Classification of Readiness of European Highways for Adopting Connected, Automated and Electric Vehicles

EAPA Discussion document

First Edition November 2020

Published by the European Asphalt Pavement Association
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The present document may be cited as:
European Asphalt Pavement Association (EAPA). Classification of Readiness of European Highways for Adopting Connected, Automated and Electric Vehicles. A discussion Document (2020) 19 pages.
https://eapa.org/eapa-position-papers/

Abstract

Automated and electric vehicles are seen nowadays as the greatest tools of humanity to meet European objectives of Zero Deaths on European roads and Carbon Neutrality by 2050. However, in order to enable these new road users to drive across the European road network, certain upgrades are necessary. In this document, the European Asphalt Pavement Association (EAPA) proposes a classification of roads (or stretches of these), which can give, in a simple way, information to the driver and/or vehicle about the available technologies supporting the automated and electrified driving. At the same time, the key parameters necessary to grant the road/stretch with a given class, are given. Hence, Road Authorities can refer to the proposed classification to determine the necessary actions to be implemented in order to make possible the circulation of vehicles under a desired level of automation and electrification.

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1. Introduction

Over the last decades, the EU road network has become the safest in the world. Nevertheless, the number of deaths and injuries is still far too high [1]. In order to eliminate these, the EU has adopted new approaches, such as Vision Zero and Safe System.

Research showed that human error causes over 90% of accidents [2]. As autonomous vehicles remove the need of a driver, they could significantly improve road safety. Among other characteristics, automated vehicles respect traffic rules better than humans and react quicker. These vehicles can impulse the car-sharing, helping to reduce congestion, making car ownership in cities less attractive and fostering new and improved business models (i.e. mobility as a service) [3].

The EU has already adopted strategies on cooperative intelligent transport systems [4], as well as on future 5G communications technology [5] and data protection rules. Unlike other parts of the world, much of the necessary legal framework is already in place in the EU, serving as a benchmark for international harmonisation with international partners in the United Nations Economic Commission for Europe.

In addition, reducing CO_2 emissions is another priority of the EU and a global challenge that affects us all. In this sense, according to the European Automobile Manufacturers Association (ACEA) [6], self-driving vehicles will help not only to save costs and make roads safer, but also to lower emissions. The transport sector must be firmly embedded in an economy-wide carbon-reduction framework, while also working to maximise CO_2 reductions through an integrated approach linking technology, energy, government and consumers.

Existing forecasts show that transport demand will increase in line with trade growth and GDP. Hence, in order to meet this demand in a sustainable way, all transport modes will need to increase their efficiency. A technology-neutral policy, which gives no preference to any mode of transport or technology, can enhance competitiveness and reinforce the potential for the overall technological progress.

According to ACEA [6], e-mobility will also need significant simultaneous investments by a variety of players to ensure that barriers to market acceptance are tackled and to realise electro-mobility's potential. Hence, an integrated approach is necessary, addressing all the ways for reducing CO_2 with all the relevant stakeholders, not just vehicle technology.

For these reasons, the roads of the future need to be adapted to all these changes in mobility. As such transition will take a series of years, roads with systems enabling self-driving and electric charge of vehicles will coexist with all those conventional roads not adapted yet. With this purpose, the European Asphalt Pavement Association has started working in identifying the improvements that European infrastructures need to adequately support autonomous and electric traffic and develop a new classification, which allows users to easily know the level of automation and electrification they can access in every moment.

2. Driving automation

2.1 Automation levels

A classification system based on six different levels (ranging from fully manual to fully automated systems) was published in 2014 by SAE International, an automotive standardization body, as J3016, Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems [7, 8]. This classification system is not focused on the vehicle capabilities, but on the required amount of driver attentiveness and intervention. Although other classifications were released, such as the one published in 2013 by the National Highway Traffic Safety Administration (NHTSA) in the United States [9] the SAE standard is the one mostly used globally nowadays. In 2016, SAE updated its classification, called J3016_201609 [10].

In SAE's system, the term "driving mode" refers to "a type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.)" [11]. The stablished levels are (see also summary Table A1 in Annex 1):

- Level 0: Automated system may momentarily intervene but has no sustained vehicle control. Warnings are also issued.
- Level 1 ("hands on"): The control of the vehicle is shared by both driver and the automated system. Examples are Adaptive Cruise Control (ACC), where the driver controls steering and the automated system controls speed; and Parking

Assistance, where steering is automated while speed is under manual control. The system may require in any moment that the driver retakes full control.

- Level 2 ("hands off"): The system can take full control of the vehicle for actions, such as accelerating, braking and steering. However, the driver must constantly monitor the driving and be ready for immediate intervention. In order to ensure this, contact between hand and wheel is often mandatory during SAE 2 driving, to confirm that the driver is able to take control anytime.
- Level 3 ("eyes off"): Although in this case, driver's attention is not necessary, the driver must still be prepared to intervene within some limited time, when the vehicle indicates so. Some commercial models already implement this technology, which can handle situations, such as slow-moving traffic (up to 60 km/h) in highways with separated traffic streams.
- Level 4 ("mind off"): The vehicle is able to handle the majority of situations, and when this is not possible, the vehicle is able to safely park until the driver retakes control. Hence, the vehicle will never request immediate human intervention and consequence, the attention of the driver is not necessary, being even able to sleep while circulating.
- Level 5 ("steering wheel optional"): No human intervention is required at all. These vehicles can circulate even without humans inside the vehicle.

Different factors must be overcome to achieve the highest automation levels [12]. These include low-angle sunlight that can be challenging for cameras reading traffic lights, or meteorological phenomena, such as snow or fog that can unable laser sensors. Moreover, current artificial intelligence systems are not fully able to interpret certain aspects of human behaviour, such common gestures to give way.

2.2. Vehicle - infrastructure interaction

It is believed that developing vehicles with automation levels higher than SAE 3 is not efficient without the parallel development of the infrastructure. In this sense, the road can guide and support these vehicles by providing real-time information of what they will find ahead. Different initiatives are being explored around the world, arising questions about the requisites that a road should have in order to actually assist an autonomous vehicle. Hence, the first step is to classify the infrastructure in this regard, being necessary for that, a common understanding between the sectors developing vehicles and roads.

Nowadays, some road infrastructure operators use environmental and traffic sensors providing information that can be processed by automated vehicles, helping them to increase their limited environmental perception. The European Road Transport Research Advisory Council (ERTRAC), by following

Table 1. Definition of Infrastructure Support levels for Automated Driving (ISAD) [13]

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

the outcomes of the EU research project INFRAMIX (www.inframix.eu), established a road classification, similar to SAE levels, based on the level of support they provide to automated vehicles [13]. Table 1 shows the description of these five levels, called Infrastructure Support levels for Automated Driving (ISAD).

It is also important to highlight that certain roads, such as motorways, could be classified as a whole, being enough the signalling of the ISAD level only at the entrance. However, for most of the roads, ISAD level can change along different stretches, letting the vehicle know in every moment, the systems that are or not available, so it can adjust the SAE driving level according to the circumstances (example in Figure 1).

3. Electrification

Electric Road Systems (ERS) is widely understood as a system that enables dynamic power transfer between the infrastructure and the vehicles, while these travel along [14]. Different technologies are being developed around the world, the vast majority of them belonging to one of the following groups:

1. Inductive (wireless)
2. Conductive (catenary/overhead)
3. Conductive (in-road rail)

These technologies are normally designed with the aim of either charging electric batteries or directly power the propulsion systems of the vehicles while these are circulating (dynamic systems). Nevertheless, they can also be used as static systems, acting complementary when the vehicles are parked. Static systems also include cable connections, which at the moment is the most spread and mature method around the world.

4. Inductive systems: by installing induction coils embedded into the pavement, vehicles can obtain electric energy when they pass or park above. The main advantage is that the energy transfer is done by the physical principle of electromagnetic induction, so no contact elements are necessary. The infrastructure is composed by (1) in-road components (primary coils, typically copper litz turnings with a ferrite core, and power cables laid beneath the road surface); and (2) roadside components include grid connections, power inverters, transformers, cooling units and communication systems. In these systems, power from the roadside is only supplied to the coils when a compliant vehicle is detected approaching the area at a certain speed.

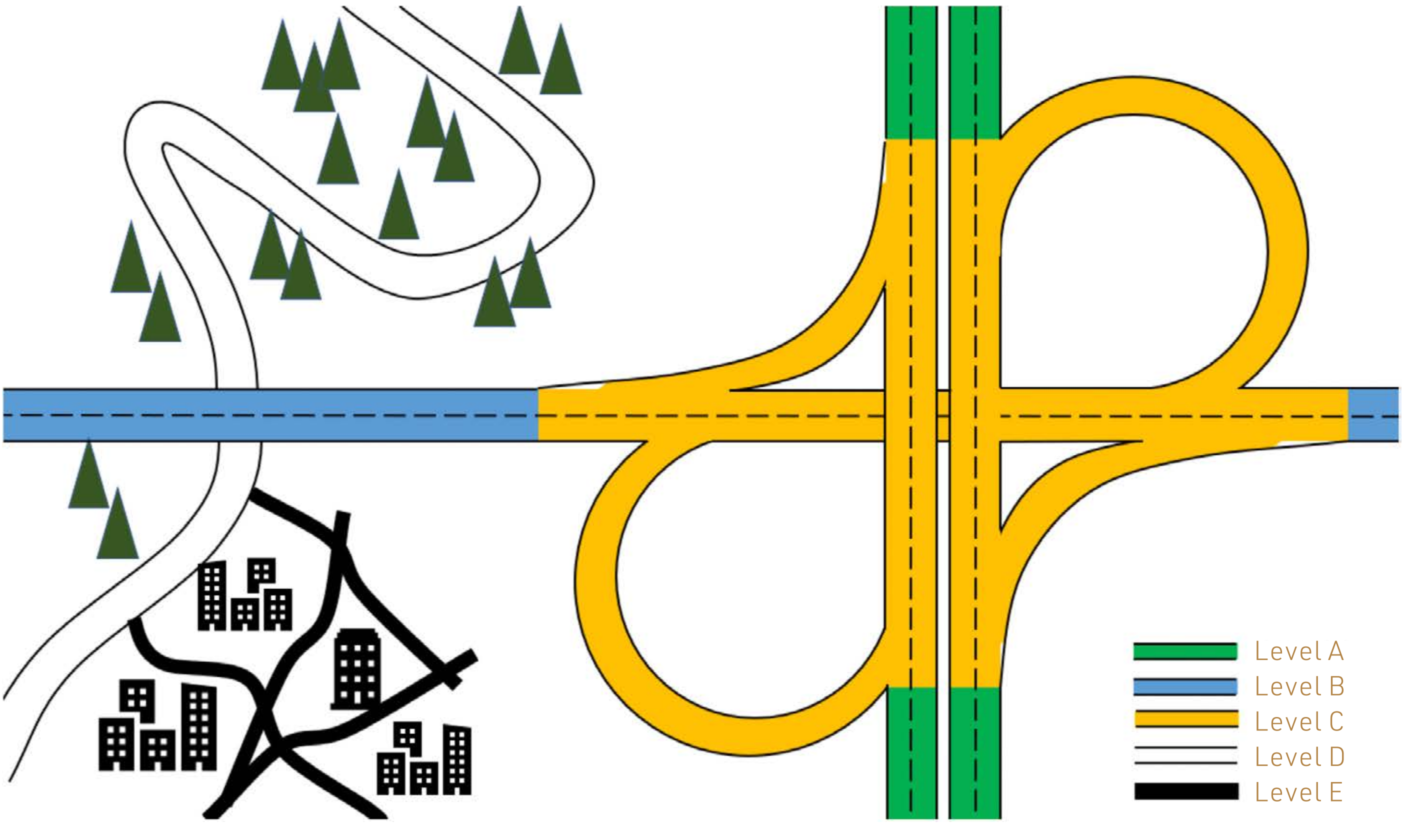

Figure 1. Example of Infrastructure Support levels for Automated Driving (ISAD)

5. Conductive catenary overhead: In these systems, vehicles draw down the energy by making contact with a conductive catenary placed above the lane. For this, vehicles need to be equipped with a pantograph (or similar device). Roadside equipment includes: continuous masts supporting tensioned power cables, and substations equipped with switchgear, power transformers, rectifiers, controlled inverters, and communication systems. These systems are being used for static applications in some bus stops of European cities, such as Brussels, and for dynamic applications, such as the so-called eHighway built in the German state of Hesse.

6. Conductive in-road rail: In this case, vehicles obtain energy through a direct contact between mechanical arms installed on-board and segmented electrified rails, which can be either embedded into the road surface or simply on top of this. The infrastructure consists on in-road equipment (i.e. rail, power cables, and drainage systems) and roadside (i.e. transformers, grid connections, and communications). Like in the case of induction systems, energy is only supplied to the segmented rails when a compliant vehicle is detected in the surroundings.

According to the World Road Association, the greatest challenges to underpin these technologies are the installation and maintenance cost and the unclear impact that the installation can do on the pavement. In a lesser extent, there are other unsolved challenges, such as the regulatory and business model, the user acceptance and public opinion, the technical feasibility, the increased electricity demand, safety and security and ownership and political influence.

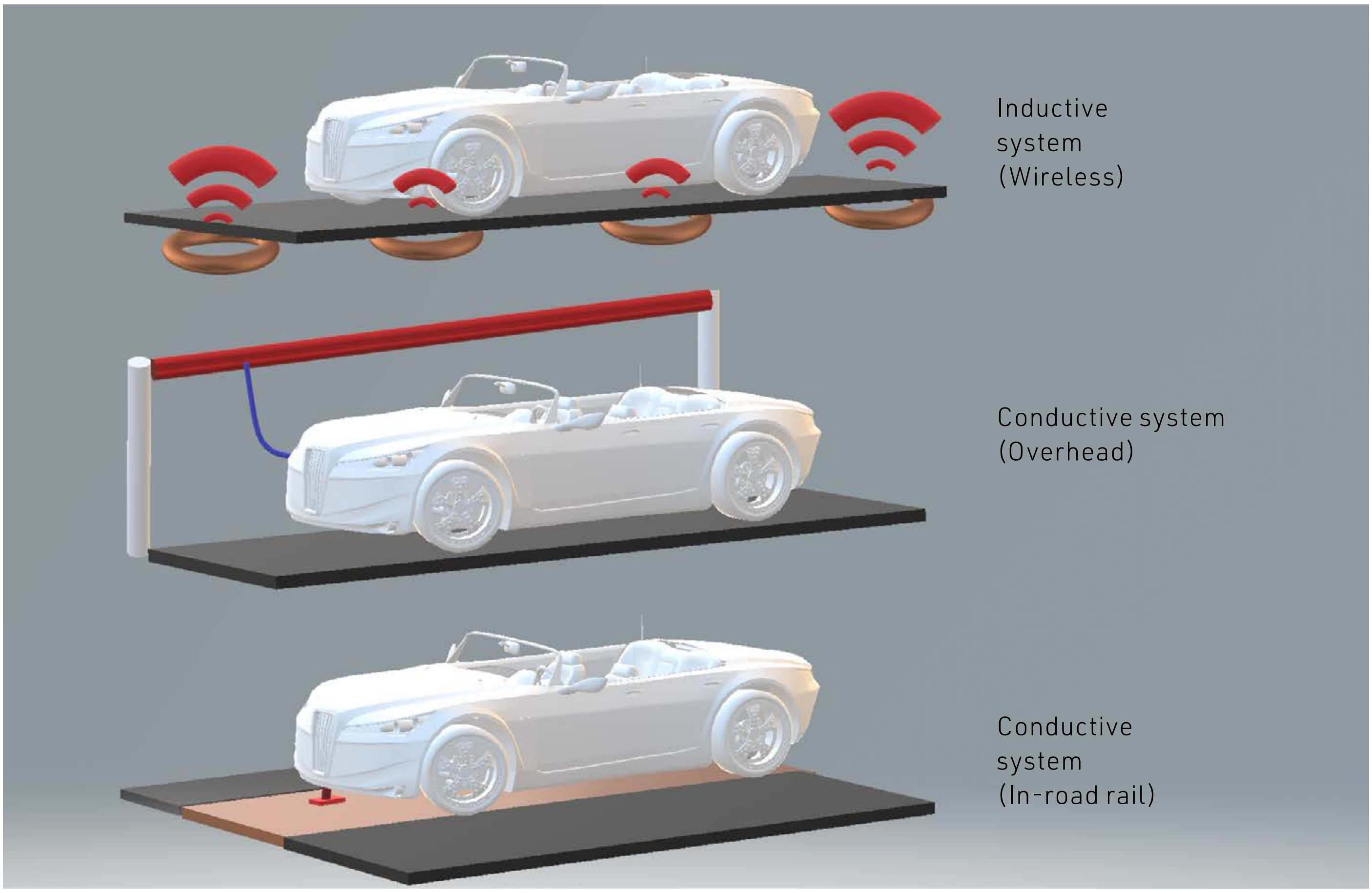

Figure 2. Classification of Electric Road Systems (ERS)

4. EAPA proposal for European classification of roads

Based on previous considerations, EAPA proposes the road classification described in Tables 2 and 3, depending on the level of support these provide for automated and electric vehicles respectively.

The Tables also show the key parameters necessary to classify a road/stretch under a given class, or what is the same, to allow driving under certain levels of automation and electrification. Hence, Road Authorities can refer to the classification to determine the necessary actions to be implemented in order to make possible the circulation of vehicles under a desired level of automation and electrification.

It must be noticed that such classification can be also dynamic, and consequently change, for instance, in case of adverse weather conditions or when certain enabling technologies are temporally out of service.

With this system, the road/stretch is classified with a letter, which gives the vehicle and the driver, information about the level of support for the automated driving, being A the top class, which allows SAE 5 under safe conditions, and F the worst, where no automation can be safely carried out. Next to the letter, a number of stars, from 0 to 3, indicates the technologies available to charge electric vehicles either statically or dynamically.

As an example, a driver accessing a road with the sign B** knows that, along this, the vehicle is effectively communicating with the infrastructure. Consequently, the car can circulate even under low-visibility conditions, and all dangerous sections (including those were the pavement in bad condition, where traffic disruptions or maintenance operation are happening, etc.) are foreseen and avoided. In addition, in case that the autonomous system cannot tackle any of these situations, the vehicle can park, out of the lane, until the driver retakes control.

Therefore, the autonomous systems of the car can be fully activated and under safe conditions. Nevertheless, the user also knows that the charging process of the electric batteries of the vehicle will only be possible, while parked in allocated areas.

Table 2. EAPA classification of roads according to the level of readiness for adopting connected and automated vehicles

Class	Description	Key parameters
F	ISAD Level E – SAE Level 0. Deficient pavement, no markings.	◦ Optical visibility not clear in at least 100m ◦ Deficient or non-existing markings, signs and traffic lights ◦ State of pavement: INADEQUATE ◦ Reference parameters can be: • IRI • Rutting • Macrotexture • Crack percentage
E	ISAD Level E – SAE Level 1. Pavement in acceptable conditions. Physical markings and signs visible and in good conditions but 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 50m ◦ Existence of markings, signs and traffic lights in good condition and clearly visible ◦ State of pavement: ADEQUATE ◦ Reference parameters can be: • IRI • Rutting • Macrotexture • Crack percentage
D	ISAD Level D – SAE Level 2. Pavement in good conditions. 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.	◦ Optical visibility clear in 100m ◦ Existence of markings, signs and traffic lights in good condition and clearly visible ◦ Digital information about road geometry and static signs available ◦ State of pavement: SATISFACTORY ◦ Reference parameters can be: • IRI • Rutting • Macrotexture • Crack percentage
C	ISAD Level C – SAE Level 3. Digital map data available. Radio transmitters and sensors replacing traffic lights, signs and markings, higher-capacity mobile and wireless data networks handling both vehicle-to-vehicle and vehicle-to-infrastructure communication. Common protocols and communications standards will have to be devised and negotiated, as they were with internet communication protocols or the Global System for Mobile Communications (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. Pavement condition is excellent. Emergency parking lanes to ensure the vehicle can stop when safety is not ensured.	◦ All static and dynamic infrastructure information available in digital form ◦ Assisted visibility systems (radio transmitters, sensors…) ◦ State of pavement: EXCELLENT ◦ Reference parameters can be: • IRI • Rutting • Macrotexture • Crack percentage ◦ 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.)

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Class	Description	Key parameters
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.	◦ All static and dynamic infrastructure information available in digital form ◦ Assisted visibility systems (radio transmitters, sensors...) ◦ State of pavement: EXCELLENT ◦ Reference parameters can be: • IRI • Rutting • Macrotexture • Crack percentage ◦ 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.) ◦ Real-time microscopic traffic situations detection systems (unexpected obstacles)
A	ISAD Level A – SAE Level 5. Guiding roads. Roads equipped with vehicle-infrastructure communication systems and integral management centre. When each vehicle accesses the road, it transfers control to the road, which synchronises all the vehicles present along. 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. Traffic measurements may be made by loop detectors, ultrasonic sensors (used in Japan), or vision systems. Information may be communicated to vehicles by infra-red beacons, by variable message signs placed on the road, or may be broadcast by radio. If there is an incident, all the cars modify speed and direction to by-pass the problem in safety conditions.	◦ All static and dynamic infrastructure information available in digital form ◦ Assisted visibility systems (radio transmitters, sensors...) ◦ State of pavement: EXCELLENT ◦ Reference parameters can be: • IRI • Rutting • Macrotexture • Crack percentage ◦ 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.) ◦ Real-time microscopic traffic situations detection systems (unexpected obstacles) ◦ Integral vehicles management system

Table 3. EAPA classification of roads according to the level of readiness for adopting electric vehicles.

Class	Description
-	No 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

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Annex 1. Tables

Table A1. SAE Automation levels

SAE Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human driver monitors the driving environment						
0	No Automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when "enhanced by warning or intervention systems"	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	The driving mode-specific execution by a driver assistance system of "either steering or acceleration/deceleration" using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
Automated driving system monitors the driving environment						
3	Conditional Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task even if a human driver does not respond appropriately to a request to intervene	System	System	System	Many driving modes
5	Full Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

Table A2. Global overview of existing inductive ERS [14]

Name	Organisations (Country)	Concept	Type Proven	TRL (1-9)	Cost	Vehicle Application
OLEV	Dongwon Inc. / KAIST (South Korea)	Inductive	Dynamic	9	€500,000/lkm[197]	Buses, Passenger vehicles, Light Duty Goods, Tram/Rail
CWD	Politecnico di Torino / CRF (Italy)	Inductive	Dynamic	3-4	N/A - Research Project	Passenger Vehicles, Light Duty Goods
IPV	Seat Group (Italy)	Inductive	Dynamic	3-4	N/A - Research Project	Passenger Vehicles, Light/Heavy Duty Goods, Buses & Shuttles
PRIMOVE	Bombardier / Scania (Germany/Sweden)	Inductive	Dynamic (under testing)	5-6	€3.25m-6.15m/lkm[45] (€1.7m/lkm final expectation)[5]	Passenger Vehicles, Light Duty Goods, Buses
HALO	Vedecom / Qualcomm (France/Germany)	Inductive	Dynamic	3-4	N/A	Passenger Vehicles, Light Duty Goods
WPT	Oak Ridge National Laboratories / OEM's (USA)	Inductive	Dynamic	3-4	€1.32m/lkm[50]	Passenger Vehicles
INTIS	Integrated Infrastructure Solutions (Sweden)	Inductive	Dynamic (under testing)	3-4	N/A	Small Plant, Passenger Vehicles
Momentum Dynamics	Momentum Dynamics (USA)	Inductive	Dynamic (under testing)	3-4	N/A	Buses and Shuttles
Electreon	Electreon Inc. (Israel)	Inductive	Dynamic	5-6	>€1m/lkm	Passenger Cars & Buses
Victoria	CIRCE (Centre of Research for Energy Resource and Consumption) (Spain)	Inductive	Dynamic	7-8	N/A – Research Project	Buses & Shuttles
WPT	University of California, Berkeley, (USA)	Inductive	Dynamic	3-4	€1.05m/lkm[5]	Passenger Cars, Light/Heavy Duty Vehicles

Table A3. Global overview of existing conductive ERS [14]

Name	Organisations (Country)	Concept	Type Proven	TRL (1-9)	Cost	Vehicle Application
eHighway	Siemens / OEMs (Sweden/Germany)	Conductive	Dynamic (overhead)	7-8	€1.07m-2.06m/lkm[5, 67, 71]	Heavy Duty Goods/Large Plant, Buses & Trams
Elways	eRoadArlanda / Elways AB (Sweden)	Conductive	Dynamic (rail)	6-7	€390k-1m/lkm[5, 79, 83]	All types
Slide-In/APS for Roads	Alstom / Volvo (Sweden)	Conductive	Dynamic (rail)	4-5	€1.08m/lkm[5]	All types
ElonRoad	Elon Road Inc. / Lund University (Sweden)	Conductive	Dynamic (rail)	4-5	€600k-€1.5m/lkm[112, 113]	All types
HPDC	Honda R&D Ltd.	Conductive	Dynamic (rail)	4-5	N/A	All types

Table A4. Global overview of novel static charging inductive systems [14]

Name	Organisations (Country)	Concept	Type Proven	Vehicle Application
OLEV	Dongwon Inc. / KAIST (South Korea)	Inductive	Static	Buses, Passenger vehicles, Light Duty Goods, Tram/Rail
PRIMOVE	Bombardier / Scania (Germany/Sweden)	Inductive	Static	Passenger Vehicles, Light Duty Goods, Buses
HALO	Vedecom / Qualcomm (France/Germany)	Inductive	Static	Passenger Vehicles, Light Duty Goods
WPT	Oak Ridge National Laboratories / OEM's (USA)	Inductive	Static	Passenger Vehicles
INTIS	Integrated Infrastructure Solutions (Sweden)	Inductive	Static	Small Plant, Passenger Vehicles
Momentum Charger	Momentum Dynamics (USA)	Inductive	Static	Buses and Shuttles
IPT	North Carolina State University (USA)	Inductive	Static	Passenger Cars
Victoria	CIRCE (Centre of Research for Energy Resource and Consumption) (Spain)	Inductive	Static	Buses & Shuttles
Unplugged	European Consortium / European Commission (UK, Spain, France, Italy, Germany, Sweden, Netherlands, Belgian)	Inductive	Static	Passenger Vehicles, Light Duty Goods

IPT	IPT Technologies (Germany)	Inductive	Static	Passenger Cars and Buses
WiT-3300, Drive-11	Witricity Corp (USA)	Inductive	Static	Passenger vehicles, Light Duty Goods, Shuttles
WAVE IPT	Wireless Advanced Vehicle Electrification Inc. (USA)	Inductive	Static	Passenger Vehicles, Light/Heavy Duty Goods, Buses & Shuttles
Plugless Power	Evatran	Inductive	Static	Passenger Cars
Magneto DC	University of British Columbia (Canada)	Inductive	Static	Passenger Cars
Inverto	Inverto GmbH (Belgium)	Inductive	Static	
Inductives	Daimler (Germany)	Inductive	Static	Passenger Cars
Wireless Charging	BMW (Germany)	Inductive	Static	Passenger Cars
Wireless Charging System	Nissan (Japan)	Inductive	Static	Passenger Cars
Inductive Charging System	Fraunhofer IISB (Germany)	Inductive	Static	Passenger Cars

Table A5. Global overview of novel static charging conductive Systems [14]

Name	Organisations (Country)	Concept	Type Proven	Vehicle Application
Busbaar. All-in-One	Furrer + Frey / Opbrid SL (Spain)	Conductive	Static (pantograph)	Buses & Coaches
Overhead Fast Charger	Proterra (USA)	Conductive	Static (pantograph)	Buses & Coaches
Fast Charge Systems	Heliox (Netherlands)	Conductive	Static (pantograph)	Buses & Coaches
Opp-Charge	Volvo Bus Corporation (Sweden)	Conductive	Static (pantograph)	Buses & Coaches
Flash Charging	ABB (Switzerland)	Conductive	Static (pantograph)	Buses & Coaches
Quick-POINT	Eko Energetyka (Poland)	Conductive	Static (pantograph)	Buses & Coaches
Charging-Panto	Faiveley Transport - Wabtec Company (France)	Conductive	Static (pantograph)	Buses & Coaches
eBus Charger	Siemens	Conductive	Static (pantograph)	Buses & Coaches

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September 2020