	Visibility (MOR)	Visibility ranges from weather stations	1000 m	1000 m	500 m	200 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	Light Snow	Light Snow	Moderate Snow	Heavy Snow	

[44] According to PIARC, most factors thresholds require further research, nevertheless some concretization values are proposed. Most urgent thresholds to the researched are circumvented in **Purple** since their effect on AD can be quite impactful.

		Dynamic	Road Section	Rainfall intensity	Rainfall may limit visibility	Light rain (<2.5 mm/h)	Moderate rain (<7.5 mm/h)	Heavy rain (<50 mm/h)	Violent rain (<100 mm/h)	

Table 13: Characterization of the infrastructure factors related to LOSAD levels, as proposed by PIARC [15]

II.1.2 Digital Infrastructure and Connectivity Factors for ISAD classification

Layer	Factor	Type	Domain	Parameter	Description	A	B	C	D	E
Digital Infrastructure	Mapping and digital information availability	Static	Road Segment	Digital map	Availability of a digital map with static road signs, junctions, etc.	HD map. MRC zones included	HD map. MRC zones are included	HD map	Standard map	
		Static	Road Segment	Digital map update frequency	How frequent are maps updated?	Real-time	Real-time	Automatic, not necessarily real-time	Manually	
		Static	Road Segment	Road traffic and events ahead	Availability of DIGITAL information related to road traffic and events ahead	YES	YES	YES		
		Static	Road Segment	Weather conditions	Availability of DIGITAL information related to weather conditions	High precision data with forecasting possibilities	High precision data with forecasting possibilities	YES		
		Static	Road Section	Variable speed limit	Availability of DIGITAL information related to Variable Speed Limit	Tailored Speed Advice is transmitted to vehicles	Variable Speed Limits are transmitted to vehicles	Variable Speed Limits are transmitted to vehicles		
		Static	Road Section	Traffic lights	Availability of DIGITAL information related to traffic lights	YES	YES	YES		
		Static	Road Section	Traffic performance information	Availability of traffic data for management, indications, and other purposes	Microscopic, obtained by the road infrastructure	Microscopic, obtained from vehicle data	Macroscopic		
		Static	Subject Vehicle	Microscopic dynamic driving guidance	Can the Digital Infrastructure provide tailored instructions in a vehicle-basis? (i.e., cooperative driving)	YES	Speed and lane advice might be sometimes provided			
	Road equipment	Static	Road Segment	Presence of RSUs	Are there RSUs?	Yes, ensuring V2I and I2V	YES, ensuring I2V			
		Static	Road segment	Sensors for trajectories of vehicles and users	Specific road sensors to detect the trajectories of vehicles/users	YES	**IOO:** YES/NO			
		Static	Road segment	Automatic road data processing	Can infrastructure automatically process multiple sensors information (e.g., in-pavement sensors, cameras, ramp metering)	YES	YES	YES		
		Dynamic	Road Segment	Positioning accuracy	Vehicle position accuracy? (RTK land stations or reference points)	Highest accuracy	Highest accuracy	Very accurate	Accurate	
Connectivity	DSRC/ITS-G5	Static	Road section	Availability	Short range communication	YES	YES	**IOO:** YES/NO		
	C-V2X (5G)	Static	Road segment	Availability	C-V2X communication	YES	Y	**IOO:** YES/NO		
	DSRC	Dynamic	Road segment	Range (m)	This range is related to RSUs density	700	1700	2000		
	Reliability	Dynamic	Road segment	% Packets received in due time	This is related to signal strength fluctuations	100.0%	99.9%	99%		
	AV Throughput	Dynamic	Road segment	Average data rate (Mbps)		30	6	3		
	Latency	Dynamic	Road segment	Time required to reach destination (ms)?	This is a measure of delay	5	40	100		
	Signal strength	Dynamic	Road segment	Reference Signal Received Power (dBm)	The average power received from a single Reference signal	-67	-82	-85		

Table 14: Characterization of the infrastructure factors related to ISAD levels, as proposed by PIARC [**¡Error! No se encuentra el origen de la referencia.**]

II.1.3 PDI, Connectivity and User Factors for SRC detailed classification

Layer	Factor	Type	Domain	Parameter	AUTOMATEDWAY (AU)	FULL AUTOMATEDWAY (FA)	AUTOMATED WAY (AT)	ASSISTEDWAY (AS)	HUMANWAY (HA)
Layer: CONNECTIVITY	DSRC/ ITS-G5	Static	Section	Availability	**IOO:** Yes	**IOO:** No/Yes	**IOO:** No/Yes		
	C-V2X (5G)	Static	Segment	Availability	**IOO:** Yes	**IOO:** No/Yes	**IOO:** No/Yes		
	DSRC	Dynamic	Segment	Range (m)	**IOO:** 700	**IOO:** 2000	**IOO:** 2000		
	Reliability	Dynamic	Segment	% Packets received in due time	**IOO:** 100.0%	**IOO:** 99%	**IOO:** 99%		
	AV Throughput	Dynamic	Segment	Average data rate (Mbps)	**IOO:** 30	**IOO:** 3	**IOO:** 3		
	Latency	Dynamic	Segment	Time required to reach destination (ms)?	**IOO:** 5	**IOO:** 100	**IOO:** 100		
	Signal strength	Dynamic	Segment	Reference Signal Received Power (RSRP) (dBm)	**IOO:** -67	**IOO:** -85	**IOO:** -85		
Layer: USERS	**Factor**	**Type**	**Domain**	**Parameter**	**AUTOMATEDWAY (AU)**	**FULL AUTOMATEDWAY (FA)**	**AUTOMATED WAY (AT)**	**ASSISTEDWAY (AS)**	**HUMANWAY (HA)**
	-	Static	Segment	Presence of passenger cars (y/n)	**IOO:** YES, only CAVs	**IOO:** YES	**IOO:** YES	**IOO:** YES	**IOO:** YES
	-	Static	Segment	Presence of heavy vehicles (y/n)	**IOO:** YES, only CAVs	**IOO:** YES	**IOO:** YES	**IOO:** YES	**IOO:** YES

		Static	Segment	Presence of motorcycles (mopeds included) (y/n)	**IOO:** NO	**IOO:** YES	**IOO:** YES	**IOO:** YES	**IOO:** YES
		Static	Segment	Presence of bicycles (y/n)	**IOO:** NO	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend other classifications
		Static	Segment	Presence of Light Mobility Vehicle (LMV) (y/n)	**IOO:** NO	**IOO:** NO	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend other classifications
		Static	Segment	Presence of pedestrians (y/n)	**IOO:** NO	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend on other classifications	**IOO:** Possible, depend other classifications

	Factor	Type	Domain	Parameter	AUTOMATEDWAY (AU)	FULL AUTOMATEDWAY (FA)	AUTOMATED WAY (AT)	ASSISTEDWAY (AS)	HUMANWAY (HA)
Layer: DIGITAL INFRASTRUCTURE	Mapping and digital information availability	Static	Segment	Digital map	**IOO:** HD map. Minimum Risk Conditions (MRC) zones are included	**IOO:** HD map	**IOO:** HD map	**IOO:** Standard map (recommended)	**IOO:** Standard map (recommended)
		Static	Segment	Digital map update frequency	**IOO:** Real-time	**IOO:** Automatic, not necessarily real-time	**IOO:** Automatic, not necessarily real-time	**IOO:** Manually	**IOO:** Manually
		Static	Segment	Road traffic and events ahead	**IOO:** YES	**IOO:** YES	**IOO:** YES		
		Static	Segment	Weather conditions	**IOO:** High precision data with forecasting possibilities	**IOO:** YES	**IOO:** YES		
		Static	Section	Variable speed limit	**IOO:** Tailored Speed Advice is transmitted to vehicles	**IOO:** Variable speed limits transmitted to vehicles	**IOO:** Variable speed limits transmitted to vehicles		
		Static	Section	Traffic lights	**IOO:** YES	**IOO:** YES	**IOO:** YES		

		Static	Section	Traffic performance information	**IOO:** Microscopic, obtained by road infrastructure	**IOO:** Macroscopic	**IOO:** Macroscopic		
		Static	Subject Vehicle	Microscopic dynamic driving guidance	**IOO:** YES	**IOO:** Speed and lane advice might be sometimes provided	**IOO:** Speed and lane advice might be sometimes provided		
		Static	Segment	Road Works	**IOO:** Road works should be included in the HD maps	**IOO:** Road works should be included in the HD maps	**IOO:** Road works should be included in the HD maps		
	Road equipment	Static	Segment	Presence of Roadside Units (RSUs)	**IOO:** Yes, ensuring V2I and I2V	**IOO:** RSUs are recommended, ensuring I2V	**IOO:** RSUs are recommended, ensuring I2V		
		Static	Segment	Sensors for trajectories of vehicles and users	**IOO:** YES				
		Static	Segment	Automatic road data processing	**IOO:** YES	**IOO:** YES	**IOO:** YES		
		Dynamic	Segment	Positioning accuracy	**IOO:** Highest Accuracy	**IOO:** Very Accurate	**IOO:** Very Accurate	**IOO:** Accurate	
	Disengagements	Dynamic	Section	Maximum disengagement density & frequency rate	IOO: 0 (TBD)	IOO: 5 (TBD)			
	Weather	Static	Segment	Weather Stations (WS)	**IOO:** Information from WS is present (high representativity, constantly updated)	**IOO:** Information from WS is present (high representativity, constantly updated)	**IOO:** Information from WS is present (low representability, hourly update)	**IOO:** Information from WS may be present	
		Dynamic	Segment	Visibility (MOR)	**IOO:** 1000 m	**IOO:** 1000 m	**IOO:** 500 m	**IOO:** 200 m	

		Dynamic	Segment	Snow/icy pavement	**IOO:** Light snow	**IOO:** Light snow	**IOO:** Moderate snow	**IOO:** Heavy snow	
		Dynamic	Section	Rainfall intensity (mm/h)	**IOO:** Moderate rain (<7.5)	**IOO:** Moderate rain (<7.5)	**IOO:** Heavy rain (<50)	**IOO:** Violent rain (<100)	
	Sensing and information systems	Static	Segment	Sensing system	**IOO:** YES	**IOO:** YES	**IOO:** NO/YES	**IOO:** No/Yes	
		Static	Segment	Availability of Stationary Object Detection System (radar-based side units)	**IOO:** YES				
		Static	Segment	Information system	**IOO:** YES	**IOO:** NO/YES	**IOO:** NO/YES	**IOO:** N0	
		Static	Segment	Intelligent Speed Adaptation (ISA)	**Veh:** Dynamic Closed	**Veh:** Dynamic Closed	**Veh:** Closed	**Veh:** Open	**Veh:** NA / Open

	Factor	Domain	Parameter	AUTOMATEDWAY (AU)	FULL AUTOMATEDWAY (FA)	AUTOMATED WAY (AT)	ASSISTEDWAY (AS)	HUMANWAY (HA)
Layer: PHYSICAL INFRASTRUCTURE[45]	Roadway type	Segment	Type	**IOO:** Freeways	**IOO:** Freeways and high-end two-lane rural roads			
		Segment	Dedicated lane	**IOO:** Optional	**IOO:** Optional	**IOO:** NO	**IOO:** NO	**IOO:** NO
	Geometric design	Segment - Horizontal curves	Minimum Radius	**IOO:** >=500 m	**IOO:** >=400 m	**IOO:** >=300 m	**IOO:** >=250 m	
		Segment - Crest vertical curves	Minimum K	**IOO:** >=30 (m/%)	**IOO:** >=25 (m/%)	**IOO:** >=15 (m/%)	**IOO:** >=10 (m/%)	
		Segment	Lane width	**IOO:** 3.5–3.6 m	**IOO:** 3.25–3.8 m	**IOO:** 3.0–4.0 m	**IOO:** 3.0–4.0 m	
		Segment	Shoulder width	**IOO:** >=2.5 m	**IOO:** >=2.5 m	**IOO:** >=2.5 m		

[45] All static factors

		Section	Available Stopping Sight Distance (ASSD) (m)	**IOO:** ASSD	**IOO:** ASSD	**IOO:** ASSD		
	Speed (km/h)	Segment/ Section	Speed limit: Static; Dynamic	**IOO:** Dynamic	**IOO:** Dynamic	**IOO:** Most static. Dynamic at critical locations		
		Section	Minimum operating speed	**Veh:** Different options	**Veh:** Different options	**Veh:** Different options	**Veh:** Different options	
		Section	Automated speed	**Veh:** Different options	**Veh:** Different options	**Veh:** Different options	**Veh:** Different options	
	Road markings	Segment	Line width	**IOO:** 150 mm	**IOO:** 150 mm	**IOO:** 150 mm	**IOO:** 150 mm	
		Segment	Contrast	**IOO:** 1:3	**IOO:** 1:3	**IOO:** 1.3	**IOO:** 1.3	
		Segment	Retroreflectivity	**IOO:** 150 mcd/m^2/lx	**IOO:** 150 mcd/m^2/lx	**IOO:** 150 mcd/m^2/lx	**IOO:** 150 mcd/m^2/lx	
		Section	Edge lines continuity	**IOO:** ALWAYS	**IOO:** ALWAYS	**IOO:** YES. Including entrance/exit ramps	**IOO:** YES. Except on entrance/exit ramps	
		Section	Prevention of sun glaring	**IOO:** If dedicated tunnel lights exit to mitigate sun glaring. **Veh:** ADSs should have features to adapt to low-contrast and sun-glared circumstances (*e.g.*, W-E road orientations).	**IOO:** If dedicated tunnel lights exit to mitigate sun glaring. **Veh:** ADSs should have features to adapt to low-contrast and sun-glared circumstances (*e.g.*, W-E road orientations).	**IOO:** If dedicated tunnel lights exit to mitigate sun glaring. **Veh:** ADSs should have features to adapt to low-contrast and sun-glared circumstances (*e.g.*, W-E road orientations).		
	Signs	Segment	Contrast	**IOO:** YES	**IOO:** YES	**IOO:** YES		
		Segment	Retroreflectivity	**IOO:** YES	**IOO:** YES	**IOO:** YES		

		Section	Contextual information	**Veh:** YES	**Veh:** YES	**Veh:** YES		
		Segment	Readability of the VMS	No restrictions (all vehicles and all information would be digital)	**IOO:** High visibility / readability standards	**IOO:** Some restrictions apply		
	Pavement	Section	International Roughness Index (IRI) (m/km)	**IOO:** <=TBD (comfort)	**IOO:** <=TBD			
		Section	Longitudinal crack sealing	**IOO:** NO	**IOO:** NO			
		Section	Hidden road markings	**IOO:** NO	**IOO:** NO			
	Road works	Segment	Compliance of geometry, markings, signs and pavement factors	**IOO:** If road works take place within an ORS, signage and geometry should meet ORS criteria	**IOO:** If road works take place within an ORS, signage and geometry should meet ORS criteria	**IOO:** If road works take place within an ORS, signage and geometry should meet ORS criteria		

Table 15: Characterization of the factors for the SRC levels related Connectivity, Users, Physical and Digital Infrastructure, as proposed by PIARC [15**¡Error! No se encuentra el origen de la referencia.**][46]

[46] The table distinguishes between aspects that should be provided by IOOs (IOO) and requirements that every vehicle (Veh) within the road segment should meet - if automation is activated.

II.2 SCR interactions with other classification dimensions

II.2.1 SCR interaction with different Road Users

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																	

Labels

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 the advantages of the road

2: The road user cannot benefit from all the 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 16: Interactions of the different Road Users with the SRC levels, as proposed by PIARC [15**¡Error! No se encuentra el origen de la referencia.**]

II.2.2 SRC Interaction with SAE Automation Levels

		Humanway (HU)	Assistedway (AS)	Automatedway (AT)	Full Automatedway (FA)	Autonomousway (AU)
SAE levels	**1**					
	2 [with Adaptative Cruise Control (ACC) + Lane Keeping Assist (LKA)]					
	3 [without Minimum Risk Condition (MRC)]					
	3 [with MRC]					
	4 [MRC included]					
	5 [MRC included]					

Labels

- 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 17: Interactions of SRC levels and SAE levels, as proposed by PIARC [15]

II.2.3 SRC Road facilities KPIs

Key Performance Indicators	
Automation	Average distance driven (km or mi.) without disengagement per road segments of each smart road level, for the entire road network
	Average distance driven (km or mi.) without disengagement per road segments of each smart road level, for the entire motorway/freeway/expressway network
Safety	Average Crash Rate involving CAVs for the entire road network
	Ratio of average CAVs Crash Rate to all Vehicles Crash Rate, for the entire road network
Operation	Average TTI (Travel Time Index) of each smart road level for the entire motorway/freeway/expressway network
Smart road level	Percentage of each smart road level for the entire road network
	Percentage of each smart road level for the entire motorway/freeway/expressway network
	Percentage of each ISAD level for the entire road network
	Percentage of each ISAD level for the entire motorway/freeway/expressway network
	Percentage of each LOSAD level for the entire road network
	Percentage of each LOSAD level for the entire motorway/freeway/expressway network

Table 18: KPIs for Road facilities, as proposed by PIARC [15]