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EVOROADS

Evolutionary Solutions for Realising a Holistic Safe System Approach for All Road Users

BEST PRACTICES AND BASELINE CATALOGUE OF SAFETY CRITERIA

Project deliverable D1.1

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EVOROADS

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PROJECT EXECUTIVE SUMMARY

The EC-funded EvoRoads (Evolutionary Solutions for Realising a Holistic Safe System Approach for All Road Users) is committed to advancing the European Union's Vision Zero initiative by implementing a comprehensive framework that integrates innovative models, tools, and services for data-driven safety assessments.

The project involves the development of a connectivity platform that digitalizes transport infrastructure assets and ensures the seamless integration of safety assessment services. By leveraging advanced artificial intelligence, EvoRoads analyses infrastructure monitoring data at various geospatial levels, enabling proactive risk warnings and supporting road operators in managing maintenance more effectively, which enhances both safety and operational efficiency. It also defines safety criteria and quantification methods for key performance indicators (KPIs) to monitor safety performance as part of the "Safe System" approach.

The results are developed alongside 5 axes: (1) an Evolutionary Safety Assessment Framework setting the basis by defining how to measure road safety in a multilayered catalog; (2) a Road Asset & Safety Management Digital Twin collecting and distributing safety data; (3) Advanced Monitoring Safety Systems using that data that enable infrastructure owners to obtain clear insights on their roads' level of safety; (4) Proactive Safety Warning Systems ensuring that critical safety issues are raised pro-actively and in real-time to prevent safety hazards; and finally, all these results are combined in (5) Solutions Integration, Augmentation and Impact Assessment tools and products allowing for take-up of the results in the wider market. These axes converge into a Safe Mobility Data Space where all data related to EvoRoads' safety criteria and solutions are combined.

EvoRoads' methodologies and technologies will be validated in four Living Labs (LLs) addressing diverse road user scenarios across urban and rural environments to ensure broad applicability and effectiveness. EvoRoads LLs are situated in Spain (focusing on Hazard-aware assets for better infrastructure safety level for existing and future roads users), Italy (focusing on Dynamic Road infrastructure safety diagnosis enhanced by emerging vehicle and digital technologies), Latvia (focusing on Automated (advanced) low-cost infrastructure monitoring and diagnostics: road hot spots, bridges, tunnels), and Romania (focusing on Remote sensing and warning technologies for better infrastructure and road conditions).

The EvoRoads project runs from May 2024 until April 2027. A scale-up event is foreseen towards the end of the project to allow for the wider market to consider EvoRoads' results and to help provide ways forward.

Social Media link:

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DELIVERABLE EXECUTIVE SUMMARY

Deliverable D1.1 is a foundational component of the EvoRoads project, aimed at advancing road safety through the implementation of the Safe System approach across Europe. The deliverable serves to establish a comprehensive baseline of road safety indicators by reviewing legislative frameworks, safety practices, and the adoption of emerging technologies across multiple European nations, focusing particularly on the four projects' pilots: Italy, Spain, Latvia, and Romania. It lays the groundwork for a harmonized catalogue of safety indicators that can be consistently applied across borders, aligned with EU road safety policies.

This work will be further expanded in Task 1.2, where stakeholders from the pilot sites will provide feedback on the catalogue of safety indicators developed in D1.1. Their insights will be crucial for refining and enhancing the proposed indicators. This ensures that the indicators reflect real-world needs and are tailored to the specific challenges faced by the four countries involved in the pilots. Additionally, Task 1.3 will build on the findings of this deliverable by focusing on the development of innovative safety indicators and methodologies. The emphasis will be on creating proactive, real-time monitoring solutions for road infrastructure and other critical elements. This task will leverage the baseline established in D1.1 to explore advanced technologies, which can detect road deterioration and hazards in real-time, offering a more comprehensive and dynamic approach to safety management.

Throughout this deliverable, a detailed analysis of different EU countries' road safety regulations and their degree of alignment with the EU Vision Zero goal has been conducted. Emphasis has been placed on identifying commonalities, divergences, and gaps in legislative approaches, particularly in how each country incorporates new technologies such as infrastructure monitoring sensors, ITS (Intelligent Transport Systems), and digital platforms into their road safety frameworks. A comparative analysis reveals varied levels of technological integration, with some countries showing significant advancements, while others require further adaptation to meet the evolving standards set forth by European directives. The deliverable also underscores the crucial role of EU-funded projects in shaping the future of road safety. Numerous initiatives, such as those focusing on the development of safety assessment frameworks and sensor technologies, are pushing towards a standardized base of indicators for evaluating road safety.

EvoRoads itself contributes to this effort by developing a multi-layered safety assessment framework integrated into a digital mobility space, leveraging innovative tools such as AI-driven analytics and sensor data fusion. This is important for fostering proactive road-user warnings and improving infrastructure maintenance, ultimately accelerating the attainment of the Vision Zero goal. The work carried out in Task 1.1 is closely aligned with EvoRoads' broader objectives, which involve creating a federated platform for infrastructure monitoring and safety management. The platform's holistic approach facilitates the analysis of correlations between safety data and advanced technologies, supporting the creation of policy recommendations and promoting standardization across European countries. Furthermore, it aims to bridge the gap between varying national legislative frameworks, enabling better cross-border cooperation and policy alignment.

Quantitatively, this deliverable introduces a structured matrix of 124 road safety indicators, categorized by their relevance to the ten categories of transport dimensions detailed in the project proposal, e.g., infrastructure, user behavior, and emerging technologies. Certain categories, particularly those related to infrastructure monitoring and vehicle technology, show a more mature integration of innovative solutions. Other areas for example concerning vulnerable road users (VRUs) and C-ITS require further research to verify correlations with incidents severity and standardization efforts. As the document highlights, continued collaboration across member states will be essential to closing these gaps and ensuring the consistent application of safety standards.

Finally, while this deliverable presents a comprehensive catalogue of safety indicators and legislative practices, it also acknowledges its inherent limitations. The rapidly evolving nature of both technology and road safety legislation means that this work must be periodically updated to remain relevant. Furthermore, as more nations adopt new technologies and refine their legislative frameworks, ongoing research and harmonization efforts will be required to ensure alignment with both national and European objectives.

1 INTRODUCTION

1.1 OBJECTIVES OF THE DELIVERABLE

This deliverable presents a comprehensive state-of-the-art review of road safety assessment relevant regulations across European states and respective safety-related Key performance indicators, aimed at developing a robust assessment framework that incorporates all dimensions of the Safe System approach, with a specific focus on diverse road users. The goal is to explore how various factors contribute to road safety by addressing the needs of both secondary and urban roads with applicability for non-trunk roads and the safety impact on all – including new – types of users. In particular, the analysis involves an in-depth review of the regulatory frameworks of countries participating in the EvoRoads project (Italy, Latvia, Romania, Spain), alongside an evaluation of best practices across the other states in Europe (Sweden, Germany, France, Norway, United Kingdom). By doing so, the document aims to establish a baseline directory of safety criteria that are currently applied in road safety assessments.

The outcome of this effort is a multilayered safety criteria catalogue, consisting of both primary and composite criteria across various categories. These categories include road infrastructure, traffic management, roadside safety devices, user behaviour, vulnerable road users (VRUs), connected, cooperative, and automated mobility (CCAM) operations, enforcement mechanisms, cooperative intelligent transport systems (C-ITS), vehicles, and emergency management strategies.

Where data is available, the catalogue will also include comprehensive metadata, identify relevant data sources for the quantification of each criterion, and explore correlations and dependencies between criteria. This enriched dataset will help to form a clearer picture of the safety landscape.

Furthermore, the catalogue is structured as a matrix, enabling a nuanced analysis of the relationships and interdependencies between safety criteria and their respective categories. This structure is designed to evaluate the non-linear and multidimensional correlations, providing a more comprehensive and flexible tool for assessing road safety across diverse environments and provide measurable societal benefits Through this approach, the document aims to enhance the understanding and application of safety frameworks, supporting future policy development and improvements in road safety strategies.

1.2 MAPPING EVOROADS OUTPUTS

Purpose of this section is to map EvoRoads Grant Agreement commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed.

EVOROADS GA COMPONENT TITLE	EVOROADS GA COMPONENT OUTLINE	RESPECTIVE DOCUMENT CHAPTER(S)	JUSTIFICATION
DELIVERABLE			
D1.1 Best practices and baseline catalogue of safety criteria	Updated review of state of the art in EvoRoads scientific areas, knowledge base of best practices in road safety assessment, and baseline catalogue of safety criteria.	Chapter 2 Chapter 3	Chapter 2 involves an in-depth review of the regulatory frameworks of countries participating in the EvoRoads project alongside an evaluation of

			best practices across Europe. Chapter 3 is the baseline multilayered road safety criteria catalogue based on the ten categories of transport dimensions proposed by EvoRoads project.
TASKS			
T1.1 Best practices and safe system assessment framework definition	T1.1 will conduct comprehensive state-of-the-art reviews encapsulating all dimensions of the safe system approach to derive a baseline directory of safety criteria currently being considered in road safety assessment. As a result, a multi-layered safety criteria catalogue will be created including metadata for the different criteria.	Chapter 3	Section 3.1 includes a description of the ten categories of transport dimensions proposed by EvoRoads project and lists road safety criteria. Section 3.2 provides detailed descriptions of road safety criteria including definition, metadata, references. Section 3.3 summarizes the complex interconnections between safety criteria and transport dimensions, providing an interactive reading methods to different typologies of readers.

Table 1 – Adherence to EvoRoads GA Deliverable & Tasks Descriptions

1.3 DELIVERABLE STRUCTURE

This section provides an overview of the structure and content of the deliverable. Chapter 2 begins with a comprehensive look at the Safe System Approach, including a brief overview on EU-wide roadmap to 2030, followed by pilots-specific analyses for Italy, Spain, Latvia, Romania, and other EU countries. Chapter 3 is the core of this Deliverable. It first introduces the multi-layered safety assessment criteria catalogue according to the ten categories of transport dimensions detailed in the project's proposal, hence detailing user behaviour, road infrastructure, roadside safety devices, traffic management, enforcement, vehicles, C-ITS, CCAM operations, VRUs, and emergency management meaning and content. Categories' description is followed by a common catalogue of safety performance indicators, which is then summarized and discussed through a matrix visual representation to underline categories interconnections. The final Chapter 4 provides deliverable conclusions.

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2 OVERVIEW OF REGULATORY NORMS AND ACTIVITIES RELEVANT FOR ROAD SAFETY ASSESSMENT ACROSS EU

2.1 SAFE SYSTEM APPROACH IN EU CONTEXT: ROADMAP TO 2030

The Safe System approach to road safety in Europe has been pivotal in guiding policies and operational actions towards reducing road fatalities and serious injuries. Rooted in the Vision Zero philosophy which saw Sweden and the Netherlands as pioneering countries in the 90s', this approach recognizes human error and vulnerability as inevitable and not to be blamed and aims to ensure that all actors involved in road safety take responsibility to build a forgiving, self-explaining, redundant system which will avoid humans to be exposed to unbearable forces in crashes.

During the 2011-2020 Decade of Action several important milestones were achieved, including the definition of the five road safety pillars: road-safety management, safe roads, safe vehicles, safe road user behaviour, and post-crash care [1]. The pillars have been fundamental tools to focus actions and research towards the ambitious Vision Zero targets, allowing for the identification of gaps and the efficient allocation of resources. In 2015, road safety was integrated into the Sustainable Development Goals (SDGs), creating an indissoluble link with climate and social justice considerations [2], opening to numerous long-term implications. Sensibility towards road safety has greatly increased during the decade leading to enhanced legislation and standards, improved road infrastructure, and a basis was formed for a more structured and widely diffused data collection to inform better policies. According to projections, road deaths were expected to reach 1.9 million by 2020 without corrective measures. The Decade of Action in 2011 set the ambitious target of reducing fatalities by 50% of the forecast level by 2020. Subsequently, the SDGs updated the target in 2015 aiming for a 50% reduction in the total number of global deaths and injuries from 2015 to 2020 (about 650000 deaths). The ambitious goal has not been met and data on injuries were insufficient to measure progress by 2020. In Europe the number of road deaths dropped by 36% during the Decade of Action but the peculiarity of 2020 must be taken into consideration, as it showed an unprecedented reduction of 17% on 2019 (4000 deaths less) due to COVID-19 mobility restrictions [3]. Figure 1 summarizes these data, which form the starting point for the new 2021-2030 Decade of Action.

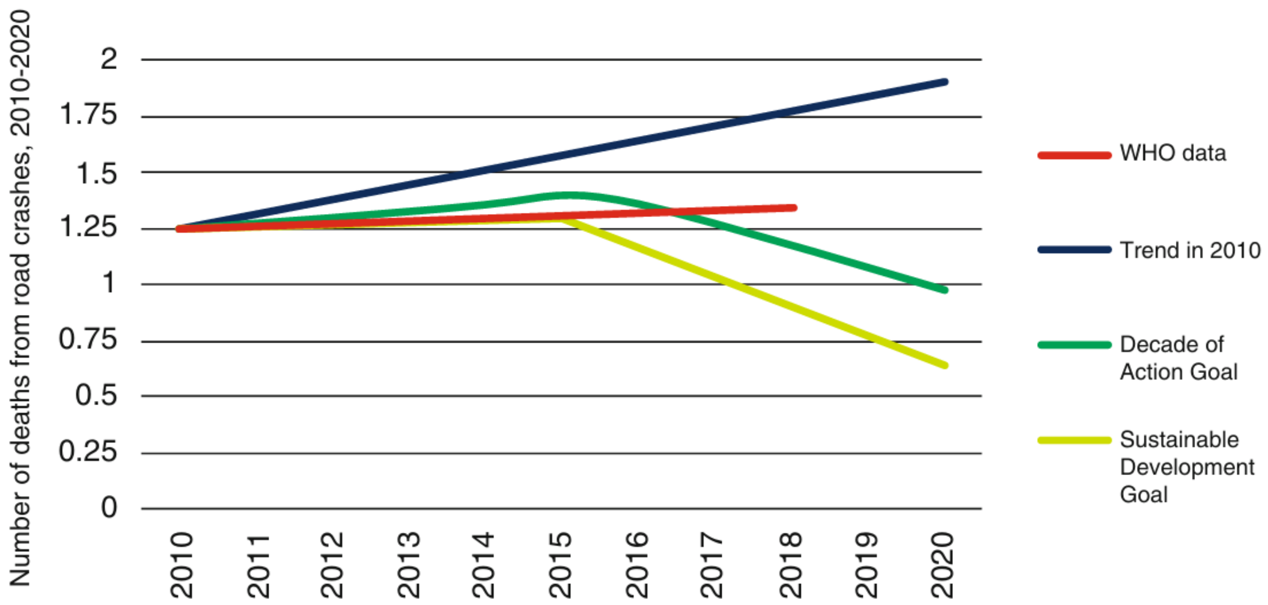

Figure 1 – Results of Decade of Action 2011-2020 [4].

Despite the 2011-2020 targets not being fully reached, the EU Road Safety Policy Framework 2021-2030 sets out even more ambitious goals for the future: to halve the number of road deaths and serious injuries by 2030, ultimately aiming for zero fatalities by 2050. Considering the peculiar 2020 pattern, data from 2019 are usually considered as the reference year for reaching the target. The new decade presents unique challenges that differ from the past. The increasing complexity and ageing of road environments, the integration of new mobility forms, and the rapid growth in digital and automated transport technologies pose both opportunities and risks. Also, the COVID-19 pandemic has influenced traffic patterns and behaviours, leading to new dynamics in road safety management which still persist. One of the critical challenges is addressing the safety of vulnerable road users (VRUs), both in terms of mode of transport and demographic condition. The EU's strategies are increasingly focusing on these groups, as evidenced by initiatives like the "Streets for Life" campaign, which promotes lower speed limits in urban areas to enhance safety for VRUs. Furthermore, the integration of automated and connected vehicles into the existing traffic systems requires comprehensive regulatory frameworks and safety standards, beside a deep infrastructure renovation. The European New Car Assessment Program (Euro NCAP) continues to evolve its protocols to include assessments of automated driving technologies, ensuring they meet high safety standards. Also, further studies are required for vehicles other than cars. Moreover, the harmonization of road safety data collection and analysis remained a critical issue. Different member states used to have varying definitions and methodologies for recording road safety data, making it difficult to compare and assess performance across the EU. In the context of the 2020 Stockholm declaration, following the Third High-Level Conference on Global Road Safety, nine interconnected recommendations were proposed to strengthen the road safety pillars action in realizing the vision of the coming decade [4]:

- *Sustainable practices and reporting*: it emphasizes the importance of integrating sustainability into road safety practices, encouraging the adoption of sustainable business practices, and reporting frameworks to measure the impact on road safety and broader environmental and social goals.
- *Safe vehicles across the globe*: it discusses the need for global vehicle safety standards, promoting the adoption of minimum safety regulations for vehicles worldwide, particularly in low- and middle-income countries, to ensure all road users benefit from advancements in vehicle safety technology.
- *Procurement*: it focuses on leveraging procurement processes to enhance road safety by requiring safer vehicles and equipment. Governments and organizations are encouraged to include safety criteria in their procurement policies to drive demand for safer products.
- *Zero speeding*: it advocates for strict enforcement of speed limits, the implementation of speed management strategies, and the promotion of a culture where speeding is socially unacceptable, as part of a broader effort to eliminate deaths and serious injuries on the road.
- *Modal shift*: it promotes a shift from car-centric transportation to more sustainable and safer modes, such as walking, cycling, and public transport. It highlights the road safety benefits of reducing the number of vehicles on the road and promoting active transportation.
- *30 km/h*: It underscores the importance of implementing 30 km/h speed limits in urban areas to protect vulnerable road users, especially in residential zones and around schools, where lower speeds can significantly reduce the risk of fatal accidents.
- *Child and youth health*: it emphasizes protecting children and young people on the roads by creating safer environments, promoting road safety education, and ensuring vehicles and road infrastructure are designed with their safety in mind.
- *Technology*: it highlights the role of emerging technologies in improving road safety, from advanced driver assistance systems (ADAS) to automated vehicles. It calls for the adoption and regulation of technologies that can prevent crashes and reduce their severity.
- *Infrastructure*: it focuses on designing and maintaining road infrastructure that prioritizes safety, including the development of safe road networks, the implementation of road safety audits, and the use of data to identify and address high-risk areas.

Several key projects and legislative measures have been initiated in the European Union to address the challenges of the 2020-2030 decade and to support the Safe System approach. For example:

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- The revised General Safety Regulation (EU) 2019/2144 mandates advanced safety features in all new vehicles, such as intelligent speed assistance and advanced emergency braking systems. This regulation is expected to significantly enhance vehicle safety and reduce road traffic injuries and fatalities.
- The Network Wide Road Safety Assessment, which comes after the revised directive (EU) 2019/1936, proposes a methodological guide for assessing the road infrastructure safety focusing particularly on highways and major rural roads. The NWRSA methodology comprises reactive (based on accidentality) and proactive (based on infrastructure characteristics) components, along with an integration phase [5].
- The Urban Mobility Framework aims to create safer urban environments through infrastructure improvements, stricter speed limits, and enhanced protection for VRUs. This policy aligns with the broader objectives of the Safe System approach by promoting safer road designs and fostering a culture of safety among all road users.
- Directive (EU) 2015/413 on cross-border exchange of information on road safety-related traffic offenses was established to facilitate the enforcement of road traffic rules across the EU. This directive ensures that offenders can be identified and prosecuted even when traffic violations occur outside their home country, thereby enhancing road safety and reducing violations that lead to accidents.

Additionally, several initiatives have been funded, e.g. under Horizon 2020, to address systematically across the union at different levels of readiness and from different perspectives crucial topics to reach 2030 targets. Particularly, the Baseline and Trendline projects are instrumental in this context.

The Baseline project [2020-2023], launched to establish a comprehensive data collection and analysis system, focuses on identifying the most critical KPIs for road safety and monitoring their progress across member states. This project provides valuable insights into the effectiveness of various safety interventions and supports evidence-based policy-making [18]. It identified 8 KPIs:

- Percentage of vehicles travelling within the speed limit
- Percentage of vehicle occupants using the safety belt or child restraint system correctly
- Percentage of riders of powered two wheelers and bicycles wearing a protective helmet
- Percentage of drivers driving within the legal limit for blood alcohol content (BAC)
- Percentage of drivers not using a handheld mobile device
- Percentage of new passenger cars with a Euro NCAP safety rating equal or above a predefined threshold
- Percentage of distance driven over roads with a safety rating above an agreed threshold
- Time elapsed in minutes and seconds between the emergency call following a collision resulting in personal injury and the arrival at the scene of the collision of the emergency services

The 18 member states participating in the Baseline project were required to deliver at least 5 of the 8 KPIs, to create an initial common database. The Trendline project [ongoing], on the other hand, aims to build on the findings of Baseline by implementing targeted interventions in pilot sites across Europe and developing new KPIs to integrate the previous eight, while continuing monitoring the 8 initial KPIs among participants (25 member states). By testing innovative safety measures and technologies in real-world settings, Trendline seeks to validate effective strategies that can be scaled across the EU [19]. This project addresses the need for dynamic and adaptable safety solutions that can respond to evolving traffic conditions. The new KPIs proposed by Trendline are:

- Driving under the influence of drugs
- Share of 30km/h road lane lengths in urban zones
- Red-light negations by road users
- Compliance with traffic rules at intersections
- Helmet wearing of PMD riders
- Self-reported risky behaviour
- Attitudes towards risky behaviour
- Use of lights by cyclists in the dark
- Enforcement of traffic regulations
- Alternative speeding indicators

Besides, Baseline and Trendline, several other projects have been funded over the years, for example:

- JUST STREETS has as main goal promoting safer and more sustainable urban environments to prioritize pedestrians, cyclists, and public transport. The goal of the project is to create more accessible public spaces, fostering healthier communities and reducing environmental impacts through improved urban planning and infrastructure design.
- SOTERIA main goal was to develop a holistic framework of innovative models, tools and services enabling data driven urban safety intelligence, easing safe travelling of VRUs and fostering the safe integration of micro-mobility services in complex environments.
- RONDA main goal was to develop a data-driven framework, pattern recognition techniques and low-cost sensor technologies (vehicle-mounted cameras, inertial sensors, etc.) for the detection, classification and georeferencing of roadway pavement surface anomalies.

Despite the important progresses towards safer roads for all road users, available trends of the past few years show a concerning situation, with increased incidents and fatalities since 2020, see Figure 2 and Figure 3. Even if absolute values show improvements with respect to 2019, this is not enough to reach 2030 targets.

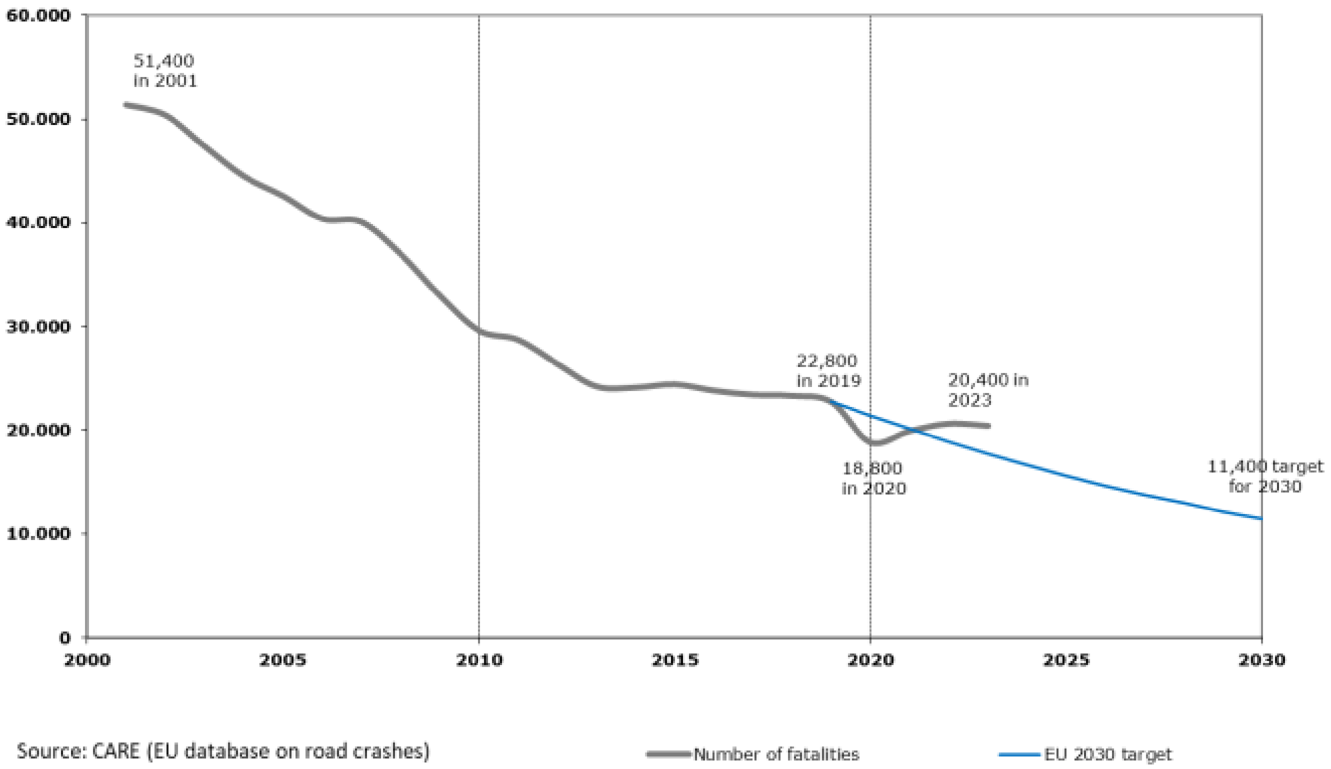

Figure 2 – Decade of Action 2021-2030 European middle term trends [6].

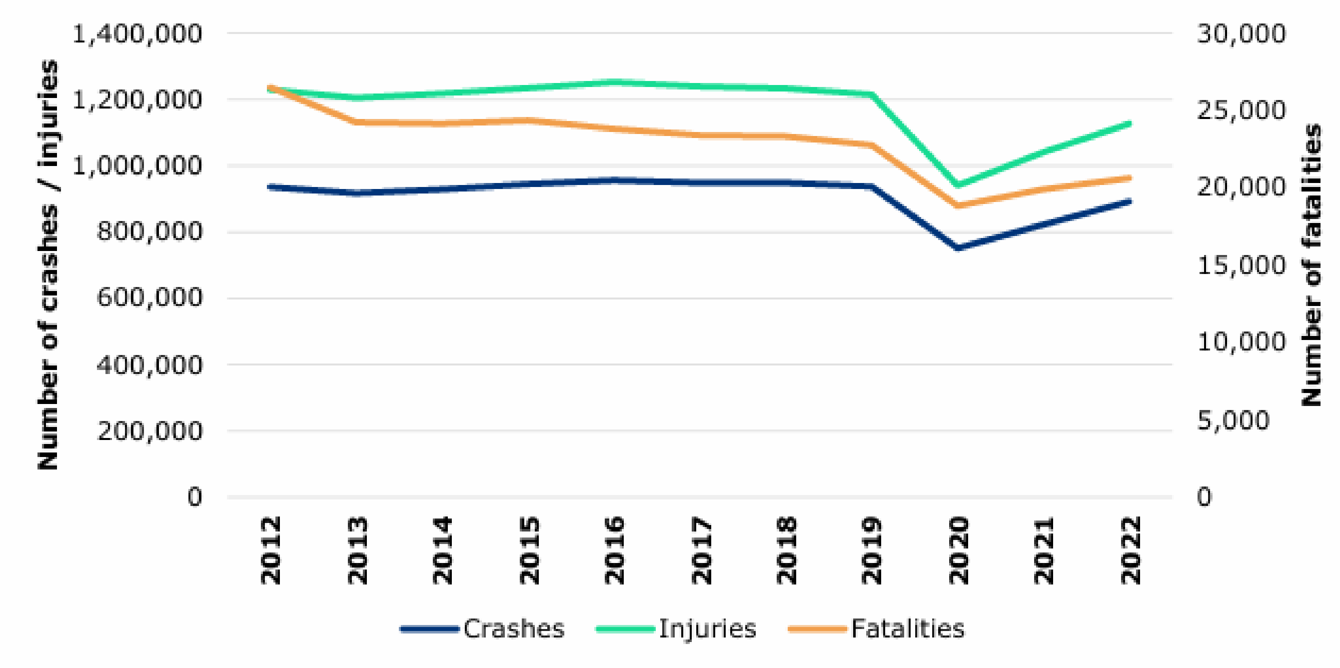

Figure 3 – Decade of Action 2021-2030 European middle term trends [7].

The following sections focus on norms, trends and Safe System approach evolution in the four EvoRoads pilots, and on global best practices. For each pilots' country an excursus on main authorities responsible for road safety management is presented, together with most recent national legislation which is directly impacting the monitoring of safety performance indicators across diverse transport dimensions. A particular focus is given to the infrastructure, which will be the main focus in the EvoRoads project. Focusing on legislation and authorities cannot give a complete vision on traffic safety actual conditions in the pilots' countries, neither on how deep the Safe System vision is rooted at different levels of society. However, it sets the legal framework on which it is currently possible to act and in which new methodologies could be organically integrated.

2.2 REGULATORY NORMS AND ACTIVITIES RELEVANT FOR ROAD SAFETY ASSESSMENT IN ITALY

In Italy, the responsibility for road safety is primarily managed by the Ministry of Infrastructure and Sustainable Mobility, specifically through its Directorate for Road Safety. This Ministry oversees the development and implementation of national road safety policies. At a more localized level, the responsibility is divided among various regional, local and private road authorities, depending on the type of road. For example, Autostrade per l'Italia and ANAS S.p.A. are responsible for the maintenance and safety of highways and major roads, while regional and municipal authorities manage the safety of rural and urban roads. Additionally, the police forces (including the Carabinieri and Polizia Stradale) are tasked with enforcing traffic laws and regulations, ensuring compliance with safety measures across all road types. The operations centres of the Carabinieri are responsible for handling the 112 emergency calls. The National Institute of Statistics (ISTAT) instead plays a crucial role in collecting and analysing road safety data, particularly regarding injury crashes on a national scale.

Italy's national Highway Code, the "Codice della Strada", is the primary legislation that governs road safety, traffic rules, and infrastructure standards. Established in 1992 (Decreto Legge 285/1992), it has been regularly updated to address emerging safety challenges and technological advancements. Furthermore, Italy's AINOP (Archivio Informatico Nazionale delle Opere Pubbliche) plays a central role in road safety management. Established as a digital archive for public works, AINOP provides comprehensive data on road infrastructures, bridges, tunnels, and other public assets, allowing for better oversight of safety measures. It also supports the regulation of exceptional transports, which is governed by specific permits that ensure infrastructure can safely accommodate oversized vehicles.

With the goal of enhancing coordination among various stakeholders, a national consultation structure has been established. A significant development in this area was the creation of the National Agency for Road Safety and Rail Infrastructure (ANSFISA) on January 1, 2019. ANSFISA is dedicated to overseeing and improving infrastructure safety across the country, with a particular focus on roads and railways. This agency also monitors compliance with safety standards and is responsible for proposing and implementing measures to reduce accidents and improve the overall safety of road infrastructure [9].

Among the latest and most significant strategic plans and legislations approved in Italy in recent years, with a particular focus on road infrastructure, there are:

- *Piano Nazionale della Sicurezza Stradale (PNSS) 2030*

The National Road Safety Plan (PNSS) 2030 is a strategic framework designed to significantly reduce road fatalities and injuries, with the goal of halving road deaths by 2030 and achieving "Vision Zero" by 2050, in line with European guidelines. The plan is built on the Safe System approach, which prioritizes road safety management, safer roads, safer vehicles, safer road users, and post-crash care. Key elements include setting specific targets for vulnerable road users, such as pedestrians, cyclists, motorcyclists, children, and the elderly, and identifying the main risk factors for each group. The plan emphasizes the importance of intermediate targets at three-year intervals, allowing for the assessment and adjustment of safety measures over time. It also outlines a series of five implementation plans, starting in 2022, to detail specific actions and policies to be enacted throughout the decade. The strategy underscores the role of infrastructure improvements, vehicle safety enhancements, and educational campaigns in fostering safer driving behaviors across Italy. The 2022 Implementation Plan should have already been executed, but as of 2024, there have been no official updates [13].

- *Decreto Legge n.35 15/03/2011*

Italy has issued guidelines pursuant to art. 8 of the Legislative Decree n.35/2011 implementing the Directive 2008/96/CE on the management of road infrastructure safety in order to establish a guidance to coordinate and standardize the activities of all those involved in road safety, including local authorities, competent bodies, road owners and operators and road safety experts, the project controllers and road inspectors. The guidelines aim to provide a tool for identifying procedural arrangements for road safety analysis and all other activities related to the road network classification process. Moreover, they establish criteria and procedures for conducting road safety checks on projects, performing safety inspections on existing infrastructure, and implementing the process for classifying road network safety.

- *Decreto Legge n. 213 15/11/2021*

This decree represents a significant update and expansion of the existing legal framework governing road safety in Italy. This decree, which aligns Italian law with the updated European Directive 2019/1936 (which modifies the Directive 2008/96/CE), builds upon the previous Legislative Decree No. 35/2011, by extending the scope of road safety management to a broader range of roads and introducing more stringent requirements for infrastructure safety assessments. It broadens the scope to include not only roads that are part of the Trans-European Transport Network (TEN-T), but also other major roads that serve critical infrastructure needs. Specifically, it mandates the application of safety management practices to roads outside urban areas that have not been primarily intended to serve adjacent public or private areas and have benefited from European Union funding. This inclusion reflects a more comprehensive approach to road safety, acknowledging the importance of these roads in the national transport infrastructure. One of the significant additions in the 2021 decree is found in Article 1, Paragraph 6, which stipulates that by December 31, 2024, regions and autonomous provinces must establish regulations for managing the safety of regional and local road infrastructures that fall outside the scope of national-level oversight, especially if they have been fully or partially financed by EU resources. This deadline compels local authorities to align their road safety management practices with the broader principles set forth in the decree, ensuring a uniform approach across all levels of road infrastructure.

The decree enhances the regulatory framework by setting forth detailed requirements for road safety audits and inspections. These must be conducted periodically — at least once every five years — for the roads covered under the decree. These audits and inspections are intended to identify potential safety hazards and implement corrective measures to mitigate the risk of accidents. Furthermore, it introduces the concept of network-wide safety assessments [5], which require a comprehensive evaluation of the entire road network's safety, considering both the likelihood of accidents and the potential severity of their impacts. This approach is designed to prioritize safety interventions on the most critical sections of the road network, thereby maximizing the effectiveness of safety measures.

- *Decreto Legge 1/04/2019*

The decree focuses on motorcycle road safety devices (DSM) establishing detailed regulations for the installation and testing of protective barriers specifically designed to enhance motorcyclist safety. It mandates that these devices comply with the UNI CEN/TS 1317-8 standard, which outlines the required performance levels, testing procedures, and installation criteria for DSMs. It specifies that DSMs must be installed on discontinuous barriers in high-risk areas, such as curves with a radius smaller than 250 meters, to prevent motorcyclists from colliding directly with hazardous barriers in the event of an accident.

The decree also includes provisions for the installation of DSMs on both new and existing barriers, ensuring that they meet safety standards. It requires technical assessments and crash tests conducted by accredited laboratories to verify compliance. Additionally, it sets guidelines for contractors and road authorities on proper installation and post-installation verification processes, emphasizing the importance of ensuring the correct placement and functioning of these safety devices.

- *Decreto Legge 4/08/2017 and Decreto legge n. 257 16/12/2016, art. 3 comma 7*

The Decree of August 4, 2017, issued by the Ministry of Infrastructure and Transport (MIT), sets guidelines for the development of Urban Sustainable Mobility Plans (PUMS) across Italy. These guidelines are in accordance with Article 3, Paragraph 7, of Legislative Decree No. 257 of December 16, 2016, and require metropolitan cities, regional entities, and municipalities with populations over 100000 to develop and adopt PUMS within 24 months of the decree's enactment. The guidelines include: a uniform procedure for drafting and approving PUMS; identification of reference strategies, macro and specific objectives, and actions that help implementing these strategies; indicators for assessing the achievement of PUMS objectives.

The approach is based on the 2014 “Guidelines. Developing and Implementing a Sustainable Urban Mobility Plan” approved by the European Commission’s Directorate-General for Mobility and Transport. This decree aims to standardize urban mobility planning across Italy, ensuring that the plans align with national and European sustainability goals. Hierarchically, the order of mobility planning tools at the municipal level in Italy is as follows: 1. Piano Urbano della Mobilità Sostenibile (PUMS): which is a strategic, medium-to-long-term plan addressing complex mobility issues requiring investments, financial resources, and the implementation of integrated urban policies; 2. Piano Urbano del Traffico (PUT): which is a short-term plan focused on optimizing existing infrastructure without assuming new investments. Hence, PUMS and PUT are interconnected, with the PUMS setting broader strategic objectives and the PUT managing the current infrastructure to meet immediate needs.

- *Decreto Legge n. 76 16/07/2020*

The Legislative Decree 76/2020 introduces numerous regulations across various sectors. Among them, it includes several amendments to the Italian Codice della Strada (Legislative Decree 285 of 1992), with a focus on enhancing bicycle infrastructure, facilitating the use of electric vehicles, and updating traffic enforcement measures.

Concerning *bicycle infrastructure improvements*, art. 49 builds upon previous measures introduced in May 2020 under the Growth Decree, which had begun incorporating urban planning tools to support cycling, such as the concept of "bike lanes" and "advanced stop lines". The new decree further refines these concepts: i.) Bike Lanes: the definition of bike lanes is tightened to ensure they are properly designated. Previously described as "a longitudinal part of the roadway, on the right, marked with a discontinuous white line and suitable for bicycles", the revised definition now specifies that bike lanes can be marked with either continuous or discontinuous lines, and they must be reserved exclusively for bicycles; ii.) Two-Way

Bike Lanes: new regulations allow for the creation of bike lanes in one-way streets, enabling cyclists to travel in the opposite direction of motor vehicles; iii.) Access to Bus Lanes: municipalities can now allow bicycles to use bus lanes. However, this is restricted to streets where sufficient width is available and does not apply on streets with tram tracks.

Concerning *electric vehicles*, art. 57 requires municipalities to establish at least one electric vehicle (EV) charging point per 1000 inhabitants within six months of the decree's implementation. This should result in up to 60000 new charging points across Italy, significantly increasing the availability of charging infrastructure. Additionally, the Italian Regulatory Authority for Energy, Networks, and Environment (ARERA) will define charging tariffs, which are expected to lower costs.

Concerning *speed cameras*, the decree expands the use of speed detection devices to all types of roads, including urban roads, while previously they were mostly restricted to highways and rural roads. New speed cameras must be approved by the local prefecture before installation.

- *Decreto Ministeriale n. 578 17/12/2020 and n.204 01/07/2022*

It provides guidelines for the classification and management of risk, safety assessment, and monitoring of existing bridges. Published by the Ministry of Infrastructure and Sustainable Mobility, this decree outlines a comprehensive framework for ensuring bridge safety. It establishes standardized criteria and procedures for classifying the risk associated with existing bridges. It details methods for evaluating the safety of these structures, including regular inspections and assessments to identify potential issues. Additionally, it sets guidelines for ongoing monitoring to ensure that bridges remain safe throughout their lifecycle.

An important update, introduced in July 2022 with Decree n. 204, further strengthened the provisions by mandating stricter guidelines for the assessment of bridge safety. This included enhanced criteria for identifying at-risk structures, the application of real-time monitoring technologies, and the requirement for more frequent inspections, especially in high-traffic or environmentally sensitive areas.

2.3 REGULATORY NORMS AND ACTIVITIES RELEVANT FOR ROAD SAFETY ASSESSMENT IN SPAIN

In Spain, road safety is primarily managed by the General Directorate for Traffic (DGT), which operates under the Ministry of the Interior. The DGT is the central agency responsible for developing and implementing national road safety policies. It oversees all interurban roads across the country, apart from the *Basque Country*, *Navarra* and *Catalonia*, where regional authorities have specific responsibilities. The DGT has several key roles, including issuing and renewing driving licenses and vehicle authorizations, and regulating and licensing private driving schools. It also manages traffic control and the enforcement of traffic laws on interurban roads, coordinating closely with the Traffic Division of the Civil Guard, dedicated to traffic law enforcement and monitoring. In addition to these core functions, the DGT centralizes road traffic statistics and coordinates accident investigations. It is responsible for developing and implementing road safety strategies and policies, working in collaboration with other relevant ministries and public bodies. An important document called “Recomendaciones para la mejora de la Seguridad Vial en entornos interurbanos” published in 2021 by DGT presents a list of technologies and road elements that could improve road safety. They are reported in the catalogue below. The DGT also oversees public education campaigns on road safety and driving information to ensure that the public is well-informed about traffic laws and safe driving practices [10].

Other authorities and organizations also play important roles in road safety and infrastructure management in Spain. The General Directorate of Roads (DGC), that belongs to the Ministry of Transport and Sustainable Mobility, is responsible for planning, constructing, and maintaining the State Road Network (Red de Carreteras del Estado), which includes 26.473 km of public motorways and accounts for 52.5% of total traffic. Regional authorities are also involved in road safety management. While the DGT handles national-level policies and enforcement, regional and local authorities manage specific local responsibilities, such as maintaining urban and rural roads.

Funded by the European Union

Among the latest and most significant strategic plans and legislations approved in Spain in recent years, there are:

- *Ley 18/1989, de 25 de julio*

The document outlines the legal framework for road safety and traffic regulations in Spain. It seeks to promote safe driving and prevent accidents both on roads and in urban areas. The law defines the distribution of responsibilities between the different levels of government for traffic regulation and road safety.

The law mandates the alignment of traffic regulations with international standards. It sets rules for safe driving, including the obligation for drivers to avoid substances that impair driving ability and adhere to safety measures. Road signs must conform to the standards established by international conventions. Specific activities, such as driving and teaching driving skills, require prior administrative authorization. The law also covers the assessment of drivers' physical and psychological fitness. The law allows for preventive measures to be taken when there is a serious threat to road safety. This includes the suspension of driving licenses and the impounding of vehicles under certain conditions.

Traffic violations are categorized as minor, serious, or very serious, with corresponding fines and penalties. Serious and very serious infractions can result in fines, suspension of driving licenses, or other penalties. The law specifies a range of offenses, including negligent or reckless driving, driving under the influence, speeding, and more. The law outlines a streamlined procedure for imposing penalties for traffic violations. It emphasizes the importance of due process, including the right to be heard before a penalty is imposed. It also defines the role of authorities in reporting and documenting traffic violations.

- *Real Decreto 345/2011, de 11 de marzo*

The document outlines various aspects of road safety management for the State Road Network in Spain. The goal is to achieve a high and uniform level of safety on the highways and other major roads. It details the requirements for assessing the impact of road infrastructure on safety during the planning phase. This includes both qualitative and quantitative analysis to ensure that new roads or substantial modifications to existing roads consider safety impacts. The decree sets out procedures for the continuous evaluation and management of road safety on roads in service, even during the different phases of design and construction. Inspections are mandated to detect hazardous conditions, and specific corrective actions are planned based on these inspections.

Special consideration is given to vulnerable road users, such as pedestrians, cyclists, and motorcyclists. Vulnerable road users are given priority in safety planning. VRUs should be separated from high-speed motor traffic whenever possible, either through dedicated lanes, barriers, or alternative routes. Proper placement and safety measures for pedestrian crossings and bicycle paths have to be considered as well.

The decree mandates the collection and management of data related to road accidents and infrastructure safety. This data is used to calculate the social costs of accidents and guide safety improvements.

- *Real Decreto Legislativo 6/2015, de 30 de octubre*

The document establishes the rules and regulations related to traffic, circulation, and road safety. Drivers and vehicle owners must comply with established traffic rules, including speed limits, use of lanes, overtaking, parking, and other behaviors critical to road safety. There are specific provisions concerning the use of alcohol and drugs by drivers, setting limits and enforcement protocols to reduce road incidents. Special rules govern the transportation of goods, including hazardous materials, to ensure safety on the roads.

The law details the criteria for road signs and signals to ensure consistent communication to road users and maintain safe road environments. It defines the types of infractions (minor, serious, and very serious) and the corresponding penalties, including fines, loss of points on the driver's license, and other sanctions. The legislation emphasizes the importance of road safety education and training, including specific programs for professional drivers and awareness campaigns for the public.

- *Ley 18/2021, de 20 de diciembre*

The document contains a comprehensive overview of Spain's updated road safety rules and regulations, specifically focusing on the amendments made to the law on traffic, vehicle circulation, and road safety.

The document discusses the point-based driving license system. Points are deducted for various infractions, such as using a mobile phone while driving, not wearing a seatbelt, or driving under the influence of alcohol or drugs. It emphasizes the importance of stricter compliance with traffic regulations, particularly concerning speed limits, distractions (such as mobile phone use), seatbelt usage, child restraint systems, and helmet usage.

The legal modification removes the allowance for cars and motorcycles to exceed speed limits by 20 km/h when overtaking on conventional roads. Increased penalties for not using seatbelts, child restraint systems, or helmets correctly. These are critical components for ensuring safety. Driving with a blood alcohol level above the legally defined limit, especially for minors and professional drivers, is strictly prohibited.

Provisions are included for the regulation of automated and autonomous driving systems, highlighting the need for new legal frameworks as these technologies become more prevalent.

The new law encourages safe and efficient driving courses, allowing drivers to regain points. These courses aim to re-educate drivers on safer driving practices and promote better driving habits. Special attention is given to protecting VRUs, including pedestrians and cyclists. The document outlines stricter regulations on overtaking cyclists, ensuring a minimum distance and prohibiting any overtaking that could endanger cyclists.

- *Orden Circular 39/2017*

In this document, the General Directorate of Roads establishes that the management of safety in the state's road infrastructure will be carried out by its various sub-directorates, as provided for in current regulations. Safety audits in the initial service phase will be the responsibility of the conservation sub-directorate, while the exploitation sub-directorate will coordinate the training of auditors. Additionally, new guidelines for conducting road safety audits are approved, repealing the previous ones and also compiled in this document.

- *Orden Circular 30/2012*

In this document, the General Directorate of Roads approves, at the proposal of the General Subdirectorate of Operation and Network Management, a series of guidelines for the evaluation and management of safety on the state road network. These include procedures for impact assessment, safety audits, management of sections with a concentration of accidents, safety inspections, and a training program for auditors. The General Subdirectorate will be responsible for implementing these procedures, which are compiled in this document.

2.4 REGULATORY NORMS AND ACTIVITIES RELEVANT FOR ROAD SAFETY ASSESSMENT IN LATVIA

The Ministry of Transport is responsible for developing, organizing, and coordinating sectoral policies in Latvia, including as subdivisions road infrastructure, road transport, and traffic safety. The Road Transport Department within the Ministry handles matters related to road transport, while the Public Transport Services Department oversees road transport and public transport. The sector's development aligns with the "National Development Plan for 2021-2027" and the "Guidelines for the Development of the Transport System for 2021-2027", which outline the progress of road infrastructure, transport, and traffic safety. To improve road safety and reduce traffic-related fatalities and injuries by 50% by 2030 compared to 2020, the Ministry of Transport has established the "Road Traffic Safety Plan for 2021-2027" [11]. The Road Traffic Safety Directorate (CSDD) monitors its implementation, which includes preventive measures, public awareness campaigns, infrastructure enhancements, and effective responses to accidents [12].

The construction, repair, and management of state road infrastructure fall under the purview of the State-Owned Limited Liability Company (SLLC) “Latvian State Roads.” This company manages the state road network, administers the State Road Fund, and handles public procurement to ensure a safe, durable, and eco-friendly road system, adhering to road safety standards. Additionally, it issues permits for oversized and overweight cargo transportation. Since July 1, 2014, Latvia has required heavy goods vehicles exceeding 3000 kilograms, and combinations with a total weight over 3500 kilograms, to pay a road user charge, known as the "vignette," for using the main state road network and certain regional roads. This electronic vignette can be purchased online or at select gas stations, with options varying in duration and cost depending on the vehicle's ecological standards and weight.

The Road Transport Administration, a state limited liability company, executes national policies concerning international transport and the licensing of commercial road transport. It oversees market access, issues licenses and permits for both domestic and international road transport and ensures compliance with regulatory requirements. This administration also actively participates in international discussions on road transport permits and works towards maintaining a competitive, safe, and sustainable public transport system.

To promote public transport over private vehicle use, the Ministry of Transport, along with the Road Transport Administration, has developed a public transport strategy for 2021-2030. This strategy emphasizes railways as the core of the transport system, complemented by buses, and includes plans for state-subsidized routes, free public transport on selected routes, and overall improvements to the public transport network.

Among the latest and most significant strategic plans and legislations approved in Latvia in recent years, there are:

- *Impact Assessment of the Road Traffic Safety Plan 2017-2020*

The impact assessment of the Road Traffic Safety Plan 2017-2020 evaluates how effectively the plan's goals were met.

Reduction in Traffic Accidents: The assessment reveals mixed results in terms of reducing the overall number of traffic accidents. While there was some progress, the targets for reduction in the total number of accidents were not fully achieved. The number of serious accidents and fatalities did see a decline, but not to the extent projected by the plan.

Improvement in Road Safety for VRUs: The plan aimed to enhance safety for vulnerable road users, including pedestrians and cyclists. The assessment indicates moderate success in this area. Improvements were noted in infrastructure and safety measures specifically designed for these groups, but challenges remain, particularly in urban areas where high pedestrian and cyclist traffic is prevalent.

Effectiveness of Measures: Several specific measures implemented, such as infrastructure upgrades, educational campaigns, and enforcement activities, showed positive impacts. For example, the introduction of speed cameras and better road signage contributed to a decrease in speeding violations. However, some measures, such as certain infrastructure projects and safety campaigns, did not fully meet their anticipated outcomes due to various delays and implementation issues.

- *Road Traffic Safety Plan for 2021-2027 – 10/2021*

It aims to enhance road safety with the primary objective of reducing road traffic fatalities and serious injuries by 35% by 2027 compared to 2020. This aligns with broader European goals, including the "Vision Zero" initiative, which seeks a 50% reduction in such incidents by 2030. The plan outlines three main areas of focus:

Safe Road Users: This includes educational campaigns, stricter enforcement of traffic laws, and promoting safer driving behaviours. Key initiatives involve targeting high-risk groups like young drivers and vulnerable road users, such as pedestrians and cyclists. Efforts will be made to reduce driving under the influence of alcohol or drugs, and distracted driving, particularly the use of mobile phones while driving.

Safe Vehicles: Latvia plans to improve vehicle safety by ensuring that cars on the road meet high safety standards. This includes promoting the use of modern vehicles equipped with advanced safety features like electronic stability control and pedestrian protection systems. The plan also encourages the regular technical inspection of vehicles to ensure they remain safe to operate.

Safe Infrastructure: Significant investments will be made in road infrastructure to reduce accident risks. This includes constructing safer roads, improving existing road conditions, and designing infrastructure with a focus on the safety of vulnerable users. For example, the plan includes measures to enhance pedestrian crossings, create safe cycling lanes, and implement traffic calming measures in high-risk areas. The state-owned company "Latvian State Roads" will oversee these infrastructure projects.

The plan emphasizes the importance of coordinated action among various governmental and non-governmental entities, with a total projected budget of EUR 19 million over the seven-year period. This funding will be allocated to different safety initiatives, with some contributions from European Union funds. Additionally, the plan includes specific targets and deadlines for implementing these measures, with progress monitored by the Road Traffic Safety Directorate.

2.5 REGULATORY NORMS AND ACTIVITIES RELEVANT FOR ROAD SAFETY ASSESSMENT IN ROMANIA

In Romania, the key authority responsible for road safety is the Romanian Road Authority (Autoritatea Rutieră Română, ARR), operating under the Ministry of Internal Affairs. The ARR handles crucial tasks such as issuing and renewing driving licenses, vehicle registration, and enforcing vehicle safety standards. It also plays a significant role in developing and implementing national road safety policies, coordinating infrastructure improvements, and running public awareness campaigns. The Romanian Police Traffic Department, part of the National Police, enforces traffic laws, monitors road conditions, and investigates traffic accidents. This department collaborates closely with the ARR to ensure compliance with safety regulations and addresses traffic violations. Additionally, the department conducts roadside checks and manages emergency responses to traffic incidents. The Romanian National Institute of Statistics (Institutul Național de Statistică, INS) provides essential data on traffic patterns and accident rates, helping to inform policy decisions and shape road safety strategies.

The National Company of Highways and National Roads of Romania (Compania Națională de Administrare a Infrastructurii Rutiere, CNAIR) is responsible for the maintenance, management, and development of the national road network, including highways and major roads. CNAIR ensures that road infrastructure meets safety standards and efficiently implements infrastructure projects to enhance road safety. Local authorities also play a crucial role in managing and maintaining local roads and implementing tailored road safety measures.

In addition to road safety, the number of incidents involving trains and vehicles in Romania is a significant concern. According to recent statistics, Romania experiences a higher frequency of train-vehicle collisions compared to many other European countries. This is attributed to a combination of factors including the age and condition of railway crossings, as well as issues with the visibility and signaling systems at level crossings. The Romanian Railway Safety Authority (Autoritatea Feroviară Română, AFER) oversees the safety of rail transport. AFER regulates railway operations, ensures compliance with safety standards, and monitors the condition of railway infrastructure.

Among the latest and most significant strategic plans and legislations approved in Romania in recent years, there are:

- *Legea 265-2008*

This law outlines the rules for managing road traffic safety on Romania's road infrastructure, including national and European networks. Key rules include road safety impact assessments, which are mandatory evaluations during the design phase of new road projects to identify and mitigate safety risks, road safety audits, that are required safety reviews at multiple stages of road projects, periodic road safety inspections, to identify and address safety hazards, auditor certification and compliance and reporting, meaning that authorities must follow EU standards, regularly update safety procedures, and report findings to the Ministry of Transport and the European Commission.

- *Legea 92-2007*

This law governs public passenger transport services within administrative-territorial units in Romania. It provides a comprehensive legal and institutional framework for establishing, organizing, authorizing, managing, financing, operating, monitoring, and controlling public transportation services at the local and county levels. Regarding road safety, it deals with emergency preparedness, as operators are required to have emergency response plans in place and coordination with emergency services, to ensure a swift and effective response. Moreover, public transport services are encouraged to provide passengers with information on safety practices, such as the proper use of seat belts (if available) and emergency procedures. Local authorities are also encouraged to conduct public safety campaigns to educate both drivers and passengers on the importance of road safety and safe behavior on public transport.

Funded by the European Union

- *OG 27*

This document is a Romanian government ordinance that outlines the regulations and legal framework for road transportation. It includes provisions regarding the safe use of road infrastructure, such as proper route planning, adherence to traffic rules, and the correct use of road signs and signals.

For passenger transport services, there are additional safety regulations. These include requirements for vehicle equipment, such as seat belts, emergency exits, and first aid kits. Passenger transport operators must also ensure that drivers and other staff are adequately trained in safety protocols and emergency procedures.

The document outlines the role of regulatory bodies in monitoring and enforcing road safety standards. This includes regular inspections, audits, and penalties for non-compliance with safety regulations.

Transport operators are required to report detailed information of any accidents involving their vehicles to the relevant authorities, that are tasked with analyzing accident data to identify patterns and recommend safety improvements.

- *OG 43*

The document governs the regulations concerning roads in Romania. It aims to ensure the safe and efficient functioning of road networks, including construction, maintenance, and modernization. The ordinance emphasizes the importance of maintaining roads in a condition that ensures the safety of all users, including vehicles, pedestrians, and cyclists. This involves regular maintenance, repair, and modernization activities to address any damage or wear that could pose safety risks. Road safety is integrated into the design and construction standards set out in the ordinance. It specifies that roads must be designed and constructed following technical norms that prioritize safety, including proper road width, curvature, signage, and lighting. The document mandates the installation and maintenance of various safety features along roadways, including guardrails and barriers, pedestrian crossings, traffic signs, signals and lighting.

The ordinance outlines the responsibilities of various road authorities in maintaining road safety through regular inspections, maintenance, and repairs. It requires that any damage or wear that could compromise safety, such as potholes or damaged barriers, be promptly addressed. Provisions are made for the rapid response to road incidents and accidents. The document stresses the importance of having a coordinated approach between road administrators, emergency services, and law enforcement to manage road safety effectively. It discusses measures for managing traffic flow to enhance safety, including traffic calming measures in high-risk areas and implementing speed limits based on road type and conditions.

Safety of non-motorized road users, such as cyclists and pedestrians, is also covered. It requires the creation of dedicated lanes or paths for cyclists and pedestrians, especially in urban areas, to separate them from vehicular traffic and reduce accident risks. While focusing primarily on infrastructure, the document also implicitly touches on the responsibility of road users to adhere to traffic laws and signals to maintain safety.

- *Ordonanta 12*

The document primarily focuses on railway transport. Within the context of railway operations, it does address certain aspects related to safety. The ordinance outlines the responsibilities of railway transport operators and infrastructure managers in ensuring the safe operation of railway services. This includes maintaining and managing railway infrastructure to meet safety standards and ensuring that railway vehicles are operated safely.

The document specifies adjacent services that are essential for maintaining safety in railway transport, including emergency train services, technical inspections, and checks of brake systems. Railway transport is defined as an essential public service that must support safe and efficient movement of people and goods, reducing risks and preventing accidents. It requires railway operators and infrastructure managers to adhere to strict safety standards to ensure the protection of passengers, goods, and railway staff.

- *Ordonanta 49*

This document regulates alternative transportation activities involving cars and drivers mediated through digital platforms in Romania. Its rules are designed to ensure that alternative transport services operate in a safe, secure, and regulated environment. By setting strict requirements for drivers, vehicles, digital platforms, and operational oversight, the ordinance aims to protect passengers, promote responsible driving behavior, and minimize the risk of accidents.

- *OUG 195*

The document outlines regulations and measures to ensure road safety in Romania. It aims to ensure the safe and smooth flow of traffic, protect life, bodily integrity, and health of traffic participants, safeguard public and private property, and protect the environment. The road administrator or contractor, with the approval of the traffic police, is responsible for installing signs and other special devices, applying markings on public roads, and maintaining them in proper condition. They also must ensure the installation, maintenance, and verification of road signs in accordance with current standards. There are specific requirements for the installation of resonant road markings and traffic calming devices in high-risk areas, before entering localities, pedestrian crossings, and railway crossings. Special provisions are included for controlling traffic near border areas and other restricted zones.

Overall, the document emphasizes the responsibilities of various authorities and entities in maintaining road safety, the importance of proper road signage and markings, and the need for coordination with the traffic police to ensure safe and efficient road traffic management.

2.6 REGULATORY NORMS AND ACTIVITIES RELEVANT FOR ROAD SAFETY ASSESSMENT IN OTHER COUNTRIES

European countries have long been at the forefront of road safety and sustainable mobility, employing various strategies aligned with the Safe System approach. While Latvia, Italy, Romania, and Spain have unique challenges and solutions, other countries such as Sweden, the Netherlands, Germany, and France have also implemented pioneering initiatives to reduce road fatalities and improve road safety.

2.6.1 SWEDEN

Sweden is the pioneer of the *Vision Zero* strategy, launched in 1997, which serves as a foundation for the Safe System approach across Europe. Sweden's road safety initiatives aim to eliminate fatalities and serious injuries on the road by building a forgiving road environment that compensates for human error.

Key initiatives include:

- *Road Design and Infrastructure*: Sweden prioritizes designing roads that reduce the severity of crashes, such as 2+1 roads with median barriers, which have been effective in reducing head-on collisions on rural roads.
- *Urban Safety Measures*: Lowering speed limits in urban areas and near vulnerable road users is a central component. Many urban zones have 30 km/h speed limits, which have drastically reduced pedestrian fatalities.
- *Cycling Safety*: Sweden has developed dedicated cycling infrastructure and implemented a strategy focused on protecting cyclists through separated lanes and safe intersection designs.
- *Integration of Technology*: The use of ITS, such as automatic speed enforcement cameras and real-time traffic management systems, plays a crucial role in maintaining road safety standards.

2.6.2 THE NETHERLANDS

The Netherlands is renowned for its *Sustainable Safety Vision*, a systematic approach that integrates road safety into every aspect of urban planning and transport policy.

Key initiatives include:

- *Safe Road Infrastructure*: The Netherlands classifies roads into three categories—through roads, distributor roads, and access roads—each with distinct design and speed limit specifications to minimize conflict points.
- *Cycling Infrastructure*: The Netherlands has the most advanced cycling infrastructure in the world. Cycle paths are separated from motorized traffic, and bicycle priority lanes are standard at intersections. This infrastructure has made cycling one of the safest and most popular modes of transport in the country.
- *Proactive Measures*: The use of roundabouts instead of signalized intersections has been instrumental in reducing severe accidents. Additionally, road safety audits and inspections are regularly conducted to identify and mitigate risks proactively.

2.6.3 GERMANY

Germany's road safety policies are characterized by a mix of engineering, enforcement, and education, focusing heavily on data-driven approaches.

Key initiatives include:

- *Infrastructure Upgrades*: Germany invests significantly in maintaining and upgrading road infrastructure, particularly on autobahns (motorways). Safety barriers, rumble strips, and well-designed rest areas contribute to safer driving conditions.
- *Vehicle Safety Standards*: Germany has stringent vehicle safety regulations, including mandatory inspections and compliance with EU standards. It also promotes the development and adoption of advanced vehicle technologies such as automated emergency braking (AEB) and lane-keeping systems.
- *Urban Mobility*: Cities like Berlin and Hamburg are implementing extensive cycling infrastructure and 30 km/h zones to protect pedestrians and cyclists, as part of broader efforts to promote sustainable urban mobility.
- *Vision Zero Initiative*: Several German cities, such as Munich and Hamburg, have adopted Vision Zero targets, focusing on reducing urban fatalities through better road design, speed management, and safer crossings.

2.6.4 FRANCE

France has made significant progress in road safety through a combination of legislative measures, enforcement, and infrastructure enhancements.

Key initiatives include:

- *Speed Management*: France reduced the speed limit on secondary roads from 90 km/h to 80 km/h, which has contributed to a decline in road deaths. The introduction of automatic speed cameras and stricter penalties for speeding has further improved compliance.
- *Alcohol and Drug Enforcement*: France has one of the strictest drink-driving policies in Europe, with random breath testing and zero-tolerance policies for commercial drivers.
- *Focus on Vulnerable Road Users*: France prioritizes pedestrian and cyclist safety through better urban planning, including safer crossings and dedicated cycle paths. The government's new mobility law ("Loi d'Orientation des Mobilités") also emphasizes enhancing safety for vulnerable road users.
- *Rural Road Safety*: Addressing rural road safety remains a key priority, with targeted campaigns and infrastructure improvements aimed at reducing fatalities on the extensive rural road network.

2.6.5 NORWAY

Norway has one of the lowest road fatality rates in the world and follows a Vision Zero strategy like Sweden.

Key initiatives include:

- *Systematic Approach*: Norway's approach focuses on improving road infrastructure, enforcing speed limits, and promoting safe vehicle standards.
- *Speed Reduction*: Norway has introduced extensive 30 km/h zones in urban areas and employs automatic speed enforcement cameras extensively.
- *Pedestrian and Cyclist Safety*: Norway emphasizes safe road crossings, pedestrian bridges, and well-maintained cycling lanes, particularly in urban areas.
- *Public Transport Integration*: Norway integrates road safety with public transport planning, reducing the need for private car use and thereby lowering exposure to road accidents.

2.6.6 UNITED KINGDOM

The UK's *Road Safety Strategy* incorporates a comprehensive approach to address the risks faced by different road users.

Key initiatives include:

- *Safe Road Infrastructure*: The UK focuses on creating safer junctions, improving road markings, and upgrading pedestrian facilities. Traffic calming measures, such as speed humps and chicanes, are used to control speeds in residential areas.
- *Data and Research*: The UK's Department for Transport (DfT) relies heavily on data-driven research to inform road safety policy. The *Road Safety Data* portal is a public resource that provides detailed information on accident trends and high-risk areas.
- *Regulatory Measures*: Strict penalties for driving under the influence and the use of mobile phones while driving have been effective in reducing accidents. The introduction of graduated driver licensing is also under consideration to improve young driver safety.
- *Vehicle Safety*: The UK promotes high safety standards for vehicles, with Euro NCAP ratings being a critical factor for vehicle purchases.

2.7 CONCLUSION

To draw a conclusion across the legislations and road safety approaches of the four EvoRoads pilots, Italy, Spain, Latvia, Romania, and the other six analyzed EU countries, several key similarities and some differences emerge. A major point of alignment lies in the collective adoption of the Safe System approach, as reflected in national road safety plans and legislative updates. For instance, Italy's Piano Nazionale della Sicurezza Stradale (PNSS) 2030 emphasizes infrastructure improvements and targets vulnerable road users. Similarly, Spain's legal framework and Real Decreto 345/2011 focus on high standards for road safety audits and give special attention to VRUs like cyclists and pedestrians. Latvia and Romania also adhere to similar overarching EU guidelines, though their respective Road Traffic Safety Plans (Latvia) and LEGEA 265-2008 (Romania) tend to highlight more local infrastructure and challenges.

One area where these nations differ involves the integration of new technologies such as Intelligent Transport Systems (ITS) and real-time monitoring. Spain has shown a proactive approach with its guidelines for traffic management systems that prioritize VRUs, such as cyclists. In Italy, digital monitoring of infrastructures, especially through the AINOP system, is going to play a central role in future road safety management. Latvia's road safety legislation, while focused on infrastructural improvements, does not yet fully emphasize advanced technological integration. However, Latvia and

Romania have both made steps toward modernizing vehicle safety standards, such as promoting the use of newer vehicles with advanced safety features. Of particular interest, the document "Recomendaciones para la mejora de la Seguridad Vial en entornos interurbanos" addresses the issue of road safety on interurban roads. It consolidates evidence-based practices that aim to improve safety through 31 detailed practical measures, such as enhanced road design, auditory and visual cues, and dynamic speed limits, without requiring extensive infrastructural changes offering a structured contribution to improving road safety. The proposed measures are included in the catalogue Section 3.2.

European directives on road safety often offer room for interpretation, leading to some variations in implementation across countries. While core legislative measures are generally consistent, there can be differences in how these guidelines are localized to fit specific national needs.

In conclusion, while alignment exists across these countries concerning Safe System principles and adherence to EU directives, localized approaches to technology integration, road user safety, and infrastructure monitoring reveal some dissimilarities. The increasing focus on European-funded road safety projects further aims to bridge these gaps, helping to create standardized safety indicators and methodologies across the continent. This harmonization effort will be crucial in the coming years as Europe moves toward its Vision Zero goal of reducing road fatalities by 50% by 2030.

3 MULTI-LAYERED SAFETY ASSESSMENT CRITERIA CATALOGUE

3.1 OVERVIEW

Traditionally the Safe System approach has been characterised by the five pillars of road safety described in the Global Plan for the Decade of Action for Road Safety (WHO, 2011) [1], which are:

- Road-safety management
- Safe roads
- Safe vehicles
- Safe road-user behaviour
- Post-crash care

Road-safety management focuses on the fact that safety needs coordinated and managed measures both at the design stage and in the maintenance phase. Safe roads refer to the elements of infrastructure: they must be designed to protect the user and limit damage caused by an incident. Along with the infrastructure, the vehicles on it must also be equipped with increasingly innovative systems to ensure driver safety. Speeding, drink and drug driving, incorrect use of protective equipment were and remain contributing factors to most incidents: compliance with laws and evidence-based standards to reduce incidents should be seek, increasing awareness among road users of main road safety risk factors. The last pillar is related to the assistance of the incidental event that once it has happened must be quickly managed to limit the damages that sometimes become irreversible.

Additionally in recent years, due to the vital importance of speed management in relation to road safety, "Safe speeds" has been increasingly considered as an additional pillar [8]. This inclusion is supported by various recommendations, such as the "zero speeding" and the "30km/h" speed limit advocated in the context of the Stockholm Declaration 2020 [4]. These road safety pillars continue to be fundamental tools for achieving the vision of the Safe System approach. Moreover, in recent years the International Transport Forum (ITF) has developed a comprehensive framework to evaluate progress for each pillar, encompassing five areas of action and proposing a detailed evaluation methodology [8].

Despite the centrality of these pillars, recent documents have emphasized the necessity of focusing on specific intervention areas to meet the ambitious road safety goals. This includes a deeper integration of climate and social justice considerations, in alignment with the Sustainable Development Goals (SDGs). Moreover, the technological transition towards safer and eventually self-driving vehicles necessitates the adaptation of infrastructure to meet the technological requirements and the development of new guidelines for vehicles other than cars. Additionally, vulnerable road users (VRUs) must be prioritized both as a mode of transport and as a demographic needing special protection, including children and the elderly. These users are often forgotten, as can be seen from some infrastructures which become real barriers for certain categories. Infrastructure and vehicles must become increasingly inclusive. Furthermore, promoting a modal shift towards cleaner, more cost-effective, and healthier forms of mobility is crucial. This involves encouraging the use of bicycles, walking, and public transportation, which not only contribute to reducing emissions but also enhance overall road safety [4]. Integrating these elements into the Safe System approach is essential for creating a comprehensive and inclusive strategy to improve road safety across all user groups and regions. In summary, integration must take place between all categories of users, infrastructure and each type of vehicle.

Hence, EvoRoads approach suggests to focus on ten categories of transport dimensions, even if potentially overlapping, to start reasoning on the state of the art, current gaps and future developments in the field of road safety performance metrics, which are:

- User Behaviour
- Road Infrastructure

- Roadside Safety Devices
- Traffic Management
- Enforcement
- Vehicles
- C-ITS
- CCAM Operations
- VRUs
- Emergency Management

The following section briefly describes these ten categories focusing on both well-established best practices and metrics and on eventual emerging metrics trying to answer emerging needs. Section 3.2 focuses on the indicators catalogue itself, proposing all metrics for the ten categories in alphabetic order, while Section 3.3 focuses on a final discussion on the categories' definition and summarizes key findings through a visual matrix form.

3.1.1 USER BEHAVIOUR

Safe road users' behaviour was firstly introduced as one of the road safety pillars in 2011 [1]. It stressed the importance of increasing awareness about road safety risks and prevention measures integrating enforcement with public education, such as social marketing campaigns to influence public attitudes. The enforcement of speed limits, drink-driving laws, helmet use, and seat-belt regulations is prioritized to reduce related injuries as they are found to be main contributing factors to fatal accidents involving motorized vehicles. Additionally, it advocates for safe practices in commercial and public transportation, promoting policies to minimize work-related road accidents, and suggests the adoption of Graduated Driver Licensing systems for novice drivers to ensure their gradual adaptation to driving responsibilities.

In a safe system vision the cause of an accident should be also analysed looking for whatever involved element (e.g. infrastructure, vehicle, legislation) that, if different, could have led to a different outcome of the event, thus contributing to maintaining proper user behaviour and increasing awareness of main road safety risk factors. It is rare that an in-depth investigation of collateral causes is performed in police or hospital reports, as their focus lies elsewhere, but from a proactive safe system perspective, human error should be seen at best as the final breakdown in a sequence of failures that ultimately leads to an incident [14]. Overemphasizing road user error can shift attention away from implementing effective countermeasures that target the underlying systemic issues within the chain of events leading to incidents. It is also worth noting that this prevalence of behavioural components as contributing factors in accidents causes is mainly characteristic of motorized vehicles, while usually incidents involving VRUs show a different distribution of contributing factors and are significantly affected by underreporting [15].

However, many reports still identify road user behaviour as a major contributing factor to road crashes, especially in motorized vehicle incidents. Behavioural components like speeding, alcohol consumption, distraction, and non-compliance with safety rules are common causes highlighted in the data. However, it is essential to understand that these behaviours are often influenced by failures in other parts of the system, that will be also addressed in the next categories sections. Figure 4 shows data from a 2021 CEREMA report [16] analysing in-depth causes of 2878 road crashes: particularly, it presents contributory factors present in more than 2% of fatal crashes. The first strictly non-behavioural contributing cause is in twelfth position and is related to bad adherence to the street in rainy conditions. Human related factors most involved in road crashes instead are: speeding, driving under the influence of alcohol, distraction (e.g. by using mobile devices), driving under influence of drugs or other psychoactive substances, non-use of protective equipment and child restraint systems and incompliance with traffic rules especially at intersections. The order of impact could vary depending on the report, but there is strong agreement on the relevance of speed among other contributing factors [17].

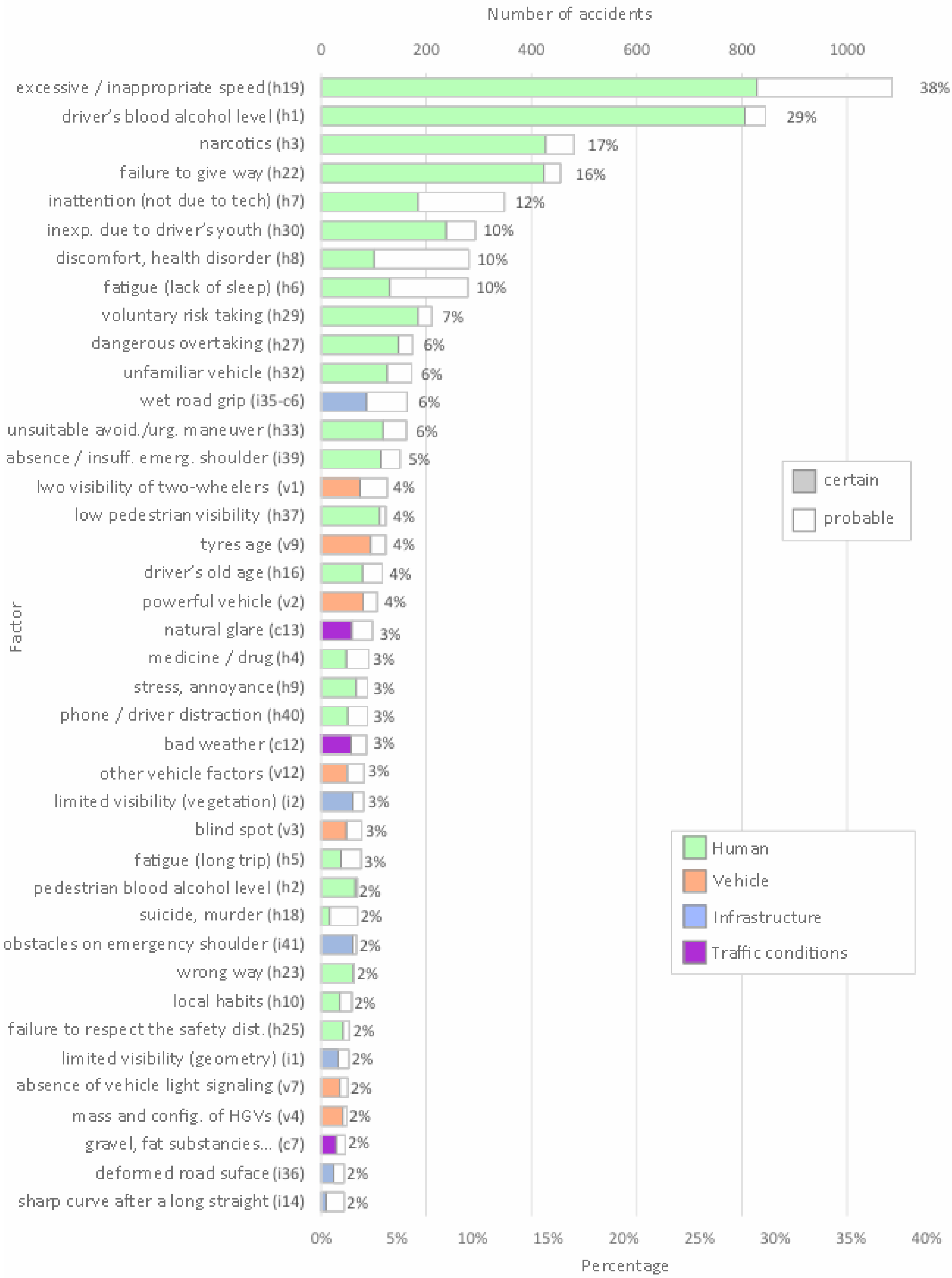

Figure 4 – Contributory factors present in more than 2% of fatal crashes with respect to number of accidents, CEREMA report 2021 [16].

Considering the importance of human related contributing factors on road accidents, several metrics have a long history of monitoring, and the Baseline project [18] has helped standardizing them among member states. Each Baseline KPI is associated with a methodological report, describing in detail how to compute it, possible data sources and different level of detail. After the publication of Baseline outcomes, some actors underlined possible future directions of improvements. For example, FEMA (Federation of European Motorcyclists Associations) suggested the distinction of "Percentage of riders wearing a protective helmet" at least between vehicles categories for which this action is mandatory and optional. Moreover, they generally suggested to keep more into considerations accidents dynamics involving users different from cars, which were mainly addressed by the proposed KPIs [20]. Additionally, several reports underlined the need of addressing more specifically VRUs, considering also accidents not involving motorized vehicles. After the end of Baseline project, the Trendline project [19] started with the goal of integrating the proposed KPIs with a new set. The project is still ongoing, hence for now the newly proposed list is available but details on meaning, calculation methodology, level of detail and data sources has not been released yet. Among proposed KPIs, several addresses additional behavioural related factors. The Baseline KPIs referred to user behaviour are:

- Percentage of vehicles travelling within the speed limit
- Percentage of vehicle occupants using the safety belt or child restraint system correctly
- Percentage of riders of PTWs and bicycles wearing a protective helmet
- Percentage of drivers driving within the legal limit for blood alcohol content (BAC)
- Percentage of drivers not using a handheld mobile device

While the Trendline KPIs referred to user behaviour are:

- Driving under the influence of drugs
- Red-light negations by road users
- Compliance with traffic rules at intersections
- Helmet wearing of PMD riders
- Self-reported risky behavior
- Attitudes towards risky behavior
- Use of lights by cyclists in the dark

Hence, several behavioural indicators are already widely diffused and are going through a standardization process in Europe. However, since behavioural contributing factors are deeply studied in the literature, additional indicators and levels of detail are proposed. These could be considered as possible future directions of improvement since additional work is needed to identify common methodologies and further investigate the indicators impact on incidents (injuries and deaths). Among newly proposed user behaviour indicators there are:

- Use of Reflective Gear
- Distraction for all road users (including bicycles, mopeds and pedestrians)
- Helmet Fit and Condition
- Speeding
- Parking Compliance
- Protective Gear Usage Beyond Helmets
- Lane Splitting Behaviour and Riding Predictably
- Use of Crosswalks
- Adherence to Rest Breaks
- Load Securement

3.1.2 ROAD INFRASTRUCTURE

The road infrastructure is a set of various complex elements that interact with each other, and each contribute with their own function to make the road network usable for users. The main element is the road that we can define as the public area intended for the circulation of VRUs and vehicles. [21] The safest roads are those which can be considered self-explaining, in which the roadway, road signs and road intersections are designed, built and maintained in such a way that they help each category of users to adopt an intrinsically safe behaviour [22].

The roadway contains two macro categories: geometry and flooring.

The track geometry data that may affect the risk of an accident are:

- Length of straight sections.
- Width of roadside.
- Radius of curvature in non-straight lines.
- Longitudinal slope.
- Appropriate transition between a straight and a curved section and the opposite.
- Appropriate visual distance.
- Dedicated lanes to divide traffic by direction.
- Presence of sidewalks.
- Presence of cycle paths.

The road surface must have the following functional characteristics on which the levels of safety and vehicle comfort depend on:

- Skid resistance or adhesion (to wheel-pavement contact).
- Regularity or roughness (of the road plan).

Road signs have a fundamental role to play in making road infrastructure legible and easily understandable as it has been designed and constructed. It can be horizontal, vertical and accessory.

The horizontal signs are used to delimit the space that can be covered by a vehicle and are used to identify certain points where it is possible or not to carry out specific manoeuvres such as overtaking, turning, stopping, etc. For this reason, it is important that they are always present and clearly visible, not subject to fading.

The purpose of vertical signs is to communicate hazards, prescriptions or indications to the road user. Therefore, it is necessary that they are present, properly positioned, clearly visible by all users in any climate context, without being obstructed or impaired.

Accessory signage consists of those elements that place us halfway between the two previous categories because they perform the functions of both. Examples are reflective roadway delimiters. Also, they must be clearly visible and well maintained over time to keep intact its characteristics.

Road intersections connect two or more roads that meet their trajectory at a given point. Depending on the road category, traffic flow and geometry, the way in which the intersection is regulated is determined. The three families of intersections are those with simple precedence, those with roundabout circulation and those with allowed circulation in alternating phases regularized using traffic lights.

The simplest intersections are those where the precedence rule applies. This rule can change from country to country, but it is in any case simple and intuitive. The intersections in question are characterized by few roads and very low traffic flows, they are typical of intersections between a main road and a secondary road. These intersections are the most sensitive to incidental events because security is left entirely to compliance with the current rule.

Roundabout intersections are the ones in which the same degree of priority is given to each road that flows into it. In fact, every road in an indistinct way must give priority to the means that already occupy the intersection. Therefore, roundabout intersections are adopted when roads have the same importance and a very similar daily traffic flow. In these intersections the accident is more contained thanks to the speed reduction imposed by roundabout traffic.

The intersections regulated by using traffic lights can assign a different degree of precedence for a certain time interval to each road and each direction of turn depending on the different traffic flows. The latest generation of traffic lights can adjust their ranges with respect to the flow detected in real time. In the semaphored intersections often are separated turning flows to limit to a minimum or totally the conflicts between different vehicular currents.

The data collected for this study [23] focused on various factors related to accidents at 120 identified blackspots, including road geometry, road characteristics, street furniture, human behaviour, environmental conditions, and vehicle characteristics. These accident spots covered incidents involving fatal, grievous, minor, and non-injury cases. The collected data were analysed using the Statistical Package for the Social Sciences (SPSS) software. A frequency index (F.I.) was calculated for each factor contributing to accidents, and the results were ranked, as shown in Figure 5, with a detailed breakdown of the rankings presented.

S. no.	Characteristics	Factors	Frequency index	Ranking
1	Traffic	V/C ratio	0.72	8
2	Road geometry	Ununiformed width of the carriageway	0.69	12
		Lack of sight distance	0.75	6
		Radius of curvature	0.63	16
		Gradient	0.21	27
		Super elevation	0.45	22
		Controlled intersection	0.32	24
		Uncontrolled intersection	0.89	3
		Lack of auxiliary lanes at the intersection	0.21	28
		Bridge approach	0.53	19
		Lack of footpath	0.83	4
3	Road characteristics	Skid resistance	0.72	9
		Roughness	0.43	23
		PSI	0.64	15
4	Street furniture	Traffic signs	0.59	18
		Road marking	0.53	20
5	Human factors	Age	0.69	13
		Male	0.72	10
		Female	0.32	25
		Drunk and driving	0.943	1
		Over speeding	0.92	2
6	Environmental factors	Rainy	0.68	14
		Sunny	0.52	21
		Day time	0.63	17
		Night time	0.74	7
7	Vehicle factors	Low-performance vehicle	0.72	11
		High-performance vehicle	0.12	29
		Brake failure	0.23	5
		Passenger vehicle	0.82	30
		Cargo vehicle	0.32	26

Figure 5 – Frequency index and ranking of each factor [23].

The table lists each factor that contributes in a percentage to accidents in the previously considered study. The factors that depend on road infrastructure are ordered in the following Table 2.

FACTORS	FREQUENCY INDEX	RANKING
Uncontrolled intersection	89 %	3
Lack of footpath	83 %	4
Lack of sight distance	75 %	6
Skid resistance	72 %	9
Ununiformed width of the carriageway	69 %	12

PSI (Present serviceability index)	64 %	15
Radius of curvature	63 %	16
Traffic signs	59 %	18
Bridge approach	53 %	19
Road marking	53 %	20
Super elevation	45 %	22
Roughness	43 %	23
Controlled intersection	32 %	24
Gradient	21 %	27
Lack of auxiliary lanes at the intersection	21 %	28

Table 2 – Road infrastructure factors contributing to accidents [23].

Road infrastructure cannot be designed and conceived solely for cars and heavy goods vehicles. Special attention should be paid to vulnerable road users who contribute to micro-mobility, including pedestrians, cyclists, and motorcyclists. These groups are particularly exposed to road risks, so thoughtful infrastructure planning is essential for ensuring their safety and comfort.

For pedestrians and cyclists, well-defined pavements or dedicated bike paths must be available and adequately protected from motorized traffic. Such paths should be segregated wherever possible, offering a safe and uninterrupted flow for these users. Additionally, ample space should be allocated for safe movement in both urban and rural areas.

Crossings, especially for pedestrians and cyclists, must be designed with maximum safety in mind. They should be clearly visible, properly marked with signposts, and equipped with both horizontal and vertical signage. A raised road surface at crossings serves to enhance their visibility and enforce a speed reduction from motorists, creating a safer environment for vulnerable users.

Lighting is another critical factor in ensuring safety, particularly in low-visibility conditions or at night. Streetlamps and ground-level lighting at pedestrian crossings can significantly improve visibility and awareness, reducing the likelihood of accidents. Adding features such as flashing lights or dynamic signage that activates when pedestrians or cyclists are present could further enhance safety.

Finally, it's important to ensure that all elements of the infrastructure are accessible to people with disabilities. This includes incorporating tactile paving, curb ramps, and auditory signals for crossings. By integrating inclusive design, infrastructure can serve a broader range of users, enhancing mobility for all. Some examples of these measures are shown in Figure 6.

Figure 6 – Examples of systems for protecting VRUs.

3.1.3 ROADSIDE SAFETY DEVICES

Passive road safety can be improved by installing devices that mitigate the effects of an incident. These devices should be implemented only when they can significantly reduce the consequences that would occur in their absence. A barrier that performs its task optimally should be able to react, in any mode of impact, to the colliding vehicle, ensuring:

- *Impassability*: The barrier must ensure the safety of everything beyond the containment structure, preventing vehicles from passing through or leaving the road.
- *Gradual Vehicle Return*: After impact, the vehicle should be gradually redirected back onto the road at an angle that avoids further collisions with other vehicles.
- *Occupant Safety*: The barrier should minimize the acceleration experienced by the vehicle's occupants, reducing damage to both the people and the vehicle.

However, given the varying vehicle masses and installation locations, no single barrier is ideal for all criteria. The design process must identify the priority requirements and allowable deformations based on boundary conditions. For instance, permissible deformations may be greater on the roadside than on viaducts. An ideal safety barrier must deform as much as possible, within acceptable limits, to dissipate large amounts of energy while limiting vehicle deceleration.

Safety barriers can be classified by their material, their behavior after impact, and their function based on installation location. The most practical classification is based on their function within the road infrastructure, as this directly informs their design and construction. In this classification, we find central safety barriers, side safety barriers, and specific safety elements that protect single points.

Central Safety Barriers: These barriers are installed in the center of the road to separate lanes of opposing traffic, preventing vehicles from entering the opposite lane. Central barriers are critical on high-speed roads where separating traffic flows reduces the risk of head-on collisions, as shown in Figure 7 and Figure 8.

Median Barriers: Concrete or steel barriers in highway medians serve as central safety barriers. They are designed to prevent crossover accidents, which are particularly dangerous. These barriers are rigid enough to stop vehicles but can also be designed with some flexibility to absorb impact energy, protecting vehicle occupants and minimizing severe damage.

Figure 7 – Central safety barriers in steel (left) and in concrete (right).

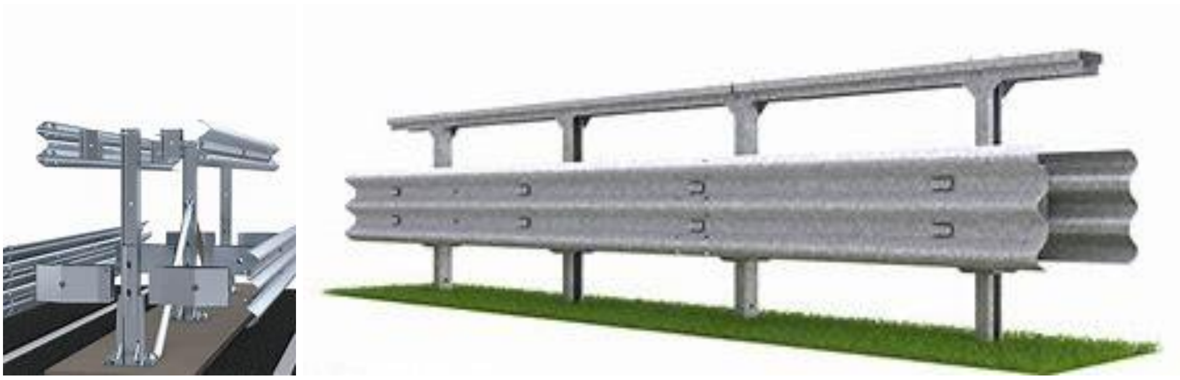

Figure 8 – Particular of central safety barriers.

Side Safety Barriers: These barriers are placed at the roadway edges to prevent vehicles from leaving the road. On bridges and viaducts, they are essential to protect vehicles from falling. Side barriers are found on all off-road roads and some urban streets with specific characteristics, as illustrated in Figure 9.

- *Guardrails (Crash Barriers):* Typically made of steel or concrete, these side barriers prevent vehicles from veering off the road. They are designed to deform upon impact, absorbing energy and minimizing the crash's severity. Their primary role is to protect vehicles from running off-road or falling from elevated roadways, such as bridges.

Figure 9 – Some examples of safety side barriers in different materials and with different characteristics.

Specific Safety Elements Protecting Individual Points: These elements function as safety barriers in specific locations, like the ends of longitudinal barriers, diverging intersections, or around dangerous roadside elements such as pillars and trees. These are present on all road types where individual hazards are particularly dangerous for vehicles, as shown in Figure 10.

- *Crash Cushions (Impact Attenuators):* These energy-absorbing devices are installed in front of solid objects like bridge supports or the ends of guardrails. Designed to cushion the impact, they reduce crash severity by gradually decelerating the vehicle.
- *End Terminals*: The ends of guardrails, known as end terminals, are designed to crumple or absorb energy upon impact, preventing the guardrail from becoming a hazard itself.

Figure 10 – Some examples of different safety elements protecting individual points.

Other Roadside Safety Devices:

- *Cable Barriers:* These flexible barriers use steel cables to catch and slow down vehicles, particularly in highway medians. Their design allows for energy absorption during collisions, reducing the risk of vehicles crossing into oncoming traffic.
- *Barrel Crash Barriers:* Clusters of barrels filled with water, sand, or other materials are placed in high-risk areas like exits. These barrels absorb the impact of a collision, dissipating the energy and reducing the severity of crashes.
- *Rumble Strips*: These are grooved patterns on the road surface that alert drivers through sound and vibration when they drift from their lane, enhancing safety by reducing run-off-road incidents.

In road design and safety, extra attention must be paid to vulnerable road users (VRUs) such as pedestrians, cyclists, and motorcyclists. For pedestrians and cyclists, separated and protected paths should be provided on roads equipped with safety devices, such as sidewalks or dedicated cycle lanes (Figure 11).

- *Bollards*: Short, sturdy posts are often installed to protect pedestrian areas and bike lanes by preventing vehicle access. They serve both as protective barriers and as visual guides.

Figure 11 – Separate and protected pedestrian and cycle paths.

For motorcyclists, specific safety devices are under development to reduce the risk of severe injuries from collisions with guardrails. Technologies such as metal profiles are installed to cover guardrail posts, preventing the sharp edges from causing severe harm during a crash, as shown in Figure 12.

Figure 12 – Protective barriers specific to motorcyclists.

Each of these roadside safety devices plays a critical role in improving road safety, mitigating the consequences of accidents, and protecting road users from dangerous incidents.

3.1.4 TRAFFIC MANAGEMENT

The category of traffic management could contain a wide range of strategies and systems designed to optimize the flow of traffic, enhance road safety, and minimize congestion. Traffic management is a task of public authorities and road operators and its operation is mostly handled by traffic control centres. There are no comprehensive definitions of this category, to the authors knowledge, but several subcategories could be included in it. Among them:

- *Traffic Flow Optimization*: it could include signal timing and coordination, traffic routing and diversion, congestion pricing policies, automated traffic management systems, traffic signs and road markings, lanes management.
- *Traffic Incident Management (TIM)*: it could include real-time monitoring and detection systems, incident response planning, incident information systems.
- *Speed Management*
- *Data Collection and Analysis*: it could include traffic flow data collections, surveys, modelling and simulation.
- *Technology Integration*: it could include the integration of intelligent transportation systems (ITS) and connected vehicles in the traffic flow.
- *Policy and Planning*: it could include traffic management area plans, regulations and enforcement.

Hence, traffic management is a dynamic and multifaceted field that seeks to balance efficiency, safety, and accessibility on the roads. By integrating various systems and strategies, it aims to create a smoother and safer driving experience for all road users. However, indicators assessing the direct impact of traffic management on road safety are difficult to be defined, because of the great complexity of the factors involved. In the following the different sides of traffic management will be briefly analysed and possible indicators related to road safety listed.

Considering traffic flow optimization, it is worth noting that several studies underlined the complex relationship between increasing traffic flow on roads and accidents. The change in traffic conditions from free flow to dense traffic will result in a negative relationship that associates more traffic with fewer accidents, mainly because of the inevitable speed reduction and additional attention required to drivers. However, above a certain volume/capacity ratio incidents probability increases again showing a u-shape relationship with vertex located around 30% of congestion (excess in travel time) [29, 30]. This could be mainly explained by difficulties of handling high speed variance [31]. However, most of the crashes happening in dense traffic conditions are property damage crashes since happening at low speeds and are consequently excluded from road safety related reports which only consider fatalities and serious injuries. Hence, it could be said that congestion has both a safety and a detrimental effect since the change from low to moderate levels of congestion leads to a decrease in the number of deaths in accidents per capita, while from moderate to high levels it happens an increase in the number of deaths in accidents. The increased number of deaths despite the lower speeds could be mainly explained because of accidents happening at the extremes of the congested zone (tail effect) where speeds are higher and congestion could be unexpected and because of mid-term effect on drivers' behaviour in post-congestion driving, which could become more aggressive and fatigued [32]. Moreover, VRUs are greatly affected by congestion, due to the massive presence of cars. Additional studies are expected in this field in the following years, especially adopting disaggregated data both spatially and temporally. Hence, concerning traffic flow optimization, valuable indicators could be:

- Variance of traffic speed
- Congestion level (volume/capacity)
- Travel time reliability
- Time spent in queuing
- Singal timing and coordination
- Pedestrian/cyclists waiting time at crossings

Another typology which can be found is Traffic Incident Management. It is the response to traffic accidents, incidents and other unplanned events that occur on the road network, often in potentially dangerous situations. The objective is to handle incidents safely and quickly, to prevent further accidents and restore traffic conditions back to normal as quickly as possible. It requires the deployment of a systematic, planned and coordinated set of response actions and resources. Some sources report that a significant percentage of crashes (that could be up to 20%) are secondary crashes, which result to be much more severe than primary ones [33, 34]. Other studies tried to determine the impact of clearance time on the probability of secondary crashes happenings, e.g. it was found [35, 34] that a clearance time greater than 75 minutes could increase probability of secondary crashes by 25%.

Traffic Incident Management proceeds through a cycle of phases starting with immediate notice of possible dangers or problems ahead – as soon as an incident occurs – in order to forewarn drivers and prevent accidents.

Incident warning and management have two main goals – to:

- prevent or minimise the risk of incidents and the consequences of incidents
- manage and resolve incidents in a safe, effective and expeditious way

Incident management requires planning, a response that is proportionate, safety at the scene of the incident and recovery. It requires attention to three main aspects – in order of priority – safety, mobility of traffic flow and control and repair of damage. To understand how control strategies and network operations can reduce the negative impact of incidents, it is important to understand the timeline and different stages of incidents, as shown in the diagram below (Figure 13).

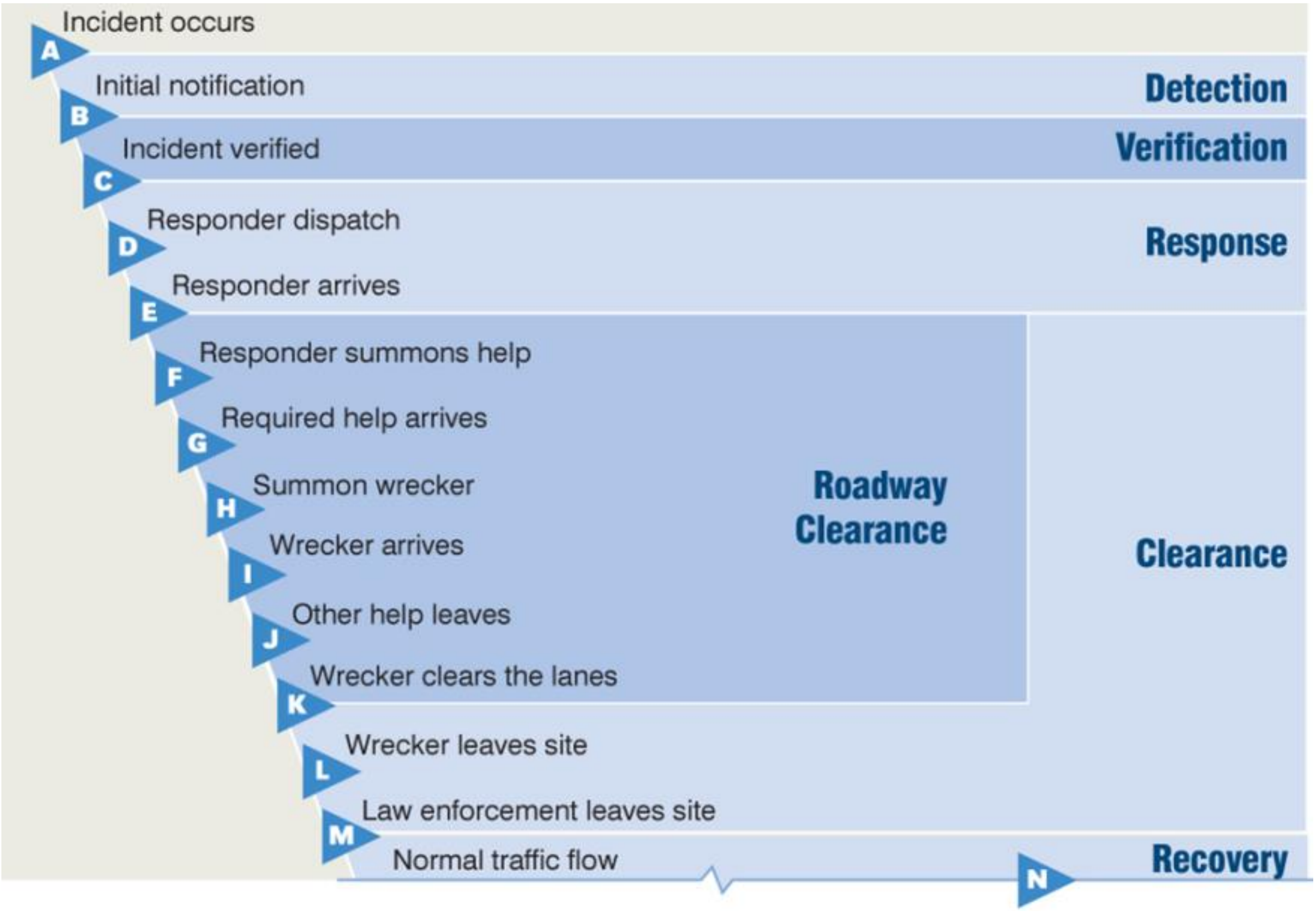

Figure 13 – Timeline and different stages of incidents [24].

The diagram might represent a collision on a motorway, a spill of materials or a disabled vehicle - resulting in the need to close one or more of the running lanes. All steps will not occur in every incident - and there may be other interwoven relationships – but the diagram represents the typical sequence for most moderate-to-serious incidents. The steps are shown in a staggered fashion simply to illustrate that the incident timeline is not uniform (the time increments are relative – and not to any scale).

The duration of particular stages in the incident are represented by the letter pairs in the diagram and are listed below. For example, the duration of the incident itself would be from *point A* on the timeline to *point M*, while the total time the incident is having an effect on traffic is from *A to N* – with the time elapsed to *point N* often proportionately much longer than shown.

Common phases of an incident are:

- *detection* that an incident has occurred: *A to B*
- *verification* that the incident has occurred, determining its location and having sufficient information to enable an appropriate response: B to C
- *response* by dispatching appropriate services to resolve the incident: *C to E*
- *clearance*, or the removal of the vehicles, damaged property and victims from the incident scene, and complete reopening of any blocked lanes: *E to M* – with roadway clearance as a subset, *E to K*
- *recovery* to normal traffic flow: *M to N*

Although not evident in the diagram, the recovery period is frequently longer than the duration of the incident itself. Incident recovery can be four-to-five times longer. This means that for every minute that can be trimmed off incident detection, verification and/or clearance, up to 5 minutes of recovery time can be saved for traffic to get back to normal [25, 26].

Another major area of traffic management is speed management. As is well known to most, speed limits vary according to the type of road and are more restrictive depending on the characteristics of the infrastructure. Speeds are determined in relation to various parameters.

The first element to be taken into consideration is the plane-altimetric trend of the road. The maximum speed at which a vehicle can drive around a bend is determined by calculation, and this is undoubtedly the most restrictive element of the road. The speed is directly proportional to the radius of curvature: the greater the radius, the higher the travelling speed.

The second parameter is related to the average traffic level of the road. This is also a very important parameter because it must guarantee a constant flow of cars, but also a safe flow, without accidents.

The third important feature is road user safety. In this sense, speeds vary both according to the territorial context in which they are located and according to the conditions surrounding them. The context in which the road is located is very important. If it is an urban context, we must consider the coexistence of several users including the most unprotected (pedestrians, cyclists, etc.) and the presence of sensitive infrastructural elements (houses, schools, etc.). In an extra-urban environment, on the other hand, there are generally fewer sensitive elements and therefore the permitted speeds are higher. Boundary conditions also affect speed. One can think of rainy weather conditions where the speed limits are restricted due to poor grip. Or when the road surface is being redone, as minimum safety conditions are not guaranteed, speed is severely restricted.

Cities have been developing "30 zones" for some time now. The "30 zone" is an urban intervention for the moderation of traffic in urban road, which consists in reducing the speed limit to 30 km/ h in a given urban area. More recently, people have started to speak of "30 cities". The term "30 city" means a measure which proposes the inversion between rule and exception in urban speed limits: instead of indicating a general limit of 50 km/h, 30 km/h becomes the norm on all roads classified as neighbourhood, inter-zonal and local, keeping only the fast-running axes at 50 km/h.

These urban speed limit measures have several advantages in terms of air pollution, noise and road safety. The last point is that which directly concerns the treatment of this document. The increase in road safety is due to the reduction of speed from 50 to 30 km/h, which according to studies reduces the braking space by more than half and increases the radius of the driver's visual cone. Cities that introduced this measure saw a 42% decrease in the total number of accidents and 46% decrease in those that caused death or serious injury. It has been shown that at 30 km/h the impact with weak road users (pedestrians, cyclists and motorcyclists) drastically reduces the chances of instant death. This is in full favour of the coexistence of all road users, even the weakest.

3.1.5 ENFORCEMENT

Enforcement plays a critical role in road safety, particularly within the framework of the Safe System approach. The primary aim of enforcement is to ensure compliance with traffic laws, ultimately reducing the likelihood of accidents caused by risky behaviours such as speeding, drink-driving, failure to wear seat belts, and distracted driving. Effective enforcement not only deters dangerous behaviours but also encourages the consistent application of road safety regulations. Its ultimate goal is to create an environment in which road users feel a strong likelihood of detection and penalty for violations. This perceived risk encourages safer behaviour, which is crucial to improving overall road safety.

The key components of enforcement are related to the most dangerous road user behaviours which can lead to most severe accidents:

Speed Enforcement: Speeding remains the leading cause of fatal road accidents, with about one-third of all road deaths attributed to excessive speed. Enforcement measures such as fixed and mobile speed cameras, time-over-distance systems, and roadside checks are key tools used to control speeding. Countries like France and Spain have seen significant reductions in speed-related accidents due to the increased use of these systems over the years.

Drink-Driving: Alcohol remains a significant factor in road fatalities, contributing to around 25% of road deaths in Europe. Enforcement strategies, including random roadside alcohol breath tests, have proven effective in reducing these incidents. Technologies like alcohol interlocks for repeat offenders and public awareness campaigns could further reinforce compliance.

Drug-Driving: Drug-driving enforcement is gaining more attention across Europe as the issue becomes more prevalent. Random roadside drug tests are increasingly being employed, using saliva testing or other methods. Like drink-driving enforcement, the goal is to identify and penalize drivers under the influence of drugs to prevent accidents caused by impaired driving. Many countries are still expanding their capabilities to deal with this issue, with efforts being made to standardize testing procedures across the EU.

Seat Belt Use: Seat belts are proven life-savers, but compliance varies across Europe, especially concerning rear seats. Enforcement measures include fines for non-compliance, along with public campaigns to raise awareness of the importance of seat belt use, particularly in rear seats where usage tends to be lower. Enhanced seat belt reminders in vehicles also play a key role in increasing compliance.

Mobile Phone Use While Driving/Distraction: Distracted driving, especially due to mobile phone use, has become a growing concern. Enforcement strategies include fines for illegal phone use and campaigns to raise awareness about the dangers of distracted driving. It is estimated that distraction could be a contributing factor to as much as 30% of road accidents.

One of the biggest challenges in road safety enforcement is the lack of consistent data on enforcement levels across different countries. While it is possible to track the number of fines issued for speeding or drink-driving, other indicators such as the total time spent on enforcement activities, or the number of checks conducted by police and safety cameras are more difficult to standardize and compare internationally. An ideal enforcement indicator would assess the time spent on enforcement or checks performed by both police and safety cameras. For example, in Ireland, the service provider GoSafe is contracted to deliver a minimum of 7400 enforcement hours and up to 100 survey hours per month. Unfortunately, such data are unavailable in most countries except for drink-driving enforcement, where the number of roadside alcohol tests is usually monitored instead of the number of tickets for drink-driving [27].

As a result, road safety reports often rely on indirect measures such as the number of tickets issued per 1000 inhabitants for offenses like speeding, failure to use seat belts, and illegal mobile phone use. While this does provide a snapshot of enforcement activity, it assumes a constant level of enforcement effort. An increase in ticket numbers could indicate either an increase in enforcement activity or a rise in violations.

Another major challenge for road safety enforcement is ensuring that non-resident drivers comply with traffic laws when traveling abroad. The Cross-Border Enforcement Directive (2015) has helped address this issue by allowing EU member states to exchange information on traffic offenses, such as speeding, drink-driving, and non-use of seat belts, committed by foreign drivers. This has enhanced the ability of national authorities to enforce penalties across borders, ensuring that

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drivers cannot evade punishment simply because they are outside their home country. The directive represents a significant step forward in improving road safety across Europe.

Several KPIs are commonly used to evaluate the effectiveness of enforcement efforts. These include:

- Number of speeding tickets issued (e.g. annual/per 1000 inhabitants)
- Number of roadside alcohol breath tests conducted (per 1000 inhabitants) and proportion of those tested found above the legal limit
- Number of roadside drug tests conducted
- Number of tickets for non-use of seatbelt (per 1000 inhabitants)
- Seatbelt wearing rates in front seats/rear seats of cars and vans
- Number of fines for illegal mobile phone use (per head of population)
- Proportion of speeding tickets generated by safety cameras
- Number of safety cameras per million inhabitants (fixed, mobile and time-over distance cameras, empty camera boxes)
- Number of speeding tickets that were paid
- Annual change (%)/Relative change (%) in the number (per 1000 population) of speeding tickets, drink driving checks, tickets for non-use of seatbelt, tickets for illegal use of a mobile phone
- Repeat offender rates
- Number of automatically detected offences committed by non-residents and the proportion of followed-up offences
- Number of Safety Checks on Commercial Vehicles
- Public Perception/Satisfaction with Traffic Law Enforcement (surveys)
- Enforcement of traffic regulations [19]

3.1.6 VEHICLES

The more time passes, the wider the spectrum of variety of vehicles that circulates on the streets becomes. In this document cars and different types of 2-wheelers are considered, motorcycles, bicycles and scooters.

The 20th century was a transformative period for vehicle safety, marked by groundbreaking innovations that have significantly reduced the risks associated with driving. As automobiles became a central part of modern life, so too did the need to make them safer for drivers, passengers, and pedestrians alike. Early cars offered little in terms of safety features, and road fatalities were common. However, as the century progressed, a wave of advancements — driven by engineering breakthroughs, changing regulations, and growing public awareness — began to reshape the way vehicles were designed and operated. From the introduction of the three-point seatbelt in the 1950s to the widespread adoption of airbags and anti-lock braking systems (ABS) by the 1990s, these innovations revolutionized automotive safety. Each development played a critical role in reducing accidents, mitigating injury, and making roads safer [97]. By the end of the 20th century, the integration of electronic systems, such as stability control and traction control, further enhanced vehicle safety, paving the way for even more advanced driver-assistance technologies in the 21st century. These features have become basic requirements that car manufacturers must comply with, and buyers take for granted. For these reasons this chapter presents Advanced Driver Assistance Systems (ADAS), one of the most significant leaps forward in automotive safety.

These systems are a collection of electronic technologies that assist drivers in driving and parking functions. By implementing a range of sensors, cameras, and artificial intelligence, ADAS enhance the safety and efficiency of driving, reduce human error, and help prevent accidents. Its key components and functionalities are:

- *Sensors*: Radar, used for detecting objects and measuring the distance and speed of other vehicles, cameras to provide visual information, lidar that utilizes laser light to create a 3D map of the environment and ultrasonic sensors.
- *Processors and algorithms*: AI and machine learning, that enable the system to interpret sensor data, recognize patterns and make decisions in real-time, and dedicated electronic control units (ECUs) used to process sensor data and coordinate the vehicle response.
- *Connectivity*: Communication between vehicles, infrastructure and pedestrians to exchange information.

The most common implementations of these systems are:

- *Adaptive cruise control*: Automatically adjusts the vehicle's speed to maintain a safe distance from the car ahead. Uses radar and cameras to monitor traffic conditions and can bring the vehicle to a complete stop if necessary [90].
- *Lane Departure Warning and Lane Keeping Assist*: The warning alerts the driver if the vehicle unintentionally drifts out of its lane, while the assist actively steers the vehicle back into the lane if the driver does not respond to the warnings [90].
- *Automatic Emergency Braking*: Detects an impending collision with another vehicle, pedestrian, or object and applies the brakes if the driver does not act in time [91].
- *Blind Spot Detection*: Monitors the vehicle's blind spots and alerts the driver to the presence of other vehicles that may not be visible in the mirrors [90, 91].
- *Traffic Sign Recognition*: Uses cameras to detect and interpret road signs, displaying this information to the driver and sometimes integrating it with the vehicle's speed control systems [89].
- *Parking Assistance*: with rearview camera, parking sensors or even an automatic parking system [94].
- *Driver Monitoring Systems*: Use internal cameras and sensors to monitor the driver's attention and alertness, warning them if signs of drowsiness or distraction are detected [92].
- *Pedestrian and Cyclist Detection*: Identifies pedestrians and cyclists in the vehicle's path and alerts the driver or automatically applies the brakes to prevent collisions.

The implementation of these feature could not only improve safety, but also reduce driver fatigue, enhance driving comfort and lower the insurance costs.

ADAS for two-wheelers, such as motorcycles and scooters, are emerging technologies designed to enhance safety and improve the riding experience. Even if the implementation of ADAS in two-wheelers is more challenging compared to four-wheelers due to factors like stability and rider behaviour, several key technologies are being developed and integrated into modern motorcycles. The components are basically the same, adapted to fit in a smaller vehicle, also the technologies are quite similar except for functionalities that consider the lean and steering angles of the bike, like smart headlights that adapt the beam direction.

3.1.7 C-ITS

Today's vehicles are already considered connected devices in many ways. However, soon they will also communicate directly with each other, vehicle to vehicle communication (V2V) and with road infrastructure, vehicle to road infrastructure communication (V2I). These two categories are merged into one category referred as vehicle to everything communication (V2X). This interaction falls under the domain of Cooperative Intelligent Transport Systems (C-ITS), allowing road users and traffic managers to share information and coordinate their actions. This cooperative element, facilitated by digital connectivity between vehicles and transport infrastructure, is expected to and aims to greatly enhance road safety, traffic efficiency, and driving comfort by assisting drivers in making informed decisions and adapting to traffic conditions through real-time information sharing and coordinated actions [28, 95].

C-ITS is a subset within the broader CCAM framework, concentrating on connectivity and information exchange. The physical components of this category are:

- *Communication systems*: allow vehicles to communicate with each other to share information about speed, location, and hazards.
- *Smart infrastructure components:* they communicate with vehicles and ease the communication of vehicles, such as traffic signals, road signs, and road sensors [96].

The first category is based on both Dedicated Short-Range Communications (DSRC), a wireless communication protocol specifically designed for automotive use, allowing fast, reliable communication between vehicles within a short range, and Cellular V2X (C-V2X), a communication protocol that leverages existing cellular networks (like 4G LTE and 5G) to enable V2V communication over a broader range than DSRC.

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The second one is a macro category that includes all the advanced systems and technologies integrated into physical infrastructure to enhance efficiency, safety, and sustainability. These components leverage data, connectivity, and automation to improve the management and operation of infrastructure. Here are some of the most employed ones:

- Smart traffic signals: adjust in real-time to traffic conditions to optimize flow and reduce congestion.
- Smart Streetlights: automatically adjust brightness based on time of day, weather conditions, or the presence of pedestrians and vehicles.
- Connected Roadside Units (RSUs): facilitate communication between vehicles and infrastructure, providing information on traffic conditions, hazards, and road status.
- Intelligent Parking Systems: guide drivers to available parking spaces and manage parking lot usage efficiently.
- Smart Bridges and Tunnels: monitor structural health, traffic flow, and environmental conditions to ensure safety and efficient operation.
- Adaptive Signage: provide real-time information to drivers about traffic conditions, road work, and other important updates.
- Smart Pavement: monitor road conditions, provide data for maintenance, and support vehicle communication.
- Weather and Environmental Monitoring Stations: track weather conditions and environmental factors that affect road safety and traffic flow.
- Smart Public Transit Systems: enhance the efficiency and user experience of public transportation through real-time tracking and communication.
- Automated Incident Detection Systems: detect accidents or unusual traffic patterns automatically and alert authorities.
- Electric Vehicle (EV) Charging Infrastructure: provide efficient and widespread charging options for electric vehicles.
- Pedestrian and Cyclist Detection Systems: enhance safety for non-motorized road users by detecting their presence and providing alerts to drivers and traffic systems.

3.1.8 CCAM OPERATIONS

Cooperative, Connected, and Automated Mobility (CCAM) is an integrated approach to modern transportation that combines the strengths of cooperative systems, connected vehicle technology, and automated driving.

Cooperative mobility involves systems and vehicles working together to optimize transportation efficiency and safety through communication and coordination. It involves V2V and V2I communication but also Vehicle-to-Pedestrian (V2P) and Vehicle-to-Network (V2N) communication. The communication with pedestrians aims to enhance their safety, while the one with network to broadcast traffic updates and cloud services. These two categories join the other two inside the macro category V2X [28, 95].

Connected mobility utilizes digital connectivity to link vehicles, infrastructure, and external systems, enabling real-time data exchange and communication. It is based on Internet of Things (IoT), data sharing and analytics and V2X. The first integrates various sensors and devices within the vehicle and infrastructure while the second involves collecting, processing, and analysing data for traffic management, predictive maintenance, and enhanced user services.

Automated mobility focuses on the development and deployment of self-driving vehicles that can operate with minimal or no human intervention. The Society of Automotive Engineers (SAE) an international association established to set and develop standards in the field of automotive engineering. It defined different levels of automation (Figure 14):

- Level 1 *(Driver Assistance)*: Basic systems like adaptive cruise control.
- Level 2 *(Partial Automation)*: Systems that control both steering and acceleration but require driver supervision.
- Level 3 *(Conditional Automation)*: Vehicles can handle most driving tasks but need driver intervention when necessary.
- Level 4 *(High Automation)*: Vehicles can perform all driving tasks in specific conditions without human input.
- Level 5 *(Full Automation)*: Fully autonomous driving in all conditions.

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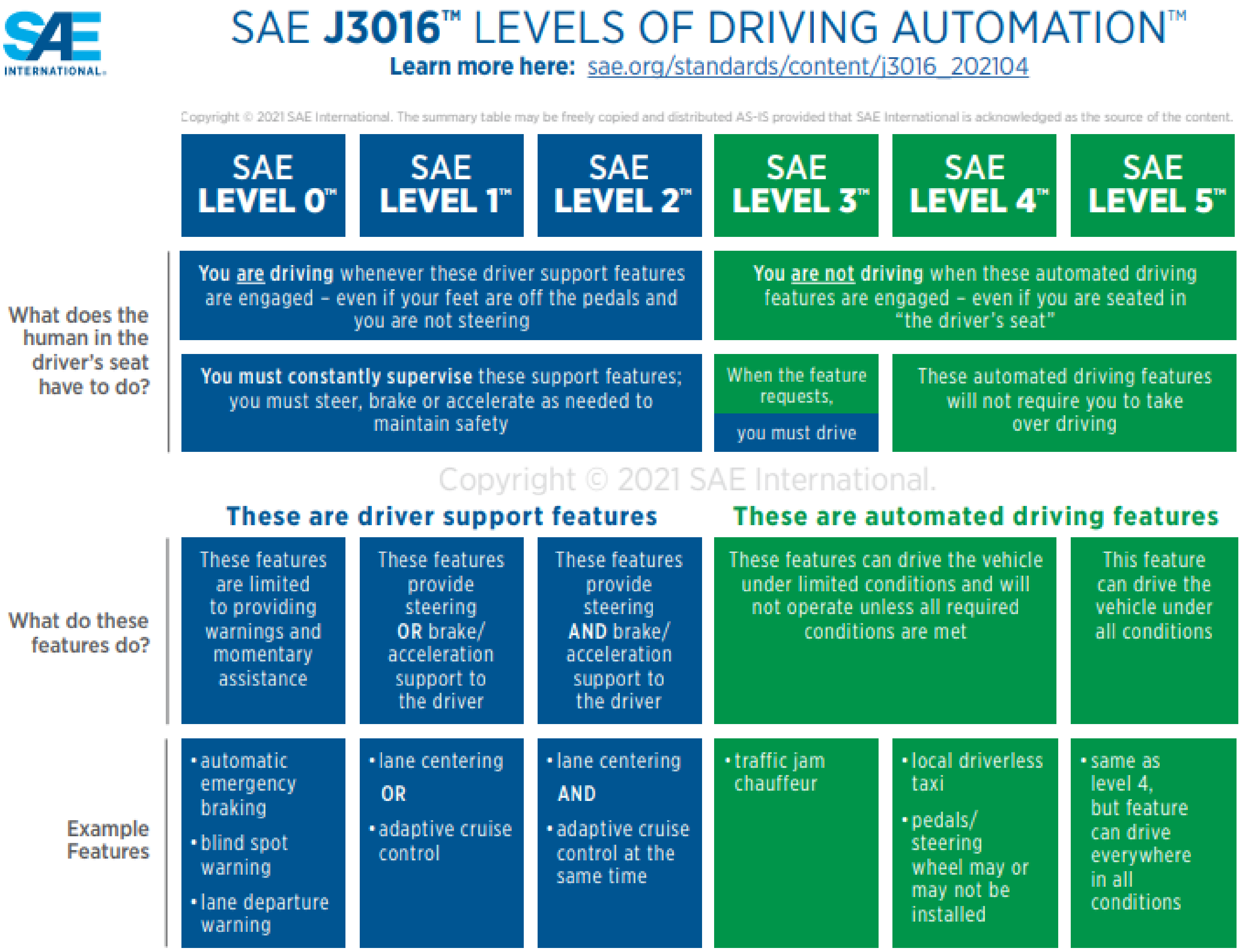

Figure 14 – Levels of Driving Automation [89].

The integration of cooperativity, connectivity and automation results in:

- *Cooperative Automated Driving*: Vehicles not only automate driving tasks but also cooperate with each other and the infrastructure for optimal performance.
- *Smart Infrastructure*: Roads, traffic signals, and other infrastructure elements are equipped with sensors and connectivity to communicate with vehicles.
- *Platooning*: Groups of vehicles travel closely together, coordinated by automated and connected systems to improve efficiency and safety [98].
- *Mobility as a Service (MaaS)*: Integrates various forms of transport services into a single accessible on-demand mobility service, leveraging connectivity and automation [99].

The implementation of this services could improve safety, by reducing the risk of accidents through real-time communication and automated driving assistance, efficiency, by enhancing traffic flow, reducing congestion, and optimizing road usage through coordinated vehicle and infrastructure interaction, environmental impact, by lowering emissions through both an optimization of driving patterns and an integration of electric and hybrid vehicles and convenience and accessibility, by providing better mobility options through seamless integration of various transport modes and improved user experiences.

3.1.9 VULNERABLE ROAD USERS

The term Vulnerable Road Users (VRUs) could be identified in relation to both the type of transport mode and the transport system a person uses. VRUs include persons walking as well as using a range of micro-mobility transport modes such as bicycles, e-bikes, and personal mobility devices (PMDs) e.g., e-scooters, e-skateboards [51,52]. These transport modes travel at lower speeds and have a lower degree of physical protection compared to motorized modes. As a result of larger speed difference and a lack of protection VRUs are more susceptible to injuries and fatalities in the event of accidents (particularly in collisions with motorized vehicles) [54]. Moreover, road user groups such as children, the elderly or those with disabilities or reduced mobility and orientation are considered vulnerable [52] since they may experience the safety risks as greater barriers to their mobility and need special protection due to their higher risk of severe injury and a lower survival rate [48,49].

Incorporating VRUs' safety criteria is important for the development of a more comprehensive and robust road safety assessment framework for several reasons. Firstly, the literature and crash data analysis show VRUs have a high risk of injury and account for a large share of fatalities in the event of a collision (see Figure 15). In EU, VRUs account for approximately 70% of total fatalities in urban areas [7] and almost half of all pedestrians and cyclists killed are more than 65 years old [48]. As such, measures related to VRUs' safety are important indicators of the safety performance of transport systems. Secondly, VRUs have different needs and capabilities compared to motorized vehicle users and overlooking the diversity of different road users' safety requirements is an impediment to the development of inclusive policy and interventions that could effectively improve road safety for all user groups. Thirdly, improving the safety of VRUs can contribute to more sustainable mobility, for instance, ensuring the safety of cyclists and pedestrians could encourage more walking or cycling (which have benefits for health, wellbeing and the environment) and reducing dependency on motorized travel modes.

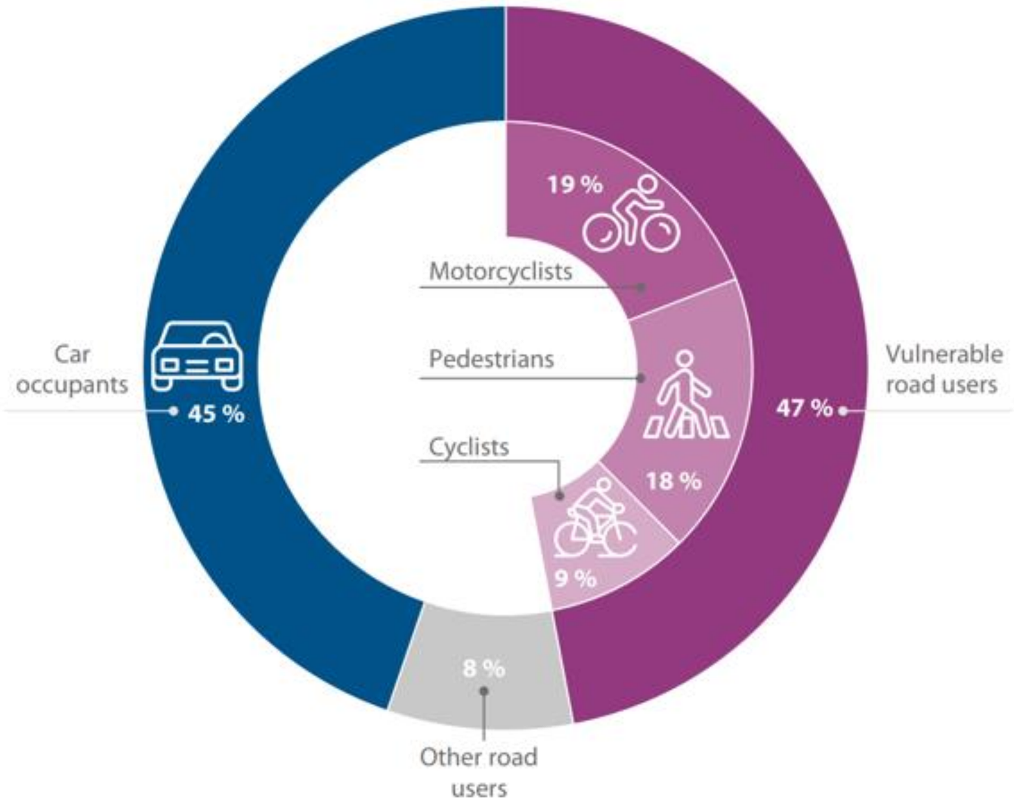

Figure 15 – EU road fatalities by road user (2021) [50]

It is worth noting that in regard to the safety assessment criteria relevant for VRUs, the current review focuses particularly on those related to walking and cycling. Assessing road safety performance in relation to these groups of VRUs entails taking into account various criteria and measures against the factors leading to crashes involving this group of road users.

Most pedestrian injuries are connected to urban areas with 66% of the crashes involving cars. The majority of crashes constitute crossing crashes and are linked to issues such as poor visibility, distraction and non-compliance with traffic rules. In rural areas, due to higher vehicle speed and lack of dedicated infrastructure, such crashes lead to more severe injuries [53]. Crossing locations are also reported as typical circumstances for crashes between cyclists and motor vehicles. However, in the case of cyclists, a significant share of crashes resulting in serious injuries or fatalities occur when cyclists turn left in front of a motor vehicle. Single-bicycle crashes which involve collisions with objects or infrastructure related issues are also reported to represent another common crash scenario. In general, visibility, weather conditions, and road surface conditions too have been reported to play a key role in such crashes. In addition to poor infrastructure design and planning problems, absence of traffic laws or lack of enforcement in combination with unsafe traffic behavior and attitude to safety are also highlighted as important factors leading to crashes involving pedestrians or cyclists. Examples include cyclists not using protective gears, use of headphones, mobile phones while walking or cycling, running red lights, speeding and cycling under the influence of alcohol [15].

To summarize, based on the review of studies on walking and cycling safety the diverse factors contributing to their crashes could be linked to infrastructure and road design, both VRUs' and other road users' attitudes and behavior, environmental conditions, vehicle design, as well as legislation and enforcement [15, 53, 56, 57].

Considering the above-mentioned factors, safety programs typically develop countermeasures that could contribute to crash avoidance and crash protection to enhance road safety for cyclists and pedestrians. It is important to consider that crashes / accidents are often the result of a combination of factors, therefore, assessing the safety performance of transport systems requires a multi-faceted approach that is based on comprehensive understanding of the diverse risks and needed countermeasures and integrates appropriate indicators / KPIs to monitor the performance against the set objectives.

Given the significance of VRUs safety, transport actors and authorities in different countries track various KPIs to assess road safety performance. The Baseline project [18] which has particularly contributed to the standardization of these indicators across EU member states recommends the following KPIs referring to VRUs' safety:

- Percentage of vehicles travelling within the speed limit
- Percentage of riders of powered two wheelers and bicycles wearing a protective helmet
- Percentage of drivers driving within the legal limit for blood alcohol content (BAC)
- Percentage of drivers not using a handheld mobile device
- Percentage of new passenger cars with a Euro NCAP safety rating equal or above a predefined threshold
- Time elapsed in minutes and seconds between the emergency call following a collision resulting in personal injury and the arrival at the scene of the collision of the emergency services

The currently ongoing Trendline project [19] aims to extend the core KPIs developed within the Baseline project with a set of complementary KPIs that are relevant for VRUs.

- Driving under the influence of drugs;
- Share of 30km/h road lane lengths in urban zones;
- Red-light violations by road users;
- Compliance with traffic rules at intersections;
- Helmet wearing of PMD riders;
- Self-reported risky behavior;
- Attitudes towards risky behavior;
- Use of lights by cyclists in the dark;
- Enforcement of traffic regulations;
- Alternative speeding indicators.

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iRAP (the International Road Assessment Programme) [58] which is a group of worldwide Road Assessment Programmes (RAPs) offering planning and policy tools to track road safety performance in different countries by employing a harmonized methodology proposes the following set of indicators that could be used in the context of VRUs' safety [59]:

- Percentage of road length with fatal and serious crashes per kilometer per year
- Percentage of travel on 3-star or better roads for pedestrians, cyclists, motorcyclist and vehicle occupants
- Percentage of travel on new or upgraded roads that are 3-star or better roads for pedestrians, cyclists, motorcyclists and vehicle occupants
- Percentage of school star rating data points that are 3-star or better for children
- Percentage of roads where pedestrians are present and traffic flows at 40km/h or more have formal footpaths or sidewalks
- Percentage of roads where pedestrians cross and traffic flows at 40km/h or more have pedestrian crossing facilities
- Percentage of pedestrian crossings that are adequately signed or maintained
- Percentage of roads where bicyclists are present and traffic flows at 40km/h or more have dedicated bicycle facilities
- Percentage of roads where traffic flows at 80km/h or more have low-risk roadsides
- Percentage of roads where traffic flows at 80km/h or more do not have sharp curves

Swedish Transport Administration (Trafikverket) monitors a set of safety KPIs (listed in Section 3.2) to follow up the traffic safety goals [46]. Moreover, regional and municipal traffic safety plans also often include safety measures that are related to pedestrian and cyclist road safety. Common to many of these plans is the use of a selection of indicators standardized by the Baseline project [18] and in some cases the Trendline project [19]. However, some municipalities have developed specific indicators that may better apply to their local context. For instance, the traffic safety plan established by Umeå municipality includes indicators related to friction – i.e. the measurement of the friction on the surface, use of spikes for pedestrians aged 50+, or use of spiked / winter tires by cyclists. Another example which relates to traffic education is the number of children in 4th grade that participated in a road safety and cycling education program organized by the municipality of Umeå, Sweden, aimed at improving traffic awareness among students [60].

The European Cyclists' Federation (ECF) has also suggested to track modal share (the numbers of cyclists and pedestrians or the distance/time they spend on the roads) as an additional indicator for assessment of VRUs safety [61]. Overall, several studies focusing on VRUs' safety note a range of aspects relevant for cycling and walking that could potentially be used as future indicators to improve the existing frameworks. For example, the use of e-bikes and potential associated safety risks are mentioned, as well as KPIs that consider behavioral data. [62]. However, there remains the work to establish a working definition, calculation methodology and data sources so that the impacts could be measured as quantifiable KPIs.

3.1.10 EMERGENCY MANAGEMENT

Emergency management in road safety focuses on mitigating the effects of accidents through timely and effective responses, aiming at drastically reducing deaths and long-term severity of injuries. WHO Global Report on Road Safety 2018 [36] highlights that emergency management involves various stages from the occurrence of the crash to post-hospitalization care, hence a series of time sensitive actions beginning with activation of the emergency care system and continuing with care at the scene (pre-hospital care), transport, facility-based emergency care (hospital care) and finally rehabilitation both in hospital and beyond. Key Performance Indicators are used to measure the effectiveness of all stages of emergency responses and to identify areas for improvement. As to authors' knowledge, there is no at present a comprehensive framework allowing to evaluate the quality of emergency management as a whole, even though it is clear in the literature that the most frequently monitored KPIs are not sufficient to punctually identify needed improvements.

It is also worth noting that data related to emergency management often suffers from underreporting, particularly for incidents involving vulnerable road users like pedestrians and cyclists, which are frequently not recorded [15]. Additionally, intrinsic challenges to emergency management performance monitoring comes from the need of integration of data from diverse sources such as police, hospitals, and the ambulance services. Moreover, achieving consistency in the definition

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of serious injuries has required a long process in Europe. Currently the accepted definition is a hospital in-patient with an injury level of MAIS3 or more, but many countries have no historical records and are consequently invited to continue collecting data also based on previous definitions in order to consistently monitor progresses [38].

All KPIs related to emergency management efficiency monitoring should be directly related to the number of deaths and especially to the number of serious injuries, but for some newly proposed indicators this correlation has not been proved yet. Moreover, some reports could refer to the Survival Rate Post-Crash, which usually refers to the percentage of serious crash victims who survive after receiving medical intervention within a specified time frame and it indicates the overall effectiveness of emergency medical interventions.

Below is a list of emergency management KPIs which are currently adopted or proposed in European or international documents and reports. Figure 16 shows the main stages characterizing the time from an accident occurrence to the provisioning of definite care: these stages can be monitored with separate indicators increasing the detail on the whole process efficiency.

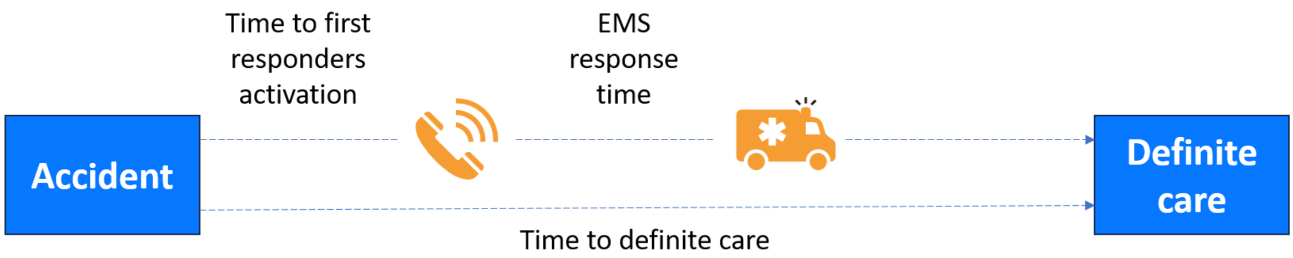

Figure 16 – Different stages from accident to definite care.

- Emergency Medical Services (EMS) Response Time
- Time to First Responder Activation
- Time to Definitive Care

Below is a list of KPIs proposed in the literature to monitor emergency management effectiveness but which do not appear yet, as to authors knowledge, in thematic reports. This could be mainly due to the absence of a recognized methodology and to the difficulty of retrieving the needed data. Moreover, a direct correlation between some of these KPIs and a reduction in mortality has not been proved yet, despite supposed.

- Lay Bystander Intervention Rate
- Post-Crash Care Training Coverage
- Rehabilitation and Recovery Rate
- Comprehensive Post-Crash Investigation Coverage
- Integration of Advanced Emergency Communication Systems (eCall)
- Frequency of SOS call boxes/defibrillators
- Rate of Use of Advanced Technologies in Post-Crash Care

3.2 SAFETY CRITERIA CATALOGUE

This section details the 124 road safety metrics introduced in the previous road transport dimensions categories' paragraphs. Each indicator is described through four fields, whenever available: i. Definition: including metrics description; ii. Method: including calculation methodology and possible data sources; iii. Reference: including relevant references; and iv. Notes: including additional relevant information, such as metrics maturity level, context of application (e.g., rural/urban, road users typology). Trendline [19] related metrics are not included in the following list since they are currently undergoing

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a standardization process and additional information on methodology are not yet available. Metrics are listed in alphabetical order in the following.

- *ACCESSORY SIGNAGE*

  Definition: Percentage of km of road with secondary signs. This category includes reflectors on the sides of the infrastructure that help the driver's visibility.
  Method: The method of assessing this feature is %km.
  Reference: Highway Code.
  Notes: Accessory signage makes the infrastructure progress more readable.

- *ADAPTIVE AND/OR SMART TRAFFIC SIGNAGE*

  Definition: Percentage of connected or adaptive signage.
  Method: The method of assessing this feature is %unit.
  Reference: [86]
  Notes: It provides real-time information to drivers about traffic conditions, road work, and other important updates.

- *ADAPTIVE CRUISE CONTROL*

  Definition: Percentage of cars that support adaptive cruise control.
  Method: The method of assessing this feature is %unit.
  Reference: [90]
  Notes: Adaptive cruise control adjusts the vehicle's speed to maintain a safe distance from the car ahead.

- *ADHERENCE TO REST BREAKS*

  Definition: It monitors the adherence of professional drivers (truck, bus drivers) to mandatory rest breaks, which are critical to avoid fatigue-related accidents.
  Method: Data can be collected automatically from digital systems used by commercial fleets, e.g. through digital tachographs, driver logbooks, GPS monitoring systems.
  Notes: Fatigue is among main contributing factors for serious accidents, despite the great difficulty of monitoring it and prevent it. Considering professional drivers, it is important to monitor the effective taking of mandated rest breaks, while for other drivers there are no proposed KPIs to address this topic. Moreover, fatigue is related also to other fatalities involving motorized vehicles such as forgetting children in hot climate. The indicator is well-established for professional drivers in Europe, while monitoring fatigue for normal drivers is still experimental and performed mainly through survey.

- *ADJUSTMENT OF CROSSINGS*

  Definition: Percentage of adjusted crossings.
  Method: The method of assessing this feature is %unit.
  Reference: [93]
  Notes: These types of actions allow the speed of vehicles to be reduced and ensure greater safety in the event of pedestrian traffic. They help to reduce the risks associated with speeding in certain areas with the presence of vulnerable users.

- *ADJUSTMENT OF PEDESTRIAN CROSSINGS ON INTERURBAN ROADS*

  Definition: Percentage of adjusted crossings.
  Method: The method of assessing this feature is %unit.
  Reference: [93]

Notes: The aim is to apply different combinations of road safety interventions that manage to reconcile interurban vehicle mobility with the demand for crossing the road by vulnerable users. Reconcile the operation of road traffic with the traffic crossing the road in road safety conditions, through homogeneous treatments in the road network. The benefits will lie in the fact that crossings will be carried out in the authorized places, under defined priority conditions, in visibility conditions, being predictable for both users, and without compromising the demand of any of the traffic flows.

- *ADJUSTMENT OF ROAD MARGINS*

Definition: Percentage of km of road with adjusted road margins.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: The objective is to reduce the severity of accidents caused by exiting the road by avoiding impacts with obstacles on the side of the road, either by ensuring that there are no elements that could be considered dangerous obstacles, or by achieving clear margins and the presence of materials such as gravel, sand, or rubber derivatives, which help the vehicle to brake before reaching any obstacle that may exist.

- *ALCOHOL USE*

Definition: Percentage of drivers driving within the legal limit for blood alcohol content (BAC).
Method: Random breath tests, breath testing from enforcement action, or self-reported behaviour.
Reference: [72]
Notes: Use KPI. Baseline KPI minimum requirement targets passenger cars on urban roads, rural roads, and motorways. Can be expanded to, for example, include other vehicle types or groupings of BAC levels. As discussed in Yannis and Folla (2022), the EC has expressed a preference for the Baseline KPI to be based on randomised breath tests. However, it is recognised that this may not be possible for all Member States due to practical or legal reasons. Therefore, the three options are available. Note that the legal limit for BAC varies between different countries. Italy, for example, has a legal limit of 0.5 g/l compared to 0.2 g/l in Sweden.

- *ALTERNATIVE SPEEDING INDICATORS*

Definition: Percentage of alternative speeding indicators for better driver awareness. This type of signal reveals in real time the speed of vehicles passing by giving a perception to the user that is able to moderate its speed in relation to the limits in force.
Method: The method of assessing this feature is %unit (in this case the unit is the alternative speeding indicators).
References: Road traffic management manuals.
Notes: The driver's perception of speed is often less than the actual one, making him or her unaware of the risks to which he or she is exposed. Data could be monitored in real time using ITS technologies.

- *ANIMAL CHANNELING AND WARNING SYSTEMS ON THE ROAD*

Definition: Percentage of km of road with animal channelling and warning systems on the road.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: Limit the areas where wildlife can cross the road to perfectly defined, signposted and tensorized sections. This results in greater credibility of wildlife danger signs and increases the likelihood that drivers will increase their alertness and adjust their speed.

- *ANNUAL CHANGE / RELATIVE CHANGE (%) IN THE NUMBER OF SPEEDING TICKETS, DRINK DRIVING CHECKS, TICKETS FOR NON-USE OF SEATBELT, TICKETS FOR ILLEGAL USE OF A MOBILE PHONE*

  Definition: The year-over-year percentage change in the number of enforcement actions (speeding tickets, drink driving checks, seatbelt tickets, mobile phone tickets) e.g., per 1000 population.
  Method: Data is collected from annual traffic violation statistics from law enforcement agencies. More specific information can be found in the description of the specific indicators on which change is evaluated *(e.g.* Number of speeding tickets, Number of alcohol tests, Number of drug tests)
  References: [27]
  Notes: This indicator is established across most European countries.

- *APPROPRIATE TRANSITION BETWEEN A STRAIGHT AND A CURVED SECTION AND THE OPPOSITE*

  Definition: Percentage of curves preceded and followed by a transition before the straight section. Generally, in the road design phase between a straight section and a cuboidal section, a transition section is placed. It serves to connect the curve with the straight line so that the driver has time to adjust the change of trajectory. *Method*: The method of assessing this feature is %unit (in this case the unit is curve preceded and followed by a transition before the straight).
  Reference: Road design and construction manuals.
  Notes: This is to limit the accidental events generated by a sharp curve.

- *APPROPRIATE VISUAL DISTANCE*

  Definition: Percentage of km of road where the distance of visibility is clear of obstacles and obstructions. Road driving is regulated by the driver in relation to his ability to see what surrounds him. For this reason, it is necessary to ensure adequate visibility so that the driver can immediately and correctly read the road.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals.
  Notes: An appropriate distance of visibility also means eliminating or mitigating as much as possible those elements that limit the driver's visibility of any type of transport (car, bus, truck, motorcycle, etc.).

- *ASYMMETRICAL ROADSIDES*

  Definition: Percentage of km of road with asymmetrical roadsides.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Provide the widest possible shoulder for cyclists in the direction of travel where it is most needed by layout or ramp to avoid dangerous interactions between motorized traffic and cyclists.

- *AUTOMATIC EMERGENCY BRAKING*

  Definition: Percentage of cars that automatic emergency braking.
  Method: The method of assessing this feature is %unit.
  Reference: [91]
  Notes: Automatic emergency braking applies the brakes in case the driver does not act in time after the detection of an impending collision with another vehicle, pedestrian, or object.

- *AUTOMATION LEVEL*

  Definition: Percentage of cars that support V2X operations and automation of a certain level.
  Method: The method of assessing this feature is %unit.
  Reference: [89]

Notes: There are different levels of automation, that are presented above CCAM Operations chapter above.

- *BEACONING AND ZEBRA-STRIPING OF HARD SHOULDERS*

  Definition: Percentage of km of hard shoulders with beaconing and zebra-striping.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: By using zebra markings and/or beaconing on the hard shoulder, the road is given a different appearance from the rest, which induces a heightened state of alertness in the driver. By introducing more visual references on the road with the presence of beacons and/or zebra markings, the subjective sensation of speed is increased, and the objective speed of circulation is reduced. The placement of beacons on the hard shoulder improves the guiding effect provided by the road markings themselves, especially in episodes of reduced visibility and at night.

- *BLIND SPOT DETECTION*

  Definition: Percentage of cars that monitors the vehicle's blind spots.
  Method: The method of assessing this feature is %unit.
  Reference: [90, 91]
  Notes: Blind spot detection alerts the driver to the presence of other vehicles that may not be visible in the mirrors.

- *CAR SAFETY RATINGS*

  Definition: Percentage of passenger cars with a Euro NCAP safety rating equal or above a threshold.
  Method: National statistics on newly registered passenger cars.
  Reference: [74]
  Notes: System KPI. Baseline KPI does not specify the threshold but focuses on 4-star and 5-star ratings in the report. The KPI is calculated in two ways: including or excluding cars without a star rating in the denominator.

- *CENTRAL SAFETY BARRIERS*

  Definition: Percentage of km of road with central safety barriers. These are very important for dividing the directions of a road.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals.
  Notes: Road safety barriers are complementary to each other in order to ensure a good level of safety.

- *COMPREHENSIVE POST-CRASH INVESTIGATION COVERAGE*

  Definition: The percentage of crashes subjected to thorough post-crash investigations to identify contributing factors and improve future response, ensuring that the underlying causes of crashes are understood and addressed to prevent recurrence.
  Method: As for previous KPIs, there is still no recognized methodology of collecting needed data. Digital data stored in event data recorders (EDR) could be very important for undertaking thorough crash analyses.
  References: [45].
  Notes: The importance of this action is underlined in multiple European and international sources and is crucial for assessing the effectiveness of the safe system approach as a whole: each accident potentially should be analyzed with a safe system vision, without blaming user behavior and incompliance with the rules, but understanding hidden causes which led to the accident.

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- *CONGESTION LEVEL (VOLUME/CAPACITY)*

  Definition: It measures the percentage of time road infrastructure operates at or above capacity, which is closely linked to accident probability due to increased driver stress and reduced responsiveness.
  Method: It is expressed as the ratio of traffic volume to road capacity, often expressed as a percentage or congestion index. Data are collected from traffic counters, GPS data, smart cameras, and ITS.
  References: Road traffic management manuals [29, 30].
  Notes: This indicator is well-established and used in urban planning and congestion management. It has high relevance for urban areas but also critical in highways and rural roads with heavy traffic. Data could be monitored in real time using ITS technologies.

- *CONNECTED ROADSIDE UNITS*

  Definition: Percentage of km of road covered by the area of action of an RSU.
  Method: The method of assessing this feature is %km.
  Reference: [88]
  Notes: RSUs facilitate communication between vehicles and infrastructure, providing information on traffic conditions, hazards, and road status.

- *CONTROLLED INTERSECTIONS USING TRAFFIC LIGHTS*

  Definition: Percentage of intersections regulated using traffic lights. This type of intersection minimises the conflicts between the various vehicles occupying the intersection.
  Method: The method of assessing this feature is %unit (in this case the unit is controlled intersection using traffic lights).
  Reference: Road design and construction manuals, road traffic management manuals.
  Notes: This type of intersection is the safest and records the least number of incidents.

- *CONTROLLED INTERSECTIONS WITH ROUNDABOUT*

  Definition: Percentage of roundabouts present. This type of intersection promotes the reduction in speed and the regularisation of traffic flows and consequently increase the level of safety.
  Method: The method of assessing this feature is %unit (in this case the unit is controlled intersection with roundabout).
  Reference: Road design and construction manuals, road traffic management manuals.
  Notes: Roundabouts are used to regulate traffic on all the routes connected to it, so combining safety and traffic management.

- *DEDICATED LANE COVERAGE*

  Definition: Percentage of km of road with dedicated lanes for bicyclists and e-scooters. Higher coverage of dedicated lanes typically leads to safer conditions for vulnerable road users by physically separating them from motor vehicle traffic.
  Method: The method of assessing this feature is %km.
  Reference: Highway Code, road design and construction manuals, road traffic management manuals.
  Notes: Separating vehicle types within the road is always good for the safety of all users.

- *DEDICATED LANES TO DIVIDE TRAFFIC BY DIRECTION AND CATEGORIES*

  Definition: Percentage of km of road with dedicated lanes to divide traffic by direction and category. Divide traffic by category (cars, buses, bicycles, etc.) or by direction (straight, right, left, etc.) is important especially near intersections to limit as much as possible the points of interference between different flows.

Method: The method of assessing this feature is %km.
Reference: Road design and construction manuals, road traffic management manuals.
Notes: The presence of lanes dedicated to specific categories or to specific manoeuvres has benefits both for safety and for traffic flow management.

- *DELIMITATION AND SEPARATION OF DIRECTIONS IN TRUMPET JUNCTIONS*

Definition: Percentage of km of road with delimitation and separation of directions in trumpet junctions.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: The purpose of this measure is to prevent drivers from entering the main road from the secondary road and using this branch line to access it from the opposite direction. This measure prevents drivers from inadvertently accessing the main road via the exit branches.

- *DISTRACTION FROM DEVICES (VRUS)*

Definition: It could measure the proportion of incidents involving VRUs (e.g., pedestrians, cyclists) distracted by devices such as mobile phones or headphones.
Method: There is no standardized methodology for this indicator yet. Data could be collected from police reports, insurance claims, hospital records, self-reports from injured parties.
References: [15]
Notes: The Baseline project addresses this contributing factor for motorized vehicles, but it is generally recognized that distraction from devices could be involved also in VRUs incidents, not only in case of handled devices but also considering isolation caused by headphones, which is not handled by Baseline. Some European countries, such as Denmark, already have regulations concerning cyclists use of devices, but most not. Moreover, it should be noted that, concerning cars, only distraction from mobile devices is currently widely monitored, while distraction coming from the advanced technology systems, screens, installed in modern cars is a recent theme, yet to be explored. However, several studies underline a maximum number of seconds (e.g. 12s) over which distraction from any causes become critical.

- *DITCH GUARDRAIL PROTECTION SYSTEMS*

Definition: Percentage of ditch guardrails with protection systems.
Method: The method of assessing this feature is %unit.
Reference: [93]
Notes: The purpose of ditch protection systems is to improve the quality of the road margins in line with the concept of lenient margins, reducing the severity of accidents that occur due to road exits. During the interaction of the vehicle with the protective system, thanks to the resistant characteristics of the latter and the arrangement of its longitudinal elements, it is able to redirect the trajectory of the vehicle, achieving, in addition to avoiding a direct impact against the obstacle, that the exit trajectory of the vehicle is aligned with the ditch itself and thus reducing the possibility of an impact against other obstacles located behind the ditch.

- *DRIVER MONITORING SYSTEMS*

Definition: Percentage of cars with driver monitoring systems.
Method: The method of assessing this feature is %unit.
Reference: [92]
Notes: Driver monitoring systems uses internal cameras and sensors to monitor the driver’s attention and alertness, warning them if signs of drowsiness or distraction are detected.

- *DRIVING ON SAFETY RATED ROADS*

  Definition: Percentage of distance driven over roads with a rating above an agreed threshold.
  Method: Not specified.
  Reference: [75]
  Notes: System KPI. Baseline KPI minimum requirement was to calculate a value for at least rural roads and motorways. A KPI value for urban roads was optional. Alternative formulations and interim KPIs were: "Percentage of the road network length of roads with a safety rating above an agreed threshold", "Percentage of the distance driven over roads either with opposite traffic separation (by barrier or area) or with a speed limit equal to or lower than xx km/h in relation to total distance travelled [on all roads]", and "Percentage of the road network length of roads either with opposite traffic separation (by barrier or area) or with a speed limit equal to or lower than xx km/h in relation to the total road network length." Safety rating system and/or speed limit thresholds were left to the discretion of the Member States.

- *DYNAMIC ADAPTATION OF SPEED LIMITS*

  Definition: Percentage of km of road with dynamic adaptation of speed limits.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: The application of variable speed limits allows authorities to dynamically adapt the speed limit depending on the prevailing traffic, weather or environmental conditions in accordance with real-time data.

- *EMS RESPONSE TIME OF POST-CRASH CARE*

  Definition: Time elapsed between the emergency call following a collision resulting in personal injury and the arrival at the scene of the collision of the emergency services.
  Method: The time starts when the call is taken by the dispatching centre and ends when the EMS unit arrives at the crash scene. KPI value is the 95th percentile.
  Reference: [39]
  Notes: System KPI. Baseline KPI minimum requirement targets one value that is representative of entire territory considered. Can be expanded to include, for example, vehicle types, road types and time periods.

- *FATALITIES*

  Definition: Number of persons who die within 30 days of a road traffic crash, as a result of that crash. Confirmed suicides and other acute diseases are excluded.
  Method: Primary source of data is police reports. Methods for separating out diseases may vary between countries.
  Reference: [63]
  Notes: Outcome KPI. One of the main outcome indicators to measure traffic safety. It is usually divided into subcategories of road user groups and crash types.

- *FREQUENCY OF SOS CALL BOXES/DEFIBRILLATORS*

  Definition: This KPI measures the frequency of emergency call boxes and defibrillators along roadways to improve emergency response.
  Method: Their importance is recognized worldwide, but there is no proved methodology to evaluate an optimal diffusion along the infrastructure
  Notes: A widely recognized need, but no standardized evaluation methodology.

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- *HANDHELD MOBILE DEVICE DISTRACTION*

  Definition: Percentage of drivers not using a handheld mobile device.
  Method: Observations at randomly selected locations.
  Reference: [73]
  Notes: Use KPI. Baseline KPI minimum requirement targets passenger cars, light goods vehicles, and buses/coaches on urban roads, rural roads, and motorways. Can be expanded to include, for example, differentiation between private/professional drivers and camera images.

- *HELMET FIT AND CONDITION*

  Definition: It could evaluate the proportion of helmets that are worn correctly and in good condition (not damaged or too old) among road users such as motorcyclists, cyclists, PMD riders, and moped riders.
  Method: There is no standardized methodology for this indicator yet. Data could be collected based on field inspections or self-reports, with a focus on helmet condition (age, visible damage) and fit (tightness, correct fastening).
  References: [20]
  Notes: FEMA, among others, highlighted the need of considering, besides the percentage of helmet wearing itself, which is easier to be detected also through cameras, the status of the helmet and the correct fit as essential elements to assure their protective function for all road users involved, e.g. motorcyclists, cyclists, PMD and MOPED riders. Hence, this is a newly proposed indicator to expand the knowledge on riders' security.

- *HELMET USE, PTWS AND CYCLISTS*

  Definition: Percentage of riders of powered two wheelers and bicycles wearing a protective helmet.
  Method: Observations. Random selection of observation points representative of the road network studied.
  Reference: [71]
  Notes: Use KPI. Baseline KPI minimum requirement targets urban roads, rural roads, and motorways and includes driver/passenger and age (if legally relevant). Can be expanded to, for example, include sex, other protective equipment and correct use of helmet.

- *HORIZONTAL SIGN*

  Definition: Percentage of km of road with road markings to indicate the road and lanes. Many roads due to poor maintenance are lacking road signs that leads the driver not to properly manage the space available for circulation.
  Method: The method of assessing this feature is %km.
  Reference: Highway Code.
  Notes: The presence of horizontal signs has benefits both for safety and for traffic flow management.

- *INFRASTRUCTURE USAGE RATE*

  Definition: Percentage of bicyclists and e-scooter riders using dedicated infrastructure like bike lanes. High usage rates indicate the infrastructure is well-designed and meets the needs of users.
  Method: The method of assessing this feature is %unit (in this case the unit is bicyclists and e-scooter riders using dedicated infrastructure like bike lanes).
  Reference: Road traffic management manuals.
  Notes: Data on infrastructure use helps to predict accidents.

- *INTEGRATION OF ADVANCED EMERGENCY COMMUNICATION SYSTEMS (ECALL)*

  Definition: Measures the usage rate and effectiveness of emergency communication systems (e.g., eCall) in crash response.

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Method: There is still no recognized methodology of collecting needed data.
References: [83, 84]
Notes: Advanced emergency communication systems can facilitate timely response, which could be critical especially in remote or less accessible areas and for motorcyclists.

- *LANE BEACONING*

Definition: Percentage of km of road with lane beaconing.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: The guiding effect of road markings is enhanced. Directional traffic demarcation is reinforced, and illegal overtaking is discouraged. An increased sense of traffic speed is achieved, thereby calming traffic. A high density of beacons can discourage improper left-turn maneuvers.

- *LANE DEPARTURE WARNING*

Definition: Percentage of cars that supports lane departure warning.
Method: The method of assessing this feature is %unit.
Reference: [90]
Notes: Lane departure warning alerts the driver if the vehicle unintentionally drifts out of its lane.

- *LANE KEEPING ASSIST*

Definition: Percentage of cars that support lane keeping assist.
Method: The method of assessing this feature is %unit.
Reference: [90]
Notes: Lane keeping assist actively steers the vehicle back into the lane if the driver does not respond to the warnings.

- *LANE SEPARATION CONTINUOUS LINE*

Definition: Percentage of km of road with lane separation continuous line.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: It allows the user to more clearly perceive the lane markings in those sections where changing lanes could entail a significant additional risk. It indirectly informs drivers that they are travelling on a section that requires lane discipline and attention.

- *LANE SPLITTING BEHAVIOUR AND RIDING PREDICTABLY*

Definition: It could measure how often motorcyclists engage in lane-splitting and/or the predictability of cyclist riding patterns (e.g., staying within lanes).
Method: There is no standardized methodology for this indicator yet. Data could be collected from camera footage, police reports, insurance claims.
References: [80]
Notes: There are risky behaviours characteristic of some road user categories, e.g. the frequency and way motorcyclists engage in lane splitting or the cyclist's riding predictability. However, these categories of risky behaviours are not usually considered in KPIs related to this theme, but more commonly in road safety research. It could be particularly relevant in traffic-congested urban areas.

- *LAY BYSTANDER INTERVENTION RATE*

  Definition: It measures the percentage of crash scenes where lay bystanders provided care before EMS arrival. This KPI highlights the importance of public awareness and first-aid training.
  Method: Since there are no historical records of this KPI or similar, there is no diffuse habit of collecting needed information. Both police and EMS reports, after arriving at crash scene, could collect this information, but common guidelines still need to be established.
  References: [42]
  Notes: The importance of bystanders' intervention is underlined in numerous European and international documents, since in general the first hour after an accident (golden hour) is crucial with respect to the final outcome. Lay bystanders could help securing the accident scene and provide first lifesaving maneuverings before EMS arrival. It is hence considered fundamental that national legislation actively supports or oblige intervention, protecting helpers from civil liability ("good Samaritans" laws). However, this indicator is still experimental and there is no widely recognized methodology.

- *LED REFLECTORS*

  Definition: Percentage of km of road with LED reflectors.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Facilitate guidance along the road layout, especially at night or in low-light conditions. Warn the driver that he or she is approaching a crossing area, dangerous curves or coexistence with vulnerable users.

- *LENGTH OF STRAIGHT SECTIONS*

  Definition: Percentage of km of straight sections. Straight sections reduce the accident rate because the driver can maintain a steady and easily manageable. However, the course curved sections require greater operations and driver concentration.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals.
  Notes: It is important that they are not too long because it has been verified that long straight sections generate distraction to the driver due to the monotony of the movements.

- *LOAD SECUREMENT*

  Definition: It monitors whether the load carried by commercial vehicles is properly secured to prevent accidents caused by shifting or falling cargo.
  Method: Data sources are roadside inspections, company audits, crash reports, performed mainly on heavy trucks.
  References: [81]
  Notes: It is well-monitored in countries with strong commercial vehicle regulations (e.g. Germany).

- *LONGITUDINAL SLOPE*

  Definition: Percentage of km of road with a longitudinal slope above 10%. The longitudinal slope of the road leads to a more demanding driving condition on flat sections, bringing the driver to a higher stress level that can cause accidents.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals.
  Notes: Excessive downhill gradients favour high speeds which are usually the cause or co-cause of incidental events.

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- *LONGITUDINAL SOUND GUIDES IN ROAD MARKINGS FOR SEPARATING DIRECTIONS*

  Definition: Percentage of km of road with longitudinal sound guides in road markings for separating directions.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Increase lane discipline and prevent inadvertent invasion of the oncoming lane on left-hand curves. Reinforce compliance with the continuous line. Inform drivers that the section is more dangerous than the rest of the road.

- *MEDIAN BARRIER ROADS*

  Definition: Share of traffic volume on roads with median barriers / Share of road length with median barriers.
  Method: Share of traffic/roads that have a median barrier installed.
  Reference: [75, 68]
  Notes: Related to Baseline KPI Driving on safety related roads, as median barriers are an effective intervention to reduce fatalities and serious injury (see, for example, 76)

- *NETWORK AVAILABILITY*

  Definition: Percentage of km of road covered by network.
  Method: The method of assessing this feature is %km.
  Notes: Network coverage is fundamental to exchange and provide to all road users real time information on combined network quality, service availability and infrastructure conditions.

- *NOT CONTROLLED INTERSECTIONS (OR SIMPLE INTERSECTIONS*)

  Definition: Percentage of uncontrolled crossings where the precedence rule applies. This type of intersection is the most dangerous for the risk of accidents and therefore must be little present especially where the traffic flow is very high.
  Method: The method of assessing this feature is %unit (in this case the unit is uncontrolled crossing where the precedence rule applies).
  Reference: Road design and construction manuals, road traffic management manuals.
  Notes: Having an unregulated intersection is acceptable only where traffic flow is very low. Otherwise, the increase in flow increases the chances of unprotected turns that can cause road accidents.

- *NUMBER OF AUTOMATICALLY DETECTED OFFENCES COMMITTED BY NON-RESIDENTS AND THE PROPORTION OF FOLLOWED-UP OFFENCES*

  Definition: The number of traffic violations committed by non-resident drivers detected through automated systems and the proportion of those violations that are successfully followed up and penalized.
  Method: Data is collected through automated enforcement systems (e.g., speed cameras, red-light cameras) and cross-border enforcement databases.
  References: [27]
  Notes: The maturity level of this indicator is growing due to enhanced cross-border cooperation in the EU. However, non-compliance by non-residents remains a significant challenge in enforcement.

- *NUMBER OF FINES FOR ILLEGAL MOBILE PHONE USE*

  Definition: The number of fines issued to drivers using mobile phones while driving, e.g., per capita.
  Method: Data can be collected through police traffic stops and occasionally by mobile phone detection technology.
  References: [27]
  Notes: The indicator itself is well-established but enforcement level on this point varies widely across countries.

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- *NUMBER OF ROADSIDE ALCOHOL BREATH TESTS CONDUCTED AND PROPORTION OF THOSE TESTED FOUND ABOVE THE LEGAL LIMIT*

  Definition: The number of roadside breath tests performed to detect drivers operating vehicles under the influence of alcohol, e.g., normalized per 1000 inhabitants. The proportion refers to the percentage of drivers who tested positive for alcohol levels above the legal limit.
  Method: Data is gathered from breathalyser tests conducted by law enforcement officers during random roadside checks or targeted enforcement operations.
  References: [27]
  Notes: Data referred to COVID-19 pandemic period showed a drastic decrease in most countries because of distancing rules. This indicator is established in legislation in most EU countries.

- *NUMBER OF ROADSIDE DRUG TESTS CONDUCTED*

  Definition: The number of roadside tests conducted to detect drug use in drivers, focusing on substances that impair driving ability.
  Method: Data is collected during random roadside checks and should not be mixed with post-crash investigations performed using saliva or blood tests.
  References: [27]
  Notes: This indicator is still emerging in some countries because of the more complex collection process than those required for alcohol tests, however it is already well-established in others (e.g., the UK, Sweden). Methods for data collection con still vary widely between countries.

- *NUMBER OF SAFETY CAMERAS*

  Definition: The number of safety cameras (eventually differencing between fixed, mobile, time-over-distance, and empty camera boxes) installed e.g., per one million inhabitants to monitor traffic offenses, particularly speeding.
  Method: Data is collected by local and national road safety agencies through reports on traffic monitoring systems.
  References: [27]
  Notes: This indicator is established across most European countries. It can be noted that fixed cameras tend to be more prevalent in urban areas, while mobile and time-over-distance cameras are common in rural and high-speed roads.

- *NUMBER OF SAFETY CHECKS ON COMMERCIAL VEHICLES*

  Definition: The total number of safety checks conducted on commercial vehicles (trucks, vans) to ensure compliance with road safety regulations (e.g., load limits, mechanical conditions).
  Method: Data collection is performed through random roadside checks or scheduled inspections at commercial vehicle depots, commonly on major highways and at border crossings.
  References: [78]
  Notes: Well-established in most EU countries.

- *NUMBER OF SPEEDING TICKETS ISSUED*

  Definition: The total number of speeding tickets issued by law enforcement authorities, e.g., annually normalized per 1000 inhabitants, to compare enforcement levels between regions and countries.
  Method: Data is collected from law enforcement databases and ticketing systems and may come from both manual police operations and automated systems (e.g., speed cameras). Main data sources can be law enforcement agencies, road safety departments, and national statistics bureaus.
  References: [27]

Notes: This indicator is well-established in legislation and operational in most EU countries. However, it may exclude minor infractions depending on national laws.

- *NUMBER OF SPEEDING TICKETS THAT WERE PAID*

Definition: The total number of speeding tickets that result in payment, reflecting both enforcement effectiveness and compliance.
Method: Data is gathered from national and local authorities responsible for processing traffic violations (e.g. law enforcement databases, court records, and municipal fines processing centres).
References: [27]
Notes: The rate of payment reflects the enforcement strength and follow-up on violations. The indicator is well-tracked in most jurisdictions.

- *NUMBER OF TICKETS FOR NON-USE OF SEATBELT*

Definition: The total number of tickets issued for the non-use of seatbelts by drivers and passengers, e.g., normalized per 1000 inhabitants.
Method: Data is derived from police traffic stops and automated seat belt detection systems.
References: [27]
Notes: This indicator is well-established in legislation and operational in most EU countries.

- *PARKING COMPLIANCE*

Definition: It could monitor the percentage of e-scooters, MOPEDs, and bicycles parked in designated parking zones to avoid obstructing pathways and creating hazards for pedestrians.
Method: There is no standardized methodology for this indicator yet.
Notes: Ensuring that e-scooters, MOPED and bicycles are parked properly It is generally recognized an important element, to avoid obstructing pathways and creating hazards for pedestrians and other moving VRUs. As to authors knowledge, there are no recognized indicators to measure this, but it could surely benefit from new technologies such as satellite imagery, to identify recurrent incompliances.

- *PEDESTRIAN/CYCLISTS WAITING TIME AT CROSSINGS*

Definition: It measures the time pedestrians or cyclists have to wait at traffic lights or crossings before they can safely cross the road, which can impact safety if wait times are too long.
Method: Data can come from traffic signal systems, pedestrian surveys, city-level transport systems.
References: Road traffic management manuals.
Notes: An increased waiting time stresses the pedestrian or cyclist who is encouraged to cross even without authorisation, thus jeopardising his safety and that of other road users. The green times for each vehicle category must be well calibrated in relation to the actual flow need. It is established but not systematically measured in many countries. Data could be monitored in real time using ITS technologies.

- *PERCENTAGE OF URBAN AREAS SUBJECT TO "ZONE 30"*

Definition: Percentage of urban areas in which "zone 30" is active. The increase of these areas increases the level of security.
Method: The method of assessing this feature is %unit (in this case the unit is the urban area subject to “zone 30”). Data can come from municipal road safety plans, or traffic signs databases.
References: Highway Code and road traffic management manuals, [13, 17, 34, 53].
Notes: This indicator is primarily relevant in urban settings where pedestrian and cyclist safety are a concern. Its implementation is increasing across Europe.

- *PHYSICAL SEPARATION OF DIRECTIONS IN CRITICAL SECTIONS*

  Definition: Percentage of km of road with physical separation of directions in critical sections.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: It is a separator or delimiter of directions to reduce the risk of head-on accidents, while the median can be used to narrow wide lanes and thus encourage lower speeds by not giving a sensation of width. It improves the definition of the curve, favoring its legibility. With less effectiveness, it can contribute to the reduction of speed and can serve as protection for left turns and/or pedestrians in crossing areas and generate sufficient width in the median to form a guardrail.

- *PIGMENTED PAVEMENT*

  Definition: Percentage of km of road with pigmented pavement.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: The main objective is to increase the driver's attention to the road and its circumstances due to the particular danger of a specific element of the route.

- *PLACEMENT OF FENCING ON MEDIAN SEPARATION ELEMENTS*

  Definition: Percentage of km of road with fencing on median separation elements.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: The placement of fencing on median separation elements prevents pedestrians from crossing the road.

- *POST-CRASH CARE TRAINING COVERAGE*

  Definition: This KPI tracks the percentage of the population trained in post-crash care and first aid, essential for effective initial response to road crashes.
  Method: There is no widely recognized methodology for this newly proposed indicator, however possible data sources can be training records from driving schools, public health agencies, and EMS organizations. There can be a focus on different demographics, such as new drivers, taxi drivers, and public transport workers.
  References: [38, 43, 44].
  Notes: It could help monitoring the overall capacity for effective initial response to road traffic injuries, by providing e.g. the percentage of the population trained in basic post-crash care and first aid. Several reports suggest the need of improving first aid training coverage, e.g. introducing mandatory courses for all new drivers, measure already implemented in some European countries such as Austria, Estonia, Germany and Hungary. It is also suggested in the literature to identify other population categories to be trained with first aid notions, based on their potential presence in road crash scenes, e.g. taxi drivers, public transport drivers.

- *PRESENCE OF CYCLE PATHS*

  Definition: percentage of km of road with cycle path or dedicate bicycle lane. The presence of cycle paths is essential to allow the transit of cyclists who would otherwise be forced to move on the road interfering with vehicle traffic.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals, road traffic management manuals.

Notes: The presence of cycle paths is a mandatory condition in urban areas as well as in extra-urban areas for more effective protection of cyclists.

- *PRESENCE OF SIDEWALKS*

Definition: percentage of km of road with sidewalks. The presence of sidewalks is essential to allow the transit of pedestrians who would otherwise be forced to walk on the road resulting in a danger for themselves and drivers.
Method: The method of assessing this feature is %km.
Reference: Road design and construction manuals, road traffic management manuals.
Notes: The presence of sidewalks is a mandatory condition in urban areas. In the outlying areas are recommended only on those streets with heavy pedestrian flow.

- *PROPORTION OF SPEEDING TICKETS GENERATED BY SAFETY CAMERAS*

Definition: The percentage of speeding tickets issued that were generated by automated safety cameras compared to those issued by manual enforcement.
Method: Data is derived from safety camera systems and law enforcement databases.
References: [27]
Notes: This indicator is well-established in legislation and operational in most EU countries.

- *PROTECTED INFRASTRUCTURE RATIO*

Definition: Percentage of km of road with protected bike lanes (those with physical barriers) to unprotected bike lanes. Protected lanes provide a higher level of safety by offering physical separation from vehicles.
Method: The method of assessing this feature is %km.
Reference: Highway Code, road design and construction manuals, road traffic management manuals.
Notes: Separating vehicle types within the road is always good for the safety of all users.

- *PROTECTIVE GEAR USAGE BEYOND HELMETS*

Definition: It could measure the usage rate of protective gear such as jackets, gloves, and boots among motorcyclists, and potentially other VRUs such as PMD riders, and MOPED users.
Method: There is no standardized methodology for this indicator yet.
References: [20]
Notes: The use of comprehensive protective gear, including jackets, gloves, and boots, is underlined as fundamental aspect for motorcyclists' security, but yet not comprehensively monitored.

- *PUBLIC PERCEPTION/SATISFACTION WITH TRAFFIC LAW ENFORCEMENT*

Definition: Measures the public's perception and satisfaction with how traffic laws are enforced in their region, typically gathered through surveys.
Method: Data collection is conducted via public opinion surveys, focus groups, or national road safety assessments.
References: [27, 79]
Notes: It provides insight into the perceived fairness and visibility of enforcement measures. Its importance is growing in importance as a feedback mechanism for policy adjustments.

- *RADIUS OF CURVATURE IN NON-STRAIGHT LINES*

Definition: Percentage of the non-straight sections with a curvature radius of less than 8 metres. Very narrow bending radius do not allow safe driving and predispose the driver to accidents.

Method: The method of assessing this feature is %unit (in this case the unit is non-straight section with a curvature radius of less than 8 metres).
Reference: Road design and construction manuals.
Notes: The curves are not only more difficult to drive but also a limitation of the driver's visibility: the shorter their range, the less visibility they have.

- *REGULARITY OR ROUGHNESS (OF THE ROAD PLAN)*

Definition: Percentage of km of road characterised by a homogeneous regularity of the road surface. The regularity of the road promotes a stable driving pattern.
Method: The method of assessing this feature is %km.
Reference: Road design and construction manuals.
Notes: This parameter depends on the type of flooring and its maintenance status. Data could be monitored in real time using sensors on board vehicles capable of detecting the condition of road surfaces.

- *REHABILITATION AND RECOVERY RATE*

Definition: The percentage of crash victims who undergo rehabilitation and recover fully, indicating the effectiveness of post-crash medical services.
Method: there is no widely recognized methodology for this indicator.
References: [42]
Notes: Several sources underline the importance of rehabilitation to reduce injuries severity in the long run and hence the need of measuring the effectiveness of these measures. However, there are no historical records of a similar KPI and there is the need of developing new methodologies.

- *REINFORCEMENT OF GUIDANCE AT CRITICAL POINTS*

Definition: Percentage of km of road with reinforcement of guidance at critical points.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: Ensure the correct interpretation of the road layout by all its users in layout elements where, for reasons intrinsic to the road or its environment, the guiding effect is compromised, affecting visibility and therefore road safety.

- *REINFORCEMENT OF SIGNAGE AT DIVERGENCES*

Definition: Percentage of km of road with reinforcement of signage at divergences.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: Provide greater comfort and safety because of greater predictability of the layout, reinforcing the zebra type islands at the point of divergence.

- *REPEAT OFFENDER RATES*

Definition: The proportion of drivers who commit multiple traffic offenses within a specified period, indicating patterns of non-compliance with traffic laws.
Method:
References: [27, 77]
Notes: Repeat offenders are generically a sign of failed enforcement strategies. However, to avoid additional transgressions they often face increased penalties, including license suspension.

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- *ROAD MARKINGS CHARACTERISTIC OF SECTIONS*

  Definition: Percentage of km of road with road markings characteristic of sections.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Colored markings give drivers the impression that the lane is narrowing to induce them to moderate their speed. It has been shown that these longitudinal colored indicators increase the correct identification of the category and function of the road. The aim is for road users to identify and associate these indications with sections of speed-controlled roads so that, once users are aware of this, in the near future the installation of speed control systems will not be necessary, and a self-explanatory road will be obtained that contributes to increasing the degree of compliance with the rules by drivers.

- *ROAD THINNING*

  Definition: Percentage of km of thinned road.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Achieve better channeling of traffic resulting in greater delimitation and homogeneity of vehicle paths. The reduction of the space available for the circulation of motor vehicles induces a reduction in speed due to optical effect and the geometry itself.

- *SAFETY BELT AND CRS USE*

  Definition: Percentage of vehicle occupants using the safety belt or child restraint system correctly.
  Method: Observations or use of camera at randomly selected locations.
  Reference: [69]
  Notes: Use KPI. Baseline KPI minimum requirement targets both front seat and backseat occupants in passenger cars on urban roads, rural roads, as well as motorways. Can be expanded to include, for example, drivers in goods vehicles

- *SAFETY DITCHES AND ADAPTATION OF BERMS*

  Definition: Percentage of km of road with safety ditches and adaptation of berms.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Achieve smooth and progressive transitions between the outer edge of the shoulder and the verge, allowing the driver to regain control of the vehicle, avoiding loss of stability or leaving the road if the driver does not do so. Allow emergency maneuvers by vehicles, reducing the risk of collision with other vehicles in circulation. Increase the lateral visibility available to drivers in accordance with the visibility calculations made when obtaining the road. Provide protection to the pavement and its lower layers to reduce erosion and instability.

- *SAFETY ELEMENTS PROTECTING INDIVIDUAL POINTS*

  Definition: Percentage of single points on the road protected with safety elements. These elements are essential to protect the points of contact which would otherwise cause serious injury to users in case of an accident.
  Method: The method of assessing this feature is %unit (in this case the unit is single point on the road protected by safety elements).
  Reference: Road design and construction manuals.
  Notes: Road safety barriers are complementary to each other in order to ensure a good level of safety.

- *SEPARATION STRIP OF DIRECTIONS*

  Definition: Percentage of km of road with separation strip of directions.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: The separation strip allows the lateral distance between vehicles travelling in the opposite direction to be increased, thereby increasing the margin of action in evasive maneuvers to avoid frontal and frontal-lateral accidents. The effective lane width available is reduced, inducing in the driver a perception of the road and his driving that naturally makes him drive at a lower speed. In the case where high-texture pavement is used in the intermediate strip, to differentiate the noise, and not necessarily high friction, it also alerts the driver when he leaves the natural lane or crosses the line that delimits his direction of travel.

- *SERIOUSLY INJURED IN PEDESTRIAN FALLS, HOSPITAL REPORTED*

  Definition: A person who has suffered at least a 1 percent permanent medical impairment as a result of a pedestrian fall.
  Method: Swedish KPI. Data is gathered from emergency hospital reports which are linked automatically to police reports in the Swedish national crash database Strada. Calculation of medical impairment is based on a method that prognosticates medical impairment based on the hospitals' AIS-coding of injuries.
  Reference: [67, 68, 66]
  Notes: Outcome KPI. Not a common road safety KPI. Pedestrian falls are not road traffic crashes by definition. However, the KPI was adopted in Sweden following the observation from hospital reports that pedestrian falls account for many injuries in the road traffic environment. In 2023, pedestrian falls were the largest group of seriously injured road users in Sweden, accounting for almost half of all seriously injured.

- *SERIOUSLY INJURED, HOSPITAL REPORTED (MAIS3+)*

  Definition: Number of persons who sustain an injury with a score of 3 or higher on the AIS-scale as a result of a road traffic crash.
  Method: Data is gathered from hospitals as the KPI requires AIS-coding of injuries performed by healthcare professionals.
  Reference: [65,66]
  Notes: Outcome KPI. One of the main outcome indicators to measure traffic safety, but may be difficult to implement in practice due to required data linkage between hospital data and crash data. In Sweden, police and hospital data are integrated automatically in the national crash database Strada. Note that other AIS-thresholds can be used in analysis, such as MAIS2+. Furthermore, other hospital-based KPIs include, for example, longer than 24-hour hospitalisation and measures of permanent medical impairment.

- *SERIOUSLY INJURED, POLICE REPORTED*

  Definition: Number of persons who sustain a police-classified serious injury as a result of a road traffic crash.
  Method: Data is gathered from police reports. Classification is usually performed at the crash site.
  Reference: [64]
  Notes: Outcome KPI. One of the main outcome indicators to measure traffic safety. It Is usually divided into subcategories of road user groups and crash types. The exact definition of serious injury as it relates to police reporting may vary between countries, but commonly includes fractures, crushes, tears, serious cuts, concussions and internal injuries.

- *SIDE SAFETY BARRIERS*

  Definition: Percentage of km of road with central safety barriers. These are very important for protecting the sides of the infrastructure.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals.
  Notes: Road safety barriers are complementary to each other in order to ensure a good level of safety.

- *SIGNAL TIMING AND COORDINATION*

  Definition: It assesses the percentage of traffic lights synchronized to allow smooth traffic flow, minimizing stop-and-go driving, which can reduce the risk of accidents and improve road safety.
  Method: Data can come from traffic signal systems, smart city infrastructures, ITS data.
  References: Road traffic management manuals.
  Notes: This indicator is not widely diffused but already implemented in most advanced traffic management systems, since it requires integration with city-level traffic management systems. It is particularly useful in congested urban centres. Data could be monitored in real time using ITS technologies.

- *SIGNAL TIMING FOR VRUS*

  Definition: Percentage of signal timing in traffic light for VRUs. This is the indication of the remaining time at the current traffic light stage concerning pedestrians and cyclists. It promotes the respect of traffic lights by discouraging passage when the remaining time is not sufficient.
  Method: The method of assessing this feature is %unit (in this case the unit is the traffic light with the indication of the remaining time).
  References: Road traffic management manuals, [15].
  Notes: The monitors signal timing at intersections to ensure sufficient crossing time for pedestrians, bicyclists and e-scooter riders. Proper timing reduces the likelihood of conflicts with motor vehicles and ensures safe crossing. The device used must be directly connected to the control unit that operates the traffic light, so that the time indication given is correct. Data could be monitored in real time using ITS technologies.

- *SIGNS ACTIVATED BY VRUS*

  Definition: Percentage of single dangerous points with signs activated by vulnerable road users.
  Method: The method of assessing this feature is %unit (in this case the unit is single point on the road protected by safety elements).
  Reference: [93]
  Notes: The purpose of the signs activated by vulnerable road users is to warn drivers of the presence of these types of users on the road, so that they can take the necessary precautions such as reducing speed and keeping distance to the sides to improve coexistence between users and ultimately avoid possible accidents. The operating principles on which this system is based are “predictability” and “signal credibility”.

- *SIGNS ACTIVATED FOR SPEED CALMING*

  Definition: Percentage of km of road with signs activated for speed calming.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: This is a driving assistance measure that aims to reduce speed when approaching points or stretches of road safety that pose a particular risk. It calms traffic on the stretches where it is installed.

- *SKID RESISTANCE OR ADHESION (TO WHEEL-PAVEMENT CONTACT)*

  Definition: Percentage of km of road surface with a wheel adhesion coefficient between 0,7 and 0,85. The coefficient of adhesion is very important for the safe movement of vehicles.
  Method: The method of assessing this feature is %km.
  Reference: Road design and construction manuals.
  Notes: This value may be affected by weather conditions and infrastructure maintenance. Adverse weather conditions such as rain, snow and ice significantly reduce the skid resistance (or adhesion). Similarly, poor maintenance of the road surface such as poor cleaning, presence of foreign material and widespread irregularities also affect the skid resistance (or adhesion). Data could be monitored in real time using sensors on board vehicles capable of detecting the condition of road surfaces. Recent studies consider the different needs of VRUs vehicles, e.g., mopeds, bicycles, which usually use specific parts of the road, different from cars, and are more susceptible also to minor imperfection of the pavement, see for example 85.

- *SMART CROSSINGS*

  Definition: Percentage of km of road with smart crossings.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: They increase road safety through elements and systems that induce and promote safe use that is adapted to the circumstances of the roads. They reinforce the signaling by being activated only when there is real danger. Smart Crossings meet the requirement of improving safety at intersections and are a proven solution that reduces the danger at them.

- *SMART STREETLIGHTS*

  Definition: Percentage of streetlights that automatically adjust brightness.
  Method: The method of assessing this feature is %unit.
  Reference: [87]
  Notes: Streetlights automatically adjust brightness based on time of day, weather conditions, or the presence of pedestrians and vehicles.

- *SOUND GUIDES FOR LANE SEPARATION*

  Definition: Percentage of km of road with sound guides for lane separation.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Reinforce lane discipline and minimize lane changes, especially indicated in sections with high vehicular intensities with capacity problems. Reinforce compliance with continuous lines in sections of trajectory channeling. Reinforce lane discipline in curved sections with high speeds to avoid shortening of routes that imply the invasion of the adjacent lane.

- *SOUND GUIDES FOR ROADSIDES*

  Definition: Percentage of km of road with sound guides for roadsides.
  Method: The method of assessing this feature is %km.
  Reference: [93]
  Notes: Prevent unintentional encroachment on hard shoulders and right-hand side road exits. Prevent motor vehicles from encroaching on the hard shoulder, thereby protecting vulnerable road users who may be travelling on it.

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- *SPEED COMPLIANCE*

  Definition: Percentage of vehicles travelling within the speed limit.
  Method: Observation of momentaneous speed in free-flowing traffic using, for example, pneumatic tubes, radar or camera systems. Measurement locations should be randomly selected and represent the entire road network studied.
  Reference: [69, 70]
  Notes: Use KPI. Baseline KPI minimum requirement targets passenger cars on urban roads, rural roads, and motorways. Can be expanded to include, for example, average speed and other vehicle types. Swedish KPI is slightly different to Baseline KPI as it considers share of traffic volume instead of share of vehicles. It is also based on more extensive, but less frequent, observations at 1 500 location every four years for the national road network.

- *SPEEDING (VRUS)*

  Definition: It could monitor the adherence to speed regulations of e-scooters, e-bikes, MOPEDs to ensure compliance with local speed limits, particularly in areas with high pedestrian activity, once proper speed limits have been set.
  Method: There is not yet a standardized methodology for this indicator.
  References: [80]
  Notes: This indicator is emerging, as e-scooter and MOPEDs regulations are still evolving across Europe. Moreover, differently from cars and motorcycles which are easily recognized by the license plate, there is the need of new methods and regulations which would allow identification of the rider also through automatic means. Otherwise, implementability remains too complex and mostly limited to on-site police checks.

- *SUICIDES IN THE ROAD TRANSPORT SECTOR*

  Definition: Number of suicides that occur in the road transport sector. Includes both road traffic suicide and jumping off bridges.
  Method: Swedish KPI, where a specialist group uses a purpose-made classification method to determine if a fatality in the road transport sector is the result of a suicide.
  Reference: [68]
  Notes: Outcome KPI. Not a common road safety KPI. Suicides are not road traffic crashes by definition, but are included in the yearly follow-ups in Sweden due to their societal impact.

- *TIME SPENT IN QUEUING*

  Definition: It monitors the proportion of travel time that drivers spend in traffic queues, which can increase driver fatigue, stress, and the likelihood of accidents.
  Method: It could be expressed as the average queuing time during peak hours as a percentage of total travel time. It is most often monitored through smart traffic management systems, but in some countries, it can be integrated with user-submitted data from navigation apps.
  References: Road traffic management manuals [32].
  Notes: Widely used in traffic management studies as it provides a very important data for traffic forecasting and its effective management. Data could be monitored in real time using ITS technologies.

- *TIME TO CLEAR INCIDENTS/RECOVERY TIME*

  Definition: Percentage of incidents resolved in a short time to allow traffic to resume normal flow. If these times are longer than necessary, the damage of the incident may affect traffic causing additional inconvenience and secondary accidents.
  Method: Time elapsed between incident detection and full traffic recovery. Data can come from traffic incident reports, real-time monitoring systems, ITS.
  References: [25, 26, 35].

Notes: The indicator is well-established in advanced traffic systems.

- *TIME TO DEFINITIVE CARE*

  Definition: This KPI measures the time from the crash event to when the victim receives definitive medical care (e.g., hospital admission). It is crucial for assessing the effectiveness of emergency medical systems.
  Method: The timestamp of the receipt of the call and the timestamp of arrival to the hospital are needed to compute this KPI. Both are usually in charge of medical care facilities, but the combination of multiple datasets could be needed depending on the specific country.
  References: [41].
  Notes: Standardized in some countries, but data integration remains complex.

- *TIME TO FIRST RESPONDER ACTIVATION*

  Definition: It measures the time between the crash occurrence and the notification of first responders (e.g., EMS, police). This KPI reflects the efficiency of the initial emergency response.
  Method: Similarly to EMS response time, the timestamp of the receipt of the call is needed, together with the time of the crash which could be more difficult to know exactly. Data from insurance companies could be useful for that, and also police reports.
  References: [41]
  Notes: Not fully standardized; data can be difficult to obtain accurately.

- *TRAFFIC CALMING AT INTERSECTIONS*

  Definition: Percentage of intersections with traffic calming technologies.
  Method: The method of assessing this feature is %unit.
  Reference: [93]
  Notes: Moderate the speed of vehicles travelling on the main road to reduce the probability of an accident, and the harm caused if one occurs. Reduce the number of points of conflict between paths. Clarify the operation of the intersection and increase its visual visibility along a route to achieve safe behavior. Alert and help the user to adapt their driving when approaching an intersection where there is danger.

- *TRAFFIC CALMING MEASURES IMPLEMENTATION*

  Definition: It could assess the implementation (e.g. percentage of roads) of traffic calming measures such as speed bumps, raised crosswalks, and curb extensions, aimed at slowing down traffic and improving VRU safety.
  Method: Data can come from municipal road planning, traffic safety audits.
  References: Road design and construction manuals and road traffic management manuals.
  Notes: Each of these measures allows better traffic management in order to organise it better and avoid as much as possible points of conflict between different road users. These elements often tend to make VRUs more secure.

- *TRAFFIC MANAGEMENT IN ROUNDABOUTS*

  Definition: Percentage of roundabouts with traffic management.
  Method: The method of assessing this feature is %unit.
  Reference: [93]
  Notes: The management of traffic flows entering roundabouts allows vehicles to be redirected to the corresponding access lane depending on the exit to be taken, to reduce or avoid conflict situations inside the roundabout due to lane changes. Drivers can make decisions before entering the roundabout in a more comfortable way and under safer conditions. Greater fluidity and traffic management is achieved inside the roundabout, reducing conflict points and

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accidents. Adapt the design of the roundabout to the prevailing traffic and movements to maximize safety and fluidity for most of its users.

- *TRAFFIC SIGN RECOGNITION*

Definition: Percentage of cars that uses cameras to detect and interpret road signs.
Method: The method of assessing this feature is %unit.
Reference: [89]
Notes: Traffic sign recognition displays this information to the driver and sometimes integrates it with the vehicle's speed control systems.

- *TRANSVERSAL ALERT BANDS*

Definition: Percentage of km of road with transversal alert bands.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: Ensure that vehicles reach a route element or area of special risk at appropriate speeds compatible with the safety of all users.

- *USE OF ADVANCED TECHNOLOGIES IN POST-CRASH CARE*

Definition: It could measure the implementation of advanced technologies such as telemedicine and drone delivery of medical supplies such as first aid kits and AEDs in post-crash scenarios, particularly in remote or congested areas.
Method: no recognized methodology.
References: [46].
Notes: Experimental indicator.

- *USE OF CROSSWALKS*

Definition: It should monitor pedestrians crossing streets outside crosswalks.
Method: There is no standardized methodology for this indicator yet. Crosswalk could be equipped with city traffic cameras that can detect not respecting timing at intersections from pedestrians, while monitoring crossings at random locations outside designated crossing areas increases the complexity and new methodologies should be needed.
Notes: Crossing streets at designated crosswalks reduces the risk of accidents involving pedestrians and VRUs in general. Hence, it could be useful to identify spots in the infrastructure in which crossing out of crosswalks is particularly present, in order to improve the infrastructure itself.

- *USE OF REFLECTIVE GEAR*

Definition: It could measure the percentage of road users (e.g., cyclists, pedestrians, motorcyclists, VRUs) who use reflective gear while traveling at night or in low-visibility conditions.
Method: There is no standardized methodology for this indicator yet.
References: [82]
Notes: The importance of wearing reflective gear in the dark has been highlighted by numerous sources, with particular relevance in northern countries, where the habit of wearing reflective gear is already more diffused also for pedestrians, and generally in rural areas.

- *VARIANCE OF TRAFFIC SPEED*

Definition: It measures the degree of variability in the speed of vehicles across a road network, which can reflect both traffic congestion and risky driving behaviour. High speed variance is linked to a higher probability of accidents.

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Method: The goal is to analyse the standard deviation of vehicle speeds within a given timeframe and location, but the spatial and temporal granularity could vary greatly in different studies. Data can be collected from speed sensors, GPS systems, traffic cameras, and intelligent transportation systems (ITS).
References: [31].
Notes: This indicator is established but used alternatively to other indicators such as congestion level. Data could be monitored in real time using ITS technologies.

- *VERTICAL SIGN*

Definition: Percentage of km of road with vertical signs where they are needed. The absence of a road sign before a specific point on the infrastructure may cause incidental events.
Method: The method of assessing this feature is %km.
Reference: Highway Code.
Notes: Statistics tell us that drivers do not read all the vertical signs on a road. For this reason, too, they must be present, clearly legible and visible.

- *VISIBILITY AND LIGHTING QUALITY*

Definition: Percentage of m^2 with sufficient lighting and visibility in the areas frequently used by cyclists and e-scooter riders, at night. Good visibility reduces the risk of accidents, especially in low-light conditions.
Method: The method of assessing this feature is $\%m^2$.
Reference: Road design and construction manuals.
Notes: The higher the visibility, the greater the ability of the driver to cope with driving and consequently avoid accidents. Data could be monitored in real time using sensors detecting the quantity and quality of lighting.

- *WIDTH OF ROADSIDE*

Definition: Percentage of track width appropriate to the number of lanes, type of vehicles passing and road category. Road width not acceptable for traffic requirements and the sudden narrowing of the road surface often causes accidents.
Method: The method of assessing this feature is %unit (in this case the unit is track width appropriate to the number of lanes).
Reference: Road design and construction manuals.
Notes: The driver's perception of a narrow road can cause sudden and dangerous actions leading to accidental events.

- *2+1 ROADS*

Definition: Percentage of km of road with 2+1 layout.
Method: The method of assessing this feature is %km.
Reference: [93]
Notes: The purpose of 2+1 roads is to create a new type of infrastructure, where there are known, planned and expected safe overtaking opportunities, to eliminate high-speed head-on collision accidents, and to reduce the stress of drivers who are following a significantly slower vehicle and do not see clear opportunities to overtake. By providing 3-lane sections where overtaking can be carried out without encroaching on the oncoming lane, and by properly signaling them in advance, predictability is increased, and overtaking on sections with one lane in each direction is discouraged. They ensure a lower speed dispersion of the vehicles travelling on them because they facilitate the overtaking of slower vehicles. 2+1 roads can be developed as an intermediate solution between conventional and dual carriageways, as they improve safety, the level of service and have a lower cost and environmental impact. They reduce stress for drivers, break up queues and allow them to overtake slower vehicles along the route, thereby locally reducing the speed dispersion of the vehicles travelling along them.

3.3 MATRIX OF METRICS AND CATEGORIES

The following matrix presented in Table 3, summarizes in alphabetic order all 124 metrics listed in Section 3.2, highlighting their potential belonging to more than one category of the ten proposed by EvoRoads project. Overlaps show the strong interconnections present between the 10 proposed transport dimensions. The matrix is here proposed as summary of the report and to provide an interactive reading method to different typologies of readers, that could be differently interested in deepening specific metrics and/or the transport category itself, without the need of going through the whole document.

Table 3 – The following matrix presents hypertextual links to previously described 10 categories of transport dimension (Section 3.1), by clicking on the coloured cells; while it also presents links to each metric (Section 3.2) by clicking on their name. Metrics are listed alphabetically.

		User Behaviour	Road Infrastructure	Roadside Safety Devices	Traffic Management	Enforcement	Vehicles	C-ITS	CCAM operations	VRUs	Emergency Management
1.	Accessory signage		x		x						
2.	Adaptive and/or smart traffic signage							x			
3.	Adaptive cruise control						x				
4.	Adherence to Rest Breaks	x				x					
5.	Adjustment of crossings		x	x	x					x	
6.	Adjustment of pedestrian crossings on interurban roads		x	x	x					x	
7.	Adjustment of road margins		x	x							
8.	Alcohol use	x				x					
9.	Alternative speeding indicators				x						
10.	Animal channelling and warning systems on the road		x								
11.	Annual change in the number of speeding tickets, drink driving checks, tickets for non use of seatbelt, tickets for illegal use of a mobile phone	x				x					
12.	Appropriate transition between a straight and a curved section and the opposite		x								
13.	Appropriate visual distance		x								
14.	Asymmetrical roadsides		x		x						
15.	Automatic Emergency Braking						x				
16.	Automation level								x		
17.	Beaconing and zebra-striping of hard shoulders										
18.	Blind Spot Detection						x				
19.	Car safety ratings						x				
20.	Central safety barriers		x	x							
21.	Comprehensive Post-Crash Investigation Coverage										x
22.	Congestion level (volume/capacity)				x						
23.	Connected Roadside Units							x			

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24.	Controlled intersections using traffic lights		X		X						
25.	Controlled intersections with roundabout		X		X						
26.	Dedicated lane coverage		X								
27.	Dedicated lanes to divide traffic by direction and categories		X		X					X	
28.	Delimitation and separation of directions in trumpet junctions										
29.	Distraction from devices (VRUs)	X				X				X	
30.	Ditch guardrail protection systems										
31.	Driver Monitoring Systems						X				
32.	Driving on safety rated roads										
33.	Dynamic adaptation of speed limits				X						
34.	EMS Response Time of post-crash care										X
35.	Fatalities										
36.	Frequency of SOS call boxes/defibrillators		X								X
37.	Handheld mobile device distraction	X				X					
38.	Helmet Fit and Condition	X								X	
39.	Helmet use, PTWs and cyclists	X				X				X	
40.	Horizontal sign		X		X						
41.	Infrastructure usage rate		X								
42.	Integration of Advanced Emergency Communication Systems (eCall)						X				X
43.	Lane beaconing										
44.	Lane Departure Warning							X			
45.	Lane Keeping Assist						X				
46.	Lane separation continuous line		X		X						
47.	Lane Splitting Behaviour and Riding Predictably	X								X	
48.	Lay Bystander Intervention Rate										X
49.	LED reflectors		X	X							
50.	Length of straight sections		X								
51.	Load Securement	X				X					
52.	Longitudinal slope		X								
53.	Longitudinal sound guides in road markings for separating directions		X		X						
54.	Median barrier roads		X								
55.	Network availability							X	X		
56.	Not controlled intersections (or simple intersections)		X		X						
57.	Number of automatically detected offences committed by non-residents and the proportion of followed-up offences					X					
58.	Number of fines for illegal mobile phone use	X				X					
59.	Number of roadside alcohol tests conducted and proportion of those tested found above the legal limit	X				X					
60.	Number of roadside drug tests conducted					X					
61.	Number of safety cameras			X		X					
62.	Number of safety checks on commercial vehicles					X					

63.	Number of speeding tickets issued	X				X					
64.	Number of speeding tickets that were paid					X					
65.	Number of tickets for non-use of seatbelt	X				X					
66.	Parking Compliance	X			X					X	
67.	Pedestrian/cyclists waiting time at crossings				X					X	
68.	Percentage of urban areas subject to "zone 30"				X					X	
69.	Physical separation of directions in critical sections		X		X						
70.	Pigmented pavement		X		X					X	
71.	Placement of fencing on median separation elements		X								
72.	Post-Crash Care Training Coverage										X
73.	Presence of cycle paths		X							X	
74.	Presence of sidewalks		X							X	
75.	Proportion of speeding tickets generated by safety cameras					X					
76.	Protected infrastructure ratio		X							X	
77.	Protective Gear Usage Beyond Helmets	X				X				X	
78.	Public perception with traffic law enforcement					X					
79.	Radius of curvature in non-straight lines		X								
80.	Regularity or roughness (of the road plan)		X							X	
81.	Rehabilitation and Recovery Rate										X
82.	Reinforcement of guidance at critical points		X	X	X						
83.	Reinforcement of signage at divergences		X	X	X						
84.	Repeat offender rates					X					
85.	Road markings characteristic of section		X		X						
86.	Road thinning										
87.	Safety belt and CRS use	X				X	X				
88.	Safety ditches and adaptation of berms		X								
89.	Safety elements protecting individual points		X	X						X	
90.	Separation strip directions		X								
91.	Seriously injured in pedestrian falls, hospital reported									X	
92.	Seriously injured, hospital reported (MAIS3+)										
93.	Seriously injured, police reported										
94.	Side safety barriers		X	X						X	
95.	Signal timing and coordination				X						
96.	Signal timing for VRUs				X					X	
97.	Signs activated by VRUs		X		X					X	
98.	Signs activated for speed calming		X		X					X	
99.	Skid resistance or adhesion (to wheel-pavement contact)		X				X			X	
100.	Smart crossings		X		X			X		X	
101.	Smart Streetlights							X			
102.	Sound guides for lane separation		X		X						
103.	Sound guides for roadsides		X	X	X						
104.	Speed compliance	X			X	X					

105.	Speeding (VRUs)	x				x				x	
106.	Suicides in the road transport sector										
107.	Time spent in queuing				x						
108.	Time to clear incidents/recovery time				x	x					x
109.	Time to Definitive Care										x
110.	Time to First Responder Activation										x
111.	Traffic calming at intersections		x		x						
112.	Traffic calming measures implementation				x						
113.	Traffic management in roundabouts		x		x						
114.	Traffic Sign Recognition						x				
115.	Transversal Alert Bands		x		x						
116.	Use of Advanced Technologies in Post-Crash Care										x
117.	Use of Crosswalks	x								x	
118.	Use of lights by cyclists in the dark	x								x	
119.	Use of Reflective Gear	x								x	
120.	Variance of traffic speed				x						
121.	Vertical sign		x		x						
122.	Visibility and lighting quality		x								
123.	Width of roadside		x								
124.	2+1 roads		x		x						

4 CONCLUSION

The comparative analysis of legislative frameworks across the four EvoRoads pilots, Italy, Spain, Latvia, and Romania, as well as for the other six analyzed EU countries, reveals both alignments and divergences in their approach to road safety. A key area of alignment is the shared adoption of the Safe System approach, which is prominently integrated into national road safety plans across these countries. Each nation has developed a strategy aligned with the European Vision Zero target, aiming to reduce fatalities and serious injuries by 50% by 2030. For example, Italy's "Piano Nazionale della Sicurezza Stradale (PNSS)" and Spain's legislative decrees both prioritize the safety of vulnerable road users, such as cyclists and pedestrians. Romania and Latvia similarly reflect EU guidelines in their respective Road Traffic Safety Plans, emphasizing infrastructure improvements and safety audits.

However, variations emerge in the integration of new technologies. Italy, for instance, has shown significant progress in digital infrastructure monitoring, particularly through the AINOP digital archive, which plays a central role in managing infrastructure safety. Spain, with its advanced ITS and traffic management systems, has also been proactive in integrating technology, particularly for urban safety. Latvia and Romania, while aligning their road safety policies with EU standards, have yet to fully adopt real-time monitoring systems or other advanced technologies at the same level. This discrepancy points to the uneven pace at which nations are integrating new technological tools into road safety strategies.

Across Europe, numerous projects aim to address these gaps and harmonize road safety indicators. The Baseline and Trendline projects, for instance, are critical in establishing a common set of road safety performance indicators to be then standardized among EU member states. These projects help lay the foundation for consistent monitoring, ensuring that EU-wide road safety goals are both measurable and comparable. Additionally, the EvoRoads project fits into this broader European effort by developing a multi-layered safety assessment framework. It seeks to integrate data from advanced infrastructure monitoring technologies and aims to create a federated platform that enhances the proactive management of urban and rural road infrastructures. This will provide a real infrastructure over time that communicates with users and self-diagnoses security problems.

In terms of road safety categories and metrics, the analysis shows that some categories are more robustly developed than others. For example, metrics related to user behavior and road infrastructure are well-established and frequently monitored across all countries but could need further studies to integrate new methodologies and technologies. Categories such as C-ITS, CCAM operations and vehicles (especially for vehicles other than cars) demonstrate a need for further research and harmonization. Innovative technologies, such as ITS and sensor-based monitoring systems, are starting to be integrated into road safety strategies, but there is still a considerable amount of work required to standardize these technologies across nations. Safety metrics related to VRUs are increasingly proposed both in legislations and in the literature but require additional and constant research to verify correlations with outcome metrics, such as fatalities and incidents severity, and stay updated to the integration of new means of transport, such as mopeds.

Lastly, it is important to recognize that while the catalogue of indicators presented in this document is comprehensive, it is not exhaustive. This is a direct consequence of the fact that the road safety sector is very large and complex, but above all it is rapidly evolving, with new technologies, policies, and research continually emerging. As such, regular updates to the indicator catalogue are necessary to ensure that it remains relevant and reflective of the latest developments in road safety, including how various nations incorporate new technologies into their strategies.

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