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Evaluate sharp turns: A Systematic Literature Review Study

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Abstract

Road development is closely linked to technological progress and economic growth. Road construction facilitates and accelerates the flow of goods and services between regions, which is one of the backbones of the national economy. Road construction has been recognised by various parties as facilitating and streamlining various types of economic activities between regions. Roads have various facilities and infrastructure such as curves, slopes, intersections, and others. For the safety and comfort of traffic flow, road users need to pay extra attention when passing through curves, slopes, and intersections. Regular maintenance of various road facilities is crucial to ensure that this infrastructure continues to function optimally in supporting economic development. Traffic accidents frequently occur on road sections, particularly those connecting tourist areas or mountainous regions, with steep or hazardous curves as vulnerable locations. To address this issue, a study is needed to identify problems, including insufficient signage, suboptimal road surfaces, or curve designs that pose potential hazards. Case studies highlight the potential impact of road geometry on accident occurrence. The objective of this steep curve case study is to comprehensively evaluate the existing curve geometry conditions in mountainous or hilly regions.

Keyword: Speed, Road geometry, Vehicle, Accident

1. Introduction

The challenge of sustainable road infrastructure development remains a key issue in many developing countries, including Ghana [1]. The development of roads is closely linked to technological progress and serves to drive economic growth. With the rapid urbanisation and growth of the global economy, the need for human movement has also increased [2] Many developed countries in the world owe their progress to adequate road infrastructure [3]. The challenge of sustainable road infrastructure development remains a major issue in many developing countries, including Ghana. Advances in science and technology in the transportation sector accelerate human interaction and drive economic, tourism, and urban development by improving vehicle safety, performance, and efficiency [4]. Roads are an important transportation infrastructure that connects various strategic locations and supports the distribution of goods and services to support economic activities [5]. Roads not only facilitate transportation but also relate to social and economic life. Roads are expected to provide comfortable, safe, and efficient transportation services for the community [6].Therefore, traffic plays a crucial role in moving regional elements, while also shaping the spatial layout of the region. [7]. This makes transportation a fundamental determinant for regional development and spatial interaction. Rapid advances in transport infrastructure, however, are met with spreading traffic problems due to urban population growth, which demands ever-increasing use of transport facilities. [8].

Roads are vital to society, enabling transportation, travel, cultural exchange, and the flow of materials and information, all of which support social and economic functions**.** [9]. Road construction is projected to facilitate and accelerate the flow of goods and services between regions as one of the backbones of the nation's economy. Highways can be classified based on their function (local, collector, arterial) or based on the type of area they pass through (village, city, district, province, and national) [10]. Roads have various facilities and infrastructure such as bends, inclines, intersections, and many others. Facilities and infrastructure supporting mobilisation are now widely accessible. [11] Road geometric design has certain rules and steps so that the design results meet standards

[12]. For the safety and comfort of traffic flow, road users need to pay extra attention when crossing bends, inclines, and intersections. Improving traffic safety through careful planning can significantly contribute to the safety of road users [13]. In designing road geometry, traffic safety and comfort aspects are crucial considerations, which are then adapted based on the function or classification of/ the road concerned [14]. Not only that, regular maintenance of various crucial road facilities is necessary to ensure that this infrastructure continues to function optimally in supporting economic development. Road network design and construction is an essential part of modern transportation infrastructure, where road geometry plays a major role in ensuring safety, efficiency and desirability [15].

A traffic accident is an event that occurs while a vehicle is in motion and results in injury or loss of life Z [16]. Traffic accidents are common on road sections, especially those leading to tourist or mountainous areas, with sharp or hazardous curves being particularly prone to incidents. According to the World Health Organization (WHO), road traffic accidents tragically result in approximately 1 million deaths, 3 million permanent disabilities, and 30 million injuries each year [17]. On mountain roads, driver behavior and speed are not only influenced by the physical characteristics of the road, but are also greatly determined by visibility conditions which are often limited or less than ideal [18]. To address this issue, an in-depth study is needed to identify the root causes, including the lack of signage, suboptimal road surfaces, or potentially dangerous curve designs. High traffic volumes can trigger problems such as traffic jams and accidents in various countries [19]. This is often exacerbated by inadequate road infrastructure or undisciplined driver behaviour. A traffic accident is an incident on the road caused by the negligence of road users, vehicle maintenance, road conditions, or environmental factors, resulting in a collision that causes death, injury, or serious injury recorded by the police [20]. This evaluation aims to recommend effective solutions for improving road user safety.

Roads are vital infrastructure that support the development of a region's potential by facilitating the movement of people and the distribution of goods [21]. Driving deep into the winding roads of the hilly region is a critical assessment of the steep geography and winding roads. Traffic accidents have always been one of the main public safety issues [22]. The case study highlights the potential impact of road geometry on road use due to the potential for accidents at bends. The majority of people's daily activities are highly dependent on transportation [23]. Analyzing factors like curve radius, superelevation, and visibility is therefore essential to pinpointing the root causes of issues. It is hoped that all evaluation findings will provide specific recommendations for improving road infrastructure. Roads are designed with stopping visibility in mind. The aim is to ensure drivers have enough time to see and safely avoid potential accidents [24]. The implementation of appropriate solutions will have a significant impact on improving traffic safety and flow in the area. The fact that most traffic accidents follow predictable patterns shows theoretical and methodological similarities with crime prediction [25]. Therefore, the bend needs further review for the sake of safety and smooth traffic flow.

The purpose of this steep curve case study is to comprehensively evaluate the geometric conditions of curves in hilly or mountainous areas. Furthermore, this study aims to identify factors that may cause accidents due to the configuration of these curves. Based on the analysis presented, the objective of this journal is to provide recommendations for improvements to the geometric design and safety facilities that comply with technical standards in the field. Ultimately, it is hoped that this case study will enhance the safety and comfort of road users.

A good geometric design of a curve takes into account the design speed of the road, the types of vehicles that will pass through, climatic conditions, and terrain characteristics. [26]. On sharp bends, drivers need time to prepare their vehicles before they can negotiate them [27]. Proper cornering planning ensures that the vehicle can maintain its planned speed safely and smoothly, so that the driver and passengers are spared sudden deceleration or uncomfortable manoeuvres. Road geometry planning includes the design of road sections, curves (both horizontal and vertical), and ensuring that the overall road plan meets the specified criteria [28]. To achieve the ideal geometric design of a bend, the implementation of superelevation and appropriate transition curves is essential.

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Not only that, sufficient visibility around the bend also plays a major role in ensuring safety and smooth traffic flow. Currently, Indonesia is facing rapid population growth, which has led to an increase in community activities and needs [29]. Thus, the allocation of resources for careful geometric planning of curves is a crucial step in building high-quality, user-focused expressway infrastructure.

Good connectivity has the potential to improve every aspect of a city or country's development [30]. Geometric road design is the process of planning and arranging the physical form of roads to ensure traffic safety, comfort, and efficiency. Traffic signs are one of the most important elements that influence how roads function [31]. Road geometry design is heavily oriented towards the stopping visibility model to ensure that drivers have sufficient visibility to stop safely [32]. There are several types of road classifications, such as straight roads, curved roads, uphill roads, and downhill roads. Curves are road infrastructure that is very important in road geometric planning, but curves must also be calculated accurately. The various road categories serve as the central element that holds the entire road infrastructure together [33]. Road bends must be in accordance with geometric road planning requirements but should not compromise driver comfort. Sharp bends can become hazardous locations for drivers, such as the Cigendel bend on the Cadas Pangeran route in Pamulihan Subdistrict, Sumedang Regency. Road safety is a major concern worldwide, both in developed and developing countries, as it has a significant impact on the global economy and public welfare [34].

An efficient road infrastructure network is a key factor in determining the socio-economic development of a region [35]. Highways have infrastructure such as curves, which are crucial elements in road geometric design that significantly affect traffic safety, comfort, and efficiency. Highway construction requires careful consideration of long-term environmental, economic, and social impacts [36]. Reliability analysis based on radius, operating speed, superelevation, and friction coefficient is essential to ensure that the curve supports vehicle safety and efficiency [37]. Highway curve design is one of the most important aspects of road engineering, aimed at facilitating safe and comfortable changes in vehicle direction.. For road users, the design must meet their needs while achieving efficiency, comfort, and safety [38]. Road bends, as part of horizontal curves, must be designed to overcome centrifugal forces, prevent vehicle skidding, and provide sufficient visibility for drivers. High emissions are often influenced by factors such as vehicle type, accident rates, or poor pedestrian safety [39].

Road designs with a speed limit of 60 km/h, a curve radius of 150 metres, a transition curve of 120 metres, and a superelevation of 6% have a significant impact on traffic safety levels [40]. Highway curve design requires careful consideration of various factors, including design speed, curve radius, superelevation, and transition length. Stated in the Study “Reliability Analysis of Horizontal Curves Using Geometric Design Consistency Assessment Criterion” that the reliability analysis of horizontal curves should consider variables such as design speed, radius, superelevation, sight distance, and transition length to ensure safety and design compliance [41]. Driver safety and comfort are the primary objectives. Minimal geometric elements, such as insufficient sight distance or extremely sharp horizontal curves, can significantly increase the risk of accidents [42]. Challenges such as operational speed compatibility, limited visibility, and environmental conditions must be overcome through careful and innovative design. In highway planning, we always make estimates for different time periods: short, medium, and long term. [43]

2. Research Methods

A quantitative methodology allows for the quantitative description of phenomena and helps establish relationships between two or more variables [44]This study uses quantitative methods with a descriptive design to explain characteristics and trends, as well as a correlational design to understand the relationships between the variables under study. International journals from Google Scholar are the main data sources for this study. These data sources were selected based on ease of access and availability, broad coverage, quality verification, and relevant up-to-date references. By facilitating access to global research and providing personalized profiles for reference management, Google Scholar contributes to the improvement of research quality [45]. Google Scholar also offers several features that make it easier for researchers to manage references and track the latest research developments. Therefore, using journals from Google Scholar not only improves the quality of research, but also broadens researchers' insights into global scientific advances.

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The research data was taken from journals published between 2000 and 2025. A time span of around 14 years is a common software technique, indicating that the study used a sufficiently long time period to allow for comprehensive data analysis [46]. The selection of a time frame spanning more than two decades aims to ensure that the information used is relevant and up to date. The time frame from 2000 to 2025 was chosen in order to build a theoretical foundation, compare and contextualise findings, and capture developments in science. Additionally, this time period allows researchers to compare the results of previous studies with new findings. This makes the analysis more accurate and relevant to current conditions.. Updating the SLR every five years to ensure it remains relevant, extending its useful life and extending its useful life to 2025 [47].

The initial screening process (using keywords and year) followed by full-text screening is crucial so that only relevant journals make it through [48]. The journals used in this study were selected based on keywords relevant to the research title, including: Road geometry, Road evaluation, Sharp curves, Roads, Traffic, and Traffic regulations. This study combines various road safety data and simulations to analyse the role of geometric design, signal configuration, and regulations in improving road safety [49]. For this systematic literature review, a total of 1,000 journals were used. Of these, 970 journals were obtained simply by entering keywords and publication years. Meanwhile, the remaining 30 journals were obtained by adding the author's name, Andri Irfan Rifa'I, as a filter, in addition to keywords and publication years. The selection of this method aims to obtain a broad and representative literature coverage, enabling the research to provide a comprehensive overview of the topic under investigation. With the massive and diverse number of journals, the analysis conducted is expected to be more valid and reliable, as it is based on a wide range of in-depth sources.

Using tools such as Publish or Perish and VOSviewer, this study will identify research trends, examine relationships between researchers, and quantify the impact of publishing knowledge in this field. Will identify research trends, examine relationships between researchers, and quantify the impact of publishing knowledge in this field [50]. Data collection was carried out using the Publish or Perish (PoP) application, by entering predetermined search criteria into the application. Publish or Perish is free software that helps academics and researchers manage and analyse references. This application works by extracting bibliographic metadata from various leading journal databases such as Google Scholar, Scopus, and Web of Science. The Publish or Perish (PoP) application allows users to track the number of citations of published scientific articles, using Google Scholar as its data source [51]. That way, PoP can automatically sort journals that are relevant to research needs. Once the journals have been selected, the data is then exported from Pop in RIS (Research Information System) format. This format is a standard for exchanging bibliographic data that is commonly used by various reference management software. The RIS file contains structured information such as title, author, publication year, and journal name, making it easier to manage and integrate reference data into other applications such as EndNote, Mendeley, or Zotero.

The research data was collected using the VOSviewer application. VOSviewer is a network visualization tool that allows the creation of maps of publications, countries, journals or keywords based on the relationships between elements [52]. Data processing is carried out by importing RIS files obtained from Publis or Perish (PoP) into VOSviewer. This application supports the RIS format as the standard for exchanging bibliographic data from various sources. After the RIS file is imported, VOSviewer automatically reads and manages the bibliographic data, then displays the results of the systematic literature review (SLR) in the form of a visualisation map. This visualisation includes keyword networks, author collaborations, publication year distribution, the number of journals related to specific keywords, publishers, authors, and the number of citations.

3. Results and Discussion

3.1. Visual keywords

Visualisation of keyword correlations in research evaluating sharp turns, based on an analysis of 970 journals indexed by Publish or Perish and visualised using VOSviewer, has identified correlations between various relevant keywords. As a graphical interface software, VOSviewer can only perform predefined tasks [53]. This visualisation specifically shows the relationship between the selected keywords, namely roads, sharp bends, curved roads, traffic, bend radius, speed, road geometry, and road signs.

Network visualization that illustrates the main keys and develops the research topic the network illustrates the main keys and develops the research topic [54]. VOSviewer plays an important role in displaying the interrelationships between these keywords. Through the visualisation produced, we can see how each keyword relates to the others and forms a thematic network within the research literature. This analysis helps us to

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understand the structure and focus of existing research, as well as to identify areas of interconnection. The image shows these correlative relationships.

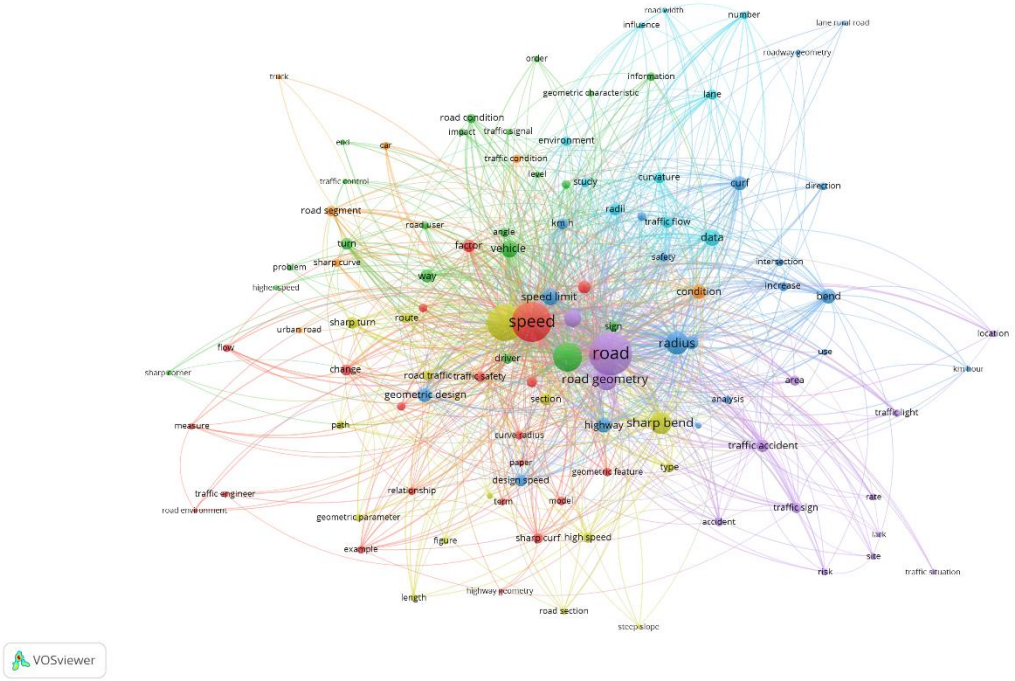

Figure 1 visualisasi jaringan

VOSviewer analyzes and visualizes a network of frequently co-occurring keywords to identify key focus areas in research [55]. This VOSviewer visualisation presents a network map that reveals the most frequently occurring keywords in research literature. On the map, the size of each circle reflects the frequency of occurrence of the keyword; the larger the circle, the more frequently the word is mentioned in publications. The results show that the keywords ‘speed,’ ‘road,’ ‘radius,’ and ‘road geometry’ are the most dominant. This indicates that these topics are the primary focus in studies related to sharp curves, roads, and speed. By utilizing the stability factor, design speed and vehicle stability on bends stability factor, design speed and vehicle stability on bends [56]. In addition, any line connecting two keywords indicates that they often appear together in a single document. For example, “speed” and “road” have a strong line of connection, which means they are often discussed simultaneously in the context of sharp turns.

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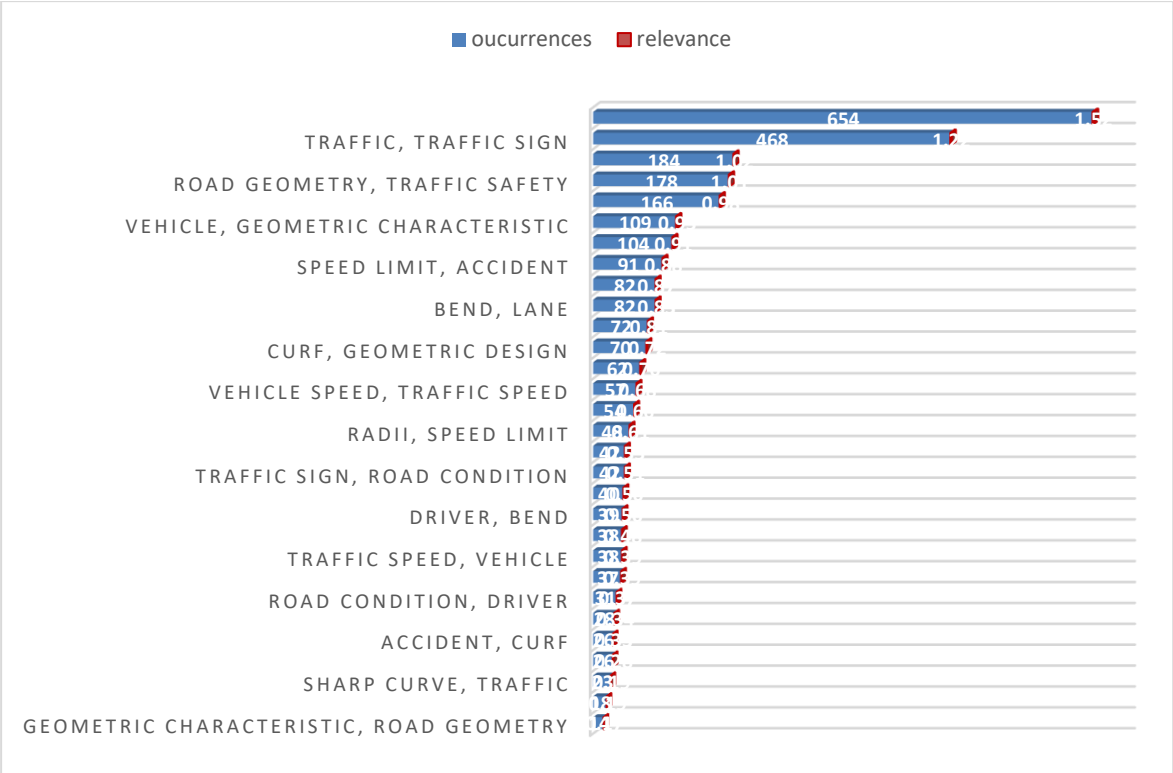

Figure 2 keyword Graphic

The bar graph presented shows the fifteen most frequent primary keywords found in the research dataset analyzed with VOSviewer, along with the number of occurrences and their level of relevance. A discipline that focuses on the quantitative and statistical study of how scientific knowledge is generated, disseminated, and used, typically by analysing bibliographic databases [57]. “Traffic” topped the list with a total of 654 occurrences. This indicates that traffic and policy issues are a major focus in the publications studied. Interestingly, despite the high frequency of occurrence, the relevance rate was 1.2. This suggests that although the word “traffic” is used frequently, it may be quite general and does not always specifically reflect the core or main focus of the research..

The graph also highlights keywords with low frequency of occurrence but high relevance such as “driver, bend” and “bend, lane”. This shows that although these words don't appear as often as others, they are very specific and crucial in describing the core of a study. This means that when these words appear, they are most likely the main discussion. Overall, this graph clearly illustrates that the focus of the research is heavily on “bends” and “traffic”. Frequently occurring keywords reflect a broad and widely discussed topic, while keywords with high relevance, despite their small number of occurrences, indicate the depth and specificity of the topic. This analysis is essential for understanding the research directions and priorities in sharp bend evaluation.

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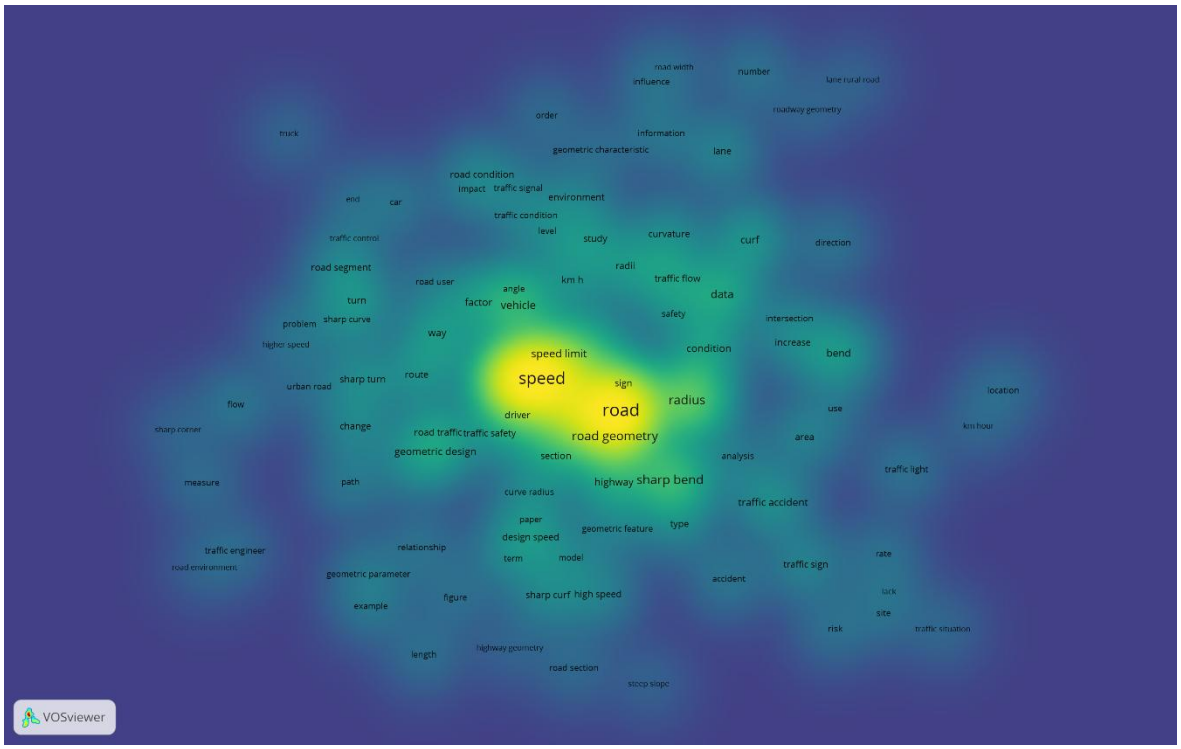

Figure 3 density visualisation

Table 1 keywords with the highest total studies

KEY WORDS	TOTAL STUDY
Traffic	654
traffic signs	654
road geometry	468
vehicle	184
accident	91

Conduct scientific research using civil engineering-related data. This data is collected globally using Harzing's (Publish or Perish) software, as shown in Table 2.

Table 2 Number of studies by publisher

PUBLISHER	STUDIES
Elsevier	92
ieeexplore.ieee.org	60
Springer	49
mdpi.com	41
OTHER	38
academia.edu	37
books.google.com	35
Google Patents	35
journals.sagepub.com	30

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Elsevier, ieeexplore, springer, are three major publishers that contribute significantly to research publications. This indicates that these platforms play a large role as channels for the dissemination of research related to steep bends. Figure 6 provides details on the different types of research publications included in this analysis. This information provides valuable insights into the diversity of the steep-slope research landscape. Journal articles, which account for the majority of this research with a total of 417 works, are the main channel for disseminating research findings in this area. Although journal articles and books dominate, other formats such as monograph datasets, and posted content may be less commonly used. This suggests that empirical data and in-depth case study data may not be as prevalent in this specific research area.

The density visualization in VOSviewer provides an overview of the popularity and focus of research based on the color distribution. The most discussed keywords are highlighted in yellow, indicating that these terms are the most frequently focused on in the research. With an intuitive interface consisting of buttons and windows, VOSviewer makes it easy for users because the functions and options are readily available [58]. In this context, “speed” and “road” appear as the most dominant keywords, confirming that these topics are very popular and often take center stage. Conversely, the bluer the color of a keyword, the fewer the number of studies covering it. These topics such as “steep slope”, “truck”, ‘location’, and “sharp corner” have not received much attention or are only lightly discussed in the analyzed literature. This visualization helps identify areas of mature research and areas that are still under-explored..

3.2. Publication development

Every year, the research landscape is constantly changing, both in terms of topics in the spotlight and the volume of publications. In this situation, we visualize how trends in topics and journal numbers have evolved over time, providing a clear picture of the dynamics of research evolution.

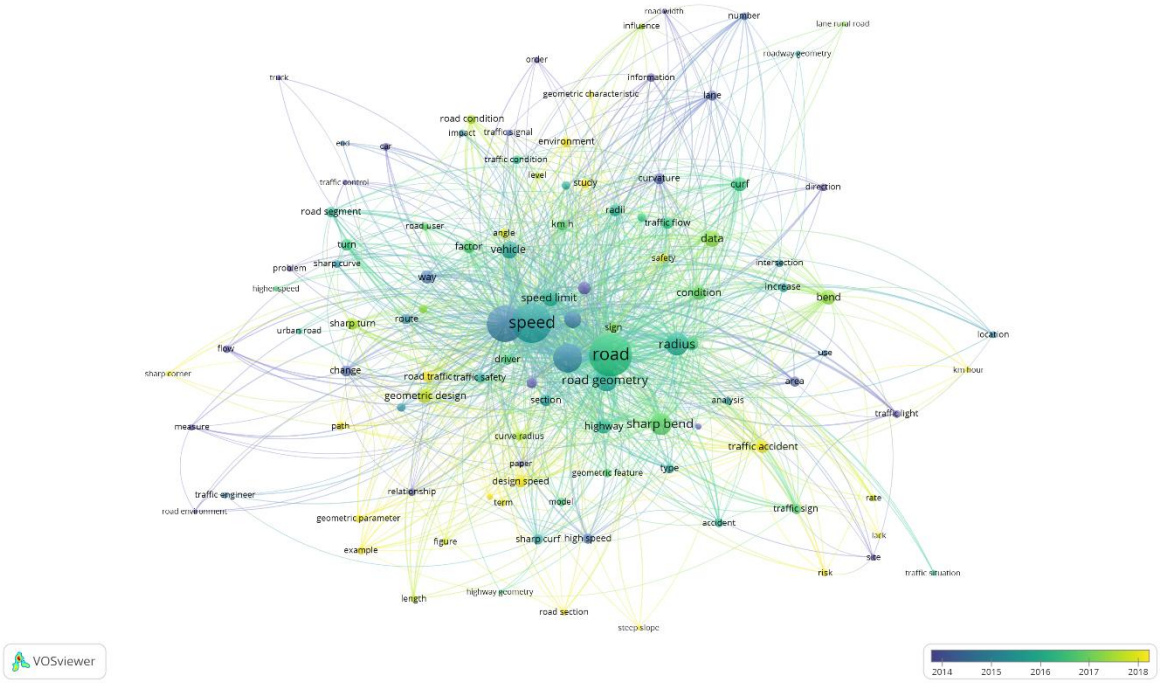

Figure 4 overlay visualisation

Citation data can be used in two contrasting ways: to measure research outcomes, or as a map representing actual knowledge and events [59]. VOSviewer's overlay visualization reveals the trend of keyword occurrence over time, showing when a topic starts to be frequently discussed and trending. This shifting typology gives an idea of how the research focus has evolved in the area of urban transportation safety [60]. The colors in this visualization are the main indicators, such as purplish keywords, indicating that the topic was a major trend in the past, around the

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year 2000. In this study, “site” and “traffic light” fall into this category, indicating that these topics were more widely discussed in the early period. On the other hand, the yellowish keywords indicate that these topics are most discussed in the more recent era, around the 2020s. Here, “safety”, “design speed”, and “road traffic” are examples of keywords that are currently trending. This overlay map is very useful for tracking the evolution of research trends, allowing us to identify hot topics as well as topics that are becoming obsolete. It provides a dynamic picture of the research focus in the field of bend evaluation over time.

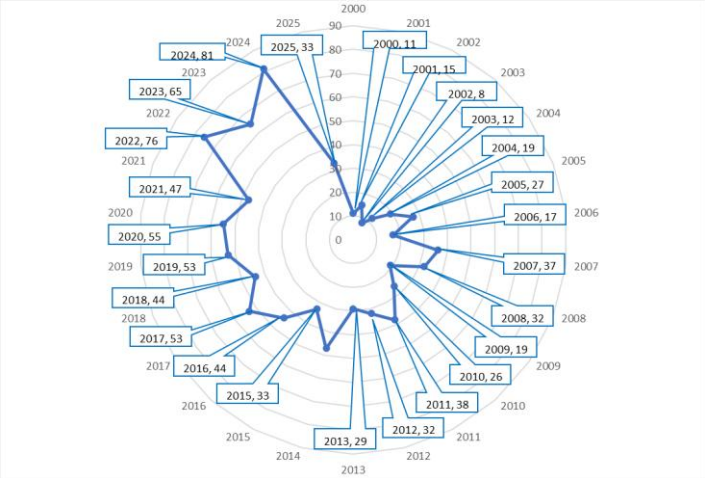

Figure 5 annual publication trend

Research volumes have increased significantly since the early 2000s with peaks occurring in 2022 and 2024. This period was characterized by high scientific productivity, most likely triggered by the increasing global focus on road geometry and traffic issues, along with growing urbanization. However, after 2005 there was a decline in the number of publications, especially between 2000 and 2002, where the graph shows a relatively low number of publications.

After a period of decline, the volume of publications began to increase gradually from 2015 to 2022, with an average of 33 to 76 publications per year. However, this trend declined again in 2023, with 65 publications recorded. Overall, the data shows fluctuations in research productivity in this field, with the most active period in 2024.

3.3. Study Type

The different types of studies used as sources in the systematic literature review, in a graph because of the variation..

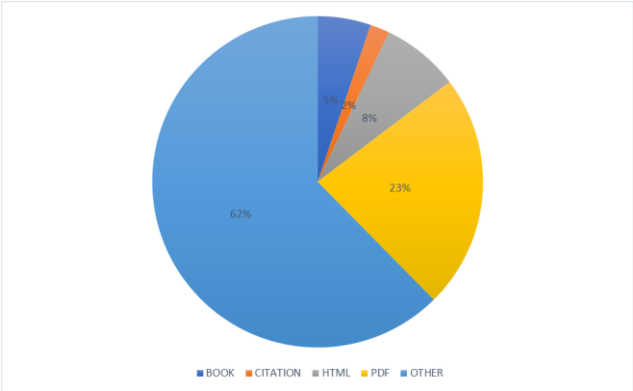

Figure 6 study tipe

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The visualization shows significant diversity in the reference sources used with each category contributing variably to the overall data. This shows that bibliometric analysis, even with the category "other," helps identify keyword linkages and measure their relevance, not just how often they appear [61]. Most of the systematic literature review results could not be classified into specific categories, so they were grouped into "other". In addition, the number of citations was relatively small, indicating that few references were derived from citations.

4. Conclusion

Research on sharp bend evaluation has predominantly centered on topics such as speed, sharp bend, traffic. These keywords not only appear frequently, but also serve as links between various themes in the sharp bend field. Elsevier is the largest publisher contributing to publications, confirming its role as a key reference source in academic studies. The annual distribution of publications peaked in 2022 to 2024, followed by fluctuations with a decline in recent years. Although the type of reference source varies, the "other" category includes document formats. Visualization of the relationship between keys shows a close connection between the concepts of traffic and road geometry. In conclusion, this study successfully mapped the trends in transportation research, helped identify the direction in which the science is developing, and highlighted future research opportunities.

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