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Roundabouts in Urban Mobility: A Bibliometric Review of Design and Performance

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ABSTRACT

Rapid urban traffic growth often outpaces infrastructure development, especially at intersections, leading to safety risks and congestion. Roundabouts are increasingly implemented to improve traffic flow, safety, and environmental sustainability. However, the environmental and social dimensions of roundabout design remain underexplored. This study conducts a systematic review and bibliometric analysis of 1,000 publications from 2020 to 2024 to evaluate roundabout designs at unsignalized intersections. Key trends, themes, and research gaps are identified using bibliometric mapping and performance metrics such as Level of Service (LOS), vehicle delays, queue lengths, and emission levels. Findings highlight the effectiveness of roundabouts in enhancing urban traffic efficiency, reducing congestion, improving safety, and lowering environmental impacts. Despite these benefits, challenges persist in adapting roundabout designs to diverse urban settings and ensuring public acceptance. The study recommends adaptive and sustainable roundabout designs tailored to specific regional conditions. It also emphasises the integration of emerging technologies, such as smart traffic monitoring systems, to optimise performance. These insights offer guidance for urban planners and policymakers in rapidly urbanising areas.

1. INTRODUCTION

Traffic rapidly develops in various cities, yet this growth has led to several issues as existing facilities struggle to expand [1]. Public acceptance and cultural factors influence the success of infrastructural adaptations and designs that are effective and responsive to community perspectives. One of the most significant challenges is at intersections, where traffic from various directions converges [2]. Inadequate design and management at intersections often result in traffic conflicts, including accidents and congestion. These conflict points impede mobility and pose safety and environmental challenges [3].

Urban intersections face similar challenges globally, with cities like Jakarta [4], Bangkok [5], and New York grappling with congestion and delays. In recent years, scientific research has increasingly focused on developing innovative intersection designs to enhance capacity and safety conditions [6]. While these studies address operational efficiency and crash reduction, they often overlook environmental concerns, costs [7], behaviour, and social impacts [8], which are equally critical in road infrastructure development [9]. For example, analysing crashes by type has provided valuable insights into the safety performance of various roundabout configurations [10]. However, further evaluation is needed to determine the broader benefits of different designs.

Mobility demands have surged, resulting in a significant rise in vehicle ownership [11]. This growth strains existing infrastructure, leading to severe traffic congestion, particularly at three unsignalized three-legged intersections in commercial and densely populated residential areas. These intersections are hotspots for congestion, delays [12], and accidents, necessitating immediate attention [13].

Bibliometric analysis can reveal research trends related to the environmental and social dimensions of roundabout design, which have been underexplored in previous studies. Unlike traditional designs, roundabouts facilitate continuous traffic flow, reducing congestion and minimising environmental impacts such as CO_2 emissions. Metrics such as LOS, vehicle delays, queue lengths, and emission levels will be used to assess the performance [14]. This study integrates bibliometric analysis and systematic review to evaluate these overlooked aspects. Unlike previous research focusing on operational efficiency and safety, this study provides a perspective by assessing the sustainability and societal implications of roundabout implementation. The findings will contribute to developing adaptive, region-specific strategies that balance traffic efficiency, environmental sustainability, and community needs. By bridging the research gap in environmental and social dimensions of intersection design, this study aims to propose sustainable solutions that enhance traffic efficiency and safety

while reducing negative impacts.

2. LITERATURE REVIEW

2.1 Roundabout effectiveness

Modern roundabouts are circular intersections with counterclockwise traffic flow designed to enhance traffic management and safety [15]. They are often implemented by converting existing intersections, improving traffic efficiency and safety compared to traditional intersections [16]. However, public misconceptions associating modern roundabouts with older traffic circles can hinder their acceptance and proper navigation [17].

Beyond safety and traffic flow improvements, roundabouts offer significant environmental benefits. By eliminating traffic signals and reducing idling time, they lower fuel consumption and CO_2 emissions, contributing to sustainability goals. Additionally, their lower maintenance requirements make roundabouts a cost-effective solution in the long run [18].

Despite these advantages, challenges remain, particularly in multi-lane roundabout designs that require careful planning to ensure driver compliance and minimise confusion [19]. Simulation tools such as PARAMICS, VISSIM, SIDRA, and SYNCHRO have become valuable for optimising roundabout designs and assessing their performance under various traffic scenarios [20]. Innovations like turbo roundabouts [21] and smart roundabouts with sensors [22] further demonstrate technological advancements that enhance roundabout efficiency.

Human behaviour plays a crucial role in the effectiveness of roundabouts [23]. Driver-yielding behaviour and pedestrian crossing patterns significantly influence safety and operational performance [24, 25]. Additionally, local traffic conditions [26] and cultural factors [27] must be considered when implementing roundabouts to ensure successful integration into the existing transportation system.

While previous studies have primarily focused on safety and capacity improvements, there is a need for more research on the broader environmental and social impacts of roundabouts. This study addresses this gap through a bibliometric analysis of roundabout design's environmental and social dimensions, particularly in high-traffic urban areas with diverse road users.

2.2 Unsignalized Intersection Performance

Environmental, human, and design factors influence intersection safety [16]. Effective intersection design, incorporating environmental considerations [28] and human behaviour [29], is crucial for enhancing safety. Unsignalized intersections, the most common intersection type globally, are often preferred in low-traffic settings due to their cost-effectiveness. However, their reliance on driver judgment and yielding behaviour increases crash risks, particularly when drivers misjudge gaps or fail to yield appropriately [30, 31].

Unsignalized intersections are prevalent in urban areas where safety concerns arise, particularly at arterial and regional road crossings. Studies indicate that right-turning vehicles at unsignalized intersections frequently disregard priority rules, significantly elevating crash risks [32]. Additionally, these intersections pose heightened risks for non-motorised users, such as cyclists and pedestrians, due to the absence of designated crossing facilities [33].

Emerging technologies, such as VISSIM simulation tools [34], these factors offer opportunities to analyse and enhance safety at unsignalized intersections. These tools help identify risky behaviours, optimise traffic flow, and evaluate design interventions under varying traffic conditions. Furthermore, public awareness campaigns and educational programs can improve driver compliance and pedestrian safety [35].

While unsignalized intersections are cost-effective for rural and low-traffic areas, their sustainability in high-traffic urban settings remains challenging [36]. This study addresses this issue by employing a bibliometric analysis to examine how design modifications, such as the introduction of roundabouts or other traffic-calming measures, enhance safety and efficiency while minimising environmental impacts [37]. This research provides strategic insights for sustainable urban infrastructure development by integrating emerging technologies and considering diverse road users.

2.3 Design effectiveness

Quantitative data is essential for substantiating claims about the effectiveness of idea-generation methods in engineering design [38]. Experimental evidence is necessary to assess the efficacy of different strategies in fostering innovation in engineering solutions. The complexity of a design problem often dictates the variety of methods required to achieve optimal solutions, as other factors influence design process variables [39].

Roundabouts and unsignalized intersections present potential benefits regarding safety, traffic flow, and environmental impact [40]. However, experimental validation is crucial to understanding the extent of these benefits under different conditions, contexts, and user behaviours. Roundabouts inherently promote sustainability by eliminating the need for power-consuming traffic signals [41]. Studies from Indonesia [42], Vietnam [43], and India [44] have demonstrated significant reductions in crash rates and traffic delays, underscoring the global relevance of roundabouts.

From a design effectiveness perspective, roundabouts perform well in moderate to high-traffic areas, balancing safety, continuous traffic flow, and environmental benefits. However, they require higher initial investments and land acquisition costs [45]. Despite these advantages, challenges such as space limitations, high implementation costs, and initial driver unfamiliarity remain barriers to widespread adoption in urban settings [46]. Public education campaigns and strategic urban planning are essential for overcoming these obstacles.

A holistic approach to intersection design integrates traffic analysis, safety evaluation, environmental sustainability, and user experience considerations [6]. Modern roundabout designs increasingly incorporate features for non-motorised users, such as raised crossings and dedicated bike lanes [47]. Furthermore, their significant fuel consumption and emissions reductions highlight their importance in contemporary urban planning.

The evolution of roundabout design, including variations tailored to specific location characteristics, underscores their potential to enhance functionality and safety [48]. However, research gaps remain, particularly regarding their long-term cost-benefit analysis and regional adaptations. This study aims to address these gaps by providing insights into the design effectiveness of roundabouts in diverse urban contexts.

3. METHODOLOGY

Due to data challenges and limited safety knowledge at roundabouts, a broad approach is essential for a thorough examination [49]. Control theory-based trajectory planning enhances problem-solving capabilities for connected and autonomous vehicles (CAVs) [50]. Intensive data processing demands limit Traditional adaptive control strategies, necessitating the development of adaptive algorithms that align with current technological advancements [51]. A method has been developed to quantify the behaviour of forceful entries under mixed-traffic conditions [52].

3.1 Database used

The use of multiple databases is essential for a thorough bibliometric analysis. However, selecting the right databases is crucial to ensure the relevance and accuracy of the results. This study used the Google Scholar database to search for relevant documents from 2020 to 2024. The selection of this time frame ensures the inclusion of the most recent and up-to-date research on the topic. According to previous literature, Google Scholar was chosen because it covers various academic publications, including journal articles, conferences, proceedings, books, theses, and other academic documents from multiple disciplines. Google Scholar offers better accessibility and a broader content range than databases such as PubMed or Scopus. For example, prior studies do not explain why Google Scholar was selected over other databases like Scopus or Web of Science, which are more commonly used in bibliometric research.

Additionally, Google Scholar is highly beneficial for studies with a regional focus, as it often includes local publications that may not be available in other databases. Google Scholar was selected due to its user-friendly interface and free access, making it accessible to a broader audience, including researchers with varying levels of experience in literature searching. Google Scholar allows for flexible keyword searches and supports using various parameters, such as titles, authors, affiliations, or publication years. This study applied specific search filters to ensure the retrieved documents were published between 2020 and 2024. It also provides inclusive results, including publications not indexed by other paid databases. Features such as "Cited by" and "Related Articles" help researchers find related works and assess the impact of literature. This method was chosen to ensure comprehensive coverage of the literature while maintaining easy access to relevant documents from the past five years, providing the research reflects the most current trends and findings in the field.

3.2 Search strategy

The effectiveness of a bibliometric analysis depends on the precision and recall of the search query used to identify relevant literature. Keyword-based searches of titles and abstracts can effectively identify relevant literature on roundabout effectiveness and intersection performance. The search query was constructed by reviewing multiple articles published as "bibliometric analyses" or "systematic reviews." The keywords used included "Roundabout Effectiveness," "Unsignalled Intersection Performance," "Design Effectiveness," "Roundabout," and "Intersection." The Publish or Perish (PoP) software conducted a search on Google Scholar for relevant articles. The objective was to identify 1,000 articles distributed evenly across five keywords, yielding approximately 200 articles for each. Additional inclusion criteria were applied; articles about roundabout design or intersection performance had to be published in English from 2000 to 2024 and meet a minimum quality threshold determined through a manual review of titles and abstracts. PoP sends search queries to Google Scholar and retrieves detailed metadata for academic articles, such as citation counts, authors, journal names, and abstracts. This metadata was then exported for further processing and analysis. Divining articles across multiple keywords ensures a more focused yet comprehensive exploration of the literature on roundabout effectiveness and intersection performance. Detailed guidance on conducting bibliometric analysis with VOSviewer, including step-by-step visuals and examples, is limited in existing research [53]. After the articles were retrieved, the data was further analysed using VOSviewer, a powerful bibliometric visualisation tool. VOSviewer generates network maps based on co-authorship, citation links, or keyword co-occurrence. For this study, VOSviewer was employed to visualise relationships and connections among keywords such as "Roundabout Effectiveness," "Unsignalized Intersection Performance," "Design Effectiveness," "Roundabout," and "Intersection." This mapping facilitated the identification of research trends, clusters, and gaps within the existing literature, enabling a deeper understanding of the study area. This structured approach ensured a systematic and comprehensive search strategy while leveraging advanced tools to refine and visualise the retrieved data.

3.3 Compiling the initial statistical data

The Research Information System (RIS) format contains the eligible documents and those from Google Scholar. This format includes bibliometric data, abstracts, keywords, and other essential data components. The PoP software can efficiently collect and present essential bibliographic information, including citation counts, author names, and publication sources in a standardised RIS format. Mapping literature sources from diverse global journals provides a comprehensive overview of research trends and knowledge distribution [54]. Selecting journals aligned with specific study topics and keywords, especially those focused on design effectiveness, can yield targeted insights into the roundabout design's impact and safety performance. Detailed guidance on conducting bibliometric analysis with VOSviewer, including step-by-step visuals and examples, is limited in existing research [55]. Similarly, comprehensive instructions on using Publish or Perish are also scarce. These data mappings, which are visualised according to scientific writing standards, will ultimately enhance the clarity and comprehensibility of bibliometric analysis results.

3.4 Inclusion and exclusion

Materials are based on predefined criteria to identify those relevant to roundabout design effectiveness. This systematic literature review employed several inclusion criteria. The initial inclusion criteria included documents published between 2000 and 2024. As illustrated in Figure 1, the document improvement process involves four key steps: selection, filtering, qualification, and summary.

The selection phase involved identifying suitable databases

or data collections to search for literature. After the methodology was outlined, Google Scholar was the primary database for the initial search. In the filtered process, the initial search on Google Scholar returned 4896 publications.

The qualification step aims to refine the initial set of publications further. Occurrence threshold: Only publications containing specific keywords with a minimum specified frequency are retained. A minimum keyword occurrence threshold of 8 was established, resulting in the exclusion of 4747 publications. Selection of primary keywords: The most relevant keywords filter the publications further. The 120 most relevant terms were identified from the initial set of terms. This selection process excluded 29 publications. In the final step of the process, select 120 documents.

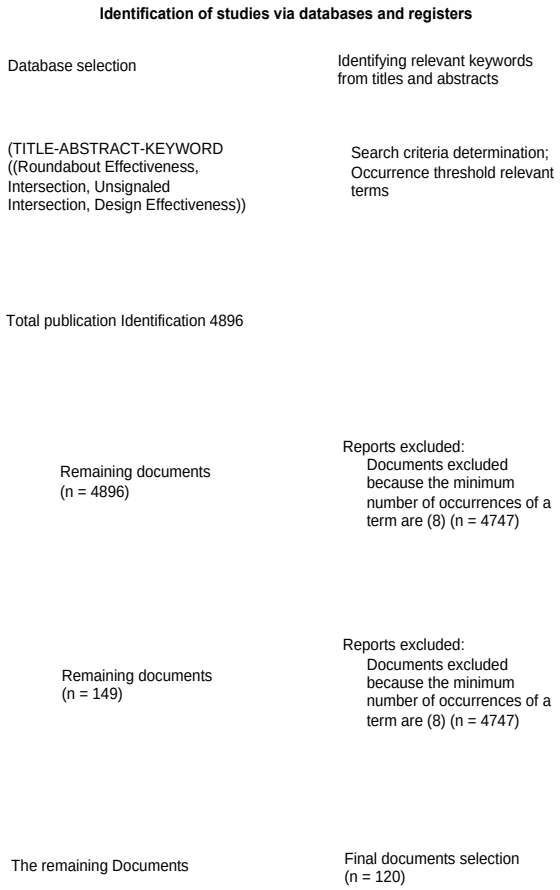

Figure 1. Flowchart of systematic bibliometric analysis

4. RESULTS AND DISCUSSION

4.1 Visualisation of research keyword connections

Visualisation of Research Keyword Connections This study used Harzing's Publish or Perish version 8 program to collect 1000 research papers from the Crossref database associated with the specified keywords: "Roundabout Effectiveness," "Unsignalized Intersection Performance," "Design Effectiveness," "Roundabout," and "Intersection". The connections between the 1,000 research journals gathered are shown using VOSviewer version 1.6.20. Bibliometric analysis of effective roundabout design influenced performance at unsignalized intersections.

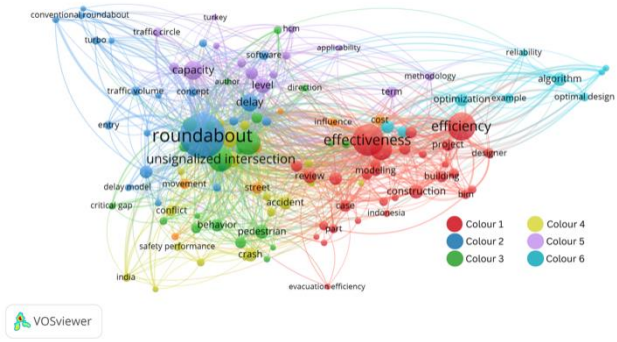

Figure 2. Keyword network visualisation using VOSviewer, highlighting dominant terms like ‘Roundabout’ and ‘Effectiveness’

The data presented in Figure 2 shows, through visualisations using the VOSviewer software, that the terms Roundabout and Effectiveness are the most relevant to the secondary keyword. These findings are consistent with upcoming research, highlighting the focus on improving roundabout performance, reducing congestion, and maximising road capacity. Keywords help encapsulate a research paper’s main ideas while honing on and clarifying its core concepts [56] publications on roundabout effectiveness that appear at least ten times. In the map, the keyword "Roundabout" is highlighted in blue and has the most significant node size with 434 occurrences. The second largest node is "Effectiveness" in six colours, with 213 occurrences, followed by "Efficiency" in the second colour, with 168 occurrences. The map visualises the global distribution of the most frequently used keywords, highlighting contributions from authors in countries like India, Italy, Turkey, Nigeria, Indonesia, and Bangladesh. The researchers identified "Roundabout" and "Effectiveness" as having the strongest link strengths.

The red colour (colour 1) is highlighted by keywords linked to the project and modelling, including "Effectiveness," "Efficiency," and "construction". These colours delve into the effectiveness, efficiency, and safety of roundabouts. They discuss topics like optimising roundabout design, using modelling techniques to evaluate performance, and addressing safety concerns, particularly for pedestrians. For example, the term "effectiveness" has 213 occurrences. Construction processes are effective, offering benefits like a better design, more straightforward implementation, improved information sharing, cost and error reduction, faster work, and greater efficiency [57].

The blue colour (colour 2) is primarily composed of roundabout design and performance, such as "Roundabout," "traffic volume," and "delay." The high frequency of "Roundabout" (434 occurrences) This colour focuses on the design and performance aspects of roundabouts, such as their capacity to handle traffic, delays, and overall efficiency. It suggests a significant body of research on designing roundabouts that perform optimally. The geometric design of a roundabout significantly affects drivers' speed choices and manoeuvring, playing a crucial role in its safety performance [58].

The green (colour 3) occurrences of keywords, including "Unsignalized intersection," "signalised intersection," and "pedestrian," are essential for improving road safety and the

overall transportation system. By considering factors such as intersection design, traffic flow, and pedestrian safety, we can create more efficient and safer urban environments.

The yellow colour (colour 4) shows strategies for safety, with keywords including "accident," “crash,” and "safety performance." The frequent occurrence of "crash" (42 occurrences) is related to safety at intersections. This indicates a concern for safety in the design and operation of intersections.

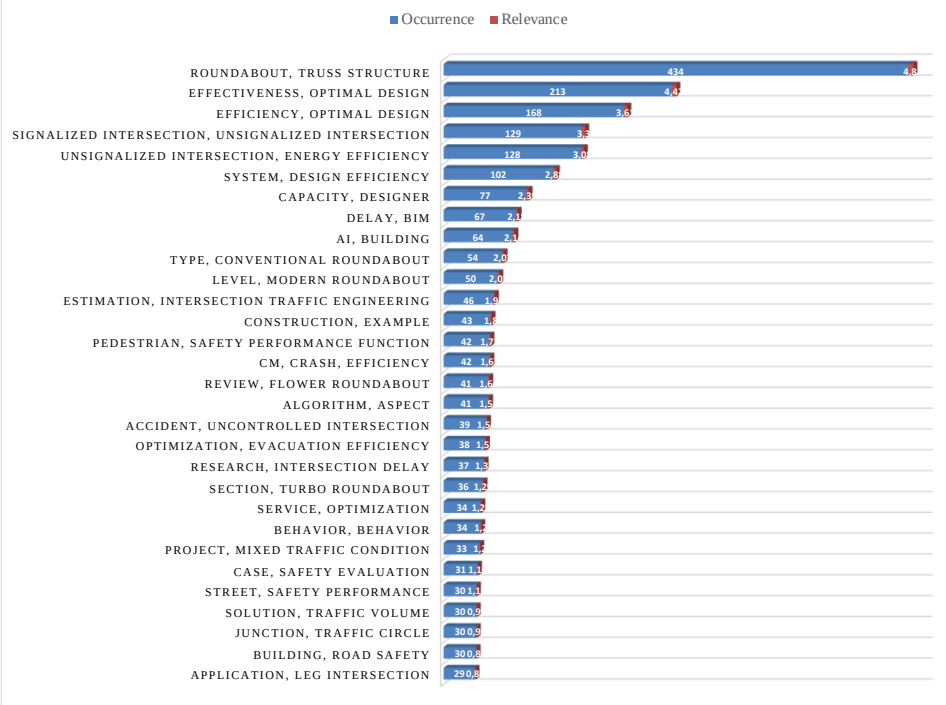

Figure 3. Keyword graphics based on the occurrence

This colour has five focuses (purple). The purple keywords might represent the concept of "capacity" and related terms such as "traffic circle." The presence of "capacity" (77 occurrences) suggests that these purple keywords are closely linked to the capacity of a roundabout, that is, its ability to handle a volume of traffic.

Colour 6 (aqua colour) focuses on roundabout design and optimization, as seen by phrases such as "Optimal design," "algorithm," and "optimisation example." With the prominence of "optimal design" (17 occurrences), we can infer that the aqua colour represents a group of keywords related to the study of optimal roundabout design and how various algorithms and optimisation techniques can be used to improve the performance and efficiency of roundabouts. The uncertainty in the calculated failure probability is crucial, especially when deciding what an acceptable failure probability is for the system design [59].

Figure 3 presents a co-occurrence and most relevant analysis, highlighting word pairs found in the authors' keyword lists or the full texts of various published articles. This co-occurrence matrix offers insights into study areas related to Roundabout and Effectiveness over a specific period, enhancing our understanding of the field's conceptual framework and scholarly network. This relevance matrix also offers insights into study areas related to truss structure and optimum design over a specific period, enhancing our understanding of the field's conceptual framework and scholarly network.

Using VOSviewer, the authors visualised the connections and co-occurrences of 149 out of 4,896 keywords chosen by researchers. The co-occurrence network created between 2004 and 2024 resulted in six clusters, as shown in Figure 1. Each keyword is shown as a circle, with larger circles indicating more connections and thicker lines representing higher co-occurrence frequencies.

The density visualisation in Figure 4 shows that keywords are denser with darker colours and larger circles. Higher keyword density means more frequent research on that topic. As colours fade, the number of studies decreases. Safety and health have the highest growth in research.

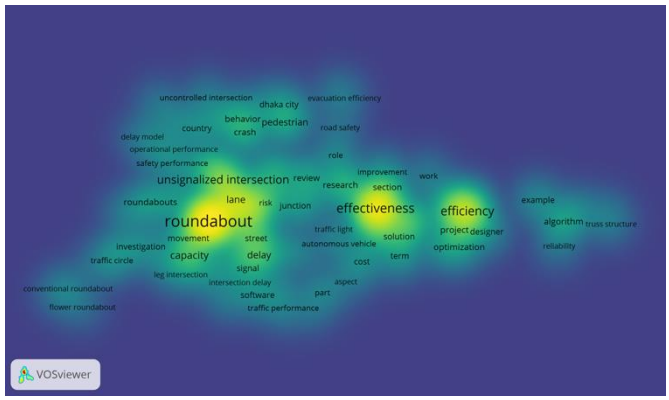

Figure 4. Keywords density

Table 1. Keywords by highest studies

Keywords	Total Studies
Roundabout	434
Effectiveness	213
Efficiency	168
Signalized Intersection	129
Unsignalized Intersection	128

Table 1 provides a clear overview of the most frequently studied keywords within the context of roundabouts. It is evident that "Roundabout" is the most researched term, appearing in a substantial 434 studies. This indicates a significant body of research dedicated to understanding, designing, and evaluating roundabouts.

Following closely behind, "Effectiveness" and "Efficiency" are key areas of interest in roundabout research, with 213 and 168 studies, respectively. These keywords suggest a strong focus on assessing the performance of roundabouts in terms of their ability to reduce congestion, improve traffic flow, and enhance safety.

The table includes "Signalized Intersection" and "Unsignalized Intersection" to highlight the comparative nature of roundabout research. By examining roundabouts alongside traditional intersection types, researchers can better understand each type's unique advantages and disadvantages.

4.2 Development of publications by year

Data was sourced from Google Scholar and analysed using Publish or Perish software to understand research trends in roundabout design effectiveness comprehensively. This analysis covered 24 years, spanning from 2000 to 2024.

Figure 5 displays total data from 1,000 investigations from 2000 to 2024. Over the previous 24 years, the image has decreased and grown in study subjects. There has been significant growth in the last ten years, from 2013 to 2024, with a high in 2022, demonstrating that the trend in roundabout design effectiveness research has improved. VOSviewer analysis revealed the most frequently used publication keywords per year, 2000 with nine papers, 2001 with five papers, 2002 with four papers, 2003 with four papers, 2004 with 18 papers, 2005 with 12 papers, 2006 with eight papers, 2007 with 11 papers, 2008 with 17 papers, 2009 with 11 papers, 2010 with 15 papers, 2011 with 31 papers, 2012 with 33 papers, 2013 with 48 papers, 2014 with 50 papers, 2015 with 43 papers, 2016 with 62 papers, 2017 with 40 papers, 2018 with 74 papers, 2019 with 82 papers, 2020 with 86 papers, 2021 with 85 papers, 2022 with 88 papers, 2023 with 81 papers, 2024 with 80 papers.

Unlike previous safety and capacity improvement studies, this research perspective utilises a 24-year bibliometric analysis. While earlier research often overlooked the environmental and social dimensions of roundabout design, our study shows a significant increase in research interest. We mapped publication trends and analysed keyword frequencies that reflect emerging themes in the field by employing tools like Publish or Perish and VOSviewer. This study's contribution lies in its comprehensive approach, which offers strategic insights into sustainable urban traffic management and roundabout designs.

4.3 Research type determined by publisher and classification of research

Table 2 provides a detailed breakdown of the publishers contributing to the research on roundabout design effectiveness. This data offers valuable insights into the diversity of sources and the global reach of this research field. The study gathered data from multiple publishers through networking, demonstrating how different publishers can advance scientific research. This data, globally connected to civil engineering, was collected using Harzing's Publish or Perish software, as shown in Table 2.

Table 2. Number of studies according to the publisher

Publisher	Studies
Springer	181
ASCE library	95
CDNsciencePub	90
Researchgate	74
Wiley Online Library	59
Academia	42
Lib.buet	35
Jurnal.UIB	26
Journals.co.za	24
pp.bme	23

Springer, ASCE Library, and CDNSciencePub are the top three publishers contributing a significant portion of the research. This suggests that these platforms are prominent outlets for disseminating research on roundabouts.

Figure 6 provides a breakdown of the different types of research publications included in the study. This information offers valuable insights into the diverse nature of the research landscape on roundabout design effectiveness. Journal articles constitute most of the research, accounting for 645 studies. This suggests that peer-reviewed journals are the primary channel for disseminating research findings in this field. While journal articles and books dominate, other formats like datasets, monographs, and posted content are less frequently used. This indicates that empirical data and in-depth case studies may be less prevalent in this specific area of research.

4.4 Type of research by the majority of countries

Research from various locations highlights the diversity of productive investigations. This diversity reflects the distribution of research topics across different global regions, characterising the current state of scientific inquiry. Country classifications in data processing help identify where specific research types are most discussed. Figure 7 shows the criteria for categorising the case study's country of origin. The volume of documentation and citations determines leadership in citation rankings.

Figure 7 provides a fascinating insight into the geographical distribution of research on roundabout design and effectiveness. This visualisation reveals the countries that have made significant contributions to the field. The United States, Singapore, and several European countries, including France, Italy, and the Netherlands, are leading roundabout research. This reflects the early adoption and extensive use of roundabouts in these regions. Growing Interest in Asia Countries like South Korea, China, and Japan are emerging as important contributors to the field. This indicates a growing interest in roundabouts as a solution to traffic congestion and safety concerns in rapidly urbanising Asian cities. The global distribution of roundabout research offers international collaboration and knowledge-sharing opportunities. By learning from the experiences of different countries, researchers can identify best practices and innovative approaches to roundabout design and implementation.

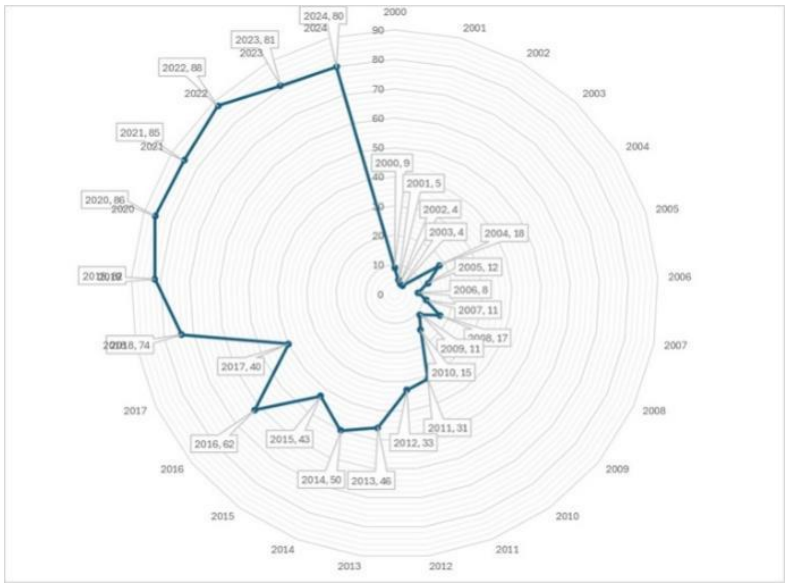

Figure 5. Annual publication trends from 2000 to 2024 show significant growth in roundabout research, with a peak in 2022

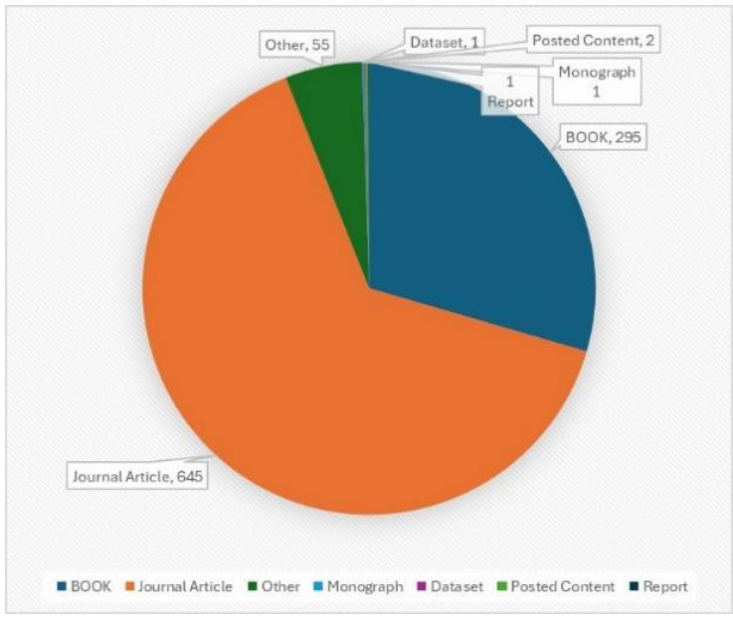

Figure 6. Number of studies based on study type

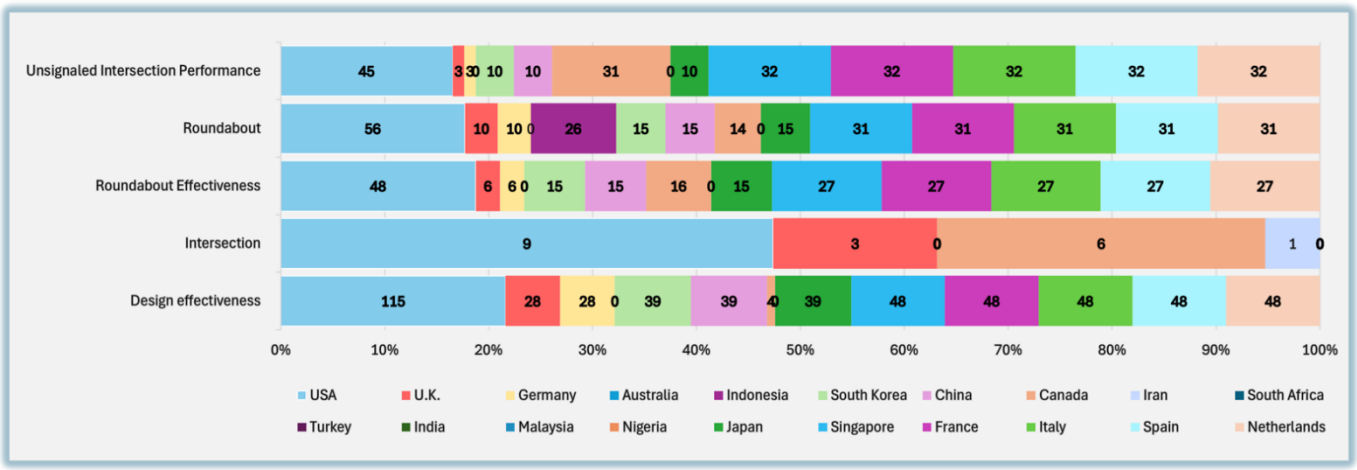

Figure 7. The geographical distribution of research on roundabouts highlights developed countries in Asia

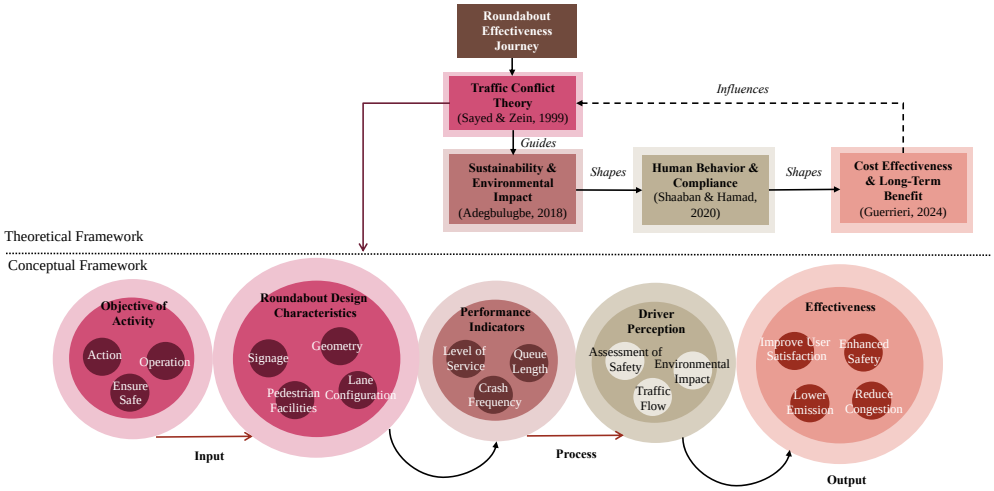

Figure 8. Theoretical framework outlining the key dimensions of roundabout effectiveness: Traffic conflict reduction, sustainability, human behaviour compliance, and cost-effectiveness

4.5 Theoretical framework and conceptual framework

A logically developed and well-connected theoretical framework derived from one or more theories positively influences the quality and validity of a study [58]. This framework (Figure 8) highlights the core information systems dimensions adapted to the Roundabout effectiveness journey. These dimensions strengthen research strategies with a solid theoretical foundation [60]. Resulting from the literature review on Roundabout Effectiveness dimensions.

The Roundabout effectiveness journey theoretical framework contains the four main components of information systems. These components are traffic conflict theory, sustainability and environmental impact, human behaviour and compliance, cost-effectiveness, and long-term sustainability. The traffic conflict theory highlights how "roundabout designs" reduce conflict points and "objectives of activity" by enabling smoother traffic flow and enhancing safety. It highlights key elements such as geometry, signage, lane configuration, and pedestrian facilities. The objective is to ensure safe and efficient operation. Sustainability and environmental and Human behaviour and compliance: Roundabouts promote reduced fuel consumption and CO_2 emissions by decreasing idling and ensuring smooth traffic movement. At the same time, their effectiveness is influenced by driver-yielding behaviour, pedestrian habits, and cultural factors. It emphasises key elements such as metrics like LOS, vehicle delay, queue length, and crash frequency, along with the assessment of safety, traffic flow, and environmental impact. Safe and efficient operations are ensured through "performance indicators" and "drivers' perception of these indicators."

The Cost-Effectiveness and Long-Term Benefits theory suggests that roundabouts offer a more cost-effective alternative to signalised intersections, with lower maintenance requirements and improved land-use efficiency, leading to long-term benefits. It illustrates the benefits of reduced congestion, better safety, lower emissions, and higher user satisfaction. The proposed flow outlines the sequence from Input (Roundabout Design) to Process (Performance Indicators) and finally to Output (Effectiveness). Framework provides practical insights for urban planners and engineers to improve roundabout designs based on local conditions while offering a foundation for research into the interrelationships between design features, operational metrics, and user outcomes.

The study's findings emphasise the global interest in roundabout design as a sustainable and efficient traffic management solution. However, regional disparities in research contributions reveal varying levels of adoption and adaptation. Developed countries dominate the research landscape, while emerging economies show limited contributions despite experiencing rapid urbanisation. This gap highlights the need for increased investment in localised studies to tailor roundabout designs to specific urban contexts. The study of Milton Keynes, United Kingdom, reported a 15 reduction in vehicle emissions, demonstrating that roundabout designs enhance traffic flow and safety and promote environmental sustainability.

Moreover, the literature's predominance of safety and efficiency themes suggests a narrower focus, often overlooking broader socio-environmental impacts. While roundabouts are recognised for reducing CO_2 emissions, their potential to enhance urban aesthetics or create community spaces remains underexplored. Future research should adopt a multidisciplinary approach, integrating urban design, environmental science, and sociology to realise the full potential of roundabouts.

5. CONCLUSION

This bibliometric analysis highlights the increasing research focus on roundabout design effectiveness and its critical role in improving urban traffic management. The study identified key themes such as safety performance, environmental benefits, and efficiency improvements, with significant global contributions from developed and emerging economies. Roundabouts have enhanced safety and reduced congestion by enabling continuous traffic flow and minimising conflict points. However, challenges remain in adapting these designs to diverse regional contexts and accommodating non-motorised users. To bridge these gaps, policymakers and planners should consider implementing pilot projects to evaluate roundabout designs in specific urban settings, particularly in high-density areas with limited space. Incorporating pedestrian crossings and cyclist lanes can improve accessibility and safety for all road users.

While this study provides valuable insights into roundabout design effectiveness, several methodological limitations must be acknowledged. The reliance on Google Scholar as the primary data source may introduce biases, such as overrepresenting English-language publications and limited access to local studies from non-English-speaking regions. Additionally, bibliometric analysis focuses primarily on quantitative trends, potentially overlooking the literature's qualitative insights and contextual nuances. Future research should consider incorporating data from a broader range of databases, such as Scopus or Web of Science, and pursue more targeted research directions, such as longitudinal studies on roundabout performance or case studies in rapidly urbanising regions to improve coverage and representativeness. Qualitative methods, such as case studies and expert interviews, could complement bibliometric findings and provide a deeper understanding of regional and cultural factors influencing roundabout design and performance.

Future designs should also integrate innovative technologies, such as sensors and automated traffic monitoring systems, to optimise roundabout performance under varying conditions. Additionally, public education campaigns are essential to ensure community acceptance and effective use of roundabouts.

The findings of this study highlight several research gaps that warrant further exploration. First, region-specific adaptations of roundabout designs are crucial to address local challenges, such as limited urban space, cultural differences in driver behaviour, and mixed traffic conditions. Second, there is a need for longitudinal studies to assess the long-term cost-benefit ratio of roundabout implementations, including maintenance costs and user satisfaction. Emerging technologies, such as smart roundabouts equipped with sensors and adaptive traffic management systems, also offer a promising avenue for future research. Additionally, exploring public perception and social acceptance of roundabouts in different cultural contexts can inform strategies to improve community engagement and compliance.

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