SMART ROADS CLASSIFICATION PROPOSAL

Executive Summary

Introduction

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

Given that the presence of Connected and Automated Vehicles (CAVs) is on the increase, it is necessary to explore a new Smart Roads Classification (SRC) system that could provide information to users and vehicles on their degree of adaptation to automated and/or connected driving. An integral road classification system would also allow an efficient planning of public investments on physical infrastructure, by enhancing operativity of driving automation, and on digital infrastructure, by increasing the benefits of connectivity between highways and their users (V2X). End users will be informed about the level of automation they can enable through each road segment. Consequently, a safer, more sustainable and comfortable road network is expected.

This system should be based on existing autonomous driving and connectivity technologies and be highly resilient, so it could be quickly adapted to the technology progress, research findings, and best practices. It should also be compatible with existing road classification systems and the coexistence with other human-driven vehicles and users. Summarizing, the SRC should fulfill the following objectives: common language; useful; universal; standardized; interoperable; robust; consistent; simple; integrable; dynamic; flexible; and no liability for road administrations or road operators.

The Smart Roads Classification Framework

The SRC model is based on two prior parameters: Level of Service for Automated Driving (LOSAD) and Infrastructure Support for Automated Driving (ISAD). The first one represents how ready the infrastructure is to host autonomous vehicles. The second one summarizes the support for connected vehicles.

Level of Service for Automated Driving (LOSAD)

Depending on geometric, environmental, weather and other factors, a road segment may be more or less ready for vehicles to use automation. Five levels are proposed with the following results on automated vehicles:

A	The road segment is compatible with the vast majority of vehicle ODDs. Level 4 vehicles will not request human intervention. Level 3 vehicles may experience very rare disengagements. Level 2 vehicles may experience very low number of them.
B	The road segment presents similar physical characteristics than LOSAD A. Dynamic aspects such as weather may limit some vehicles, requesting human intervention or presenting very few disengagements.
C	The road segment is not fully compatible with all known ODDs. Drivers are encouraged to activate their driving automation systems but being aware if any takeover request or disengagement appears.
D	The road segment presents fair compatibility with some ODDs. Drivers of level 4 and level 3 vehicles may activate their systems, being aware of the road and traffic conditions. Drivers of level 2 vehicles are discouraged from doing so.
E	The road segment presents nearly null compatibility with most automation systems. Drivers should perform in manual mode.
Note: please see Table 2 in the Document to see which factors are used to determine the LOSAD.	

An Operational Design Domain (ODD) refers to the operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. Therefore, an ODD can be defined as a road section that meets some characteristics that allow a driving automation system to perform.

Within a certain road segment, the different vehicles will present specific ODD-compliant sections. The zones that are ODD-compliant to all vehicles are indeed sections that can be driven autonomously by all vehicles. Knowing this information is very important for Road Administrations and Operators, since they could actively work towards increasing their length and adapting new sections. These sections are proposed to be called Operational Road Sections (ORS).

Finally, it is important to introduce the concept of disengagement and takeover request. A disengagement takes place when a driving automation system cannot keep the control of the vehicle and releases it to the driver in an unplanned manner. These events are common to level 2 vehicles and may take place even within ODD-compliant road segments.

Level 3 and level 4 vehicles are technologically more robust, being able to foresee when the driving automation system would stop performing the Driving Dynamic Task. Instead of instantly releasing control to the driver, these can request the human driver to intervene (takeover request). This may happen to level 3 vehicles even within an ODD-compliant section, which cannot happen to level 4 ones.

Infrastructure Support for Autonomous Driving (ISAD)

An adequate connectivity and digital information are key to share information to connected vehicles. The ISAD parameter can be used to rank how road segments provide this service. Like LOSAD, it presents five levels, as follows:

A	The road segment supports cooperative driving: the infrastructure can perceive information and give orders to vehicles to improve safety and traffic operation.
B	The road segment supports cooperative perception: vehicles can inform the infrastructure through V2I about microscopic traffic and road conditions.
C	Digital information about the road segment is available (such as HD maps). Dynamic information (e.g., signs, weather, etc.) is regularly updated.
D	Static digital information available. This information is not updated in real time.
E	Conventional infrastructure with no digital support.
Note: please see Table 3 in the Document to see which factors are used to determine the ISAD.	

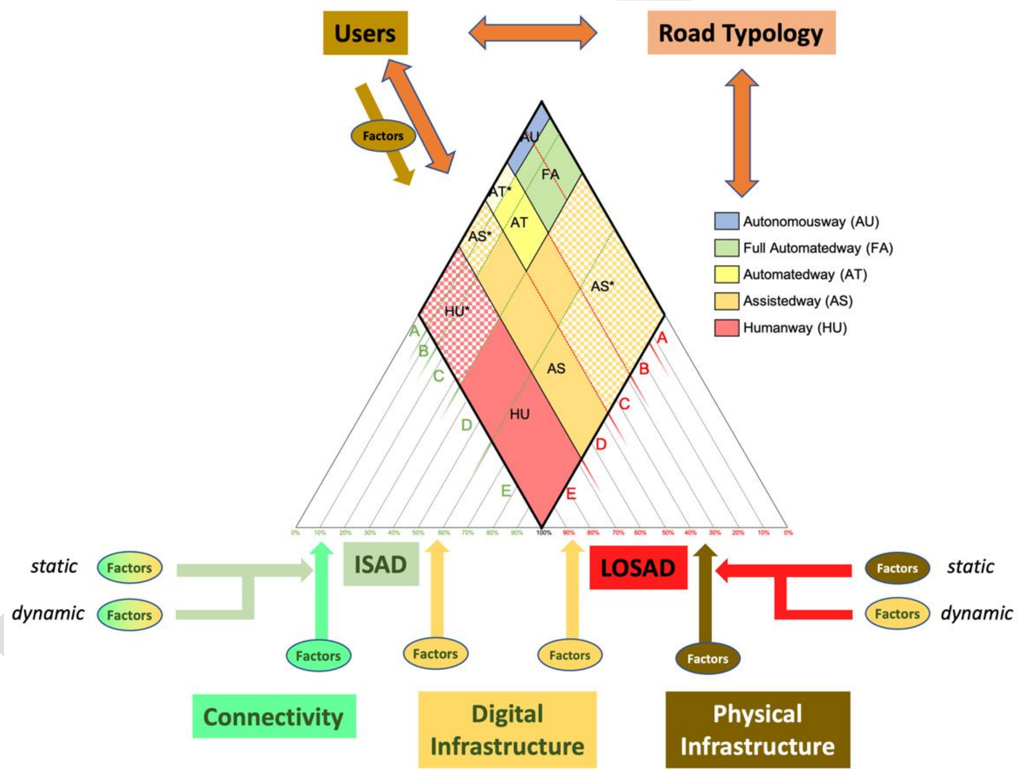
Smart Roads Classification Levels

A road segment may present particular support capabilities to host Connected and Autonomous Vehicles (CAVs), which can be determined with the interaction of LOSAD and ISAD levels. The five road smart levels are as follows (from worst to best support):

HU	**Humanway**. The road segment is not ready to host CAVs, due to the high number of disengagements, and/or the low capability to share digital data to inform vehicles about their ODDs.
AS	**Assistedway**. The road segment is adequate to perform autonomously, but this condition may stop due to different factors (not as frequently as HU segments). Therefore, drivers of automation levels 1 to 4 vehicles should be attentive to the road to disengagements or takeover requests.
AT	**Automatedway**. The road segment presents reasonably good connectivity and physical infrastructure capabilities, so disengagements or takeover requests would be quite lower compared to AS and HU. Vehicles can match their ODD limitations with the digital information shared by the road segments, so most takeover requests (levels 3-4) are planned.

FA	**Full Automatedway**. The road presents a continuous ORS, ensuring ODD compatibility with far most level 3-4 vehicles. Digital information is shared, so these vehicles can plan any takeover request. Therefore, an experience without disengagements can be attained. Level 2 vehicles would experience very low number of disengagements.
AU	**Autonomousway**. Similar than FA, the connectivity infrastructure supports cooperative driving, so the infrastructure can receive and transmit tailored instructions to all vehicles, micromanaging traffic performance. This road segment type is exclusive for level 4-5 CAVs. This highest smart level may be designated to some lanes.

The following figure clarifies which LOSAD/ISAD combinations are behind each Smart Road Level. Some slight differences may exist within every single level, without compromising the description mentioned above. Some LOSAD/ISAD combinations are not recommended and have been cleared with a white pattern. The diamond shape aims at emphasizing the bottom-to-top path that a road segment would follow in order to improve its SRC level.



Note: to facilitate application by Road Administrations and Operators, as well as interpretation by vehicle manufacturers, a detailed approach to the same SRC levels is given, by making all underlying LOSAD and ISAD factors explicit (named as **detailed classification system**, Tables 7 to 11 in the Document).

Possible Applications

There are many applications of the SRC framework, either by itself or combined with other classification systems. Connectivity of vehicles and their interaction to other vehicles and the infrastructure would dramatically change, opening the floor to new services and stakeholders. Some of these possible applications are drafted as follows, but others remain unknown to date. The intention of Questionnaire 3 is also to obtain feedback on these possible new uses.

Road Administrations and Road Operators

Currently, there is a high variability of the roles of Road Administrations (RAs) and Road Operators (ROs), depending on the country. Tasks can be grouped in two main areas:

- Planning and investment. In this area, RAs and ROs would be responsible of determining the SRC level of their road segments, either by means of LOSAD/ISAD or through the detailed classification system. With it, investments could be planned in order to maximize the number of users benefited with higher SRC levels.
- Management. ROs would be responsible for monitoring how vehicles perform throughout their road network. In combination with RAs, they could also decide about the specific thresholds for the dynamic factors of the SRC levels.

These decisions are extremely dependent on the information provided by vehicle manufacturers – such as explicit ODDs or disengagements. This information is not available nowadays, so how RAs and ROs use the SRC will differ in time, as explained below.

Short-term

Nowadays, driving automation system levels 4-5 do not exist, and level 3 are starting to appear. The digital infrastructure and connectivity factors are still in an early stage of development. Therefore, **AT**, **FA** and **AU** road segments cannot be delimited and would not have any significant impact.

RAs should therefore only focus on determining and physically delimiting **AS** road segments. Users of SAE levels 2-3 vehicles would then know where it is recommended to activate the automation assistance. The thresholds to identify these road segments should be obtained from literature, provided that explicit ODDs and information about disengagements will presumably not be available.

Mid- and long-term

In a mid-to-long term, explicit information about ODDs and/or disengagements is expected to be available. With it, researchers, RAs and ROs could better decide which thresholds are recommended for the different SRC levels.

LOSAD and ISAD could be used by RAs and ROs in order to automatically determine the support of their road networks for CAVs – e.g., using GIS-based tools. This would help in deciding where and when would optimize the outcome of their investments.

When level 4 vehicles become a reality – even for very specific conditions – RAs and ROs could decide the optimal distribution of **FA** and **AU** road segments.

Traffic performance and safety monitoring would also become of major importance, giving valuable information about the impact of higher SRC levels that could be used for planning, or dynamically deciding when the SRC level of a road segment must change.

Some key performance indicators (KPIs) have been proposed to know the performance situation of the road network and make strategic decisions, maximizing the outcome of investments. The KPIs can also be used to compare the situation of a road network longitudinally (i.e., in time) and to the road networks of other countries or regions.

Users

Users are the ultimate and most important target of the SRC system. The goal is that they receive very clear information regarding whether to activate the system or not. Like for RAs and ROs, this is fully dependent on the timeframe.

Short-term

In a short-term, many drivers are unfamiliar with autonomous vehicles – some of them even reluctant to using them. Without the SRC, drivers of levels 2-3 vehicles are using automation assistance with a variety of outcomes. At high-end roads, these systems work well but driver should know that they must be attentive to the road to takeover when disengagements appear. At other roads, drivers might experience far-from-comfortable driving due to very frequent disengagements.

By delimiting the **AS** segments, this situation would presumably change since drivers would be physically informed about where automation is recommended (they would always be reminded about the necessity of staying aware of the road since disengagements would still exist). When entering a road segment without this indication, drivers would know that driving assistance is not encouraged. This would work on safety and user acceptance.

Mid- and long-term

In more distant scenarios, physical and digital signs would exist for all different SRC levels. Level 2-3 drivers should always be attentive to the road to react to disengagements – although a lower number of them would be expected with higher SRC levels. Level 4 vehicles could operate fully autonomously when entering **FA** and **AU** road segments, and with a very low number of disengagements at **AS** and **AT**.

Vehicle manufacturers

Nowadays, vehicle manufacturers invest enormous amount of money in research driving automation systems. Their objective is to maximize the environments where these systems can perform. However, there is a lack of specific regulations about this performance. While level 2 driving automation systems can basically rely on sensor-captured information, higher levels of automation would require information about the road infrastructure, environment, safe harbors, etc. to match with the systems' ODDs. This is particularly important for level 3 vehicles, for which the road digital information can provide a very important extra time for the driver in order to respond to takeover requests.

Therefore, a tight connection between vehicle manufacturers, road infrastructure and connectivity providers should be established, defining which information would be valuable for manufacturers to expand their ODDs. An open and comprehensive ODD taxonomy would help vehicle manufacturers to express their operational conditions, this being the basis of Operational Road Sections. This connection can also be perfectly seen at **AU** road segments and connectivity-based intersection optimization.

Other stakeholders

New services and business opportunities will appear in the future, both private and public. HD map providers could match the specific road circumstances with every single ODD, providing tailored information to drivers and CAVs or foreseeing possible disengagements sooner.

By using the sensors of vehicles and connectivity, information about traffic and pavement condition could also be retrieved and transmitted to Road Administrations and Operators or Traffic Management Centers for multiple purposes, such as supporting road maintenance, exploitation, or inform the final users about road events.

Conclusions

As autonomous vehicles become more common in our road networks, it seems necessary to define how these should interact with the road infrastructure. On the one hand, drivers of low automated systems should have clear indications about where they could activate their systems in a confident and safe way. On the other hand, higher levels of automation would be really benefited from digital information coming from the infrastructure and environment, complementing data that can be perceived by vehicle sensors. This would be especially beneficial to the safe and fast deployment of level 4 vehicles.

In both cases, a Smart Roads Classification Framework could help all stakeholders and users to know what they can provide and expect from the road infrastructure. This framework is far from being fully detailed, which is something that will come in the near future as technology evolves, standards are defined, road infrastructure is adapted, connectivity facilities are deployed and users become familiar with CAVs.