Road Safety Performance Monitoring Practices: A Literature Review

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Abstract: Road traffic crashes remain a major concern worldwide. They are considered by the World Health Organization as one of the leading causes of death worldwide. To address this road insecurity, many countries are developing national strategies and trying to put in place the necessary action plans for their implementation. At this stage, monitoring of performance is crucial to ensure the efficacy of these road safety systems. The primary objective of this study is to examine the state-of-the-art practices employed in researches for managing road safety systems, specifically performance monitoring, and present the results in an engaging and informative manner. Through a comprehensive review of existing literature, the study seeks to identify essential components to help policymakers develop and monitor the performance of their road safety systems. The findings of this study can serve as a foundation for decision-makers in their efforts to develop and manage effective road safety systems.

Keywords: Road safety, Management system, Road safety strategy, Performance monitoring, Road safety measures.

Introduction

Given the significant social and economic costs associated with road accidents, road safety has become a major concern for governments and stakeholders worldwide. Countries have adopted various road safety measures, policies and systems to reduce the number of deaths and injuries. However, simply implementing these measures is not enough. Decision-makers are also required to adopt a clear and strategic approach and design a guiding framework to effectively manage their road safety system. Two distinct approaches are primarily available: the traditional approach and the systemic approach. The traditional approach tends to focus on changing the behavior of road users and reducing human errors. Users are considered as primarily responsible for the occurrence of road accidents. As a result, the emphasis on human error encourages road safety managers to adress more actions related to users. Unlike the traditional approach, the systemic approach to road safety recognizes the interdependence of the components of a safe system: safe roads, safe road users and safe vehicles, and seeks to continuously improve these elements to prevent all collisions and ensure that road users are not severely injured in case of an accident. This approach emphasizes that the road system must be designed to address human vulnerability and error (Safarpour et al., 2020). In recent years, there has been an increasing awareness that effective road safety management practices generally involve a systemic approach, resulting in the emergence of the "safe system approach", which addresses the issue in an integrated manner. This approach is the foundation of the two Decade of Action for Road Safety 2011-2020 and 2021-2030 proclaimed by UN General Assembly, and has since been adopted by a growing number of countries (WHO, 2021).

Exploring the tools, frameworks, and data sources that have been commonly used in managing road safety systems is an interesting area of investigation, which could inspire policymakers when developing and monitoring the performance of their road safety systems. Thus, the main objective of this study is to carry out a comprehensive analysis of the existing literature on road safety management to adress the following research objectives:

- ▪ Provide a comprehensive review of the current state of the art in monitoring road safety performance;
- ▪ Systematically analyze identified publications to gather data that could assit in the development and management of effective road safety systems.

In the remainder of this paper, we will first provide the background information about the study. Next, we will describe the methodology we adopted to conduct our research. Finally, we will present and discuss the findings of our research, drawing conclusions and implications from these results.

Background of the Study

Effective performance monitoring is crucial for the development of a successful road safety system. To achieve this, researchers and policy-makers in this field need to have a comprehensive understanding of the various tools, approaches, frameworks and data sources used to effectively manage and monitor road safety systems. They need to recognize, among other things, the best means of monitoring their planned actions for the various components of road safety. By categorizing their actions, policymakers can identify where interventions are effective and where more work is needed. A clear classification system can also facilitate data comparison across jurisdictions and countries, providing valuable insights into best practices in road safety management. In addition, decision makers need to identify the different types of measures that are commonly implemented as part of an effective road safety monitoring system in order to determine the most appropriate measures for their own context. By examining existing ones, decision-makers can better tailor their own road safety measures to their specific needs and challenges.

Access to international data sources is also crucial, as it allows policymakers to compare their road safety systems with those of other countries, to better understand best practices, and identify areas for improvement. By accessing reliable data sources from other countries, policymakers can also identify effective measures and best practices that have been implemented elsewhere. In addition, international data sources provide a broader perspective on road safety issues, including emerging trends and challenges that may not be evident in domestic data sources. This helps policymakers to develop more comprehensive and effective road safety policies and strategies. With the aformentioned needs in mind, the purpose of this study is to provide a relevant review of the current literature on monitoring road safety performance. Our objective is to categorize the study outcomes in a manner that can assist policymakers and researchers in their quest to develop and manage effective road safety systems. By offering valuable insights, this study aims to inspire and guide decision makers in their efforts to improve road safety management practices.

Review Methodology

This section provides an overview of the methodology used to conduct the literature review on road safety performance monitoring. The review process involved four steps, starting with (1) **the definition** of research objectives and questions, (2) **the identification** of the search terms and database to identify publications relevant for the review, (3) **the selection** process based on predefined inclusion and exclusion criteria, and finally, (4) **a data collection and analysis** approach to classify relevant information collected from the selected publications.

Research Objectives and Questions

To initiate the review process, the identification of clear objectives and research questions was paramount. The main objective of this review is to provide a comprehensive overview of the existing literature on monitoring road safety performance and to assess the current state of the art in this area. To achieve this goal, we formulated the following research questions:

RQ1: What is the overall view of the field? When and which journals and countries have shown interest in monitoring road safety performance?
Are there any frameworks and flagship projects being used or implemented in the context of road safety performance monitoring?
RQ2: What are the most commonly used sources of data in this field, and which organizations provide them?
RQ3: What are the most common types of measures identified in this field of research?
RQ4: Which road safety components have generated the most interest among researchers in the selected papers?

These research questions guided the literature review and provided a framework for the selection and analysis of relevant publications. By answering these questions, we aimed to contribute to the development of a foundation that can help decision-makers in developing effective road safety management practices and policies.

Papers Search Process

To ensure a comprehensive review of existing literature on monitoring road safety performance, a systematic research process was used. This approach includes the use of specific search terms and criteria to identify relevant publications that meet the research objectives. By using a systematic approach, the risk of missing important publications or biases in the selection process is minimized. The search process thus employed the following search string "Road safety" AND ("management system" OR strategy) AND performance AND (evaluation OR assessment OR monitoring OR measure), without any time limit. The research was conducted in Science Direct database, a widely recognized and reputable academic database, to ensure the quality and relevance of the retrieved publications. This aformentionned search string was selected in order to identify relevant publications that adress topics related to road safety management systems and strategies, along with their performance measurement, monitoring and evaluation.

Papers Selection Process

The selection process aimed to help us identify papers that were most relevant to the research questions and objectives of this literature review. To achieve this, we first established inclusion and exclusion criteria for candidate papers. At first, only papers that met the search keywords on their title, abstract or author-specified keywords were considered. Additionally, these papers had to be available, written in English, and published as a journal or conference paper. Secondly, the studies needed to be focused on road safety management systems and strategies with an emphasis on performance measurement, monitoring and evaluation. Once the initial selection was made, a full-text review was conducted to assess the relevance of the selected papers to the research objectives. Any papers that did not meet the objectives were excluded.

Data Collection and Analysis

In this step, our goal was to carefully review the selected articles and gather relevant information pertinent to the research questions. To achieve this, we extracted all relevant data from the selected studies, including their title, author, year of publication, source, type of publication and location (journal, conference, etc.), as well as specific data answering our predefined research questions. Subsequently, we devised a comprehensive classification system to categorize the data collected into four categories, specificallly; (1) General overview of selected papers, (2) International road safety data sources and organizations, (3) Selection of road safety measures and (4) Selection of road safety components. This classification system enabled us to efficiently analyze the gathered data in order to address the four research questions outlined in the previous step.

Results

In the present section, we present the results of our study. Initially, a considerable number of 5592 papers were identified through a systematic search process. However, after applying our selection process, which included the application of previously cited inclusion and exclusion criteria and also a manual evaluation of each paper's relevance to the research questions, only 57 papers were finally selected. An overview of the data collected is provided in the next subsections, based on the proposed classification of results.

General Overview of Papers

This section presents below an initial overview of the selected papers:

Publication Characteristics:

The selection process yielded a publication range from 2002 to 2023. İt is important to note that our search process did not impose any time limits. Based on our finding, we observed that interest in this field of reserach began to emerge from 2002. Of the selected studies, almost 60% were conducted between 2018 and 2021, comprising 34 articles. İn terms of publication type, 87.7% of the studies were published in Journals and 12.3% were presented at Conferences (Figure 1).
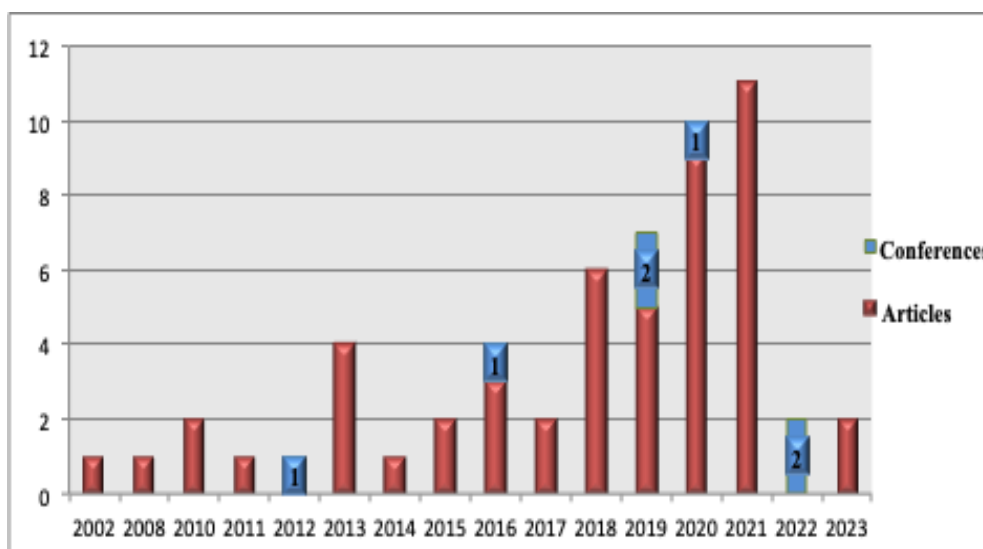

Figure 1. Number of papers published per year and by publication venue.

Table 1. Publication sources of the selected papers.

PUBLICATION SOURCE	Number	%
JOURNALS		
Accident Analysis and Prevention	17	34
Traffic Injury Prevention	5	10
Transportation Research	5	10
Journal of Traffic and Transportation Engineering	4	8
Journal of Safety Research	3	6
Safety Science	3	6
Journal of Transport & Health	2	4
Biomedical Signal Processing and Control	1	2
Global Transitions	1	2
Human Movement Science	1	2
IATSS Research	1	2
International Journal of Transportation Science and Technology	1	2
Microprocessors and Microsystems	1	2
Reliability Engineering and System Safety	1	2
Transport Policy	1	2
Transportation Letters	1	2
Transportation Engineering	1	2
Vehicular Communications	1	2
TOTAL JOURNALS	*50*	*100*
CONFERENCES		
International Conference on Transport Infrastructure and Systems (TIS)	4	57
Transport Research Arena	2	29
EURO Working Group on Transportation (EWGT)	1	14
TOTAL CONFERENCES	*7*	*100*

These selected publications were distributed across various venues, with approximately 50% of papers published in three specific journals: Accident Analysis and Prevention Journal, Traffic Injury Prevention Journal, and Transportation Research Journal. Notably, the latter journal comprises several parts from A to E that cover complementary topics within the realm of transportation science, making it one of the most comprehensive references in the field.

Regarding conference proceedings, the International Conference on Transport Infrastructure and Systems was the most frequent event for this research domain, with 57% of the conference papers being published in its proceedings. This conference was held in 2019 and 2022. The distribution of articles selected by different venues is presented below (Table 1).

Subject Area and The Monitoring Level of the Study:

Regarding the subject areas, the studies were classified into seven different fields related to road safety monitoring research. More than half (50.9%) of the papers were published in journals related to Social Sciences, followed by engineering-related journals (21.1%). Computer science and psychology-related journals accounted for 7% and 5.3%, respectively, while Medicine and Dentistry and Arts and Humanities-related journals accounted for 3.5% and 1.8% respectively. The remaining 8.8% of studies addressed miscellaneous topics. Furthermore, we examined the level at which the studies were conducted. The majority (66.7%) of the articles were conducted at the local or national level, while the remaining 33.3% were conducted at the international level.

Geographical Distribution:

The selected papers were also analyzed based on their geographical distribution. The studies were dispersed across 24 countries, with researchers from Australia, China, Italy, Brazil, and Greece contributing the most (57.9%) to the field of road safety monitoring research. Australia had the highest number of selected studies (11), followed by China (6), Italy (3), Brazil (3), and Greece (3) (Figure 2).
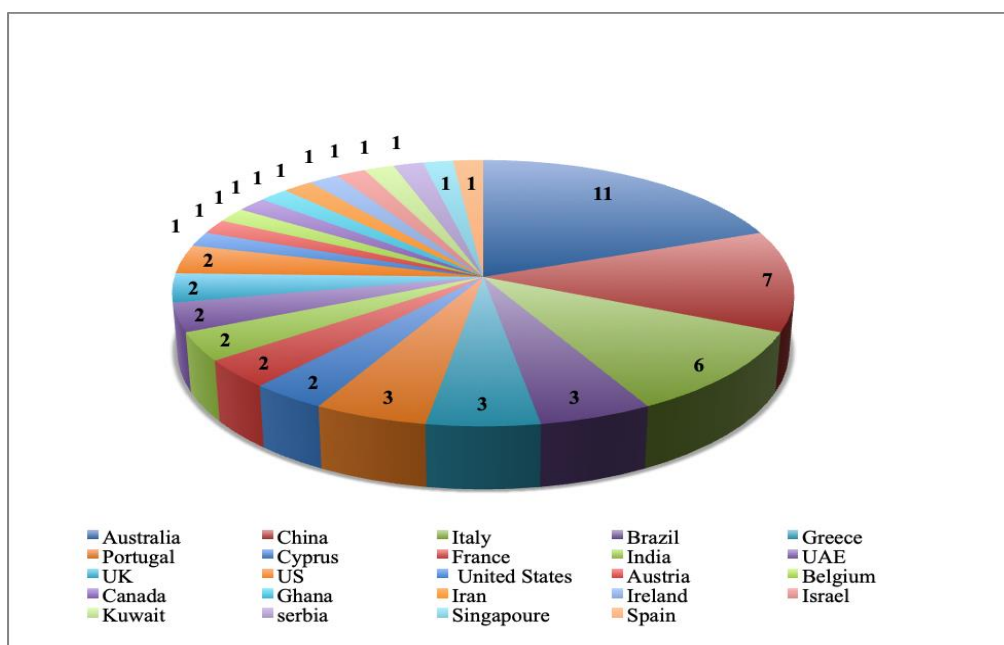

Figure 2. The geographical distribution

Frameworks and Flagship Projects

Road safety performance monitoring can benefit from frameworks that offer guidelines, methodologies, and tools for measuring, analyzing, and enhancing road safety outcomes. The selected papers highlight the importance of a comprehensive and multi-disciplinary approach to road safety performance monitoring. Some

of the frameworks identified in the papers include the Pyramid of Road Safety and the Sunflower Pyramid (Chen et al,. 2016), (Papadimitriou & Yannis, 2013), (Pešić & Pešić, 2020). Additionally, some studies utilized the Five Pillars of Road Safety Development and the Three Layers of Road Safety Management (institutional management functions, interventions, and results) as a framework for their research (Behnood, 2018). The Safe System Matrix, originally from Australia, was also employed in some studies (Corben et al., 2010).

In addition to frameworks, identifying flagship projects in this area can serve as models for best practices and demonstrate the potential of innovative approaches to road safety performance monitoring implemented in different parts of the world. For example, the DaCoTa Project, the Safetynet Project, (Pešić & Pešić, 2020), (Papadimitriou & Yannis, 2013) and the Sunflower Project (Papadimitriou & Yannis, 2013), (Chen et al., 2016) were all important projects that contributed significantly to road safety management. Other projects identified in the studies, such as the i-DREAMS Project (Michelaraki et al., 2021) and the DICA-VE Project (Coelho & Guarnaccia, 2020), were focused on specific road safety components such as road users or vehicles. These projects demonstrate the potential of innovative solutions to address road safety challenges faced by different countries. Policy makers and researchers interested in this area are encouraged to further research these identified frameworks and projects and to explore potential projects not mentioned here.

Identification of International Road Safety Data Sources and Organizations

The identification of international road safety data sources and organizations was an important aspect of this study. To accomplish this, we conducted a thorough analysis of the selected papers and extracted relevant information regarding the sources of data and organizations involved in road safety management. Our findings revealed that a number of international organizations play a critical role in promoting road safety and developing strategies to reduce roads accidents and fatalities. The most commonly cited organizations in the studies we reviewed were the World Health Organization (WHO), the International Transport Forum (ITF), the European Transport Safety Council (ETSC), the European Road Safety Observatory (ERSO), the International Road Traffic and Accident Database (IRTAD), the Organization for Economic Co-operation and Development (OECD), the European Commission (EC), the United Nations (UN), and also the Global Burden of Disease study (GBD).

The data sources used in the studies varied, with some using local or European datasets, while others used databases and publications from the aforementioned organizations. Additionally, some studies utilized data from flagship projects such as the DaCoTa Project and the Sunflower Project. In some cases, data were collected through targeted surveys and questionnaires. By analyzing these sources of data and organizations, we were able to identify reliable sources to inform future research and provide valuable insights for decision makers.

Identification of Main Road Safety Measures Used

In this section, we identified the different measures used in the selected documents to assess road safety. The identified measures were classified into six main categories:

1. Background /socio-economic measures (used 23 times with a percentage of 20%): These measures captured the volume and characteristics of various road safety components, such as demographics of road users, the level of motorisation. They also included measures of housing conditions, wealth levels, and education, such as the Gross Domestic Product (GDP) per capita, and employment.
2. Process measures (used 27 times with a percentage of 23%): These measures are related to the safety programs and measures implemented to manage road safety, such as the strategy implemented, the road safety audits performed. The measures in this category can be both quantitative and qualitative.
3. Behavioral measures (used 44 times with a percentage of 38%): These measures were used to assess the performance of the actions affecting the behavior of road users, such as speeding, drink driving, use of seat belts and helmets, and use of mobile phones.
4. Outcome measures (used 20 times with a percentage of 17%): These measures were used to assess the final impact of road safety measures, such as the number of fatalities and serious injuries, and the reduction in the number of fatalities and serious injuries.
5. Economic measures (used 1time with a percentage of 1%): These measures were used to assess the economic impact of road safety interventions, such as the cost savings associated with reducing fatalities and serious injuries.

6. Environmental measures (used 1time with a percentage of 1%): These measures were used to assess the impact of road safety interventions on the environment, such as the reduction in greenhouse gas emissions from more sustainable transport modes.

It is important to note that more than one measure could be used in one study. These results provide insight into the various measures that need to be considered when assessing road safety interventions (Table 2).

Table 2. Paper's classification by types of measures used

Road safety measures	Papers
Background /socio-economic measures	(Nikolaou et al., 2021); (Astarita et al,. 2023); (De Bartolomeo et al., 2023); (Chen et al,. 2020); (Papadimitriou & Yannis, 2013); (Behnood, 2018); (Nikolaou & Dimitriou, 2018); (Chen et al,. 2016); (Bastos et al.,2015); (Mooren et al.,2014); (Albalate & Yarygina, 2013); (Cafiso & D'Agostino, 2016); (Horswill et al., 2011); (Vankov & Schroeter, 2021) ; (Islam et al., 2021); (Tarasi et al., 2021); (Osei et al,. 2021); (Lu et al, 2019); (Chajmowicz & Cuny, 2019); (Oviedo-Trespalacios et al., 2016); (Yadav & Velaga, 2020); (AlRukaibi et al., 2021); (Marciano et al., 2015).
Process measures	(De Bartolomeo et al., 2023); (El-Sayed et al., 2021); (Papadimitriou & Yannis, 2013); (Behnood, 2018); (Chapelon & Lassarre, 2010); (Fwa, 2017); (Chen et al,. 2016); (Ansari et al,. 2023); (Corben et al., 2010); (Sun & Xiang, 2019); (Horswill et al., 2021); (Mooren et al.,2014); (Albalate & Yarygina, 2013); (Cafiso & D'Agostino, 2016); (Sangrar et al., 2019); (Michelaraki et al., 2021); (Domenichini et al., 2018); (Fu & Mao, 2018); (Nogal & Honfi, 2019); (Islam et al., 2021); (Osei et al,. 2021); (Lu et al, 2019); (Connors et al., 2013); (Chajmowicz & Cuny, 2019); (Oviedo-Trespalacios et al., 2016); (Marciano et al., 2015); (Huertas-Leyva et al., 2019).
Behavioral measures	(Pešić & Pešić, 2020); (Nikolaou et al., 2021); (Astarita et al,. 2023); (Chen et al,. 2020); (Papadimitriou & Yannis, 2013); (Reis et al,. 2023); (Behnood, 2018); (Chapelon & Lassarre, 2010); (Fwa, 2017);(Chen et al,. 2016); (Baulk et al,. 2008); (El-Sayed et al., 2020); (Singh & Kathuria, 2021); (Ansari et al,. 2023); (Corben et al., 2010); (Coffey & Park, 2020); (Kaulich et al., 2016); (Habtemichael & Santos, 2012); (Zhao & Wang, 2020); (Sun & Xiang, 2019); (Horswill et al., 2021); (Mooren et al.,2014); (Sinha et al., 2020); (Bosso et al., 2020); (Twisk et al., 2018); (Silva et al., 2021); (Horswill et al., 2011); (Vankov & Schroeter, 2021); (Rossi et al., 2021); (Domenichini et al., 2018); (Chen et al,. 2021); (Nogal & Honfi, 2019); (Islam et al., 2021); (Tarasi et al., 2021); (Tapp & White, 2013); (Coelho & Guarnaccia, 2020); (Treffner et al., 2002); (Lu et al, 2019); (Chajmowicz & Cuny, 2019); (Oviedo-Trespalacios et al., 2016); (Yadav & Velaga, 2020); (AlRukaibi et al., 2021); (Marciano et al., 2015); (Huertas-Leyva et al., 2019).
Outcome measures	(Nikolaou et al., 2021); (Astarita et al,. 2023); (Chen et al,. 2020); (Papadimitriou & Yannis, 2013); (Behnood, 2018); (Chapelon & Lassarre, 2010); (Nikolaou & Dimitriou, 2018); (Chen et al,. 2016); (Cheng et al., 2018); (Corben et al., 2010); (Bastos et al.,2015); (Mooren et al.,2014); (Albalate & Yarygina, 2013); (Cafiso & D'Agostino, 2016); (Silva et al., 2020); (Sinha et al., 2020); (Chajmowicz & Cuny, 2019); (Oviedo-Trespalacios et al., 2016);(Yadav & Velaga, 2020); (AlRukaibi et al., 2021).
Economic measures	(Cafiso & D'Agostino, 2016).
Environmental measures	(Coelho & Guarnaccia, 2020).

Identification of Main Road Safety Components Explored.

The main objective of this subsection is to identify the main road safety components explored in the selected papers. We carefully reviewed the papers to determine which components were monitored or studied. We classified the papers into four categories representing three main road safety components adressed in the studies: road users, road infrastructure, and vehicle. The fourth category represents studies that take into account different components, and we named it road safety system. This classification was chosen to ensure consistency with the road safety system approach, which considers road safety as a combination of multiple components that interact with each other to prevent or mitigate road accidents.

Road users were the most commonly explored component, with 36.8% of the selected papers primarily analyzing, predicting, or simulating road user behavior and its effect on road safety. Road safety systems were the second most explored, with 31.6% of the selected papers monitoring or assessing the effectiveness of road safety managemnt systems while taking into account different components. Road infrastructure was the focus of 19.3% of the selected papers, examining various aspects such as the effect of road design, maintenance, and management on road safety performance. Vehicle components were the focus of 26.3% of the selected papers, discussing for example the safety management of particular vehicle type (Table 3).

Overall, the selected studies showed a broad range of road safety components explored in the literature. The findings of this subsection provide insight into the various measures that need to be monitored, specifically on individual components, to guide decision makers on road safety interventions to improve road safety.

Table 3. Paper classification by road safety components addressed

Road safety components	Papers
Road user	(Reis et al,. 2023); (Baulk et al,. 2008); (Singh & Kathuria, 2021); (Ansari et al,. 2023); (Kaulich et al., 2016); (Zhao & Wang, 2020); (Horswill et al., 2021); (Sangrar et al., 2019); (Twisk et al., 2018); (Horswill et al., 2011); (Vankov & Schroeter, 2021); (Rossi et al., 2021); (Michelaraki et al., 2021); (Chen et al,. 2021); (Nogal & Honfi, 2019); (Tapp & White, 2013) ;(Treffner et al., 2002); (Oviedo-Trespalacios et al., 2016); (Yadav & Velaga, 2020); (Marciano et al., 2015); (Huertas-Leyva et al., 2019).
RS system	(Pešić & Pešić, 2020); (Nikolaou et al., 2021); (Astarita et al,. 2023); (Chen et al,. 2020); (Papadimitriou & Yannis, 2013); (Behnood, 2018); (Chapelon & Lassarre, 2010); (Nikolaou & Dimitriou, 2018); (Chen et al,. 2016); (Cheng et al., 2018); (Corben et al., 2010); (Habtemichael & Santos, 2012); (Bastos et al.,2015); (Cafiso & D'Agostino, 2016); (Silva et al., 2020); (Tarasi et al., 2021); (Connors et al., 2013); (AlRukaibi et al., 2021).
Road infrastructure	(De Bartolomeo et al., 2023); (Fwa, 2017); (Coffey & Park, 2020); (Sun & Xiang, 2019); (Albalate & Yarygina, 2013); (Silva et al., 2021); (Domenichini et al., 2018); (Fu & Mao, 2018); (Islam et al., 2021); (Osei et al,. 2021); (Lu et al, 2019).
Vehicle	(El-Sayed et al., 2021); (El-Sayed et al., 2020); (Mooren et al.,2014); (Sinha et al., 2020); (Bosso et al., 2020); (Coelho & Guarnaccia, 2020); (Chajmowicz & Cuny, 2019).

Discussion

Several of the selected studies in this review have emphasized the importance of adopting a systematic approach to road safety management. Our study has shown that researchers have given varying levels of attention to different elements and aspects of measuring the performance of road safety systems. Given the importance of adopting a systematic approach, decision-makers should consider a classification framework that can effectively manage their actions and give equal importance to all components. The five pillars proposed in the WHO Global Plan for the Decade of Action for Road Safety, which include Road Safety Management,Safer Roads and Mobility,Safer Vehicles,Safer Road Users,Post-Crash Response have been proven effective in this regard.

Our study also revealed the existence of several measures used to monitor road safety performance. However, to effectively and comprehensively assess the performance of road safety systems, a hierarchy of measures should be established based on models linking results of different levels, accounting for socio-economic measures, actions implemented, performance of those measures, final results, and their costs. These models should interpret the results based on country's context and interventions undertaken in the field of road safety, to adapt the measures to the specific needs and challenges of each country. The Pyramid of Road Safety is a good example of such a model.

It is important to note that this study has limitations, such as the choice of keywords and the selection of articles, which may have excluded relevant publications. Despite these limitations, our findings provide valuable information that can be useful in the area of road safety management. Further studies and reviews can be conducted to complement this study, such as the identification of various technical methods used in this field. This could serve as a basis for choosing the best tools to adopt in future road safety studies.

Conclusion

This study offers a comprehensive review of the existing literature on road safety management systems. Our analysis of 57 relevant publications emphasizes the importance of adopting a systematic approach to road safety management that considers all aspects of road safety. By adopting a comprehensive and systematic approach, policymakers and stakeholders can effectively manage road safety, which will ultimately save lives and reduce the economic and social costs of road accidents. Our findings also highlight the importance of using reliable performance indicators and structured frameworks to represent the hierarchical levels of these road safety indicators. Moreover, our study identified reputable international data sources and organizations, that can offer a reliable source to inform future research and furnish decision makers with valuable insights. In conclusion, this study provides valuable insights into the current state of knowledge on road safety management systems. Policymakers can use this information to develop more effective road safety management strategies. It is crucial to continue investing in research in this area to enhance road safety and reduce the number of road accidents and fatalities.

Recommendations

Based on the findings of this study, it is recommended that decision-makers give high priority to data collection, analysis, and evaluation when designing road safety management systems. To ensure the sustainability and continuous improvement of road safety management systems, decision-makers should invest in ongoing research and learn from previous studies in the field. By doing so, they will be better equipped to address the challenges and opportunities that arise, and to continuously improve the effectiveness of their systems.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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