XL Simpozijum o novim tehnologijama u poštanskom i telekomunikacionom saobraćaju – PosTel 2022, Beograd, 29-30. Novembar 2022.

https://doi.org/10.37528/FTTE/9788673954165/POSTEL.2022.036

ROAD SAFETY KEY PERFORMANCE INDICATORS COLLECTING AND SHARING OVER INTERNET OF VEHICLE INFRASTRUCTURES

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Abstract: *Road safety key performance indicators (KPI) are the indicators reflecting those operational conditions of the road traffic system that are influencing the system's safety performance. The European Commission developed a set of common methodological guidelines for the data collection and estimation of the KPIs in the EU countries. In the near future, the automated process of KPIs data collection, accompanied by advanced smart solutions in urban areas, smart in-car solutions, etc. can significantly improve data quality. The objective of this paper is to explore the process of road safety KPIs data collection and sharing using Internet of Vehicles (IoV) networking. In that context, a star rating of driver's behaviour could be done and such data could be shared aiming to better improve drivers' safety behaviour.*

Keywords: *Road safety, internet of vehicles, key performance indicators*

1. Introduction

In order to better handle the road safety problem in the EU (*European Union*) Member States, the EC (*European Commission*) adopted the EU Road Safety Policy Framework 2021-2030, in which emphasis has been placed on monitoring road safety progress. To that end, a set of eight road safety key performance indicators has been suggested to be collected under a common methodology to better grasp different road safety issues and define the earlier goal-oriented actions for improving the road safety [1].

Over the last years, digital technologies have been transforming the economy and society, affecting all sectors of activity, especially those of transport and mobility. With an aspiration to become a global "digital data hub" the EC adopted the European strategy for data in 2020 [2]. Building on the ongoing experience of the research community with regard to the EOSC (*European Open Science Cloud*), the EC will support the establishment of nine common European data spaces, including also a common European mobility data space. Based on the growing need to facilitate data-sharing/reuse, the EC has initiated the development of the EOSC since 2016 [3]. The aim was to link the existing infrastructures from research sectors and MS (*Member States*) in order to ensure sharing of research data [4]. The EOSC is the basis for a science, research and innovation data space that will bring together data resulting from research and deployment programs and will be connected and fully articulated with the different sector data spaces [5], [1]. Within this context, the need for establishing a TRC (*Transport Research Cloud*) as a subset of the EOSC platform has already been declared [6], [4].

Recent progress in the development of AI (*Artificial Intelligence*) tools, supported by the development of cloud computing technologies and 5G mobile communication networks is a strong driving factor for upgrading traditional VANETs (*Vehicular Ad-hoc Networks*) into flexible heterogeneous IoV (*Internet of Vehicles*) global communication architectures, which are expected to satisfy strict communication requirements related to the networking of a wide range of entities (vehicles, pedestrians, infrastructure equipment, personal devices, sensors, etc.) for the needs of future IoV applications. Such a level of coordination will be necessary for the provision of the pace and the critical mass of road safety data required for comprehensive and in-depth analysis of the road safety situation in a territory, detection of emergency problems at an earlier stage, evaluation of road safety measures, exchange of best knowledge, etc.

The objective of this paper is to explore the development of a road safety KPIs data ecosystem that could be integrated into the TRC as a subset of the EOSC platform. The Section 2 reviews the basis and road safety KPI in the EU and Serbia. The Section 3 presents IoV models of connectivity and integration of some software and cloud technologies into a single platform. The open data platform for road safety KPIs and a proper governance plan are explored in the Section 4. Finally, conclusions are drawn in the Section 5.

2. Road safety key performance indicators

2.1. The basis of road safety KPI

The development of the modern, more human method of road safety management is underway worldwide, based on the monitoring of a variety of safety (key) performance indicators. Until now, in a not-so-insignificant number of countries, road safety management has been based only on road crashes and their consequences. From [7], via the most important projects dealing with the research of safety performance indicators in a territory, up until the third Mobility Package Europe on the move – Sustainable Mobility for Europe: safe, connected, and clean [8], many individual studies and research have been carried out globally dealing with road safety performance indicators. KPIs can give a more complete picture of the level of road safety and detect the emergence of problems at an earlier stage [9]. The compromise between the need for as many indicators as possible and the real situation (availability of only a limited number of indicators for specific territories) eventually means identifying the most significant indicators (a comprehensive set of performance indicators).

2.2. Road safety KPI in the EU and the Republic of Serbia

The Staff Working Document titled EU Road Safety Policy Framework 2021-2030 – Next steps towards “Vision Zero” recommended the establishment of a range of road safety KPIs that are directly related to the prevention of road deaths and serious injuries. The EC has defined a general methodological consideration applicable to all indicators. Also, the EC-funded project Baseline has further developed a set of common methodological guidelines for the data collection and estimation of the KPIs in the EU countries, including minimum data requirements, measurement procedure and data analysis requirements. With these methodological considerations, the various restraints can be overcome and the standardization of the suggested key indicators for international comparisons can be achieved. Nevertheless, the Republic of Serbia has been monitoring and measuring safety performance indicators following the best practices since 2013. The Road Traffic Safety Agency is the main road safety stakeholder responsible for monitoring road users' behavior.

Although a road safety assessment level obtained on the basis of a narrower comprehensive set of KPIs can offer an adequate and efficient way of road safety monitoring [10], the road safety assessment performed based on a broader set of KPIs will provide a more accurate identification of good and poor road safety performances, which is in line with the recommendations by [9].

3. Internet of vehicles networking in urban environments

3.1. IoV models of connectivity

The IoV concept presents a complex heterogeneous system of hierarchically organized communication networks and includes different modes of connectivity (V2X, *Vehicle-to-Everything*), such as communications between vehicles, V2V (*Vehicle-to-Vehicle*), vehicle communications with traffic infrastructure, V2I (*Vehicle-to-Infrastructure*), connecting vehicles to the Internet and other communication networks, V2N (*Vehicle-to-Network*), vehicle communications with pedestrians/personal devices in the environment, V2P (*Vehicle-to-Personal Device*) and gathering information from various sensors, V2S (*Vehicle-to-Sensor*). IoV focuses on the intelligent integration of people, vehicles, things and environments with the aim to provide different services. It implies an open and integrated traffic management network system and consists of multiple users, multiple vehicles, multiple things and multiple networks. Intelligent interfaces are used to integrate heterogeneous networks. IoV services offer road users numerous benefits (level of service, safety, etc.) and also have a significant impact on the reduction of energy consumption and minimization of costs and travel time.

Wireless technologies and protocols used in IoV networking can be divided into three general categories: mobile cellular networks (Wi-Max, 4G/LTE, 5G/NR); dedicated networks for vehicles (DSRC/WAVE) and short-range networks (WiFi, Bluetooth, ZigBee, NFC and others). Table 1 shows some WAT (*Wireless Access Technology*) technologies that can be used for the networking needs of various entities in IoV systems. Selection of appropriate WAT technology for specific IoV application and QoS (*Quality of Service*) requirements is done according to priority, data transfer rates, communication range, mobility support, delay, security level, network compatibility, etc. As one of the promising solutions for future IoV systems, the upcoming 5G mobile cellular network certainly stands out, thanks to a range of advanced technologies, such as mm-waves, ultra-dense networks, massive MIMO (*Multiple Input Multiple Output*) antenna concept, beamforming and full-duplex technology. The mentioned technologies provide numerous advantages in terms of the ability to meet the requirements of future IoV applications, providing increased bandwidth, high data transfer rates, high reliability of communications, low delays, etc.

Table 1. Characteristics of different wireless technologies for IoV applications [11]

Type of network	**Name of technology**	**Standard**	**Frequency range**	**Maximum range**
Mobile cellular networks	Wi-Max	IEEE 802.16 d/e	2-11 GHz	50 km
	4G/LTE	3GPP	700 MHz - 2.7GHz	10 m - 100 km
	5G/NR		700 MHz - 6 GHz > 24GHz (mm)	~ 4G/LTE < 500m
Dedicated networks for vehicles	DSRC/WAVE	IEEE 802.11 p	5.9 GHz	1000 m
Wireless networks for short ranges	Wi-Fi	IEEE 802.11 a/b/g/n	2.4 - 5 GHz	100 m
	Bluetooth	IEEE 802.15.1	2.4 GHz	10 - 100 m
	ZigBee	IEEE 802.15.4	868-915 MHz, 2.4 GHz	10 - 100 m
	NFC	ISO/IEC 18092	13.56 MHz	< 10 cm

The abbreviations in the table imply: Wi-Max (*Worldwide Interoperability for Microwave Access*), LTE (*Long Term Evolution*), NR (*New Radio*), DSRC (*Dedicated Short Range Communication*), WAVE (*Wireless Access in Vehicular Environments*), 3GPP (*The 3rd Generation Partnership Program*), Wi-Fi (*Wireless Fidelity*), NFC (*Near Field Communications*), IEEE (*Institute of Electrical and Electronics Engineers*), ISO/IEC (*International Organization for Standardization/International Electrotechnical Commission*).

Effective planning and allocation of IoV network resources is a challenging task. Considering that urban environments include a large number of intersections and frequent changes in topology, it is necessary to bear in mind that the density of the distribution of vehicles is uneven, that is, the density of a network is variable, which can affect the functionality of the communication network. The model of a heterogeneous IoV architecture in an urban area consists of vehicles equipped with appropriate wireless communication equipment, network gateways at intersections, cellular base stations, RSU (Road Side Unit) units and other infrastructure equipment [12],[13]. If a vehicle speed is known, the range of wireless devices for vehicle networking and the density of vehicles on a certain road section, it is possible, according to the analysis presented in [12], to model the connectivity of network nodes in a dynamic IoV environment through the following four attributes: the probability of establishing connections, time data packet forwarding capacity, data forwarding link capability and packet error probability.

3.2. Integration of software and cloud technologies into a single IoV platform

The concept of IoV requires new perspectives on the development of platforms, algorithms and techniques for controlling vehicles and traffic generated by users through a combination of cloud, network and virtualization techniques. This includes software-defined networking (SDN), network function virtualization (NFV, *Network Function*

Virtualization), fog/edge computing and the use of containers [14]. SDN is based on the separation of the control plane and the user plane. NFV, standardized by ETSI (*European Telecommunications Standards Institute*), involves the creation of a dynamic network in a virtual environment, enabling any network configuration required for testing. Edge/fog computing enables data processing and storage to be brought closer to end users. It is implemented in the form of an intermediary between the cloud and IoT infrastructure [15]. Containers enable virtualization at the application level, by running services across different platforms.

In existing networks, each technology has its own control planes, which is why the network consists of several layers, each of them having its own configuration and resource reservation, and the management of such a network through several control planes is very complex. Software-defined networking implies the separation of the data plane from the control plane. In this way, the limitations of distributed routing related to configuration mechanisms, data duplication, etc. are overcome. The data plane includes the transmission of data, while the control plane implies a centralized system that manages the forwarding of such data.

The SDN vehicle network architecture includes SDN-based components, such as RSUs, base stations or even individual vehicles, which achieve a higher level of control and automation of VANET networks and enable the realization of SDVN (*Software Defined Vehicular Networking*) networking. The control plane enables the establishment, maintenance and management of connections through regulated paths. In this way, the efficient transfer of user data from the initial node to the end node through different domains is enabled. The exchange of signalling messages takes place through a special protocol between software components that we call signalling controllers. Signalling controllers (switches/routers) collect data on traffic (e.g., speed and density of vehicles) and application characteristics and make a decision on the routing method. By integrating SDN and SDN-enabled equipment (RSU, base stations or vehicles), the network manager is allowed to allocate resources, avoid interference, integrate multiple types of technologies (Wi-Fi, Wi-Max, LTE, NR), control traffic congestion and serve traffic demands evenly [16].

Network virtualization aims to minimize hardware by using a generic infrastructure based on servers and virtual machines (VMs) that adapt to the physical infrastructure. In this way, any configuration or addition of resources is enabled according to the requirements. NFV is highly dependent on cloud computing, and hypervisors that are responsible for separating processing and memory resources from hardware. This makes it possible to develop software independently of hardware and vice versa. A software called a hypervisor fully emulates the server's hardware resources, which allows them to be shared between a large number of VMs.

Applying the concept of cloud computing to support big-data-based IoV services leads to numerous disadvantages, such as increased delay, insufficient efficiency and poor scalability of the system. The key cause of these problems stems from the centralized concept of cloud service data processing and storage. To overcome these problems, advanced solutions based on distributed fog/edge computing are proposed, which achieve the localization of cloud services (cloudification of the network).

Fog Computing (FC) represents an extension of the cloud environment, which is realized as an intermediary step between the cloud and the IoV infrastructure with the aim of bringing computer resources and fast data transfer closer to the end users (data sources). It significantly reduces the delay compared to the centralized cloud architecture. Any device that has the ability to process, store and transmit information is called a fog node, regardless of whether it is an industrial controller, switch, router, embedded server, advanced surveillance camera, etc. [15]. Although FC does not have the processing and memory capabilities of cloud resources, its most important feature is to ensure sufficiently low latency within the operation of the corresponding IoV applications.

Edge computing (EC) or computing at the edge of the network is also a distributed concept of computing, where all computing operations are performed directly on end devices (e.g. sensors/actuators, vehicles) or on their interfaces. EC has similar functionalities to FC, and the basic difference between these two concepts stems from the different positions where data processing is performed. Unlike FC, which involves the transfer of data from end devices/interfaces to fog nodes within the local computer network (LAN) for their processing, with EC all computer operations are performed on end devices, without the need for data exchange via the LAN network.

Software containers are a way to run applications in their own isolated process. As their name suggests, containers are used to "pack" only what is needed to run the application. The integration of containers into a single IoV platform refers to the application of virtualization, that is, the virtual creation of services or applications. An application that runs using a container means that the libraries are installed in the containers, not in the operating system. Containers are executed as separate (isolated) processes that share the resources of the operating system on which they are launched, and their launch takes significantly less time. Because they require fewer resources (they don't need an entire operating system), they are easier to ship and provide the ability to run multiple services using the same hardware. The container contains only the application, the necessary libraries, components on which the application depends and configuration files, which makes the application independent of the infrastructure on which it runs [17].

4. Open data platform for road safety KPIs

4.1. Platform concept

Over recent years, the need for open data in the transport research area has been more relevant than ever, due to the great number of different types of data collected by researchers, transport stakeholders, private companies and public authorities associated with the increasingly real-time data collection from vehicles, infrastructure and various applications. One of the biggest initiatives to promote Open Science in transport research is the H2020 project BE OPEN, funded by the EC. Within this context, the importance of collecting performance indicators has been also emphasized in [18], including them in the structure of road safety management, as part of the platform for global road safety data analysis. The synthesis of the results of the [4] led to the formulation of ten recommendations grouped into five thematic areas, which are considered essential for the development of a sustainable TRC, as a subset of the EOSC platform. Following the EC's efforts to ensure the collection and monitoring of KPIs at the EU level, as useful tools for monitoring road safety progress, the need to define an open data platform for road safety KPIs (OPEN RSPIs) has been widely recognized. Further on, the platform is compatible with the EOSC principles, such as: multi-stakeholders, openness, FAIR principles, the federation of infrastructures, and machine-actionable.

The EOSC system consists of three layers: 1) the federating core (or the EOSC-Core), 2) the federation of existing and planned research data infrastructures, and 3) the EOSC-Exchange that builds on the EOSC-Core to ensure a rich set of services (common and thematic). In accordance with the EOSC structure, an open data platform for road safety KPIs engagement of the wider public/ government sector and private sectors have been proposed. As shown in Figure 1, the platform proposed can be exploited by both the EC/DG Move and the MS to monitor road safety progress, identify and exchange best practices through cross-country comparisons, as well as to identify major road safety problems. The governance plan implies a proxy at the national level (Route 1) between the EOSC-TRC and the leading government road safety stakeholder, which is responsible for KPIs measurement, collecting and monitoring at national level, as well as for national research and science stakeholders or private sector. In addition, the leading government road safety stakeholder and research stakeholders may engage in the EOSC via one or more umbrella organizations (Route 2), (i.e., ECTRI, FEHRL, etc.), addressing different layers of the EOSC, primarily the providers of the EOSC-Core and those enabling the EOSC-Exchange. Initially, both routes are acceptable since umbrella organizations are expected to bring their members closer to the EOSC and align their needs with EOSC principles. But in the long-term and within the context of established open science culture, Route 1 is indeed the most appropriate.

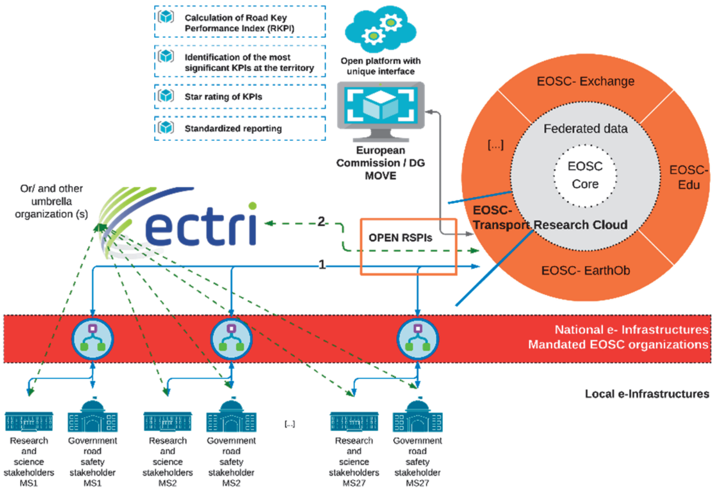

Figure 1. Concept of the open data platform for road safety KPIs (OPEN RSPIs) [19]

No matter which route is used for communication with the EOSC, all Member States need to define a comprehensive methodology for collecting and monitoring KPIs at the national level, which is completely in line with the EC minimum methodological requirements. Nevertheless, this methodology should define a leading road safety stakeholder for collecting KPIs (e.g., ministry of transport or leading traffic safety agency), the list of KPIs (in line with EC recommendations) and a list of additional safety performance indicators (e.g., related to vulnerable road users), a sustainable funding source for periodic, long-term monitoring of indicators, as well as mechanisms for reporting to the parliament, citizens, etc. Being able to recognize the importance and generate the proposed platform value, as part of the EOSC- TRC, the governance plan implies direct involvement of the EC/DG Move, as a focal point for KPIs management at the EU level.

The results of [4] indicate that a culture and practices of data sharing still need to be developed in the area of transport research. The establishment of an open data platform for road safety KPIs will contribute to building a research road safety environment that will promote the Open Science and increase the trust and reproducibility of research outcomes.

The MS should ensure: 1) data management planning and 2) research data resulting from publicly funded research being findable, accessible, interoperable and reusable ('FAIR principles') within a secure and trusted environment, through digital infrastructures. All potential types of road safety KPI data (original research data obtained by observations; operational data and data from published research in transport) should follow the FAIR principles, being 'as open as possible, as closed as necessary'.

In the context of an open KPI data ecosystem, data policies could be issued by the EC/DG Move, leading road safety stakeholders at the EU MS level, as well as by research and other related stakeholders. Additionally, data management plans, which will articulate all relevant information concerning the generation or collection of publicly funded research data, will hold valuable information on the data and related outputs should also be ensured and structured in a machine-actionable way.

4.2. Data sharing

In open science, data must be shared in such a way that both humans and machines are able to access, understand, and reuse them [20]. A key issue of the reusability of KPIs dataset is the availability of high-quality metadata, which will provide precise information on data collection procedure and methodology, data process, data owners, access to data, etc. To provide a higher level of interoperability and reuse, the OPEN RSPIs platform should enable exporting or generating standardized reports which will be published by the EC/DG Move or the leading road safety stakeholders of the EU.

Moreover, AI technology is expected to contribute to the improvement of the safety level of vehicles, drivers, and roads. Automated process of KPIs data collection by using the AI, communication between the vehicle, infrastructure, and driver (i.e., V2X) and the IoT system, will enable the management of the road safety performance generally, management of driver's behavior and identification of the most common risky behavior, which can lead to a reduction of harmful impacts of traffic in the said transition period. Under this assumption, it is possible to generate large amounts of KPIs data, obtained from various projects, naturalistic driving studies, field operational tests, smart cameras, advanced smart solutions in urban areas, smart in-car solutions, etc.

However, the numerous challenges that can hinder the reuse of KPI data are listed in [4], among which the following ones stand out: data storage, fragmentation of data ownership, a lack of interoperability between datasets and platforms, etc. Shortly, the automated process of KPIs data collection, accompanied by advanced smart solutions in urban areas, smart in-car solutions, etc. can significantly improve data quality, by taking into account that data providers may be unwilling to use cloud services for fear of data breaches or unauthorized access. All potential restrictions should be listed in the data management process until a clear legal framework supporting data security, data protection and privacy has been developed.

5. Conclusion

In order to have a better understanding of the road safety problem and define the earlier goal-oriented actions for improving road safety, the EC has set an initial set of eight road safety KPIs to be measured across the EU Member States, which will be further enriched in the forthcoming years. The IoV concept enables an automated process of such measurements and data collection. Simultaneously, the development of a TRC as a subset of an EOSC platform provides the conditions for comprehensive management of the KPIs data. Through the paper, guidelines are given for the development of an open data platform for road safety KPIs that could be integrated into the European TRC.

The development of the OPEN RSPIs platform enables comprehensive and periodic monitoring and management of the KPIs at the EU level, sets ambitious national KPI targets, more accurate identification of good and poor road safety points, as well as strengthening proactive road safety management. In order to make the transition period as safe and efficient as possible, the development of the star rating for assessing the road safety performance of a territory should be a possible game-changer for the systematic management of road user behavior, especially in case of automated process of KPIs data collection and sharing by using the IoV concept. The OPEN RSPIs platform ensures a high level of openness, integrity, fairness, interconnectedness of people, services, and content, as well as the reproducibility and reuse of KPIs data.

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Rezime: *Ključni indikatori bezbednosti saobraćaja (KIBS) su mere onih radnih uslova u drumskom saobraćajnom sistemu koji utiču na performanse bezbednosti saobraćaja. Evropska komisija je razvila set smernica za prikupljanje i merenje KIBS. U bliskoj budućnosti, automatski procees prikupljanja KIBS, uključujući napredne pametne sisteme u urbanim sredinama, vozilima, itd. može značajno unaprediti kvalitet prikupljenih podataka. Cilj rada je istražiti proces prikupljanja i razmene KIBS korišćenjem koncepta Internet vozila. Na taj način moguće je izvršiti ocenjivanje ponašanja vozača sa aspekta bezbednosti saobraćaja i razmenu takvih podataka jer ponašanje vozača najviše utiče na bezbednost saobraćaja.*

Ključne reči: *bezbednost saobraćaja, internet vozila, ključni indikatori bezbednosti saobraćaja*

PRIKUPLJANJE I RAZMENA PODATAKA O KLJUČNIM INDIKATORIMA BEZBEDNOSTI SAOBRAĆAJA PUTEM INFRASTRUKTURE INTERNET VOZILA

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