



Department of Digital Business

Journal of Artificial Intelligence and Digital Business (RIGGS)

Homepage: <https://journal.ilmudata.co.id/index.php/RIGGS>

Vol. 4 No. 2 (2025) pp: 5578-5589

P-ISSN: 2963-9298, e-ISSN: 2963-914X

A Systematic Literature Review on the Influence of Road Curves on Urban Mobility Performance and Safety

Royhan Farhan Habibi, Cepy Prasetyo, M. Taufik Ivan, Arief Rijaluddin, Joewono Prasetijo

^{1,2,3,4} Faculty of Engineering, Universitas Majalengka, Indonesia

⁵Department of Transportation Engineering, Faculty of Universiti Tun Hussein Onn Malaysia

^{1*}froyhan38@gmail.com, ²cepyprasetyo22@gmail.com, ³muhammadtaufik20189@gmail.com,

⁴arief_rijaluddin@unma.ac.id, ⁵joewono@uthm.edu.my

Abstrak

The geometric design of road bends is essential to smooth mobility and traffic safety in urban areas. This study systematically evaluates how bend radius, superelevation and sight distance affect traffic performance and crash risk. The Systematic Literature Review (SLR) method was used concerning the PRISMA protocol, analyzing 970 scientific publications from 2000 to 2025 obtained through Google Scholar using Publish or Perish. Bibliometric data were analyzed and visualized with VOSviewer to identify research trends, keyword linkages, and author collaboration patterns. The results showed five main clusters, namely horizontal design, user safety, driver behavior, traffic efficiency, and socio-environmental impacts. It was found that sub-optimal corner design significantly increases crash potential, especially in sharply curved areas with low visibility and heavy traffic. The study also showed the dominance of contributions from developed countries, while developing countries are still limited despite facing the challenges of greater urbanization and complex infrastructure. Therefore, a multidisciplinary and contextual approach is needed in planning curve designs responsive to local conditions. This study emphasizes the importance of utilizing bibliometric technology for bend designs. Therefore, a multidisciplinary and contextual approach is needed in planning bend designs that are responsive to local conditions. This study emphasizes the importance of utilizing bibliometric technology to support data-driven decision-making, strengthen the integration of technical, social, and environmental aspects, and design adaptive and sustainable urban transport.

Keywords: Road Bend Design, Urban Mobility, Systematic Literature Review, VOSviewer, Traffic Safety

1. Introduction

Community activities have risen due to the rapid expansion of large cities across the world, particularly in emerging nations. [1]. Future studies should use a multidisciplinary approach that incorporates sociology, environmental science, and urban planning in order to fully exploit the potential of bend design [2]. Roads are a useful way to distribute products and services to promote economic activity and to connect different places, including communities, agricultural areas, and industrial hubs [3]. Urban mobility [4] [5] [6]. The geometric design of road bends plays an important role, as it can influence driver perception and behavior. [7] claimed that when driving on curves, The driver overestimates their speed most at the tangent to-spiral (TS) point, and their perceived speed is lower than their actual speed. Poorly designed bends also increase the risk of accidents because traffic accidents will be far more severe when there is insufficient friction, especially on horizontal bends [8]. In addition, the driver's perception of speed may be impacted by the geometric shift that occurs as the curve enters their field of vision [9]. Additionally, the issue has gotten so bad that improving urban traffic safety is now urgently needed [10] [11]. So, elements like radius, superelevation, and visibility are crucial for safety. The curve radius is influenced by superelevation and lateral friction and determines the stopping sight distance (SSD), which is essential in the design of horizontal curves [12].

The road's geometric design seeks to increase road users' comfort and safety while preserving traffic operations' effectiveness [13]. Road accidents result in significant human and material losses every year worldwide, making road safety a significant concern in modern nations [14]. Many accidents in Indonesia occur on sharp curves because drivers do not anticipate the direction of the road or reduce speed. Driving mistakes and collisions can result from poor geometric design, such as uneven lane placement and insufficient lane spacing [15]. [16] also said that planning that does not take visibility into account is often the leading cause of accidents. To allow a more gradual ascent or descent, hairpin bends are usually built on steep hillsides. While traffic accidents are a major

cause of mortality for people of all ages, they have an especially large impact on those who are more susceptible, such children and individuals aged 5 to 29 [17] [18] [19]. To allow a more gradual ascent or descent, hairpin bends are usually built on steep hillsides. [20]. To allow for a more gradual climb or descent, which can solve accidents in the area. Geometry, such as curve length and deflection angle, affects driver risk perception [21]. The design of geometry is a crucial element that greatly affects how new routes align [22]. The number of accident victims in Indonesia that still occur and have reached saturation point shows the enormous potential and untapped space for safety improvements that can be used if accidents can be predicted more accurately [23]. The risk of accidents also increases on curves with a small radius and limited visibility, especially at night, in heavy traffic, or in bad weather [24]. Curving highways have a far greater accident risk than straight ones, a worldwide safety issue [25]. When constructing a road that connects or accesses another, the initial step is road geometric planning [26].

There is evidence that the design of road bends strongly influences how traffic moves in urban areas and how people survive [27]. The skills and desires of all users, including pedestrians, cyclists, motorcyclists, and users of all forms of transportation, including public transit, should be included in the road's actual design. [28]. However, related research is still isolated, focusing on technical, behavioural or safety elements. A more structured study is needed to unify the different findings. A structured literature review method, Systematic Literature Review (SLR), was used in this research [29] [30] [31]. A structural research study is known as an SLR [32]. Before the review is conducted, the methodology and criteria for finding, assessing, and contrasting the literature with a set of questions are decided. [33]. Roads' efficiency and safety are greatly influenced by horizontal curves. [13]. To locate and evaluate studies on how road curve design affects urban mobility and traffic safety. If not anticipated with transportation facilities and infrastructure accompanied by reasonable transportation regulations, this will hurt transportation, namely in the form of traffic congestion and environmental impacts (pollution) that will affect the surrounding community [34].

2. Research Methods

To capitalize on new datasets and technology, various data-driven transport planning techniques have emerged in recent years [35]. A systematic literature review approach (SLR) is used in this study [36]. To find, evaluate, and synthesize research results on how road curve geometry impacts mobility and safety performance in urban environments. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed for conducting the study, which are acknowledged as the industry standard for performing SLRs [37].

2.1 The database used

To ensure broad and relevant literature coverage, database selection is an essential stage in Systematic Literature Review (SLR)-based research. Google Scholar was the primary source for collecting literature data in this study as it provides access to various scientific publications, such as journal articles, conference proceedings, dissertations, and academic books from various fields. The search period was limited between 2021 and 2025. This study will examine trends, identify patterns among academics, and assess the influence of research in this area using tools like VOSviewer and Publish or Perish [38]. Nearly all of the citations discovered by the remaining sources (89–94%) and 88% of all citations, many of which were not found by the other sources, were found by Google Scholar [39]. This procedure offers a strong foundation for methodically locating pertinent material with high rigor and little bias [40].

2.2 Search Strategy

Systematic analysis relies heavily on how effective the literature search techniques used to find relevant publications are. SLR technique is used methodically by following the steps and protocols to protect the researcher from bias and subjectivity in the article writing [41]. Search queries were based on an initial understanding of how road curve geometry impacts mobility performance and transportation safety in urban areas. Previous articles discussing traffic analysis and road geometric design were used to create keywords. This research used words such as "curve", "road", "bend", "mobility", "urban", "safety", "traffic", "horizontal line". Combining these eight keywords created a comprehensive and focused literature search query. The Publish or Perish (PoP) software can access Google Scholar data. The main goal of this method was to find at least 970 scientific articles. All English-language articles published between 2000 and 2025 and publicly accessible were included in the inclusion criteria. Articles should also be thematically relevant to the relationship between bend geometry and indicators of traffic safety or mobility performance. Information such as citation count, author name, journal, publication year, and abstract were extracted from the articles for documentation and screening [42].

Once the data were exported, articles were categorized based on their thematic relevance and methodological clarity. Two independent reviewers conducted screening based on exclusion criteria: duplication, non-urban

highest number of nodes, with 333 nodes. The keyword "Traffic", marked in purple, has the second largest number of nodes, with 170.

The red color highlighted by keywords such as "analysis", "time", and "world" indicates data analysis approaches and global-scale studies. These words indicate research clusters that focus on processing traffic data in temporal and spatial dimensions, as well as studies across countries or regions. This cluster represents efforts to study road safety trends, traffic changes, and comparisons of transportation policies and conditions around the world.

The green colour is highlighted by keywords such as "horizontal lines", "system" and "safety", indicating research clusters that focus on the relationship between road horizontal line design and traffic safety systems. This cluster shows research on how horizontal geometry elements such as curves, grades, and road alignment contribute to supporting or inhibiting the overall driving safety system. Highway geometry components should be chosen, measured, and positioned to meet design requirements for things like economy, drainage, driver comfort, visibility, vehicle stability, and aesthetics [52].

The blue colours are highlighted using keywords related to road infrastructure and general study approaches in the transportation field, such as "road", "research", and "road". These colours indicate research clusters that focus on analyzing the physical characteristics of roads, general traffic study methods, and systematic approaches to evaluating road function and performance. Because they enable decision-makers to systematically organize and evaluate important elements like congestion, route patterns, and environmental implications, these clusters enhance our understanding of road planning, design, and assessment in terms of transportation efficiency and safety [53].

The yellow colour is highlighted by terms such as "Curve", "Line", and "Curf", which relate to elements of road geometry. This research group concentrates on evaluating the shape of road curves and their effects on driver behaviour and traffic safety. These colours indicate this research cluster. This cluster reflects research that looks at the design of curves, horizontal lines, and other geometry parameters to improve driving comfort and reduce crash risk, particularly in areas of curvy roads or with limited visibility [54].

The purple colour is highlighted with keywords such as "Traffic", "Mobility", and "City", indicating research clusters focusing on managing traffic and mobility in urban environments. Research that examines contemporary transportation challenges, including traffic, multimodal integration, sustainable mobility-based urban planning, and the application of technology to enhance the effectiveness and ease of urban transportation systems, is reflected in this cluster. This relates to ensuring that traffic is safe for walking and driving [55].

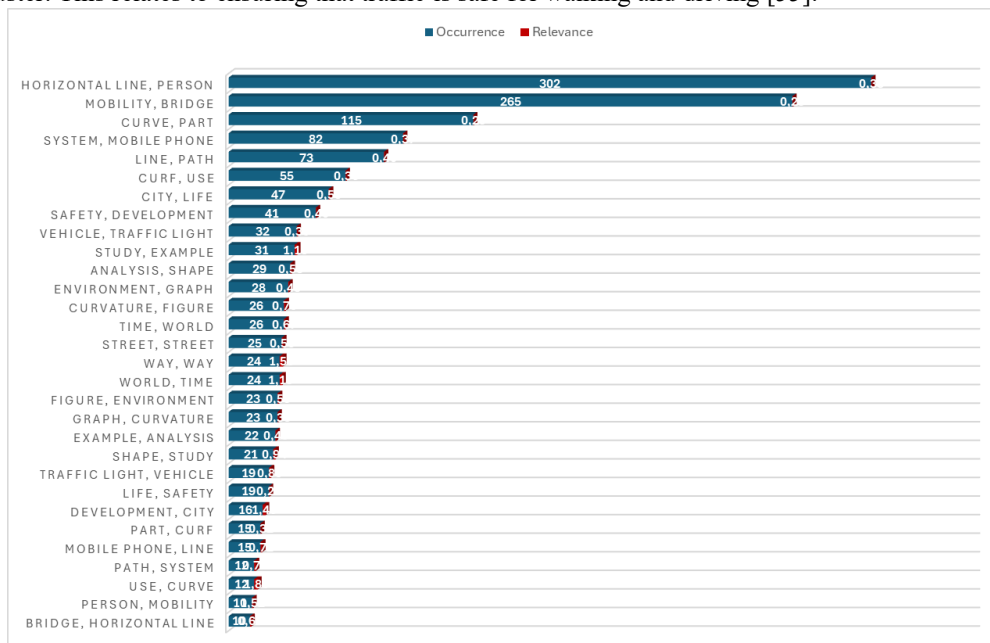


Figure 2. Keyword graphics based on the occurrence

Figure 2 outlines the results of the co-occurrence and relevance analysis. This highlights the connection between the author's keyword list and the complete content of different scientific papers. This co-occurrence matrix provides an in depth picture of research trends in the field of transportation infrastructure, such as roads, particularly in the Bend section, and how effective they have been in a given timeframe. We also gain a better understanding of the academic networks and conceptual underpinning of the topic. Furthermore, the matrix helps us identify the structure and pattern of research development over a certain period of time, which improves our comprehension of the conceptual design and pertinent academic networks.

With the help of VOSviewer software, we mapped the relationship and co-occurrence frequency of 30 selected keywords, which came from a total of 970 keywords used in the study. As seen in Figure 1, the investigation, which spanned the years 2000–2025, produced five major clusters.

Every phrase appears as a circle in the visual aid. Thick lines show a higher frequency of phrase co-occurrence, whereas larger circles show more linkages.

Figure 3 shows the keyword density mapping that represents the frequency with which certain topics are researched. A large circle with a darker colour indicates that the keyword is the main focus of many studies. Conversely, if the circle is smaller and lighter in colour, it indicates a low intensity of studies on the topic. In this case, safety and health-related themes show the most prominent growth trend in scientific publications.

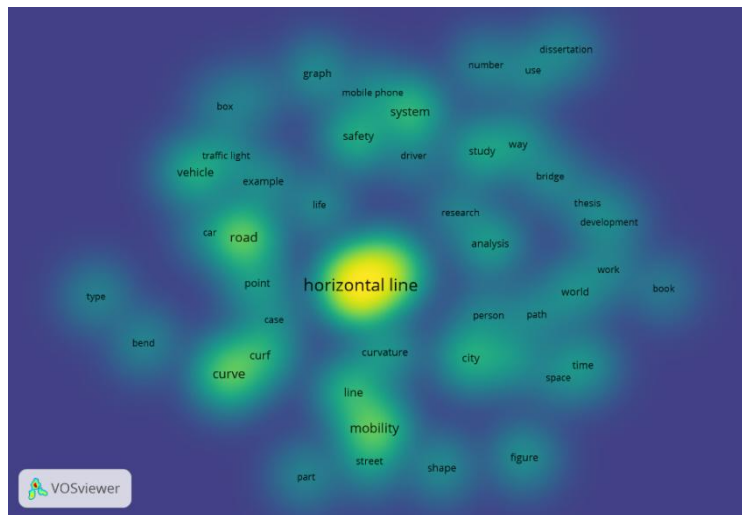


Figure 3. Keyword density

Tabel 1. Keywords from the best research

| Keyword | Total Studies |
|-----------------|---------------|
| Horizontal Line | 302 |
| Mobility | 265 |
| Curve | 115 |
| System | 82 |
| Line | 73 |

Table 1 clearly displays the phrases that have been studied the most in connection to road design and safety. With 302 studies, it is clear that "Horizontal Line" is the most researched term. This shows how much research has been done on how horizontal line features can improve vision and driving comfort. With 265 and 115 studies, respectively, "Mobility" and "Curves" are the two most popular topics in environmental geometry research. These keywords show that researchers are interested in the dynamics of traffic flow and how curve geometry affects road user safety.

3.2 Publication Development by Year

The efficiency of bend design research trends were thoroughly examined by using data from Google Scholar using the Publish or Perish program. The study was conducted between 2000 and 2025, a span of 25 years.

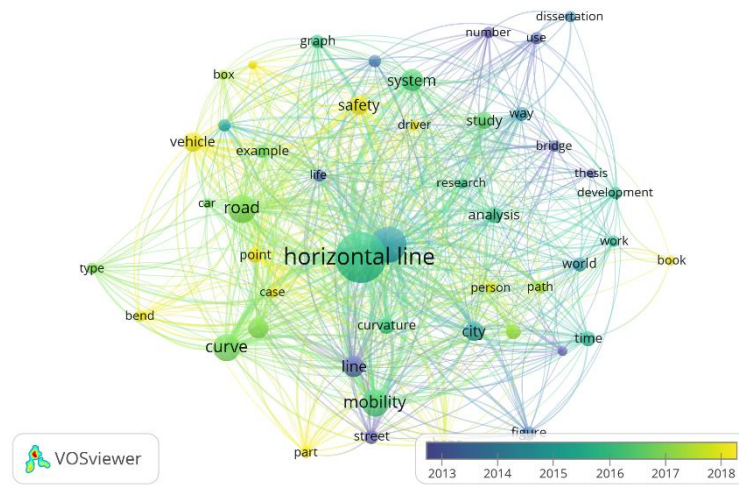


Figure 4. Keywords by years

The complete data from 970 research from 2000 to 2025 is shown in Figure 4. The statistic shows that throughout the previous 25 years, the number of study subjects has both decreased and increased. The trend of research on the usefulness of roundabout designs has grown significantly over the past ten years, from 2010 to 2024, with a peak in 2022. The most commonly used publication keywords per year are as follows, according to VOSviewer analysis: 2000 with nine papers, 2001 with ten, 2002 with fourteen, 2003 with thirteen, 2004 with eighteen, 2005 with twenty-seven, 2006 with fourteen, 2007 with thirty, 2008 with twenty-seven, 2009 with twenty-seven, 2010 with forty-one, 2011 with forty-eight, 2012 with thirty-four, 2014 with forty-four, 2015 with fifty, 2017 with forty-three, 2019 with fifty-six, 2020 with fifty-five, 2021 with fifty-two, 2022 with sixty-six, 2023 with fifty-four, 2024 with fifty-six, and 2025 with twenty-six papers.

This study uses a 25-year bibliometric analysis, in contrast to previous research on safety and capacity improvements. Although road geometry, particularly curve appropriateness, has frequently been disregarded in earlier research, our analysis demonstrates a strong interest in the topic. We plotted publication patterns and examined keyword frequencies that represent new problems in the industry using tools like VOSviewer and Publish or Perish. The advantages of this research are provided by its thorough approach to bend appropriateness for road user safety.

3.3 The publisher and research classification decide the sort of research.

The publishers that have contributed to research on the relationship between road geometry and traffic safety are detailed in Table 2. These statistics provide a valuable perspective on the multiple sources and global reach of this area of research. Through linkages, this research collects data from a variety of publishers, demonstrating how diverse publishers can contribute diverse viewpoints and methodologies to scientific research. As shown in Table 2, this data was collected from the civil engineering sector worldwide using the Publish or Perish software.

Tabel 2. According to the publisher, the number of studies

| Publisher | Studies |
|-----------------------------------|---------|
| books.google.com | 245 |
| search.proquest.com | 157 |
| Springer | 48 |
| Google Patents | 28 |
| core.ac.uk | 14 |
| ijoms.internationaljournalabs.com | 14 |
| rosap.nfl.bts.gov | 14 |
| Elsevier | 12 |
| ieeexplore.ieee.org | 11 |

books.google.com, search.proquest.com and Springer are the three main publishers that contributed the highest number of studies to this review, with 245, 157 and 48 publications respectively. These three platforms dominate, suggesting that they are the main avenues for research on how road bends impact mobility and safety performance in urban areas.

The many categories of research articles that were part of this analysis are detailed in Table 2. This data offers important insight into the wide range of bend design efficacy studies. With a total of 970 studies, journal papers comprise the majority of the research. This implies that the most effective means of sharing research findings in this field is through peer-reviewed journals. Journal articles were used more often than data collections, monographs, and uploaded content. This implies that in-depth case studies and empirical data might not be pertinent to this specific field of study

3.4 Types of research by the majority of countries

Studies conducted by most countries examined road curve design and how it impacts mobility and safety in urban areas. The findings show that there are significant differences between the research methods used in each country in terms of level of development, infrastructure maturity and road safety priorities. In high-income nations like the US, Germany, and Japan, much research is quantitative and data-driven, utilizing huge statistics on traffic patterns and crashes, sophisticated statistical modeling, and simulation tools. The main focus of this research is to optimize operational efficiency, reduce crash rates through improved road geometry, and support evidence-based policies. Recent research also confirms that locally tailored road design and safety interventions are essential to maximize their effectiveness [56].

On the other hand, research contributions in developing countries such as India [57], Indonesia [58] and Brazil [59] have mostly used mixed and qualitative methods. Driver behavior in the local environment, the level of compliance with traffic laws, and specific urban constraints are factors that influence how effective road design interventions are. In these countries, methods such as case studies, focus group discussions and observational surveys were used. This demonstrates the need to adapt worldwide best practices to local circumstances.

Among these countries, there are differences that show how important contextual research is in the field of road geometric design. Countries with advanced data collection systems and strong institutional capacity are able to conduct more precise experimental studies, while countries with developing infrastructure require exploratory and adaptive research. This underscores the importance of cooperating and exchanging information across the globe to address research gaps and promote more equitable urban mobility around the world.

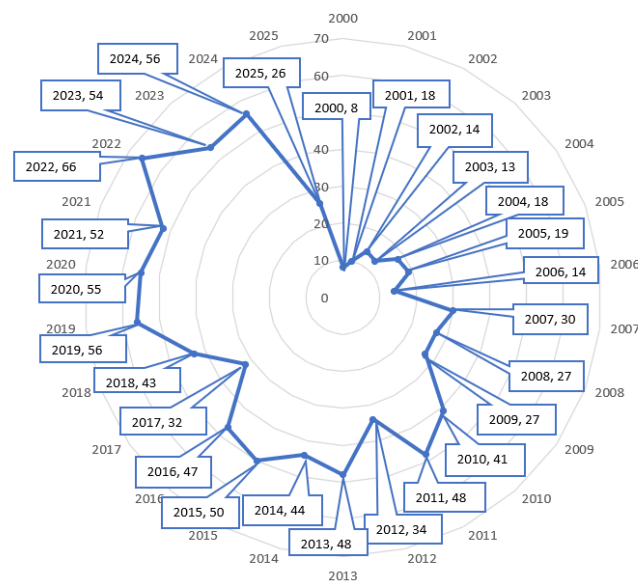


Figure 5. Road bend research has expanded significantly, reaching a peak in 2022, according to the trend of annual publications from 2000 to 2025.

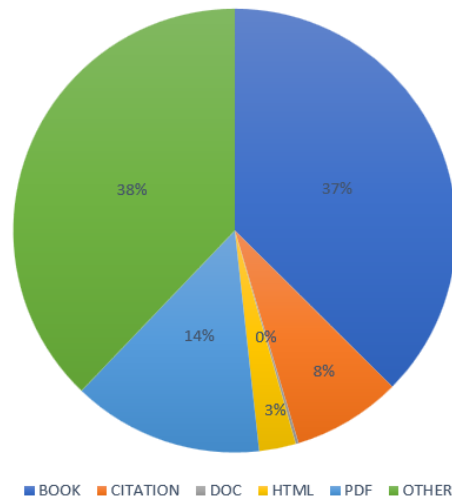


Figure 6. Number of studies by type of study.

Each component contributed differently to the total data, and Figure 6 demonstrates the wide range of reference sources employed. Since the majority of the results from the systematic literature review did not fall into one category, they were categorized under various headings. The references were also quite limited because there were so few sources.

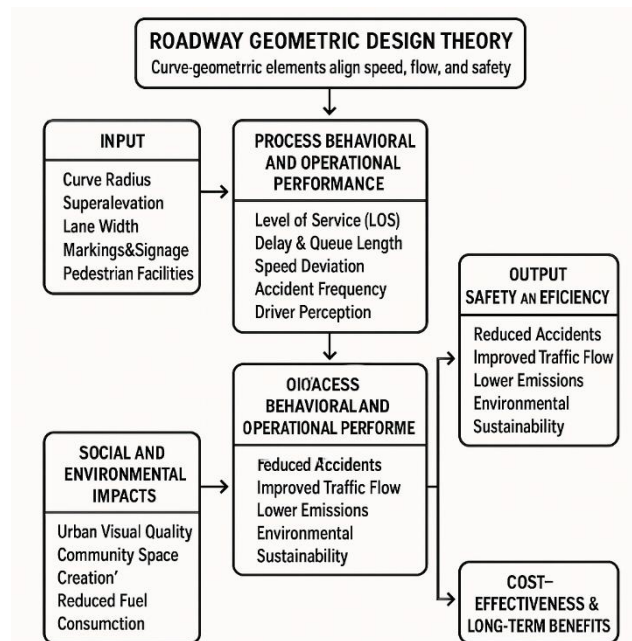


Figure 7. Theoretical framework outlining the key dimensions of roadway geometric design theory on operational performance, user safety, and socio-environmental impacts

3.5 Theoretical Framework and Conceptual Framework

The theoretical framework presented in Figure 7 summarizes the main elements of the road geometry system, with a particular emphasis on the role of road bends in influencing urban mobility performance and user safety. This systematic review shows that the integration of aspects such as geometric design, user behavior, and safety factors is critical in understanding the impact of curves on traffic dynamics. These elements strengthen the research approach by providing a comprehensive theoretical basis that links the physical characteristics of road infrastructure and the safety and efficiency outcomes of mobility in urban environments. In addition, the safety analysis of horizontal curve performance in urban areas found that not only the radius and length of the curve, but also the proximity of the curve to the intersection significantly increased the risk of collision [60].

The theoretical framework in this study includes four main components that are relevant in understanding the effect of road bends on mobility and safety performance in urban areas. Road user behavior and compliance, sustainability and environmental effects, traffic conflict theory, cost-effectiveness, and long-term sustainability are some of these elements. According to traffic conflict theory, bend geometry design helps to improve road user safety and flow by lowering conflict locations. Key elements such as bend radius, superelevation, markings and signs, and the presence of pedestrian facilities are analyzed in the context of improving operational efficiency and safety. From an environmental perspective, optimally designed bends can reduce fuel consumption and exhaust emissions by minimizing sudden vehicle deceleration and acceleration. However, their effectiveness is highly dependent on driver behavior, regulatory compliance, as well as cultural factors and local context. Indicators like level of service (LOS), delay, queue length, crash frequency, and environmental impact are used to evaluate curve performance. When evaluating the curve design's overall impact on urban traffic mobility and safety, driver perception of these factors is also crucial.

According to the theory of cost-effectiveness and long-term benefits, proper design of road bends can be a more cost-effective option than straight road infrastructure or complex intersections, particularly with regard to upkeep and the sustainable, effective use of urban space. In addition to lowering operating expenses, well-designed bends have long-term advantages like less traffic, enhanced safety, lower pollutants, and happier drivers. The study's suggested flowchart shows the steps from Input (Bend Geometry Design) to Process (Evaluation using Performance Indicators including traffic flow, collision rate, and operating speed), to Output (Overall Effectiveness on Mobility and Safety). The framework offers road engineers and transportation planners useful advice for assessing and improving bend design in light of regional circumstances. The model also serves as a foundation for future studies on the connections between geometric design elements, operational metrics, and their effects on urban road user safety and experience.

Emphasizing that road curve design is critical to urban mobility performance and safety. However, differences in research contributions across countries indicate different levels of adoption and adaptation. Developing countries make limited contributions despite their rapid urbanization, while developed countries dominate the research landscape. These shortcomings suggest that greater local research is needed to adapt bend design to specific urban contexts.

In addition, it was pointed out that the themes of safety and efficiency are often central in the literature, but they often neglect the wider socio-environmental impacts. Although corner designs are thought to reduce CO2 emissions, not much research has been done on how they can improve the visual quality of cities or provide spaces for community interaction. Future studies should take a multidisciplinary approach that combines sociology, environmental science, and urban planning in order to optimize bend design's entire potential.

4. Conclusion

This study shows that the geometric design of road bends has a significant impact on mobility and safety performance in urban areas. The study found five main clusters that reflect the topic focus in the literature: horizontal line design, driver behavior, traffic efficiency, and environmental and social impacts. With the use of Publish or Perish and VOSviewer, this was accomplished through the use of bibliometric analysis and the Systematic Literature Review (SLR) approach. The results show that elements such as sight distance, bend radius, and superelevation are critical to lowering crash risk and improving traffic comfort and efficiency. Although the region is experiencing rapid urbanization growth and facing complex infrastructure problems, contributions from developing countries are still small, despite advances in global research. Therefore, strengthening contextual studies requires a multidisciplinary approach that incorporates behavioral and technical elements as well as social aspects and environmental sustainability. This research aims to provide a theoretical and practical foundation for transportation planners, road engineers and policy makers to make the design of road bends safer, more effective and appropriate to local needs.

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