Smart Roads Classification

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THE NEED OF A SMART ROADS CLASSIFICATION SYSTEM

Recently, road classification systems have not only focused on mobility and accessibility, but also on different types of road users, various contexts and functionality. However, with Connected and Automated Vehicles (CAVs) coming into play, the situation has become quite more challenging than before, requiring the definition of new criteria to classify our roads.

In order to clarify the capabilities of these new vehicles, the Society of Automotive Engineers (SAE) developed a classification system that grouped these capabilities in six levels *[1]*. Nowadays, the Penetration Market Rate of SAE level 2 vehicles is on the increase, and the first SAE level 3 vehicles are showing up.

In this context, three major challenges arise for the deployment of CAVs:

1. Safety concerns due to sudden automated driving disconnection (hereinafter referred to as disengagement). A driver would probably disable the driving automation system at winding roads, with many disengagements that prevent a smooth automation. In contrast, freeways may present a very good automated experience, but a sudden disengagement may have severe consequences on a distracted driver.
2. Given the variety of driving automation systems, a certain road feature may trigger a disengagement in some vehicles and not in others. Therefore, roads cannot be directly classified according to a sort of 'automation-readiness' parameter.
3. There is a lack of information for drivers about automation, i.e., drivers are sometimes misinformed about the capabilities of their own vehicles.

These barriers would not prevent automation but slow down its deployment. Customers may be reluctant to acquire and use these technologies if they do not see relevant advantages, even more if there are safety concerns.

In addition to the development of Automated Vehicles, there is also a boost in making use of connectivity and information-sharing to further enhance traffic operation and safety. Connectivity could improve automation –where available– and traffic performance, especially on high-volume road facilities. Therefore, automated and connected driving goes hand in hand with different political goals that diverse countries have been pursuing for years, most of them related with safety and the reduction of fatal crashes.

Considering the variety of road facilities and connectivity capabilities to come, recent few research projects have pointed out the necessity to explore a Smart Roads Classification (SRC) that helps users and CAVs know what to expect from the different road facilities *[2, 3]*. This information should range from road segments that do not support automation, to road segments that will even be able to take control of thousands

1 https://www.piarc.org/en/activities/PIARC-Directory-Technical-Reports/PIARC-Technical-Reports-2020-2023

of vehicles at a time to optimize safety and performance in a cooperative way.

An SRC should therefore comply with a number of objectives. The most important one is safety. An SRC should increase the road safety levels, either by presenting a geometry, signage and pavement conditions that prevent most disengagements, or by sharing detailed information with users and connected vehicles.

Other important objectives are: a common language to facilitate communication between all stakeholders and be a universal framework, taking into account the different constraints faced by diverse countries; simple, to ensure understanding by users, both drivers and automated vehicles, so as to generate confidence in the user; and dynamic, to reduce the assigned Smart Road Level when sudden variations in environmental and operational factors occur.

OPPORTUNITIES AND CHALLENGES

Given the necessity of an SRC to be a universal framework, a questionnaire was launched to retrieve opinions and thoughts from stakeholders worldwide.

The most important benefits and opportunities of an SRC are:

- **Efficient planning of investments on physical and digital infrastructure**. Smart Road Levels (SRLs) should rely on physical and digital information of roads. In this way, RAs and ROs could compare their road networks to the proposed criteria to identify the most cost-effective investments for CAVs deployment. Several researchers have outlined that the road infrastructure could be adapted to existing CAVs' capabilities, which would result in a faster and safer deployment of CAVs. An SRC could prevent unnecessary investments by adequately planning their allocation.
- **Identification of CAVs' limitations**. Original Equipment Manufacturers (OEMs) are continuously improving driving automation systems, but their efforts are in many different directions. An SRC would help OEMs direct their efforts based on the thresholds associated with each SRL.
- **Clear and simple indications for users.** An SRC would present clear messages to users, explaining what to expect from the road facility regarding automation and connectivity, and facilitating the use of Advanced Driver Assistance Systems (ADAS).

The most remarkable challenges and barriers of an SRC are the following ones:

- **Lack of coordination between stakeholders.** Many stakeholders are involved in the process (RAs, ROs, OEMs, users, etc.) and should come to different agreements as CAVs –especially the highest SAE levels– are introduced in the market.
- **Uncertainty.** There are still too many uncertainties in several aspects, such as how the automation technology will evolve or what and how information should be provided to users.
- **Heterogeneity across countries.** New road-related guidelines should meet the requirements established by the SRC but the adaptation to the new requirements should be performed gradually in time considering previous national/regional regulations. Sharing experiences and best practices can help to minimize the different level of adoption among administrations and countries.
- **Costs.** An extensive digital infrastructure is expected to be deployed. Regardless how it is achieved, it will imply significant costs that are still to be determined and shared.

FEASIBILITY

After determining that an SRC would be useful to deploy CAVs in a faster and safer way and better target road investments, this section outlines its possible levels and constraints. These are presented after introducing the involved stakeholders and the possible future scenarios.

Involved Stakeholders

The most important stakeholders that intervene in road management with mixed traffic involving CAVs are:

- **Road Administrations (RAs).** These own the road infrastructure and are usually in charge of the planning and investment of new facilities.
- **Road Operators (ROs).** They oversee the traffic operation and safety management, ensuring adequate conditions for users.
- **Original Equipment Manufacturers (OEMs).** Automakers and their suppliers (TIER1s) are working hard expanding the capabilities of CAVs.
- **Mobile Network Operators (MNOs).** These stakeholders are the providers of the wireless connectivity.
- **Users.** These are the most important agents, since will interact along the road facilities.
- **Information Management Providers (IMPs).** These will collect, process, and share the road-related information once the Digital Infrastructure is available and connected vehicles become a reality.

Scenarios

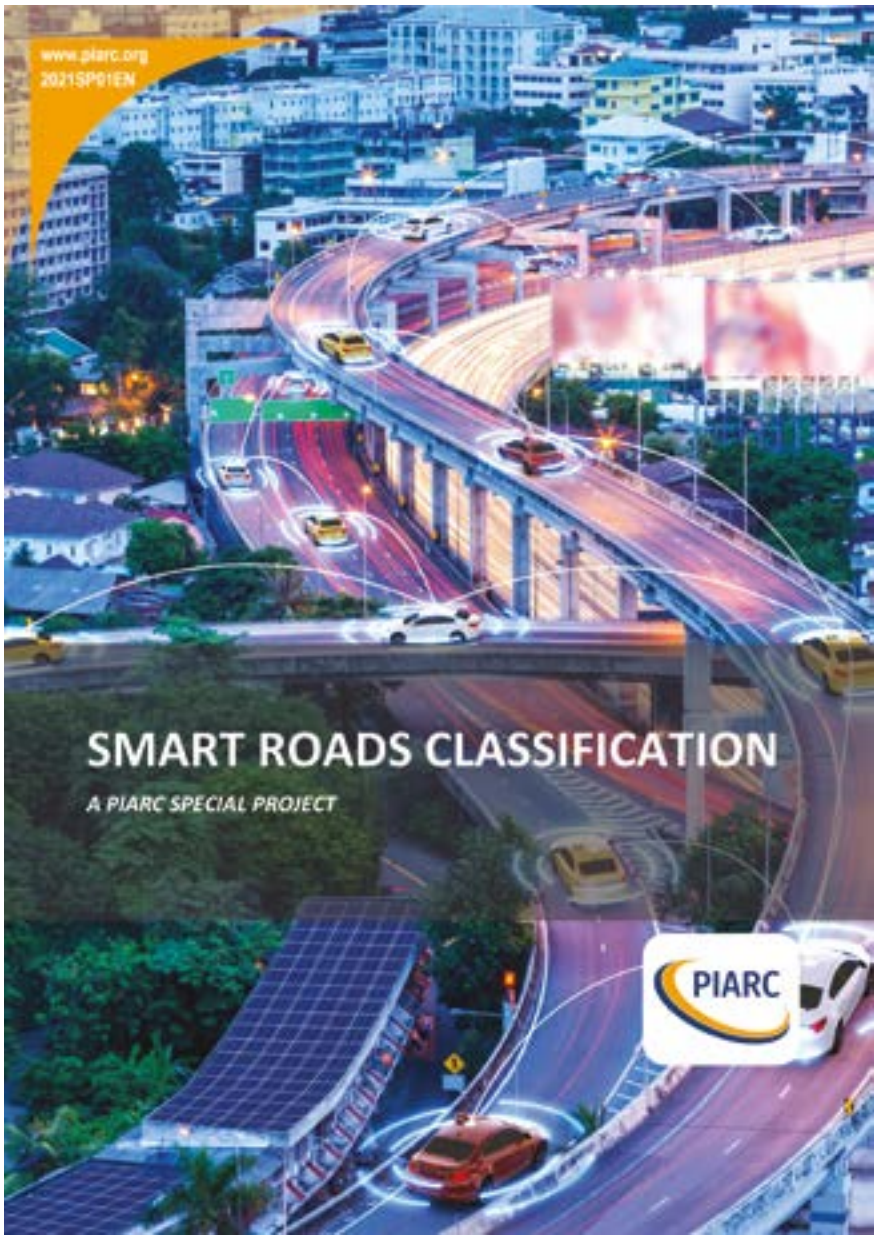
The high uncertainty associated with this phenomenon can be grouped into four different factors:

- SRC application (yes/no). This factor indicates whether a Smart Roads Classification system exists.
- SAE levels on the market (levels 0 to 5). This factor indicates which SAE levels operate on the road network.
- Digital Infrastructure (yes/no). This factor refers to whether a Digital Infrastructure exists and is available in all or part of the road network.

- Existence of data about disengagements and Operational Design Domains (ODDs) *[4]* (no/only disengagements/ disengagements and ODD). This information would be helpful for RAs and ROs to know which facilities should receive attention regarding automation.

A total of eight scenarios were defined by combining these factors *(illustration 1)*.

- **Scenario A** represents a very near future for the existing situation. There are up to SAE level 3 vehicles, an SRC does not exist, a digital infrastructure is not available, and disengagement data is not publicly available. SAE level 2 vehicles present disengagements whereas SAE level 3 vehicles present Take Over Requests with variable timing. Drivers would not have any insight about where to activate their driving automation systems.
- **Scenario B** adds an SRC to scenario A, which should focus on recommending drivers where to enable or disable their driving automation systems. Given the variety of CAVs, these indications should be established in a conservative way, i.e., clearly indicating the road segments that could be run automatedly by very few vehicles (red level), and by far most vehicles (orange level).
- **Scenario C** adds a digital infrastructure to scenario B. This does not mean that all road segments must present connectivity support, but that some road segments may have it. These road segments could therefore share valuable information with SAE level 3 vehicles that could use it to foresee disengagements and even avoid some of them. An SRC should therefore present a specific level for road segments with this feature and that physically can support automation (yellow level).
- **Scenario D** is very similar to scenario C, but having public information about disengagements, provided by OEMs. Road Authorities would benefit from this real-time disengagement data, by rapidly detecting zones with sudden increase of disengagements.
- **Scenario E** is the natural evolution of scenario A. In this case, SAE level 4 vehicles exist in the market, a digital infrastructure is also available, but an SRC does not exist. The digital information provided to



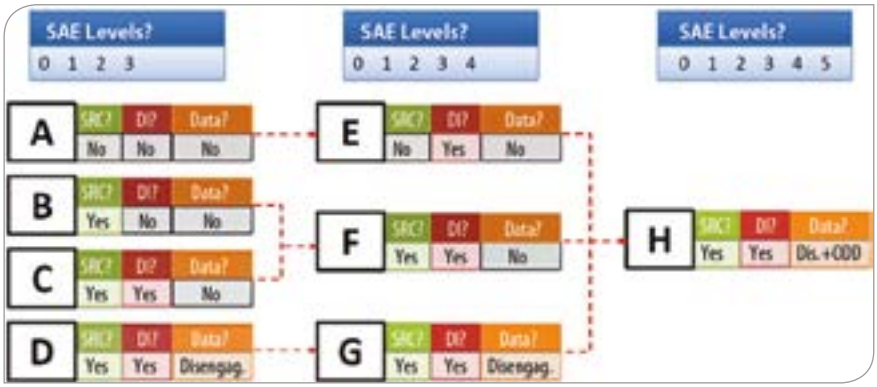


Illustration 1- Interaction among the different Scenarios © Authors

vehicles would help them foresee and avoid some disengagements. Non-connected SAE level 2 and 3 vehicles would still present the same limitations than for scenario A. SAE level 4 vehicles may not fully benefit from their capabilities as they may not know when they are exiting ODD-compatible zones.

- **Scenario F** is the natural evolution of scenarios B and C. Compared to scenario E, it adds the existence of an SRC. Having an SRC is particularly important with SAE level 4 vehicles, since they cannot present disengagements within their ODD-compatible zones. Therefore, road segments with very good physical properties and connectivity features could be tagged with a new fourth SRL (green level). This level indicates that a driver of a SAE level 4 vehicle can fully release control to the vehicle whereas drivers of lower SAE levels would experience very few disengagements. The previous Smart Road Levels would coexist in other zones with worse physical properties. To improve traffic performance when SAE level 4 vehicles become general, a new fifth Smart Road Level (blue level) that support cooperative driving is suggested, to indicate which road facilities are exclusive for CAVs.
- **Scenario G.** This scenario is similar to scenario F, adding real-time disengagement data. Like scenario D, this information does not require new levels from the SRC but adds the possibility of a real-time management by RAs and ROs.
- **Scenario H.** This is a long-term scenario, in which SAE level 5 vehicles would be available too. SAE level 4 vehicles would be still a majority, and lower levels might exist but would not be common. Digital information is available in almost all the road network. An SRC is considered necessary to determine where non-CAV vehicles are not allowed (i.e., blue level). Lower SRLs may not be necessary in rural environments, given the large ODDs expected.

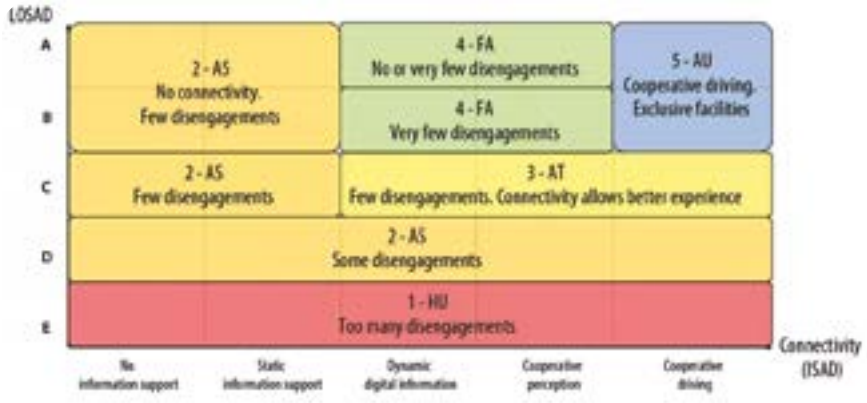


Illustration 2 - Determination of the SRL as a function of LOSAD and ISAD © Authors

SRC Proposal

Considering the previous scenarios, a five-level SRC is suggested:

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

Road authorities should establish what properties and thresholds should be considered for each SRL. For that purpose, two indicators have been proposed: the Level of Service for Automated Driving (LOSAD) and the Infrastructure Support for Automated Driving (ISAD). The first one represents the physical readiness of the road segment to support automation, while the second one focuses on the connectivity support. Thus, the SRL could be determined by combining them as shown in *illustration 2*.

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RECOMMENDATIONS FOR AN SRC IMPLEMENTATION

The feasibility of a Smart Roads Classification system was discussed by means of an online questionnaire and the development of two webinars. This section presents the most important contributions about follow-up proposals from different stakeholders.

Road Administrations and Road Operators

RAs and ROs should define a clear physical sign to identify HU and AS road segments (in an advisory, non-mandatory way). HU road segments should be a priority, indicating drivers when the automated driving is clearly discouraged. A second step could be identifying AS road segments, i.e., which road segments present physical features that allow automation on most existing SAE level 2 vehicles. Once the Digital Infrastructure is available, AT road segments could also be identified.

These measures should go hand in hand with information and education campaigns to drivers and other users. In addition, pilot tests are considered a key factor as they can be used to check CAVs' capabilities under real-world conditions.

Automotive Industry

A critical key issue to be addressed is how to involve the automotive industry in the development and application of the SRC. Their collaboration in the Special Project has been remarkable scarce.

Mobile Network Operators (MNOs)

These stakeholders should be involved in the application of an SRC through pilot tests focused on main highways.

Users

They should be informed about the capabilities of their vehicles, receive clear and simple information about the SRLs, and be able to know the smart properties of the road segments.

Information Management Providers

These stakeholders will collect, process, and share information with all other stakeholders. Communication with RAs and ROs should be very direct, given the massive data exchange for a road network.

PIARC

It is not suggested that PIARC undertakes an additional Special Project on this topic until smart roads become more mature. Other possible actions could be to organize webinars or conferences, disseminate best practices or share findings from pilot studies.

LMICs

Considering that Low-Medium Income Countries present many constraints, their global priority should be set to shift from Humanways (HU) to Assistedways (AS) as many roads as possible, starting with main highways and corridors. In addition, if the situation of the country allows it to plan and construct new road facilities, these should be designed to achieve the highest SRLs. For that purpose, their actions should be directed towards implementing and expanding their 5G coverage, at least along their main corridors.

The upgrading of some highways to Assistedway (AS) will encourage safer roads for both human-driven vehicles and automated vehicles. Therefore, the benefits will be higher than in other countries with this first step.#