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Geometric Evaluation of Bends: Systematic Literature Review on Suitability to Driver Safety

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Abstract

Road safety issues on curves are a significant concern in reducing traffic accidents in Indonesia. Roads like the Cibatu–Sidamukti route have sharp bends that pose serious risks, worsened by natural factors (heavy rain, slippery surfaces) and inadequate infrastructure (lack of signage, poor road conditions, ineffective drainage). Additional risks come from poor lighting and undisciplined driver behavior. This study highlights the importance of addressing curve-related hazards by examining technical (road geometry, surface quality, signage, markings, lighting) and non-technical (driver behavior, vehicle condition) causes of accidents. Using a literature review method, the study analyzes scientific articles, journals, and books to build a strong theoretical foundation and identify research gaps. The primary focus is evaluating curve geometry's suitability for driver safety, especially in tourist areas with high accident potential. This evaluation is intended to support recommendations for road design improvements and the implementation of necessary safety measures. The findings are expected to serve as valuable input for local governments and stakeholders to improve road safety.

Keywords: Driver safety, Road geometric, Accident, Safety, Road user, Transportation

1. Introduction

Transportation safety is becoming an essential issue at the international level, especially regarding the design and infrastructure of safe and efficient roads. Transportation is a community service system that facilitates the Transportation of people or things [1]. In many nations, roads are crucial infrastructure since they facilitate all Transportation [2]. One of the most essential elements of a road is the curve, which is often a hotspot for traffic accidents in many countries. A sound pavement management system should be able to provide decision support that facilitates road maintenance, including evaluating the suitability of curves for road user safety [3]. Several global reports show that traffic crashes on curves are still the leading cause of injury and death in many countries, especially on mountain roads or winding inter-city roads. However, many countries still face challenges in designing and maintaining safe and convenient curves for road users. Therefore, attention to the design and treatment of curves is essential to improve driving safety globally. Geometric evaluation of curves is performed by analyzing horizontal alignment, curve radius, and curve widening to ensure that the curves are safe and comply with technical standards [4].

Road safety issues at curves are also a serious concern to reduce the number of traffic accidents in Indonesia. Unavoidably, traffic accidents can happen anywhere, at any moment [5]. Many traffic accidents occur on sharp curves, whether on highways, national roads, or local roads. Due to its limited length, the design of a bend in a straight line will not meet all the requirements [6]. Many drivers do not understand safe driving techniques when crossing bends, such as reducing speed or maintaining distance, which also causes accidents.

Furthermore, some cities have shown inadequate maintenance of their road networks [7]. The Indonesian government has issued various guidelines on safe driving procedures, but implementation in the field still needs to be improved. Improving infrastructure and educating drivers are essential steps in addressing this issue. However, safety and energy consumption remain the two main issues facing the superhighway's growth [8]. This guarantees the driver can operate the vehicle safely and without significant difficulties in routine and emergencies [9].

West Java is a glaring example where curves constitute a significant concern. With the region's contours dominated by hills and mountains, many connecting roads between areas in the province have narrow bends with sharp turning angles. One of the most significant factors influencing the effectiveness and safety of roads is horizontal curves [10]. Data from the West Java Transportation Agency shows that 25% of traffic accidents in the region occur at curves, especially at night or during the rainy season. It is crucial to assess the features and categorization of traffic accidents to ascertain the degree of safety of the bend since geometric road designs that do not adhere to regulations have the potential to result in accidents on bends [11]. High vehicle volumes, including freight transport and public vehicles, also increase the risk of accidents in these areas. Highway infrastructure guarantees that national Transportation operates as intended [12]. Despite ongoing road improvement efforts, not all areas receive the same attention from the central or local governments. Infrastructure and facilities must remain prioritized while managing a government system or bureaucracy [13]. As a result, many accident-prone spots remain in a condition that endangers road users. Therefore, government efforts are needed to develop improvements to geometric highway construction [14].

Weather is one of the most influential external factors on corner safety. Crashes on curves are often triggered by natural factors such as heavy rain or fog and slippery road conditions. Many roads in these areas do not have adequate bend signs, good road surfaces, or effective drainage systems. Road design must consider the flow of rainwater [15]. Lack of street lighting, fading markings, and undisciplined driver behavior exacerbate the situation. Geometric evaluation of roads on accident-prone bends must consider the bend radius, superelevation, and design speed to reduce the potential for traffic accidents [16]. People will be less motivated to act or take self-protective behaviors when the risk is not perceived or is unlikely to cause an accident [17]. This shows that attention to curves cannot be separated from the context of each region. Road safety facilities such as convex mirrors and traffic markers must be installed on bends with a small radius to minimize the risk of accidents [18].

Based on these conditions, this paper aims to evaluate and discuss the importance of attention to curves as part of efforts to improve driving safety. Geometric evaluation of curves using Bina Marga standards can be an essential tool in preventing traffic accidents by ensuring curves meet safety criteria [19]. By identifying the technical and non-technical factors that contribute to crashes at curves, the reader will see that the problem of curves is not trivial. This paper will highlight the importance of adaptive road planning for geographical and climatic conditions and the need for synergy between local governments, communities, and stakeholders in realizing safer roads. In addition to providing safe infrastructure and effective traffic flow services, road geometric planning seeks to optimize the ratio of implementation costs to the level of use [20]. It is hoped that through this paper, there is a realization that corner improvements are not just a technical matter but also an essential step towards better accessibility and safety for motorists. The geometric design of this roadway is intended to create a route that prioritizes safety features. Much of the research on safe road design elements is centered on examining how geometric aspects connect with other design factors and safety. [21].

2. Research Methods

Because the survey was psychometric, it required a basic understanding of RIS/PACS usage [22]. The literature review system is the methodology used in this study, which methodically examines and evaluates a range of relevant literature sources, including books, papers, and scientific journals, to develop a theoretical framework and a comprehensive grasp of the subject matter. In a systematic literature review, researchers identify academic journal references and other research sources that can be used as a reference or theoretical basis for new research to find a fundamental framework and problem formulation, which is then expanded into analysis through structured steps [23]. To address predetermined research questions, it also highlights that a systematic literature review is a technique that finds, assesses, and interprets all of the findings of a study issue. The study used the SLR method to review previous research on assessing the acceptance of personnel information systems, which was carried out systematically and explicitly [24].

2.1 Database Used

Google Scholar is the study's primary data source, and the System Literature Review (SLR) methodology uses it. The project will investigate researcher tendencies, identify research trends, and assess the impact of scientific publications on this subject using tools like VOSviewer and Publish or Perish [25]. To facilitate the search and management of literature, Publish or Perish software was used, which allows data to be searched based on keywords, year of publication, and number of citations. This combination facilitated a structured, relevant, and accountable literature collection process.

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2.2 Search Strategy

The literature search strategy was done using Google Scholar and the help of Publish or Perish software. The SLR approach is applied methodically by adhering to the steps and procedures that shield article writing from subjectivity and bias on the researcher's part [26]. Search terms were organized in detail according to the research topic and then entered into the search system to filter results based on relevance, year of publication, and number of citations. The results were then evaluated according to the criteria set for inclusion and exclusion so that the search process was focused, efficient, and organized, supporting the quality of the Systematic Literature review.

2.3 Compiling the Initial Statistical Data

Google Scholar data is in a document that is compliant with the Research Information System (RIS) format. It contains summaries, keywords, bibliometric data, and other crucial elements. This study will map several journal literature sources worldwide as part of its methodology [27]. In the standardized RIS format, Publish, or Perish software can efficiently gather and display relevant reference information, including authors' names, number of citations, and publication sources. Besides confirming the method's accuracy and dependability, this careful strategy makes the methodology less clear for researchers and professionals who could benefit from meta-analyses. [28]. The source mapping of numerous international publications offers a thorough understanding of research trends and the spread of knowledge. The literature lacks comprehensive guidance on using VOSviewer for bibliometric analysis, including step-by-step examples and visualizations. Additionally, there aren't many comprehensive guidelines for using Publish or Perish. Visual data mapping that adheres to the standards of scientific writing would improve the bibliometric analysis's readability and clarity. 2.1. The length of the manuscript (subtitles are not bold).

3. Results and Discussion

3.1 Display of Research Keyword Relationships

Harzing's Publish or Perish version 8 tool, which is intended to collect 1000 scholarly articles, was utilized, along with the following predetermined keywords. papers from the study's pertinent Crossref database: "driver safety," "road geometric," "accident," "safety," "road user," and "transportation." The relationships between the 30 journals and the 1,000 research articles that author Andri Irfan Rifai collected as references are displayed in VOSviewer version 1. 6. 20. The applicability of geometric curves to driver safety issues was examined using bibliometrics. The program (www.vosviewer.com) is freely available to bibliometric scholars [29]. This process provides a solid basis for finding relevant material methodically, rigorously, and slightly biasedly [30].

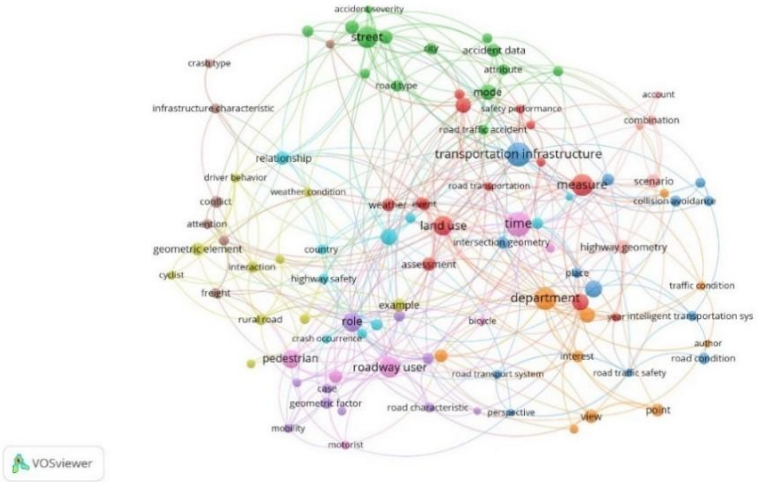

Figure 1. Visualization of the Keyword Network Using VOSviewer

Using VOSviewer software to visualize the data, Figure 1 demonstrates that "transport infrastructure" and "road users" are most closely associated with the secondary keywords. This result aligns with subsequent research emphasizing how frequently drivers are involved in traffic accidents—furthermore, SLR searches for the theory pertinent to the study's case [31].

Blue color (color 1) This cluster includes terms such as transportation infrastructure, measurement, time, collision avoidance, road traffic safety, and scenarios. It focuses on the systemic elements of Transportation, including how the effectiveness of infrastructure design (including corner angles) is measured in crash prevention and safety

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improvement. Traffic safety is a crucial component of the transportation system. Therefore, improving road safety facility planning is one of the most critical topics since a safe and comfortable design will make driving safer and more comfortable for the driver [32]. Much of the research in this cluster emphasizes the importance of data-driven evaluation, simulation testing, and the application of quantitative indicators to measure the effect of geometric design on driver behavior. The current study investigated how the steering trajectories in left and right curves, which are represented by several feature points both before and along the curve, can help clarify these issues [33].

Red color (color 2) This cluster includes crash data, modes, safety performance, land use, intersection geometry, and crash occurrence. Studies in this cluster focus on using real crash data to assess safety, the relationship between road form (especially at intersections and curves), and the types of crashes. Consequently, measures for improvement that additionally consider knowledge of environmental and Road elements will be more successful in lowering the likelihood of traffic accidents [34]. This supports an evidence-based method of assessing whether the design of curves conforms to safety principles. A subfield of road engineering called "road geometric design" concerns producing concrete shapes for use in road operations [35].

Green color (color 3) Within this cluster, terms such as road type, city, crash severity, and attributes are highlighted. Many road network routes are designed to achieve goals and offer mobility [36]. This research investigates the differences between geometric and safety characteristics on urban and non-urban roads and how crash severity varies by road function. These linkages are essential, as the curves' design must consider the Road context. Highway geometry components should be chosen, measured, and positioned to meet design requirements for economy, drainage, driver comfort, visibility, vehicle stability, and aesthetics [37].

Purple and yellow (color 4) This cluster features keywords such as road users, geometric factors, cyclists, geometric elements, driver behavior, interaction, and pedestrians. Research in this cluster concentrates on the behavior of all road users, including drivers, pedestrians, and cyclists, and how they interact with the geometric elements of curves that can affect safety. According to a study, although pedestrians are incredibly adaptable and quick to react to situations, their unexpected conduct makes them more likely to be involved in accidents. Because of these incidents, pedestrians have a right to certain facilities and infrastructure that are secure and comfortable [38]. This involves ensuring traffic is safe while driving and walking [39].

Orange color (color 5) Keywords such as departments, interests, perspectives, and views reflect the evaluative dimension taken by relevant agencies in assessing road safety. This shows the vital role of government agencies and academia in setting norms and evaluating the implementation of geometric designs, especially in high-risk areas such as curves. The development of contemporary technology has made building roads easier and more affordable, enhancing the value of road transportation in connecting far-flung locations [40]. Freeways are crucial for determining the economic speed and societal prosperity in the transportation sector, especially in land transportation [41].

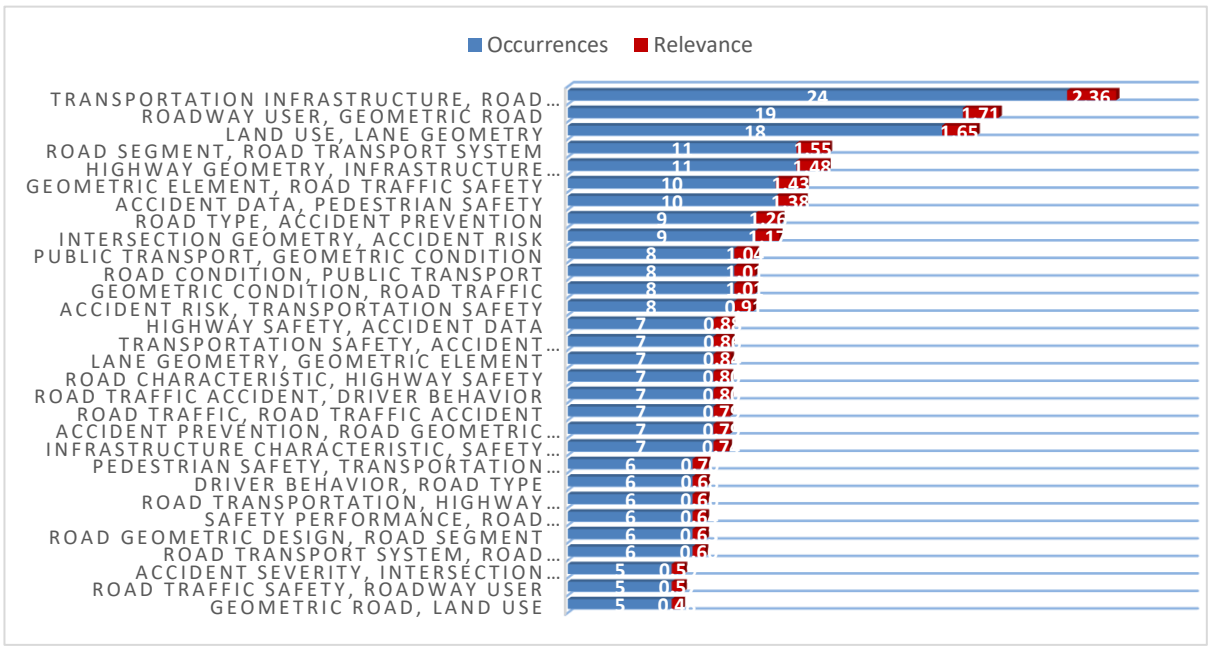

Figure 2. Occurrence-Based Keyword Graphics

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Figure 2 displays the co-occurrence and most pertinent analysis, concentrating on word pairs discovered in published journal full texts or author keyword lists. This methodical technique guarantees an orderly evaluation extraction by defining research questions and locating relevant studies to evaluate their findings for insightful information [42]. This co-occurrence matrix improves our comprehension of the conceptual framework and academic networks in this field by offering a viewpoint on research about road users and transportation infrastructure across time. The authors demonstrated the connections between the co-occurrence of 30 of the 1030 terms the researchers chose using Vosviewer. Figure 1 shows the five groups from the co-occurrence network created between 2000 and 2025. Every group is shown as a circle, with thicker lines denoting a higher frequency of co-occurrence and larger circles signifying more links. Figure 3's density visualization demonstrates that the keywords are darker and denser, with larger circles signifying that the keywords are frequently the focus of inquiry. Still, as the color in Figure 3 fades, it means a decrease in studies. Transportation infrastructure and road users recorded the highest growth in this study.

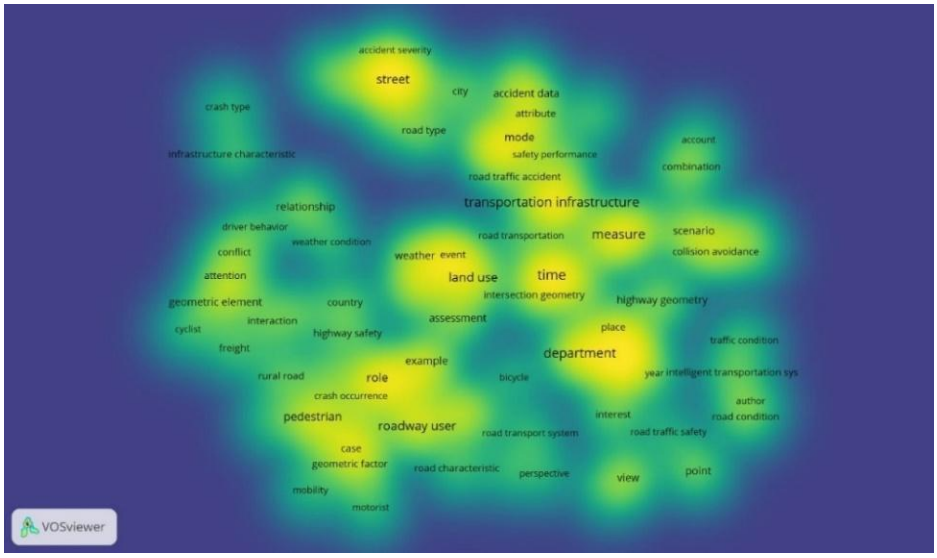

Figure 3. Density of Keywords

Table 1. Keywords From the Best Research

Keywords	Total Study
Transportation	224
Infrastructure	160
Road Geometric	135
Accident	166
Safety	121
Road User	104
Driver Safety	120

Table 1 clearly shows the most researched keywords related to bend geometrics. More traffic data (traffic load, volume, etc.) must be obtained in light of the growing traffic volume to serve as a resource for sensible traffic flow planning [43]. It can be seen that transportation infrastructure and road users are the most researched topics and have a significant relationship with road user safety. Congestion will worsen as the number of vehicles increases if infrastructure and transit amenities are not improved [44]. This suggests that much research is directed toward understanding, designing, and evaluating geometric aspects of road user safety.

Subsequently, road geometrics became the primary focus of this study. This keyword reflects the strong interest in evaluating the performance of road bends, especially in terms of their ability to reduce the number of crashes, increase safety, and improve the roadway. The geometry of the highway is greatly impacted by the characteristics of the traffic, cars, and drivers [45]. A 2021 study from the Indonesian Ministry of Public Works states that over 40% of rural Indonesia's roads are in poor condition, which raises the possibility of accidents [46]. Because traffic safety affects both the global economy and the welfare of individuals, it has become a significant issue for both developed and developing countries [47].

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3.2 Publications' Evolution by Year

The Publish or Perish software was used to analyze data from Google Scholar to determine research trends regarding whether bend geometrics are enough for driver safety. The study covers twenty to five years, from 2000 to 2025.

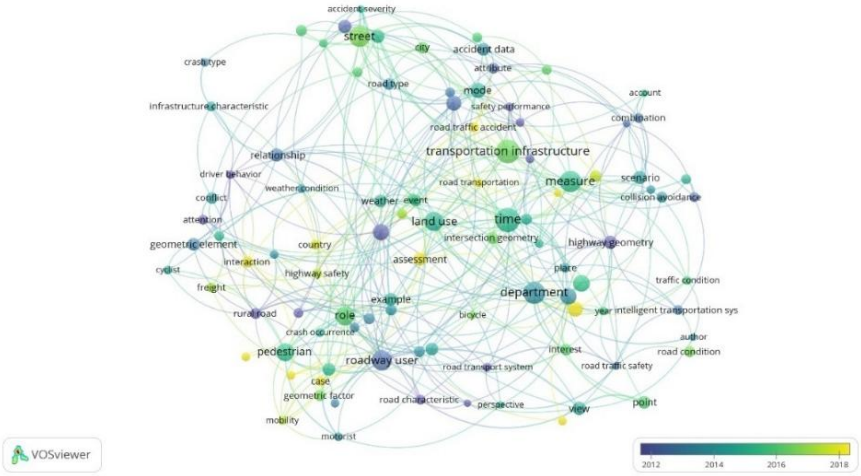

Figure 4. Keyword by Year

Figure 4 shows author Andri Irfan Rifai's research data from 2000 to 2025 across 1,000 general journals and 30 reference journals. As the graphic illustrates, the number of research subjects has decreased and increased throughout the previous 25 years. According to the data, the research trend on Road geometric suitability for road user safety has grown over the past ten years, with the most significant point occurring in 2022. The VOSviewer research revealed the following as the most frequently used publishing keywords annually: Eight publications were published in 2000, three in 2001, and six in 2002. Twelve papers were published in 2004, fifteen in 2005, fifteen in 2006, twenty-four in 2007, twenty-one in 2008, twenty-eight in 2009, fifty-three in 2011, fifty-two in 2012, forty-one in 2014, forty-nine in 2015, 148 in 2020, 144 in 2021, 155 in 2022, 47 in 2023, 45 in 2024, and twelve in 2025.

In contrast to earlier studies on capacity improvement and safety, this viewpoint uses a 25-year bibliometric analysis. Bibliometrics has been applied in numerous research fields [48]. Our research indicates a considerable increase in interest in road geometry, particularly curve conformance, which has been neglected in prior studies. We looked at keyword frequencies that indicate new issues in the field and plotted publishing trends using programs like Publish or Perish and VOSviewer. The comprehensive approach of this study offers strategic insights regarding bend suitability for road user safety, which is its contribution. 3.3 The publisher decides the study's direction and classification.

3.3 Type of study determined by publisher categorizes it

Table 2 presents in-depth information on the publishers that have contributed to studying the relationship between curves and road user safety. This information is crucial given this research subject's variety of sources and global scope. This study collected data from multiple publications through linkages, demonstrating how many publishers could improve science research. This data, pertinent to civil engineering worldwide and shown in Table 2, was gathered using Harzing's Publish or Perish program.

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

Publisher	Study
Elsevier	340
Journals.sagepub.com	92
Taylor & Francis	90
MDPI	72
Wiley Online Library	72
Springer	49
IEEE Xplore	34
ResearchGate	23
SpringerLink	16
Academia.edu	11
Other	238

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Elsevier, Sagepup Journal, and Taylor & Francis are the top three publishers that contribute many studies. This implies that these platforms are the primary means of sharing research on road user safety and bend suitability. The various research publications that are part of this study are listed in Table 2. This data provides an essential context for understanding the wide range of road geometry research. With 238 studies, journal articles made up the majority of the research. This illustrates how author-published journals are the primary medium for sharing research findings in this area. The most popular formats were books and journal articles, whereas datasets, monographs, and posted material were less common.

3.4 The Bulk of Countries' Research Kind

Research from different countries shows different ways of assessing the suitability of bend shapes for driver safety. These differences reflect the traffic needs, regional characteristics, and level of concern for safety in each country. Grouping the research locations by country of origin gives a clear picture of the distribution of scientific contributions and global trends in road geometric studies. In Asia, there has been an increase in contributions from countries such as China, Japan, and South Korea. This shows the increasing attention to curve geometric design as a key element in reducing crashes, especially in dense and fast-growing urban areas. Concerns about motorcycle safety have grown over the past 20 years, mainly due to the rise in the use of these two-wheeled vehicles (more than 50 cc) in cities [49]. Research from these countries often addresses issues such as the impact of bend radius, superelevation, and design speed on crash severity. The wide geographic spread of research creates opportunities for international collaboration and deeper integration of global data. By comparing countries, researchers can find best design practices and develop geometric guidelines that can be adapted to different traffic and social conditions. This is critical to creating a practical global approach to improving rider safety through appropriate geometric design, especially in curves that have long been crash-prone.

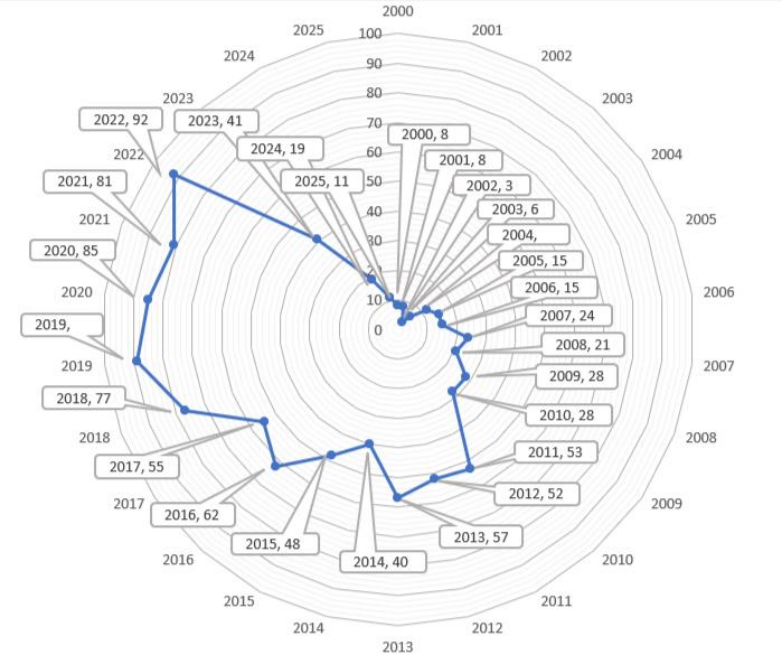

Figure 5. Trends in Publications Every Year From 2000 to 2025

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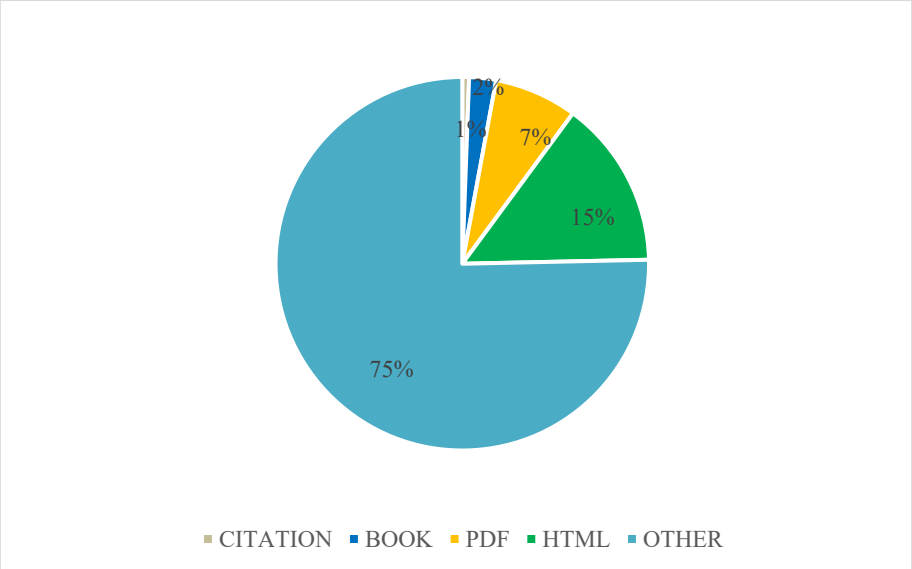

Figure 6. Number of Studies by Type of Study

Figure 6 shows that the various reference sources used are diverse, and each section contributes differently to the total data. Most of the findings from the systematic literature review did not fall into a particular category, so they were grouped into other categories; in addition to the small number of citations, the references from the citation results were minimal.

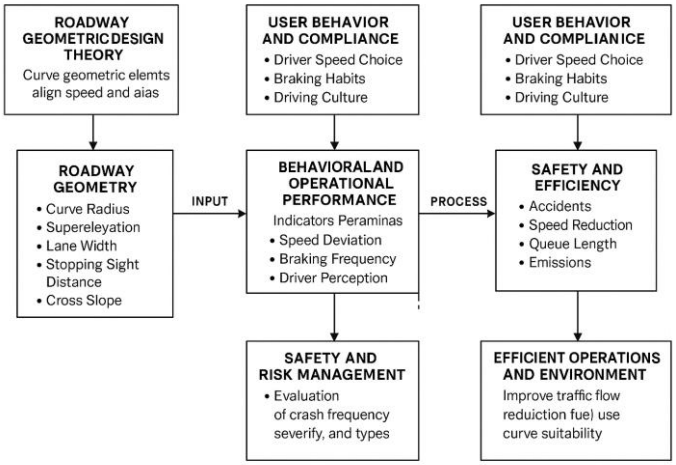

Figure 7. Theoretical Framework Outlining the Key Dimensions of Geometric Bend Conformity on Road User Safety

3.5 Conceptual and Theoretical Frameworks

A logically developed and integrated theoretical framework significantly impacts the quality and validity of research on road infrastructure. Figure 7 shows the theoretical framework outlining the main elements of the road geometry system, which are analyzed with a focus on the relevance of curves about road user safety. These elements reinforce the research approach through theoretical foundations on traffic, user behavior, and road safety. Road security must be improved to increase road user safety, and driving cautiously is one approach to achieve this [50].

The road geometry framework highlights four main interconnected elements: road engineering theory, driver behavior analysis, safety and risk management, and traffic operational efficiency. Building construction also affects nearby roads by lowering service quality, eventually leading to traffic jams [51].

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Road Geometry Engineering Theory: This theory explains how design elements such as bend radius, superelevation, lane width, stopping sight distance, and cross slope can affect vehicle dynamics when traveling through a bend. Road geometric planning cannot be separated from horizontal alignment or horizontal curvature, including the length of sections, straight and curved roads, bend radius to superelevation, and vertical alignment, including at roads and slopes up and down. [52]. These elements are essential in creating a match between the design speed and the operating speed. A mismatch between design and actual user behavior can lead to traffic accidents, especially at sharp curves with low visibility conditions. Several areas of West Java have a hilly and mountainous morphology, with slopes that vary from relatively steep to steep, according to the information that is currently accessible [53].

Driver Behavior and Compliance Analysis: The success of a bent design is strongly influenced by driver behavior - including the speed traveled, braking habits, and turning ability. Understanding driver-roadway interaction may enhance road design processes to provide a safer environment, as most road design regulations are based on the physics of cars and preset design speeds rather than driving behavior. Driver education, risk perception, and local driving culture play a significant role. Indicators such as the rate of speed limit violations, frequency of sudden braking, and inappropriate lane usage are benchmarks for assessing the suitability of geometric design to user behavior. Generally speaking, the trend of driver behavior has some reasonable consistency and may be analytically evaluated, even though Indonesian drivers behave differently depending on the traffic circumstances [54].

In many nations, the number of automobiles has grown, but in Indonesia, the number of vehicles has significantly increased [55]. Safety and Risk Management Road bends are frequent crash sites, especially those that do not meet geometric standards or are poorly managed. Safety assessment involves metrics such as the number and severity of crashes, the frequency of loss of vehicle control, and the number of conflicts between vehicles or between vehicles and pedestrians. Traffic conflict theory is applied to study crash hotspots and determine the need for design interventions such as the addition of warning signs, speed markings, or road reflectors. To provide economical, optimal, and effective road planning, topography conditions and the surrounding environment must be considered using geometric road planning [56].

Operational Efficiency and Environmental Impact: Proper corner design improves safety and facilitates traffic flow. Bends that are too narrow or with non-ideal radii cause sudden speed drops, long queues, and increased fuel consumption. The impacts of improper design include increased CO2 emissions and decreased driving comfort. Road users are most negatively impacted by time loss, energy waste, health issues brought on by automobile pollution, stress, and a decline in productivity [57]. Indicators, including level of service (LOS), delay time, queue length, and frequency of abrupt braking, are used in the evaluation.

The proposed workflow describes the relationship between Input (Bend Geometric Parameters), Process (User Behavior Interaction and Operational Performance), and Output (Safety and Efficiency). The model offers a practical approach for transportation planners and civil engineers in tailoring the design of bends to local conditions and traffic characteristics in a given area. Efficient Transportation can enhance other economic growth drivers and population mobility services. The smooth traffic flow also reflects the regularity and order of road users [58]. The vegetation on a greenway should also be considered [59].

Furthermore, social and environmental aspects of corner design are frequently overlooked in favor of the technical and quantitative features currently dominating the research. Not much attention has been paid to the potential of corner design as a place for community interaction or as an aesthetic component of the city. The performance of road segments, often referred to as road services, is typically described in terms of safety, comfort, speed, and freedom of movement [60]. Thus, future studies must employ a multidisciplinary approach incorporating road user psychology, traffic engineering, urban design, and Sustainability to ensure that corner designs are effective, safe, human-centered, and ecologically friendly.

4. Conclusion

The primary focus in studies on the suitability of road geometric bends for road user safety is usually on issues such as road geometrics, rider safety, and high accident rates. These terms appear frequently and serve as a link between various topics in the road geometrics and road user sectors. The leading publisher in terms of publications is Elsevier, which indicates that journals from this publisher constitute a significant reference in academic research in the road geometry sector. Additionally, the smooth traffic flow reflects the regularity and order of road users [58]. One should also take into account the vegetation on a greenway. The types of reference sources used vary but are dominated by the Other category, which includes a variety of unclassified document formats and books, demonstrating the importance of theoretical sources. Visualizations of the relationship between keywords and their

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distribution show a strong connection between road geometrics, driver safety, and the overall high crash rate. Overall, the research provides an overview of research trends in the road geometrics sector and helps to identify directions for scientific development and opportunities for further study.

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