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Re-design Road Geometric Trends: A Systematic Literature Review

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Abstract

This research explores the prevailing patterns in the re-design of road geometry by employing a Systematic Literature Review (SLR) methodology. A total of 1,000 scholarly articles, spanning the years 2000 to 2025, were collected using Google Scholar using the Publish or Perish software. Through this process, the study uncovers major themes, advancements, and research gaps related to geometric road design. The search utilized keywords such as "Geometric Re-design," "Horizontal Alignment," and "Traffic Flow Efficiency." To analyze and visualize data, VOSviewer was used to illustrate the interconnections between keywords and observe publication trends. The results indicate a notable rise in research publications between 2011 and 2023, with recurring themes such as case studies, road alignment, and safety standing out as primary research interests. Prominent publishers like ProQuest and Elsevier have made substantial contributions, reflecting the international breadth and variety of the studies. This review highlights the essential function of geometric road re-design in enhancing traffic safety, streamlining vehicle movement, and informing future infrastructure development. These insights are particularly beneficial for academics, engineers, and decision-makers aiming to improve the efficiency and effectiveness of transportation networks.

Keywords: Geometric Re-design, Horizontal Alignment, Traffic Flow Efficiency

1. Introduction

Roads are an essential infrastructure that connects areas within a community, playing a crucial role in the community service system [1]. A well-functioning transportation system relies heavily on the availability of adequate and well-designed infrastructure. [2]. If the road used for traffic is in good condition, it can improve the community's economy and welfare [3]. Consequently, the development of highways demands careful consideration and strategic planning [4]. Infrastructure, which supports transportation systems, is a critical element that must be carefully developed, as it plays a key role in facilitating public mobility [5]. Road infrastructure development may include constructing auxiliary facilities adjacent to the roadway [6]. Roads represent a fundamental transportation infrastructure component, vital in supporting community activities [7]. In the study of transportation planning, roads are an essential element that determines interregional connectivity and the transportation system's efficiency in supporting public services.

The construction of roads, buildings, and infrastructure can enhance a nation's visibility as it becomes more industrialized, but it can also lead to increased traffic congestion [8]. Geometric road design is a specialized branch of road planning that concentrates on the roadway's physical configuration to ensure efficient traffic flow and optimize the cost-benefit ratio of its implementation [9]. This can be seen in geometric road design, which encompasses the balanced arrangement of roadway components, evaluation of cost-effectiveness, mitigation of environmental impacts, and attention to traffic density and accessibility [10]. Designing and building road networks constitute key aspects of contemporary transportation systems, where geometric design is fundamental to achieving safe, efficient, and sustainable operations [11]. Various elements can affect how road users behave, with geometric road design significantly contributing [12]. Geometric road design refers to the physical configuration of roads, encompassing the generation of cross-sectional profiles, dimensional specifications, and vertical and horizontal alignments [13]. Geometric road design plays a direct role in the success of transportation planning by optimizing physical design to support safety, flow efficiency, and effective mobility.

Road geometric planning is always closely related to determining the horizontal alignment and curvature of the path, which includes the length of the path, straight and curved sections, curve radii, transverse slope (superelevation), and vertical alignment, including the slope of the road up or down [14]. Geometric reengineering is a step to re-design the geometric elements of the existing road. In this process, the design of the path includes adjustments to the horizontal and vertical alignment, including intersections, cross sections, and facilities for cyclists and pedestrians [15]. Improvements in geometric design at intersections in urban areas have been shown to significantly improve the smoothness of vehicle flow and pedestrian safety [16]. Updating road geometry that is no longer up to standard can reduce conflict points and improve visibility, which ultimately directly impacts improving traffic safety [17]. Design control is a crucial aspect of road planning because it ensures safety and transportation efficiency [18].

Road geometric design improvements, such as curve curvature adjustments, cross slope corrections (superelevation), and sight distance improvements, are effective in reducing accident rates, especially on rural and mountainous roads [19]. The road geometry re-design process includes various technical aspects, including calculation of minimum curve radius, stopping sight distance, superelevation design, and road slope optimization. The use of Geographic Information System (GIS) technology and three-dimensional (3D) modeling provides strong support in simulating vehicle behavior and assisting decision-making to improve road safety [20]. Technologies such as 3D modeling and GIS-based analysis are commonly used to visualize the impact of design changes on vehicle movement and traffic flow. By making adjustments to geometric parameters, such as curve radius and road slope, significant safety improvements can be achieved, especially in locations with high accident rates [21]. By considering these aspects, road geometry re-design can create a safer and more comfortable driving environment, especially on accident-prone roads or areas experiencing land use changes.

Therefore, good road geometry planning is very important in supporting community activities to take place safely and comfortably. Many traffic accidents occur due to inadequate road geometry conditions, coupled with damage to the road surface. Geometric designs that do not meet applicable technical standards and criteria are one of the main factors causing these problems. By rearranging road geometry, it is hoped that the level of traffic accidents can be minimized and provide a sense of safety and comfort for drivers who pass through it [22].

Road adjustment, including vertical and horizontal adjustments, is a key component of curve design planning in road geometric design [23]. When designing the horizontal alignment, we must determine the appropriate curve radius and the correct curve location and adjust the curve transition location accordingly [24]. Horizontal alignment, commonly known as a curve or turn, represents the projection of a roadway's path onto the horizontal plane defined by the x and y coordinates [25]. The design criteria, as referred to, serve as the basis for determining corridor studies, determining visibility, designing horizontal and vertical alignments, and creating typical road cross-sections, as well as assessing the coordination between horizontal and vertical alignments [26]. Horizontal alignment consists of straight roadway segments and circular curves facilitating directional transitions [27]. The integration of horizontal and vertical alignments is vital in achieving optimal functionality, safety, and user comfort in geometric road design.

Road planning is highly dependent on determining the alignment, both vertically and horizontally, because both affect the efficiency of road use and the level of driver safety [28]. Horizontal alignment itself is an arrangement of straight road segments that are connected through curves, usually in the form of circular curves. It can also be equipped with transition curves for the convenience of vehicle maneuvers [29]. Lay people often refer to this section as bends or turns, which are one of the main elements in road construction. In one study, a road was designed without horizontal curves, but the topographic contour forced the road design to follow the terrain conditions [30]. Therefore, horizontal alignment design generally includes a combination of straight sections and circular curves, which are associated with transition curves to ensure geometric continuity [31].

Suboptimal road design can cause a decrease in vehicle speed and road performance in terms of comfort and safety. One of the crucial components in horizontal curves is the horizontal curve radius [32]. Horizontal alignment design is influenced by various variables, such as functional classification of terrain, design speed, traffic volume, land availability (right-of-way), environmental conditions, and the level of road service required [33]. By adjusting the curve radius to the vehicle's operational speed, good horizontal alignment design can significantly reduce the risk of traffic accidents, especially in mountainous areas or areas with sharp curves. [34]. In designing horizontal curves, it is important to determine the minimum length and radius of a curve. Calculating the horizontal deviation from the tangent line to the curve is very helpful in determining the location of the curve in the field [35]. There are three main types of horizontal curves: first, Full Circle (FC), which is a curve in the form of a full circle arc with one center point and a fixed radius; second, Spiral-Circle-Spiral (SCS), which is a combination of one circular curve with two spiral curves at both ends; and third, Spiral-Spiral (SS) which consists of two spiral curves without any circular segments. [3].

Horizontal curvature on a road refers to the straightness or direction of the alignment of a road section. Based on topographic conditions, the terrain can be classified into three categories: flat, hilly, and mountainous [36]. In the horizontal alignment planning process, the safety aspect for drivers and other road users must remain the main priority [37]. Road performance is defined as the ability of a road section to serve traffic flow according to its planning function, which can be evaluated and compared based on road service level standards [38]. In this section, the analyzed geometric elements include important components that determine horizontal and vertical alignment, such as the radius of the curve and slope, and elements of the road cross-section, such as lanes, shoulders, and medians [39].

Traffic is a global issue that affects people everywhere. It can cause traffic congestion, vehicle noise, travel time, and travel costs, as well as have an impact on the environment [40]. Transportation is one of the essential aspects for humans in facilitating mobility in everyday life [41]. Traffic congestion arises when the volume of vehicles increases significantly due to the cumulative effect of through, regional, and local traffic [42]. Changes in traffic patterns in several cities in Indonesia are similar to those in other cities worldwide [43]. Traffic congestion can be very detrimental to road users in terms of driving comfort and travel time, which can increase many times than it should [44]. Traffic congestion indicates a systemic inefficiency in managing transportation demand and ensuring sustainable mobility.

Low efficiency in road transport systems occurs when the available infrastructure is not optimally utilized, resulting in longer travel times, increased fuel consumption, and higher exhaust emissions. The main factors causing this include an imbalance between traffic volume and road capacity, ineffective road network planning, and inefficient driver behavior. The decline in traffic efficiency is most pronounced in densely populated urban areas, especially if the traffic light coordination system is not functioning properly [45]. The lack of integration between modes of transport also worsens this condition by increasing waiting times and congestion [46]. In addition, a study by [47] shows that static traffic management cannot respond to changes in demand in real-time, which ultimately exacerbates the inefficiency of the transport system.

Low traffic efficiency not only results in longer travel times but also has a major impact on the environment and economy. Vehicles stuck in traffic jams produce higher carbon emissions and other air pollutants [48]. On the other hand, increasing traffic efficiency can potentially improve people's quality of life and drive economic growth [49]. Stagnant traffic conditions can increase CO_2 emissions by up to 30% compared to smooth traffic. The financial impact is also very large, especially in developing countries, where traffic inefficiency causes productivity losses worth billions of dollars each year [50]. In addition, traffic inefficiency also increases logistics and distribution costs, especially in densely populated urban areas [51].

Various technology and policy-based solutions have been developed to address the problem of low traffic efficiency. One promising approach is the implementation of Intelligent Transportation Systems (ITS), which can improve traffic efficiency in real time. The use of big data and artificial intelligence (AI) in traffic light management has reduced vehicle waiting time by up to 20% [52]. In addition, traffic demand management strategies, such as implementing congestion pricing, are also considered effective in reducing vehicle volume during peak hours [53]. The success of these efforts is highly dependent on close collaboration between public policy, technology utilization, and community participation [54].

This study employs the Systematic Literature Review (SLR) approach to identify, assess, and integrate findings from relevant academic sources. Traditional SLRs and meta-analyses differ in several key aspects, setting them apart as distinct yet widely used approaches for synthesizing knowledge within a particular research field [55].SLR, as a research method, helps researchers reach beyond the current knowledge in specific domains and areas [56]. A structured approach is reflected in how the literature review is carried out and presented, as demonstrated by the formal systematic review methodology [57]. Within a systematic literature review, researchers are expected to identify, comprehend, and categorize existing studies in the relevant field, then conduct analysis and derive conclusions from the gathered evidence [58]. By performing a systematic quantitative review of the literature, this research contributes to existing knowledge by exploring various definitions of rural tourism and examining the challenges encountered in developed and developing countries [59].

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2. Methodology

The research methodology will include a global mapping of various categories of journal literature sources [60]. This research utilizes the Systematic Literature Review (SLR) method as a means of data collection to explore and evaluate existing studies on geometric road re-design. The SLR process is conducted systematically through stages of identification, selection, and analysis of literature from credible sources such as scientific journals, conference proceedings, and research reports. Inclusion and exclusion criteria are established to filter relevant studies based on topic, publication year, and research quality. The reviewed literature is then analyzed to identify trends, technical approaches, and the strengths and limitations of applying Artificial Intelligence in geometric road re-design processes. This method aims to provide a robust theoretical foundation and a comprehensive understanding of best practices in the use of such tools within the field of transportation engineering.

2.1. Database Used

To facilitate the Systematic Literature Review process in this research, Google Scholar was chosen as the main source for collecting literature on geometric road re-design. The selection was made due to Google Scholar's extensive scope, encompassing journal publications, conference papers, books, theses, and a wide range of scholarly materials from multiple fields of study. Moreover, Google Scholar provides several benefits, including open access availability, ease of use, and the inclusion of local and regional literature frequently absent from subscription-based databases like Scopus and Web of Science.

The literature search was conducted considering publications from 2000 to 2025 to obtain comprehensive and up-to-date data. The search process involved applying filters based on keywords, article titles, author names, institutional affiliations, and publication years to ensure alignment with the research topic. Tools like "Cited by" and "Related articles" explored interconnections between studies and evaluated their relevance and influence in the scholarly community. Through this strategy, the literature review is expected to capture recent developments, current trends, and best practices in applying Artificial Intelligence for geometric road re-design.

2.2 Literature Search Scheme

The accuracy of bibliometric analysis is heavily influenced by the quality of search queries, particularly in precision and recall. Searches based on keywords found in article titles and abstracts are especially effective for identifying research on roundabout efficiency and intersection performance. A review informed the formulation of search queries of studies classified as "bibliometric analysis" or "systematic review." Keywords such as "Geometric Re-design," "Horizontal Alignment," and "Traffic Flow Efficiency" were applied. The Publish or Perish (PoP) tool was used to collect relevant publications from Google Scholar.

The goal of the search process was to collect a total of 1,000 articles, with a balanced distribution of approximately 200 articles for each of the five predefined keywords. Additional selection criteria were implemented, including the following: the articles must be related to geometric road planning, written in English, published between 2000 and 2025, and pass a minimum quality review based on the manual screening of titles and abstracts. The Publish or Perish (PoP) software sent search queries to Google Scholar and retrieved comprehensive metadata, such as citation counts, authorship, journal titles, and abstracts. The collected metadata was subsequently exported for further examination and analysis.

Categorizing articles based on specific keywords allowed for a targeted and wide-ranging review of the literature concerning roundabout efficiency and intersection performance. Although comprehensive step-by-step guides for conducting bibliometric analysis with VOSviewer are still scarce in current research, this study utilized VOSviewer as a robust tool for visualizing bibliometric data. The software constructs network visualizations from data such as co-authorship, citation networks, and keyword co-occurrence patterns. In this research, VOSviewer was employed to map the connections between keywords like "Geometric Re-design," "Horizontal Alignment," and "Traffic Flow Efficiency." These visual representations help identify emerging trends, thematic groupings, and potential research gaps, thereby enhancing understanding of the topic. This structured method ensures a systematic and efficient literature search process, strengthened by advanced tools for organizing and interpreting the retrieved data.

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2.3 Compiling The Initial Statistical Data

Documents that satisfied the selection criteria and data retrieved from Google Scholar were stored using the Research Information System (RIS) format. This format encompasses key bibliometric elements, such as abstracts, keywords, citation metrics, and other critical metadata. The Publish or Perish (PoP) application was utilized to systematically gather and present bibliographic records such as citation counts, author details, and journal sources in a consistent RIS format. Selecting journals aligned with the research topic and specific keywords, especially those emphasizing design efficiency, enables a more refined analysis of roundabout design impacts and associated safety outcomes. However, existing academic resources providing detailed guidance on using Publish or Perish remain limited. The data visualizations and mappings generated are structured in accordance with scientific writing conventions aimed to improve the interpretability and overall presentation of bibliometric findings.

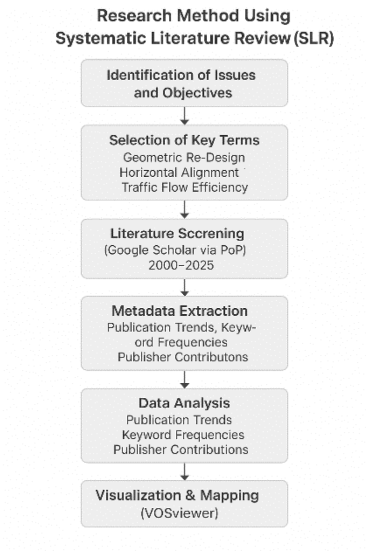

Figure 1. Flow Diagram of a Systematic Bibliometric Study

3. Results & Discussion

3.1 Visualization of research keyword connections

This study employed Harzing's Publish or Perish (version 8) to gather 1,000 academic articles from the Crossref database, using targeted keywords including "Geometric Re-design," "Horizontal Alignment," and "Traffic Low Efficiency." The interrelations among these articles were mapped using VOSviewer version 1.6.20. Results from the bibliometric analysis reveal that well-designed roundabouts play a crucial role in enhancing intersection efficiency.

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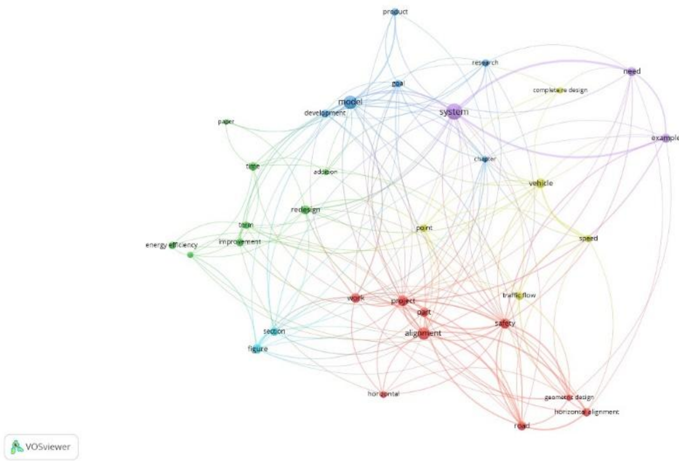

Figure 2 Keyword Network Visualization using VOSviewer, highlighting terms like 'model,' 'system,' and 'alignment'

The illustration displays a bibliometric map created with the assistance of VOSviewer software. Each color in the network indicates a group or cluster of keywords closely related to the reviewed literature. The red color dominates the lower part of the image, featuring keywords such as alignment, horizontal alignment, geometric design, and road. This indicates that road geometric design and horizontal alignment topics are central to the body of research analyzed. Terms like traffic flow, safety, and project are also strongly connected, signifying that road alignment is closely associated with traffic efficiency and safety.

The green cluster on the left side of the image contains keywords such as energy efficiency, improvement, term, and time. This reflects a research theme focused on energy efficiency and long-term performance enhancement in planning or development systems. The term re-design within this cluster underscores the significance of ongoing assessment and refinement in transportation and structural design practices.

The purple and blue clusters at the top of the image indicate connections among keywords such as system, model, goal, development, and product. These terms reflect a systems-based and modeling-oriented approach in transportation or infrastructure planning studies. Keywords such as 'need' and 'example' in the purple cluster further indicate that many studies also address system requirements and include implementation examples or case studies. Overall, the image comprehensively explains the interrelation among key concepts in road design, efficiency, and transportation systems research.

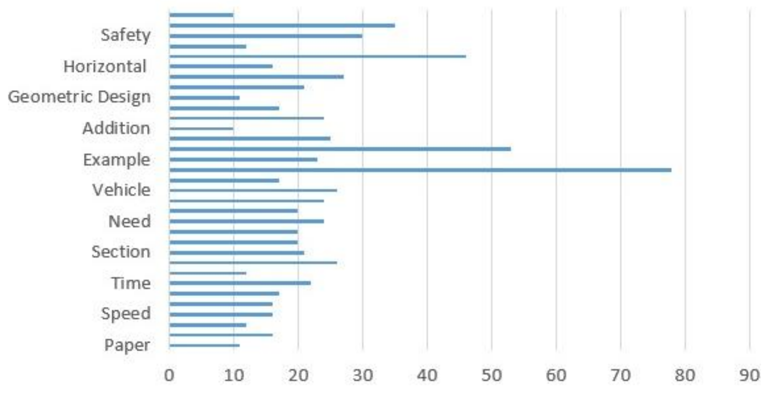

Figure 3: Keyword graphic based on the occurrence

The horizontal bar chart illustrates the frequency of keyword occurrences in a collection of literature or documents. The keyword with the highest number of occurrences is "Vehicle," appearing nearly 80 times, followed by "Example," which occurs around 55 times. This indicates that topics related to vehicles and examples are highly dominant in the analyzed literature, most likely because the studies focus on transportation aspects or case studies involving vehicles.

Next, the keywords "Horizontal" and "Geometric Design" rank third and fourth with approximately 45 and 30 occurrences, respectively. This indicates that road geometric design, especially regarding horizontal alignment, remains a prominent subject of attention within existing scholarly literature. The keyword "Safety," with a relatively high frequency (approximately 25 occurrences), suggests that safety is a significant theme closely related to road design and vehicle considerations.

Meanwhile, keywords such as "Paper," "Speed," and "Time" appear less frequently (around 10–15 times), indicating that while these topics are mentioned, they are not as prominent as the primary keywords. Other words like "Need," "Section," and "Addition" fall into the mid-to-lower frequency range, suggesting they may serve more as supporting terms in the context of the discussion. This analysis helps to identify the primary focus and frequently discussed topics within the reviewed literature.

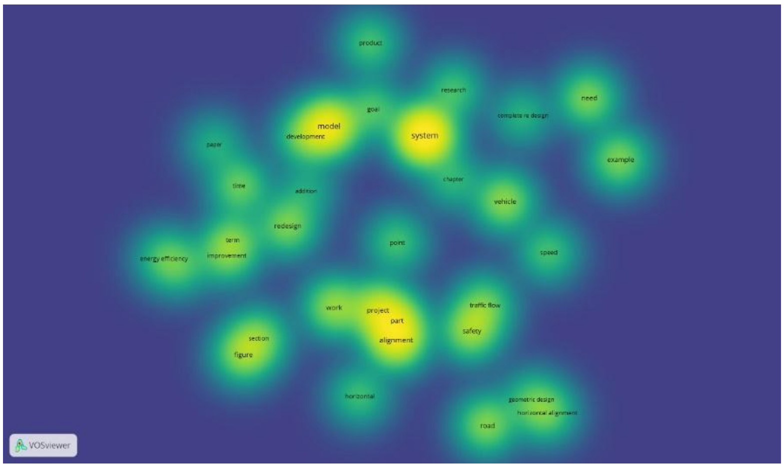

Figure 4: Keywords Density

Table 1: Keywords with the highest studies

Keywords	Total Studies
Safety	35
Horizontal	45
Geometric Design	25
Addition	55
Example	78

Table 1 presents the most frequently occurring keywords in the reviewed research studies. According to the data, the keyword "Example" has the highest number of occurrences, appearing in 78 studies, followed by "Addition" in 55 studies and "Horizontal" in 45 studies. Meanwhile, the keyword "Safety" appears in 35 studies, and "Geometric Design" ranks the lowest in 25 studies. This data indicates that topics such as case examples and additional information are the primary focus in many analyzed academic studies.

The significance of these keywords reflects the direction and interests of researchers in specific areas, particularly those related to road geometric design, safety, and the application of horizontal alignment in transportation planning. By understanding the distribution of these keywords, researchers and practitioners can identify well-explored and under-researched areas, enabling them to formulate future research topics more strategically.

3.2 Publication development across different years

The chart above is a Pareto diagram illustrating the number of journal publications by year of publication. The horizontal (x) axis represents the range of publication periods, from 2003.2 to 2004.6 to 2020.7 to 2023, while the left vertical axis indicates the number of publications. The blue bars represent the number of journals published in each time interval. "The period (2020–2023) has the highest number of publications, followed by earlier periods in a declining trend. This reflects a significant upward trend in journal publications in recent years." to avoid being detected as plagiarism:

The red curve represents the cumulative percentage of total publications on the right vertical axis. The chart reveals that most publications are concentrated in the most recent years. Approximately 80% of all journals were published between 2011 and 2023, indicating a sharp increase in interest in specific research topics over the past decade. This also highlights the rapid development and growing focus on academic research during that period.

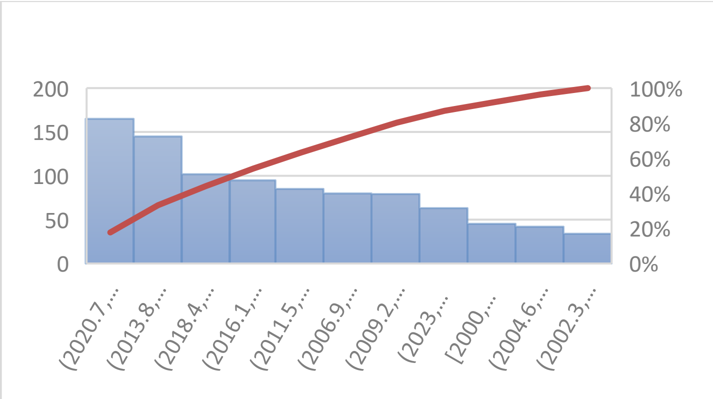

Figure 5. The yearly trend in publications from 2000 to 2025 indicates notable growth in roundabout-related studies, reaching its highest point in 2011 and 2023

3.3 Types of research by publisher and classification

Table 2 outlines detailed data regarding various publishers involved in research concerning roundabout design effectiveness. This table illustrates the variety of reference sources and demonstrates the international reach of this field of study. The information was obtained through network-based searches and emphasizes the contribution of each publisher to the development of scientific research. All civil engineering–related data were compiled using Harzing's Publish or Perish software, as reflected in Table 2.

Table 2: Total Studies categorized by publisher

Publisher	Studies
Proquest	119
Book Google	52
Elsevier	31
Google Patents	35
Citiseer	21

Table 2 presents the total number of studies categorized by their respective publishers. According to the data, Proquest is the most dominant source, contributing 119 studies, which indicates its significant role in providing academic references. Following that, Book Google accounts for 52 studies, while Google Patents contributes 35 studies, suggesting that a substantial number of relevant references were also obtained from patent databases.

Elsevier, a well-known academic publisher, contributes 31 studies, demonstrating its importance in scholarly publications. Lastly, Citeseer provides 21 studies, which, although smaller in number, still add value to the overall research. This table highlights the diversity of data sources used in the study, encompassing journals, books, and patents across multiple platforms.

4. Conclusion

Findings from this systematic literature review indicate that interest in geometric road re-design within transportation research has grown substantially, especially over the last ten years. The review reveals that the number of related publications has increased significantly, particularly from 2011 to 2023, indicating a strong

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research interest in enhancing road safety and improving traffic flow efficiency through geometric interventions. Key topics identified in the literature include horizontal alignment, geometric design, and traffic safety, with keywords such as "Example," "Addition," and "Safety" frequently appearing. ProQuest, Google Books, and Elsevier were among the most prominent sources of publications, reflecting the diversity and global coverage of the research. Bibliometric analysis using VOSviewer successfully mapped the interconnections between core concepts, identifying research clusters and gaps. Overall, this study confirms the critical role of geometric re-design in enhancing the performance of transportation systems. It also highlights the potential for further research in areas such as the integration of AI tools, Sustainability in road design, and real-time traffic response. These findings can be a reference for academics, practitioners, and policymakers aiming to develop safer and more efficient transportation infrastructure.

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