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Critical Evaluation of Road Bends on User Safety: A Systematic Literature Review Study

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Abstract

Road curves often become vulnerable to traffic accidents, which remain a significant worldwide issue. This study provides an essential analysis of the effects of road geometry on curves on user safety. The main objective of this research is to identify the relationship between the features of curve infrastructure, such as radius, superelevation, and lane width, and the traffic accident rate. Accident data from various road segments in Indonesia was thoroughly analyzed. Special emphasis is placed on the types of accidents, their severity levels, and the contributing factors to these accidents. Studies show that curves with suboptimal designs, such as small radii or lack of superelevation, significantly increase the risk of accidents. Additionally, the consistency of geometric design and the visual perception of curves significantly affect the safety of drivers and other road users. This study highlights the importance of using a comprehensive approach in the planning and designing road curves to enhance overall transportation safety. The proposed recommendations include stricter design guidelines, improved maintenance, and better instructions for road users to reduce the risk of curve accidents.

Keywords: Accident, Road Geometric, Infrastructure, Transportation, Safety, Driver Safety, Road User

1. Introduction

Considering the high accident rates involving various groups of road users, evaluating the safety of road curves is very important at the international level. The goal is to provide an analytical and/or forecasting tool that can be utilized at the operational level to be prepared to act in areas where accidents may occur, as well as at the planning level to specify appropriate strategies to prevent accidents [1]. The promoted global safety standards emphasize the importance of conducting a thorough road audit that assesses curve design aspects such as radius, superelevation, and sight distance. For example, prototypes have used various sorts of lighting on vehicles to indicate the state of automation (on/of) and movement, even though little is currently known about how these designs affect actual road-user behavior. Purpose (halting, beginning, or slowing down), in addition to using light reflections on sidewalks and roadways to convey information and messages [2]. Globally, improvement efforts focus on implementing proper traffic engineering, which includes the installation of effective warning signs and clear road markings. It is also essential to raise awareness and knowledge among all road users about safe driving practices when navigating curves. The effects of centrifugal force and lateral jerk on vehicle stability are minimal because hairpin curves are always traversed at extremely low speeds (often less than 20 km/h). [3]. The goal is to create a safer transportation system for everyone in various countries and significantly reduce traffic accident rates.

In most situations, the final two are the most critical factors, particularly when there are uneven road profiles and fast-moving cars [4]. There are significant differences in infrastructure standards and driving habits in adjacent areas. Certain infrastructures are considered essential because of their substantial effects on public health and safety, economic stability, and national security [5]. Accidents at regional intersections can involve various road users, such as pedestrians, cyclists, and motor vehicle drivers, with significant social and economic

impacts on the local community. Local governments must collaborate to evaluate and improve at the regional level. To save expenses and environmental harm, geometric design aims to maximize safety and efficiency [6]. This is necessary to improve coordination in road maintenance, implement safety campaigns tailored to regional needs, and harmonize safety standards. One of the primary issues that public administrations have about road user safety is poor road surfaces. [7]. The goal is to enhance traffic safety and reduce the number of accidents at bends across the region.

Considering the high number of traffic accidents in the area, which affects various groups of road users throughout Indonesia, evaluating road curves for road user safety is an essential issue at the national level. Nearly 1.35 million people are killed or disabled in traffic accidents each year, and approximately 3700 people die in fatal accidents alone every day; of these, half are cyclists, motorcyclists, or pedestrians, making them vulnerable road users. Traffic accidents are a significant health concern for health institutions worldwide [8]. For many years, traffic-related issues have been a key concern in civilizations, particularly those about increasing safety and transportation efficiency [9]. To improve safety, the primary focus is on national standards for curve design, the installation of signs and road markings, and law enforcement. A nationally integrated evaluation and solution approach is necessary due to the differences in geographical conditions and road user characteristics throughout Indonesia. They also stated that, regardless of the kind of driver, it seems to be true that more extended workdays are associated with riskier driving practices.

In summary, the conversation above demonstrated that encouraging a culture of road safety and enhancing road safety behavior depends heavily on the behavior of road users [10]. Improvements include upgrading curve infrastructure, conducting regular road safety audits, and extensive safety education campaigns to raise awareness and compliance among road users. The primary goal of accident data analysis is to determine the variables influencing the frequency of traffic accidents to address the primary concerns in the field of road safety [11]. The ultimate goal is to improve road safety and reduce the number of traffic accidents in Indonesia. Theories, methods, and techniques of accident-prone point identification are not systematic and perfect due to the limitations of research data. There is also a gap between these theories and their universal application, which makes it challenging to guide the safety design, operation, and management of roads [12].

High-traffic accidents on the road are often caused by curves that do not meet safety requirements. One of the factors suspected to contribute to this condition is the suboptimal design of the curves. One of the most crucial and difficult responsibilities for both travelers and the transportation management industry is the real-time detection and monitoring of traffic accidents [13]. To identify potential hazards, these curves must be examined, which includes analyzing the curve radius, superelevation, sight distance, and installed traffic signs. When FMEA seeks to identify all possible risk factors in a system, rank them, and implement corrective measures to reduce or eliminate the high-risk ones, system safety is improved [14]. We have seen a proliferation of research and ensuing survey studies examining various facets of road safety in recent years due to the growing interest in this field. For traffic safety, efficient road surface monitoring is essential [15]. This case study will help develop recommendations for improving the geometric design of curves and adding appropriate road safety facilities to enhance the safety and comfort of all road users.

A series of comprehensive data collection activities are carried out during the in-depth investigation of the curve on the road section. The curve radius, lane width, actual superelevation, and road surface conditions are recorded through direct observation and detailed measurements. In addition, a list of road markings, traffic signs, and other safety facilities are also recorded in full. Data on traffic accidents that occur around the curve over a specific period of time are collected to determine the pattern and source of accidents. Pavement cracks are a prevalent problem that has a negative impact on driving conditions and road safety. To ensure road safety in the majority of provinces and cities, transportation agencies must maintain high-quality roads [16]. In addition, interviews can be conducted with road users and residents around the road to obtain subjective views on the conditions and potential hazards at the curve. To help address behavior-analytic questions, the authors here encourage behavior analysts to supplement single-case design research approaches with qualitative techniques [17].

2. Research Methods

To collect data and analyze various previous studies on the Evaluation of Curves on Road User Safety, this research uses a Systematic Literature Review (SLR) approach. The SLR is conducted systematically through the stages of identification, selection, and analysis of literature from various reliable sources, such as research reports, scientific journals, and conference proceedings. Criteria were established based on the topic, year of publication, and quality

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of the research to include and exclude literature. Next, the results of the literature review are analyzed to identify trends, methods, and shortcomings in implementing road user safety. In conclusion, surrogate safety assessment's growth as a desirable substitute for crash-based safety assessment is severely hampered by the absence of unified knowledge regarding its many facets [18]. This method aims to provide a strong theoretical foundation and a comprehensive understanding of best practices in road use. This study's goal was to provide a systematic evaluation of conflict-based safety measures to fully comprehend the context in which they are applied, as well as to pinpoint important areas for future research [19].

2.1. Data Basis Used

Google Scholar was the central database for the literature search related to the Evaluation of Curves on Road User Safety. To support the implementation of a Systematic Literature Review in this research, this selection is based on the extensive coverage of Google Scholar, which includes scientific journal articles, proceedings, books, theses, and other academic documents from various fields of study. Web of Science (WoS) and Scopus were chosen as the databases from which to get information [20]. Furthermore, Google Scholar is superior in terms of open access, usability, and accessibility to local and regional papers frequently unavailable in premium databases such as Web of Science and Scopus.

To obtain current and comprehensive data, literature was searched from 2000 to 2025. To ensure that the results align with the research topic, the search process is conducted using filters that include keywords, article titles, author names, institutional affiliations, and publication years. Features like "Cited by" and "Related articles" are also used to determine the connections between studies and to evaluate their importance and influence in the academic community.

2.2. Search Strategy

The accuracy and recall of the search terms used to locate pertinent material are critical components of bibliometric analysis. Use keyword-based searches in abstracts and titles to find research on roundabout effectiveness and intersection performance. The Publish or Perish 8 software gathers important information like publisher, author, title, citation information, and keyword information. Consequently, 909 papers are extracted and examined to offer a perceptive and representative viewpoint on the facts [21]. To find pertinent documents, the Publish or Perish (PoP) software reviews a variety of articles classified as "bibliometric analysis" or "systematic review," using keywords such as "Bends, Safety, Road Users." The goal of the search is to find 1,000 articles evenly distributed based on those five keywords; the result will include approximately 200 articles for each keyword.

2.3. *Colectting Initial Statistical Data*

The Research Information System (RIS) format stores documents that fit the requirements and information gleaned from Google Scholar. Keywords, abstracts, bibliometric data, and other crucial data components are all included in the RIS format. The data was gathered using the reference managers application. A research reference manager's motto is "publish or perish" [22]. Bibliographic data, such as the number of citations, author names, and publication sources, can be gathered and shown using the Publish or Perish (PoP) program in a standardized RIS format. A more detailed understanding of the impacts of roundabout design and its safety performance can be obtained by choosing publications pertinent to the study topic and particular keywords, particularly those that concentrate on design effectiveness. Similarly, it is still uncommon to find detailed instructions on how to use Publish or Perish. The data mapping produced and presented by these guidelines for scientific writing would improve the overall bibliometric analysis results' readability and clarity.

3. Results and Discussions

3.1. Visualization of Research Keyword Connections

This study gathered 1,000 scholarly publications from the Crossref database with the keywords "Accident, Road Geometric, Infrastructure, Transportation, Safety, Driver Safety, Road User" using the Publish or Perish version 8 software."To investigate and evaluate scientific data and enable researchers to characterize phenomena and their attributes, this study used the bibliometric analysis method with VOSviewer [23]. Using VOSviewer version 1.6.20, the relationships between the gathered research journals are displayed. Bibliometric analysis measures the

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production of individuals or groups of researchers, organizations, and nations by using data on the quantity and authors of scientific publications and referenced papers. Bibliographic analysis also makes it possible to chart the evolution of scientific topics and find national and international networks [24]. As a result of the bibliometric study, the Evaluation of Turns on Road User Safety shows that it benefits users. However, new issues may arise due to problems geometric with roadways at bend points or horizontal paragraphs, as well as bend planning that does not adhere to existing norms [25]. So there are many issues related to the winding road that do not follow the applicable standards, leading to many problems associated with the winding road.

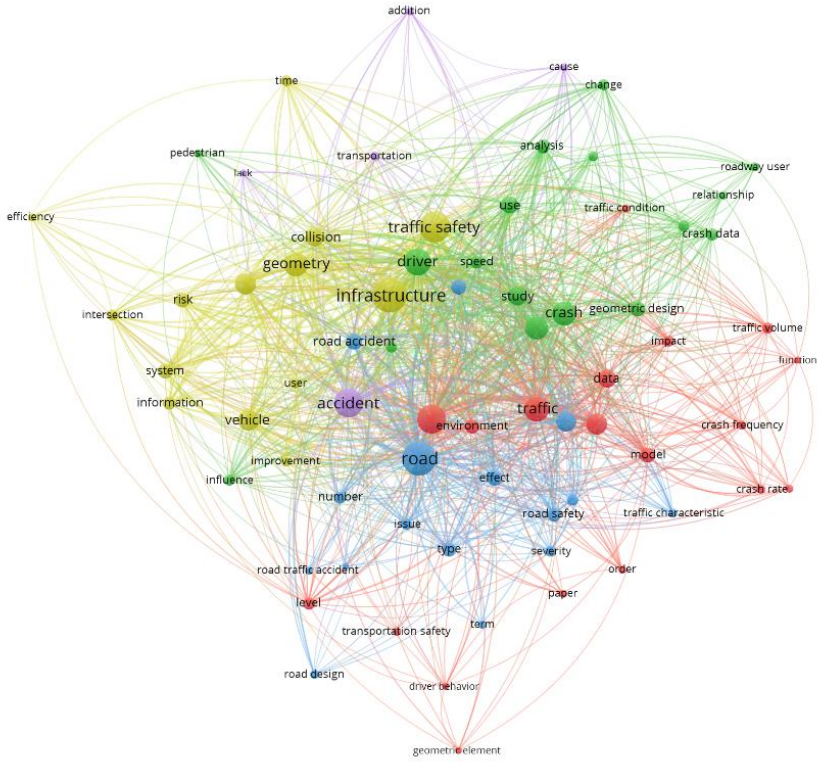

Figure 1. Visualization of Keyword Network Using VOSviewer, Highlighting Dominant Terms Such as "Traffic Safety," "Infrastructure," and "Road"

In this analysis, VOSviewer mapped the authors' keywords [26]. Using the VOSviewer software for data visualization, Figure 1 shows that road user safety, infrastructure, and roads are the most relevant secondary keywords. These results align with upcoming research focusing on the high traffic accident rates caused by road users.

This red cluster emphasizes the relationship between traffic, accidents, and roads. Words like "traffic," "accidents," and "roads" are key, indicating that the focus is on road accidents and traffic characteristics. The analysis of the causes and direct effects of accidents may be the primary focus of research in this cluster. More simply put, "normal" or "defensive" driving, which includes keeping safe time gaps and not shocking other drivers, is another method to characterize conflict avoidance behavior [27].

With "traffic safety," "infrastructure," and "drivers" as the main components, this green group emphasizes the importance of adequate infrastructure and responsible driver behavior in achieving safety. It focuses on methods and implementations that can be undertaken to reduce the risk of accidents.

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With the keywords "road," "accident," and "impact" as its axis, this blue cluster discusses aspects of roads, accidents, and their impacts. They are also related to "density" and "accident rate," which indicate the severity and frequency of accidents. The research here tends to study the consequences of accidents and how road conditions affect the outcomes.

This yellow cluster encompasses a broader scope of transportation, focusing on "transportation," "systems," and "vehicles." This cluster also discusses "efficiency" and "walking," indicating that an efficient and safe transportation system should be thoroughly considered. The focus of this research may be on the interaction of various transportation components and system optimization.

Although this purple group is smaller, it shows a focus on methodological elements and research dynamics. This cluster can describe the process of data addition, the analysis techniques used, and the research of trends or changes with the keywords "addition," "analysis," and "change." This cluster illustrates aspects of knowledge and analytical development in the relevant field.

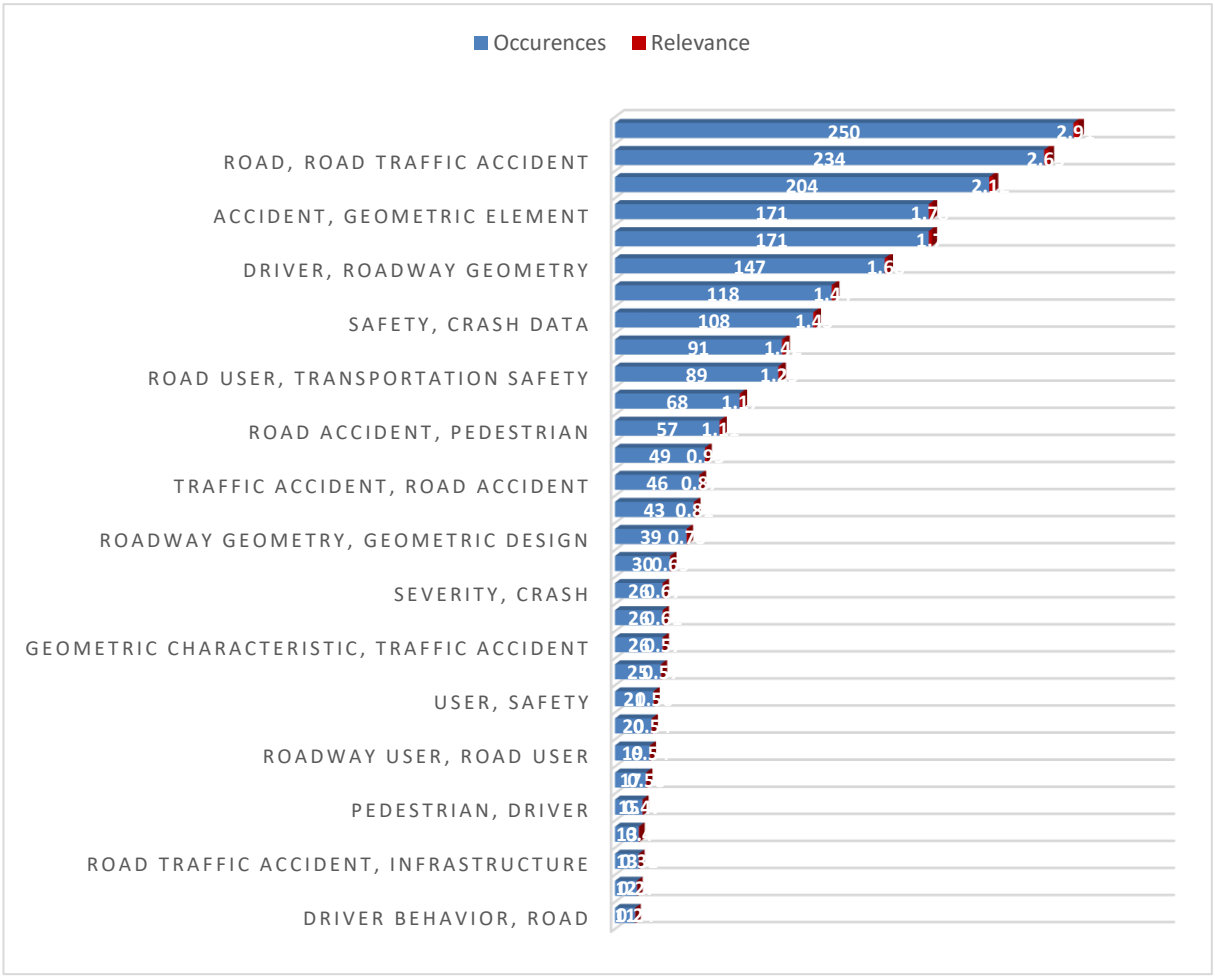

Figure 2. Keyword frequency graph

In the diagram, the analysis of the main keywords related to the research theme is visible; the most frequently appearing keyword, "Infrastructure, Roadway User," with 259 occurrences, indicates the importance of infrastructure and roadway users in this research. Other highly relevant and frequently appearing keywords are "Road, Road Accident" (234 times) and "Road Accident, Accident Frequency" (204 times), indicating that elements such as "Accident, Geometric Elements" and "Road Geometry, Driver Behavior" also appear with high frequency. This suggests that road geometric design and driver behavior are critical components analyzed in this research. Driving performance, environmental awareness, risk-taking propensity, and cognitive abilities are just a

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few variables and aspects that might influence driving behavior [28]. Overall, this graph shows that traffic safety issues, road infrastructure, and human factors are the main topics of discussion in the relevant field.

In image 3, the keyword density map, also called the "keyword density map," shows the main topics of publications or research on a specific subject. The bright yellow and green colors indicate many keywords present, suggesting frequently discussed topics. Words like "traffic safety," "highway," "infrastructure," "criminals," "accidents," and "collisions" most clearly appear in this image, indicating that these topics are subjects of research. This shows the importance of traffic accident analysis, road safety, infrastructure function, and driver behavior.

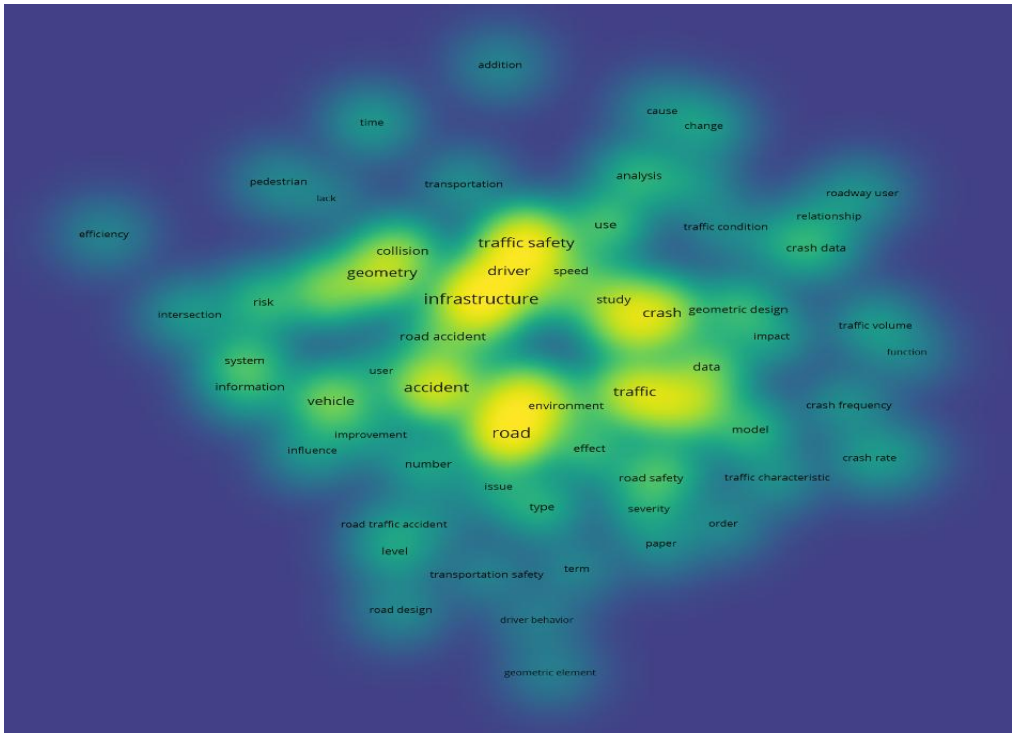

Figure 3. Keyword density

Table 1. Keywords according to the highest studies

Keywords	Total Studies
Infrastructure	250
Road	234
Traffic Safety	204
Accident	171
Road Geometry	171
Driver	147
Crash	118

Based on Table 1, out of the 250 studies conducted, the keyword "infrastructure" dominates, indicating a primary focus on infrastructure. The keywords "road" and "traffic safety" are also vital, with 234 and 204 studies, respectively, highlighting the significance of roads and traffic safety. The keywords "accident" and "road design" have 171 studies, indicating attention to accidents and road design. Lastly, overall, this table clearly shows the most frequently reviewed research areas.

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3.2. Development of publications by year

With the aid of Publish or Perish 8 software, a map will be produced using all VOSviewer data [29]. Based on Google Scholar data processed with Publish or Perish, the analysis of scientific publication trends from 2000 to 2025 shows an increasing interest in the critical evaluation of road curves concerning user safety. This increase indicates a growing awareness of the importance of safe road design, driven by advancements in survey and modeling technology, as well as the impact of funding programs and accident incidents. Although the data for 2024 and 2025 may not be complete, the general trend shows that the research industry continues to grow. This indicates that researchers continue to evolve to find new ways to reduce the risk of traffic accidents.

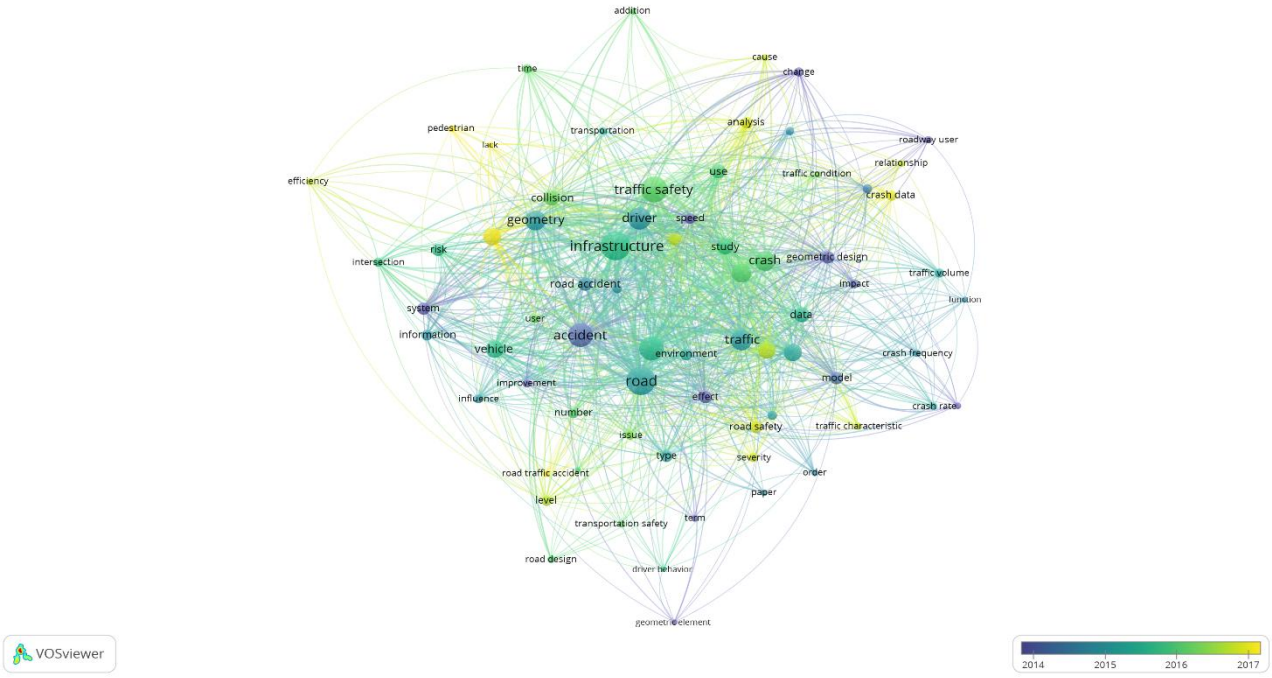

Figure 4. Keywords by year

This figure shows a network visualization created by VOSviewer, which illustrates the relationships between essential terms in research on road safety and geometric design. This study uses the VOSViewer application to do bibliometric analysis. According to the goals of this study, a thorough search was carried out utilizing the Scopus database [30]. Each circle represents a key term, with its size indicating how often the term appears in publications. The color of the circles varies from purple around the year 2014 to yellow around the year 2017. The lines connecting these nodes indicate co-occurrence or correlation between terms, and the thickness of the lines represents the strength of the relationship. This visualization effectively maps the research landscape by showing the main topics and their relationships with each other in the study of traffic safety and infrastructure.

In more detail, this network shows several main clusters: "incidents," "roads," "traffic flow," "infrastructure," and "traffic safety." The focus of this research is on these clusters. These main clusters also connect terms such as "geometry," "road design," and "driver behavior," indicating the relationship between road design, driver behavior, and accidents. The different colors on the nodes, from purple to yellow, suggest that the topics of research focus have changed or evolved. For example, the other colors suggest that newer concepts emerged around 2017. This pattern indicates that research in this field is constantly changing because of new knowledge and road safety challenges.

3.3. The publisher and the research's classification define the sort of study

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The publishers engaged in the study on the connection between curves and road user safety are shown in Table 2. This study shows how different publishers might enhance scientific research by gathering data from several publishers through links. This information provides an essential context for understanding the diversity of sources and the worldwide reach of this field of study. Table 2 shows that the Publish or Perish software developed by Harzing was used to collect data related to civil engineering worldwide.

Table 2. Number of studies by publisher

Penerbit	Studi
Elsevier	375
Taylor & Francis	93
Ieeexplore.Ieee.org	86
Journal.sagepub.com	71
Mdpi.com	63
Springer	52
Wiley Online Library	31
Researchgate.net	18
Ijoms.internationaljournal.com	17
Google Patents	13
Lainnya	211

Ieeexplore, Elsevier, Taylor & Francis, and others. Three leading publishers make significant research contributions, one of which is Ieee.org. This shows that this platform is a primary source of research on critical user safety evaluations. Various research publications included in this study are described in Table 2. This information provides a valuable understanding of the different research landscapes related to critical turn evaluation. A total of 211 studies were produced from journal articles. This suggests that the main channel for sharing research findings in this area is through author-published journals. The most popular formats are books and journal articles; data sets, monographs, and uploaded content are less commonly utilized.

3.4. Research type based on the majority of nations

In general, critical evaluations of curves regarding user safety in various countries use quantitative research to measure the influence of geometric and environmental elements on the number of accidents. In this case, data such as the radius of the curve, lane width, visibility, and accident frequency are collected. In addition, qualitative research is also often used to understand the perceptions and experiences of road users, such as conducting interviews with drivers or analyzing dashboard camera footage to identify risky behaviors. Mixed methods that combine subjective and objective data are becoming increasingly popular, allowing for the identification of the most dangerous curve areas and more efficient resolutions. Research like this helps the government and relevant authorities design appropriate solutions to improve road safety.

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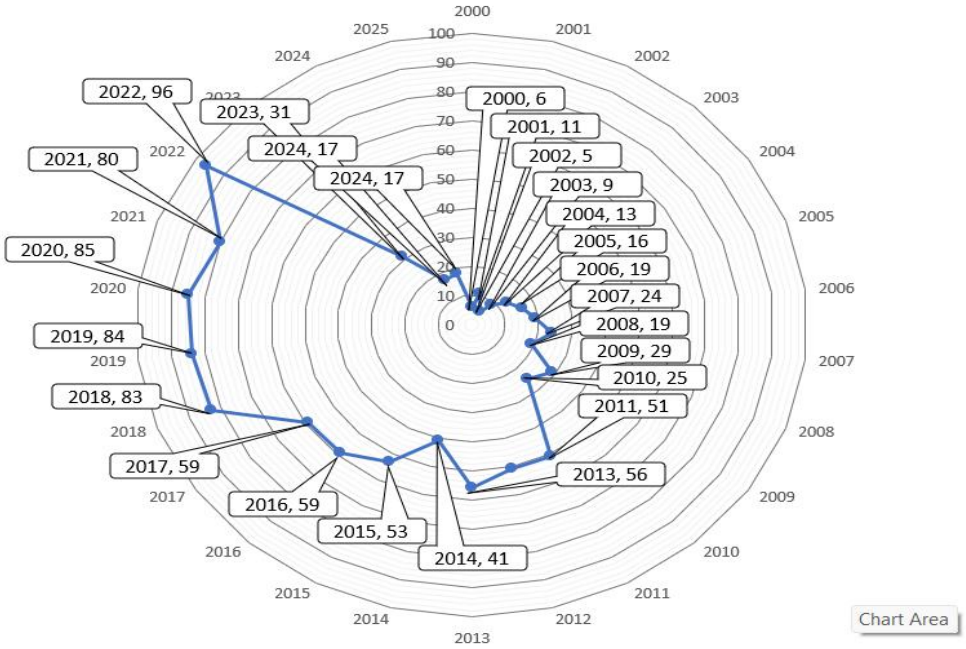

Figure 5. Circular research has grown significantly between 2000 and 2025, as evidenced by the annual publication trend, which peaked in 2022.

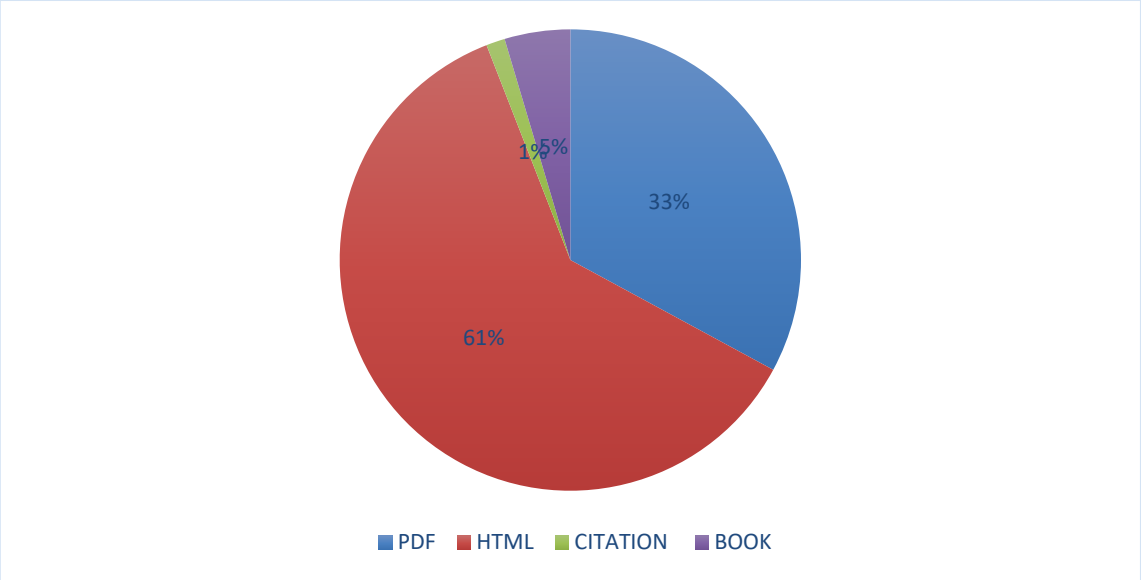

Figure 6. Number of studies by research type

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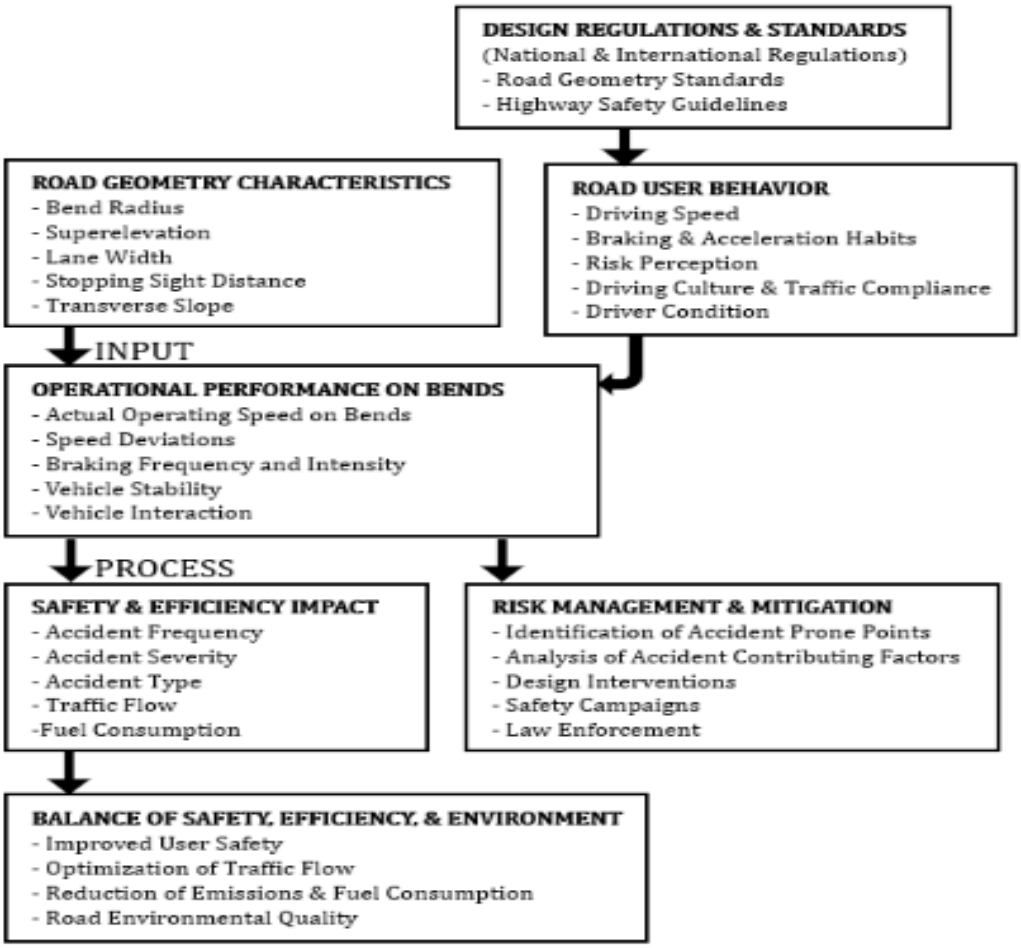

Figure 7. The conceptual model defining the essential elements of the critical assessment of road curves' effects on user safety

The percentage distribution of document types is shown in Figure 6 above. Most of the available documents are in HTML format, reaching 61%, indicating a high preference or availability for this format. PDF documents occupy the second position, with 33%, and this type of document is less common or represented to a lesser extent in this dataset. "CITATION" and "BOOK" each have smaller portions, 1%, and 5%, respectively. Overall, this diagram shows that digital formats such as HTML and PDF are the most popular regarding document availability.

3.5. Research type based on the majority of nations

The geometric suitability of curves, which includes various essential dimensions, is crucial for the safety of road users. The radius of the curve, superelevation, lane width, and transition length are dimensions that fall into this category. The theoretical framework related to the geometric suitability of curves for road user safety is illustrated in 7. This shows how road geometry elements such as curve radius, superelevation, and lane width (input) relate to user behavior, such as speed choice and braking habits. Operational performance and behavior are influenced by this interaction, which in turn impacts road safety, accident risk, and operational efficiency. The goal is to improve traffic safety and speed at turns.

This framework emphasizes various important aspects that contribute to the evaluation and improvement of road bend safety by starting with the geographical characteristics of the road and the behavior of road users as inputs. These factors then influence operational performance in the field, which subsequently becomes part of the process of measuring safety and efficiency impacts and implementing risk management and mitigation. The ultimate goal is to achieve an optimal balance between safety, efficiency, and the environment.

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The geometric characteristics of the road, also known as "Road Geometric Characteristics," are shown in the image. This explains the physical road design components that are important for performance and safety. Curve radius (curve radius), superelevation (cross slope of the road at a curve), lane width (lane width), stopping sight distance (stopping sight distance), and general cross slope are the highlighted points. All these components are critical in road planning and construction to ensure smooth and safe traffic.

Operational performance on road curves, or "operational performance on spans," is explained in this image. The Actual Operational Speed Indicator on Curves is included, which shows how fast the vehicle is moving. Additionally, there are deviations in speed, frequency, and intensity of braking, vehicle stability, and vehicle interactions. All these points explain how vehicles behave in turn and are crucial for assessing road efficiency and safety.

Safety and Efficiency Impact, or safety and efficiency impact, discusses specific components of vital benchmarks to evaluate the effect of road conditions and user behavior. Frequency, severity level, type of accidents, traffic flow, and fuel consumption are prioritized indicators. To determine how safe and effective a road system or design is, all these components are very important.

Traffic accident risk management and mitigation are clear. A series of proactive measures are taken to reduce the likelihood of hazards on the road. It starts with identifying accident-prone spots and then analyzing the factors causing the accidents. In addition, there are design actions to raise user awareness about road safety and improve road conditions. Finally, overall, these efforts create a safer traffic environment thanks to the crucial role of law enforcement in ensuring compliance.

The balance of Safety, Efficiency, and Environment is the ultimate goal of a broad framework. This shows how important it is to balance various components so that the transportation system can operate sustainably. The first point is to enhance user safety, which means keeping the roads safe for everyone. Additionally, there is a Traffic Flow Optimization function to improve the smoothness of vehicle movement. Reducing emissions and fuel consumption, which enhances energy efficiency, is another critical component. Lastly, to reduce the negative impact on the environment, it also aims to improve the quality of the road environment.

Often, when people focus on the geographical characteristics of roads, especially in rural areas, they overlook the complex relationship between the road and operational performance and its effects on safety. Observations show that different topographies and characteristics of rice field land significantly affect driver speed and behavior, requiring consideration beyond conventional technical design. Therefore, it is essential to create adaptive and proactive mitigation and risk management plans that thoroughly consider environmental aspects. To make a sustainable road system, an integrated approach that goes beyond geometric calculations is needed to balance safety, traffic efficiency, and ecological sustainability.

4. Conclusion

A critical evaluation of curves concerning road user safety conducted through a Systematic Literature Review (SLR) focuses on how various geometric elements, such as curve radius, superelevation, and transition length, empirically affect accident risk and driver behavior. While findings on speed thresholds and driver responses vary, the reviewed studies often reach a strong consensus on the benefits of larger curve radii for safety. SLR also usually shows significant differences in research on how geometric design interacts with human factors (such as risk perception, fatigue) and environmental conditions (such as bad weather), which often lead to cornering accidents. Therefore, this review not only summarizes what is already known but is also essential for identifying additional research topics needed to produce broader and more flexible design guidelines.

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