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Bibliometric Analysis of Road Performance and Level of Service (LoS) Using VOSviewer

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ABSTRACT

This study aims to identify research trends, dominant themes, and keyword linkages in the scientific literature on road performance and level of service (LoS) using a bibliometric approach. Bibliographic data were collected from 1,000 publications using Publish or Perish and analyzed using VOSviewer software. The visualization results showed that the keywords "road performance", "traffic volume", "delay" and "capacity" were the main focus of the studies, reflecting the dominance of technical approaches based on operational indicators. The analysis also revealed a division of themes into several clusters, such as policy evaluation, technical aspects, and methodological approaches. The distribution of publications shows a significant upward trend since 2011, with a peak in 2022-2023. Authors from Indonesia are the largest contributors, although international publications are still dominated by developed countries. These findings indicate the need for a multidisciplinary approach to road performance assessment, including the integration of technical and social data, and the use of spatial technologies such as GIS to support more inclusive and sustainable transportation planning.

1. Introduction

Traffic congestion is seen as a global issue because of its impact on increasing air pollution, noise from vehicles, and the length of travel time for both private vehicles and public transportation [1]. In carrying out movement activities, citizen use transportation facilities and infrastructure [2]. Road performance and Level of Service (LoS) have become a global focus in an effort to improve transportation efficiency and sustainability. In both developed and developing countries, the rapid increase in the number of motorized vehicles has had a major impact on traffic congestion, energy use, and greenhouse gas emissions [3]. The World Bank and the United Nations have highlighted the significance of effective road infrastructure in supporting economic growth and reducing access disparities [4]. In this situation, road performance assessment becomes an important instrument for transportation planning that is based on road user data and needs. Through the revision of the quality of transportation services by producing urban universal transportation that is comfortable, safe, orderly, cheap,affordable and scheduled, it will increase the use of universal transportation [5]. . Various methods have been developed internationally, including traffic simulation as well as predictive modeling based on big data. One approach that is

gaining popularity in international scientific research is bibliometric analysis to identify research trends on road performance and LoS.

To promote economic growth and connectivity between regions in Indonesia, the development and maintenance of road infrastructure is a top priority for the government [6]. However, efforts to improve road performance and level of service (LoS) are often hampered by constraints such as limited budget, poor material quality, and lack of collaboration between relevant agencies [7]. . In addition, Indonesia is an archipelago consisting of various volcanic mountainous regions, making it have very diverse geographical conditions [1]. From lowlands to mountains, building and maintaining roads that meet international standards is a challenge. Therefore, comprehensive plans and policies are needed to address these issues and ensure that road infrastructure remains high quality and sustainable.

To support economic and social activities, local governments at the regional level must also pay attention to road performance issues. Increasing the number of vehicles will cause congestion and congestion if transportation facilities and infrastructure are not upgraded [8]. In addition, damaged roads can also hamper the distribution of goods and services, increase transportation costs, and reduce local competitiveness. Road damage can also result in traffic accidents and threaten the safety of road users [9]. Therefore, local governments should provide sufficient budget for road maintenance and improvement, as well as to improve the quality supervision of road infrastructure projects. Inter-regional cooperation is also needed to build an integrated road network and promote local economic growth.

Majalengka Regency as part of West Java is now growing rapidly after the construction of Kertajati International Airport [10]. Transportation affects the location and range of productive and recreational activities; the location of residence; and the range and supply of goods and services available for consumption [11]. Poor road conditions can hamper economic operations, especially in agriculture and tourism. In addition, road damage can isolate areas and limit people's access to public services, As a result, roads have a more significant influence than other infrastructure in boosting economic growth [12]. The case study in Majalengka can be used to identify factors that affect road performance, such as material quality, construction techniques, and drainage systems. At various levels of damage, road damage sometimes causes puddles, landslides and others [13]. The findings of this study can be used as a basis for making policy recommendations and strategies to improve road performance that are appropriate to local conditions.

Road performance is a crucial aspect of transportation planning that reflects how efficiently a road infrastructure serves the movement of vehicles and people. Road performance is whether the road responds well to human movement [14]. road performance is assessed using parameters such as capacity, degree of saturation, average speed, and others [15]. The imbalance between capacity and demand is an indicator of declining road performance that causes traffic congestion, especially in dense urban areas. In the urban context, the primary cause is population growth, which has increased the number of vehicles on the road [16]. This causes congestion in traffic flow due to inadequate infrastructure. Transportation infrastructure such as roads may impact regional productivity through their effect on employment, private investment, and the returns to schooling [17]. If it is not anticipated with transportation facilities and infrastructure accompanied by good transportation regulations, it will have a bad impact on transportation, namely in the form of traffic jams and environmental impacts (pollution) which will affect the surrounding community [18]. In addition, investors tend to be more interested in investing in areas that have good infrastructure because it supports the effective distribution of goods and services. Equally important, easier access to education facilities can increase

participation and quality of education, which in turn contributes to improving labor competencies and overall regional productivity.

Level of service (LOS) is a standard measurement for determining an acceptable level of quality of services using specific attributes, such as service frequency and service hours [19]. LOS helps in evaluating the extent to which public transportation services or road infrastructure meet users' expectations and needs. The higher the LOS level, the better the user's perception of the service provided. LOS measurement procedures suitable for developed countries are not usable for developing countries due to the differences in road geometry, presence of non-motorized vehicles, and control delay at intersections [20]. In developed countries, road systems generally have more uniform geometry, more modern facilities, and traffic dominated by motorized vehicles with integrated and efficient traffic control. this study proposes an IoRT-based real-time traffic monitoring system to enhance mobility. The system integrates IoT sensor nodes and cameras to collect real-time traffic data, which are then processed using various image processing and two proposed deep learning techniques before being wirelessly transferred to the cloud and made available to drivers and commuters through the ROSNOS [21].

Bibliometric analysis is a quantitative approach to assessing the development of scientific literature in a particular field of study. It examines a wide range of bibliographic data, such as citation counts, co-authorship networks, keyword co-occurrence, and journal impact, to provide a structured overview of research landscapes [22]. In the context of road performance and LoS, bibliometric analysis is important to understand how methodological developments and the focus of studies have changed in recent decades. that the use of tools like the Analytic Hierarchy Process (AHP), simulation, and a Geographic Information System (GIS) underscores a comprehensive approach to sustainable urban mobility planning, helping planners make data-driven decisions [23]. With the help of software such as VOSviewer, researchers can visualize the relationships between scientific articles and group key themes based on citation strength and frequency. This study presents a current and extensive bibliometric analysis of pavement deterioration detection, monitoring, and assessment using various sensors alongside machine learning and deep learning algorithms. The findings reveal a significant recent increase in studies in this area [24]. This reflects a significant increase in research related to pavement condition monitoring using sensors and machine learning algorithms, which is gaining popularity in the quest for more efficient and sustainable transportation system improvements. Visualizations using VOSviewer can help policy makers and academics identify research gaps and potential international collaborations. As stated, 'China has the highest number of publications (803). China was followed by Brazil (701), the USA (559), and Italy (512) [25].

The purpose of this bibliometric analysis is to describe trends and research progress in the field of road performance and level of service (LoS) using VOSviewer software. As a quantitative method, bibliometric analysis uses evaluative and descriptive approaches to represent trends and research characteristics from a series of publications [26]. By utilizing data from various sources such as academic journals, conference proceedings, and books, this analysis is able to provide a comprehensive picture of the progress of road performance research over time. In addition, it highlights the most popular research topics, the most influential authors and institutions, and the collaboration networks among researchers. The analysis is expected to provide valuable insights for researchers, practitioners, and policymakers in the road infrastructure sector to develop more efficient and effective strategies and policies. The advantage of this research is the application of VOSviewer to visualize bibliometric data, which makes it easier for researchers to identify complex patterns and relationships in research data.

2. Literature Review

21. Road Performance

Road performance is a crucial aspect of transportation planning that reflects how efficiently a road infrastructure serves the movement of vehicles and people. road performance is assessed using parameters such as capacity, degree of saturation, average speed, and others [15]. The imbalance between capacity and demand is an indicator of declining road performance that causes traffic congestion, especially in dense urban areas. Road performance is a road's capability to serve every need of traffic flow by its function and can also be measured by the level of service standards on the road [27]. This performance evaluation is generally done by observational methods or through software-based traffic simulation modeling.

In the urban context, the primary cause is population growth, which has increased the number of vehicles on the road [16]. This causes congestion in traffic flow due to inadequate infrastructure. Poorly maintained roads constrain mobility, significantly raise vehicle operating costs, increase accident rates and their associated human and property costs, and aggravate isolation, poverty, poor health, and illiteracy in rural communities [28]. Road network planning needs to consider complex daily travel patterns and traffic dynamics [29]. Therefore, technologies such as intelligent transportation systems (ITS) and real-time data collection are being applied to measure road performance more accurately and adaptively to changing traffic situations.

Transportation infrastructure such as roads may impact regional productivity through their effect on employment, private investment, and the returns to schooling [17]. With the availability of adequate transportation access, labor mobility becomes more efficient, thus expanding opportunities for people to get better jobs. the definition of transportation is the movement of goods or passengers from one location to another, with products being moved or moved to the required or desired location [30]. In addition, investors tend to be more interested in investing in areas that have good infrastructure because it supports the distribution of goods and services effectively. Hence, the road construction activity is growing rapidly in order to accommodate the traffic volume [31]. Last but not least, easier access to education facilities can increase participation and quality of education, which in turn contributes to improving workforce competencies and overall regional productivity [32].

2.2 Level of Service

The term ―Level of Service‖ (L.O.S.) has been introduced by the Highway Capacity Manual (HCM) which represents the level of facility an user can derive from a road under various operating characteristics and traffic volumes [33]. Level of service (LOS) is a standard measurement for determining an acceptable level of quality of services using specific attributes, such as service frequency and service hours [19]. LOS helps evaluate the extent to which public transportation services or road infrastructure meet user expectations and needs. In order to ensure that the full range of road users are appropriately serviced, road asset managers need to improve their understanding of the requirements of the freight and logistics industry [34]. The higher the LOS level, the better the user's perception of the service provided. Conversely, a low LOS indicates a decrease in service quality which can have an impact on decreasing user satisfaction as well as the overall efficiency of the transportation system [35]. Therefore, LOS is an important tool in planning, managing, and improving transportation systems to be more responsive to the dynamics of public demand.

LOS measurement procedures suitable for developed countries are not useable for developing countries due to the difference in road geometry, presence of non-motorized vehicles, and control delay at intersections [20]. In developed countries, road systems generally have more uniform geometry, more modern facilities, and traffic dominated by motorized vehicles with integrated and efficient traffic

management. In contrast, in developing countries, road conditions tend to be more varied, often narrow, and less standardized. The presence of non-motorized vehicles such as rickshaws, bicycles, or carts adds to the complexity of traffic flow [36]. In addition, delays at intersections caused by the lack of traffic control or suboptimal signal systems are also significant factors. Therefore, the LOS approach used in developed countries needs to be adapted or modified to be relevant to the context and reality of transportation in developing countries, so that the evaluation results remain accurate and can be used as a basis for effective planning.

The implementation of traffic sensors, CCTV cameras, and GPS-based data collection has significantly contributed to real-time LoS monitoring. This allows traffic authorities to respond to road conditions more quickly and precisely. This study proposes an IoRT-based real-time traffic monitoring system to enhance mobility. The system integrates IoT sensor nodes and cameras to collect real-time traffic data, which are then processed using various image processing and two proposed deep learning techniques before being wirelessly transferred to the cloud and made available to drivers and commuters through the ROSNOS [21].

2.3 Bibliomatric Analysis

Bibliometric analysis is a quantitative approach to assess the development of scientific literature in a particular field of study. This method allows researchers to identify research trends, collaboration between authors, institutional networks, as well as dominant keywords in a particular topic. It examines a wide range of bibliographic data, such as citation counts, co-authorship networks, keyword co-occurrence, and journal impact, to provide a structured overview of research landscapes [22]. In the context of road performance and LoS, bibliometric analysis is important to understand how methodological developments and the focus of studies have changed in recent decades.

With the help of software such as VOSviewer, researchers can visualize the relationships between scientific articles and group key themes based on citation strength and frequency. This visualization allows for a more in-depth analysis of the structure and dynamics of knowledge within a field of study. In the context of transportation studies, bibliometric analysis conducted in recent years shows a significant increase in topics related to urban mobility, smart transportation, and sustainability. This trend reflects a paradigm shift in transportation research from the conventional approach that focuses on physical infrastructure, to one that is more based on smart technology and environmental awareness. This is in line with the findings of İnce (2025) who states that the use of tools such as the Analytic Hierarchy Process (AHP), simulation, and a Geographic Information System (GIS) underscores a comprehensive approach to sustainable urban mobility planning, helping planners make data-driven decisions [25]. Which shows the global trend of utilizing technology and data to formulate more sustainable transportation policies.

Through bibliometric analysis, it was found that publications related to road performance and Level of Service (LoS) have been consistently increasing since 2018, especially after the introduction of various sensor technologies and automated monitoring systems. This trend indicates a global interest in the continuous improvement of transportation systems. For example, Rizelioğlu in his study mentioned that This study presents a current and extensive bibliometric analysis of pavement deterioration detection, monitoring, and assessment using various sensors alongside machine learning and deep learning algorithms. The findings reveal a significant recent increase in studies in this area [24]. This reflects a significant increase in research related to pavement condition monitoring using sensors and machine learning algorithms, which is gaining popularity in the quest for more efficient and sustainable transportation system improvements.

Bibliometrics show the dominance of publications by countries such as China, the United States, and India in the field of urban transportation. China has the highest number of publications (803), followed by the United States (559), and India with significant contributions in this field. Visualizations using VOSviewer can help policy makers and academics identify research gaps and potential international collaborations. As stated, 'China has the highest number of publications (803). China was followed by Brazil (701), the USA (559), and Italy (512) [25].

3 Method

3.1 Database Used

To achieve comprehensive and relevant literature coverage in the bibliometric analysis of road performance and Level of Service (LoS), this study utilized Google Scholar as the main source of publication data. Google Scholar was chosen because it offers extensive access to various types of academic documents, including journal articles, conference proceedings, books, theses, and research reports [37]. One of the main advantages of Google Scholar is its ability to cover publications that are often not indexed in paid databases such as Scopus or Web of Science, which makes it possible to access literature that is more local or regional in nature. The use of Google Scholar also provides an advantage in terms of wider coverage, given the wide range of document types that can be found [38]. The time span of the search was limited between 2020 and 2024, to ensure that only the most recent literature would be analyzed, which is relevant to current research trends in the topic of road performance and LoS.

In a later stage, supporting features on Google Scholar were utilized to expand the network of literature analyzed. Features such as "Cited by" were used to trace citations and see the influence of a publication on subsequent studies, while the "Related articles" option helped to automatically find documents with similar topics [39]. This approach allows the identification of conceptually related literature, even if it comes from different sources and formats. Searches were conducted with a combination of specific keywords that reflected the focus of the study, as well as the selection of the most relevant results based on content, not just rank order. With this strategy, the data collection process not only includes documents that are popularly cited, but also pays attention to the diversity of viewpoints and local contexts that are often missed in commercial databases [40].

3.2 Search Strategy

The literature search strategy was conducted systematically using Publish or Perish (PoP) software to collect data from Google Scholar. The keywords used in the search focused on key themes in road performance and LoS studies, including: "road performance," "level of service," "LoS," "intersection performance," "traffic flow," and "urban road." Searches were conducted on the title, abstract, and keywords of the articles, aiming to obtain more relevant and focused search results. Each of these keywords was combined with a Boolean operator (AND/OR), which made it possible to broaden or narrow the scope of the search. This aims to obtain relevant articles that are still specific to the topic under study [41]. The screening process was conducted by setting some strict inclusion criteria, including: articles had to be published within 2020-2024, focused on the topic of road performance, LoS,or intersection analysis, and available in the format of journals, proceedings, or research reports published in English or Indonesian.

Once the data was collected through Publish or Perish, each entry was evaluated to ensure its relevance to the research focus. Bibliographic information such as author name, year of publication, publication title, and publication source were organized into a tabular format to facilitate the next stage of

analysis*[42].*. Documents that did not meet the criteria, such as duplicate articles, non-scientific content, or irrelevant references, were manually eliminated. The end result of this stage is a filtered dataset ready for processing using bibliometric software. The validity of the analysis results relies heavily on the rigor of this initial selection process, so each step is conducted with the accuracy and representativeness of the sources under review in mind.

3.3 Data Extraction and Preparation

Once the search results were obtained, the data was exported into .ris or .csv format for further processing. This data extraction process involves separating relevant information such as author name, article title, year of publication, keywords, and other relevant information [43]. The extracted data is then subjected to a cleaning stage, which aims to remove duplicates, correct metadata errors, and ensure consistency of information. This is important to ensure that only relevant and non-flawed publications will be analyzed [44]. The cleaned data is then grouped by categories such as publication year, author, institution, and keywords. Thus, this process will result in a well-structured dataset ready for further analysis.

2.3.1 Bibliometric Analysis with VOSviewer

The bibliometric analysis in this study was conducted using VOSviewer software, which is known as an effective tool for visualizing and analyzing bibliographic data in network form. The selection is taken from trusted, qualified, and accurately considered sources so that the bibliometric method is needed in the research process [45]. This analysis process includes several main approaches. First, co-occurrence analysis was used to evaluate the interrelationships between important keywords such as "level of service", "road performance", and "traffic flow", in order to identify dominant themes and topic trends in the literature. This method also enables researchers to work with vast samples of articles, which is crucial for the study's objective because structuring a whole topic requires managing a significant sample of articles [46]. Secondly, co-authorship analysis was conducted, which aims to map the collaboration network between authors and institutions, as well as measure the productivity level of researchers who contribute significantly in this field. Next, in the citation and bibliographic coupling stage, the relationship between citations is analyzed to determine the most influential publications and group documents into research clusters based on their reference links. Finally, all the results of this analysis are presented in visual forms such as network visualization, density visualization, and overlay visualization, which facilitate interpretation of the patterns of connectedness and dynamics in the road performance and LoS research ecosystem. Complete guidance on the application of bibliometric analysis with the help of VOSviewer, especially with visualizations and practical steps, is still rare in the existing literature. Similarly, detailed explanations on how to optimally use Publish or Perish are limited. Visualization of data mapping results compiled based on scientific writing rules is believed to be able to clarify and facilitate understanding of bibliometric findings [47]. On that basis, this research is here to fill the gap by presenting a structured and comprehensive bibliometric approach.

2.3.2 Performance Metrics

In analyzing road performance and Level of Service (LoS), various metrics are used to provide a more thorough understanding of the issue under study. Some of the key indicators analyzed include the Level of Service (LoS) itself, which evaluates the quality of road service based on parameters such as capacity, average speed, and traffic density. In addition, the vehicle delay metric is used to measure the travel time required for a vehicle to cross a point, as a representation of potential congestion [48]. Queue length is also taken into account to illustrate the accumulation of vehicles at strategic locations, which has a direct impact on the smooth flow. Average speed metrics provide an overview of the general traffic performance of a particular section or segment. Where available, vehicle emissions are also analyzed to understand the environmental impact of non-optimal traffic conditions. These metrics were identified through a process of keyword extraction and abstract review of selected publications, which was then used to categorize the documents into specific themes within road performance and LoS studies *[49]*.

2.3.3 Interpretation and Research Gap Identification

Once the bibliometric analysis is completed, the mapping results will be used for several important purposes. First, to identify key trends and emerging topics in road performance and LoS research. The visualization results from VOSviewer will provide a clear picture of how certain topics relate to each other and how they evolve over time. Secondly, this process will help in discovering research gaps, especially those related to the environmental and social aspects of road performance and LoS, which are still rarely addressed in the existing literature. Finally, based on the analysis conducted, this study will provide recommendations for future research, with reference to the research clusters and networks formed from the bibliometric analysis [50]This is expected to provide a clearer direction for future researchers to explore areas that have not been widely researched or that have great potential for further development.

Result dan Discussion

4.1. Visualization of Research Keyword Connections

This research applied a bibliometric approach to identify trends and dominant themes in the scientific literature addressing the topics of road performance and level of service (LoS). Through data processing using VOSviewer software, a visual analysis of the keyword network and density of terms was conducted. Bibliographic data was obtained from 1,000 publications searched on Google Scholar using Publish or Perish software. The main focus of the analysis was to explore the most frequently used key terms, identify relationships between keywords, and uncover research areas that have received less attention in the context of road transportation.

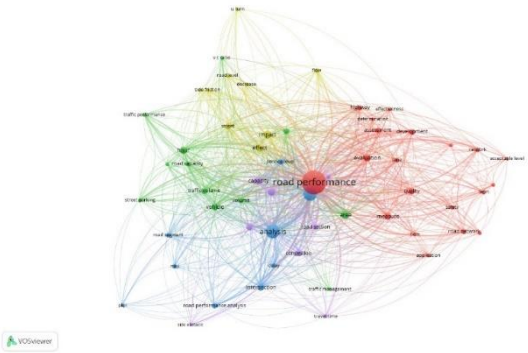

Figure 1 Visualization of the keyword network using VOSviewer, highlighting dominant terms such as 'Road Performance' and 'Analysis'.

The co-occurrence network visualization shown in Figure 1 demonstrates the conceptual linkages between terms frequently used in related studies. The keyword "road performance" is shown as the central node with the largest size and the most connections with other terms. This reflects the topic's position as the center of attention in the road transportation literature. The term is closely related to other keywords such as analysis, traffic volume, road capacity, vehicle, service level, delay, evaluation, congestion, and road network. These relationships show that road performance evaluation generally uses an approach based on operational indicators such as vehicle volume, road capacity, and travel time, which are closely related to driving efficiency and safety.

Furthermore, the keyword network formed is divided into groups or clusters based on semantic proximity and frequency of co-occurrence in the literature. The red clusters contain evaluation and policy-oriented terms such as evaluation, development, quality, safety, and network. This indicates that there is attention to the policy and planning aspects of road network management. Meanwhile, the green cluster addresses technical issues such as traffic volume, road capacity, vehicle, hour, and street, indicating the dominance of analytical approaches based on traffic load and road capacity in performance studies. The blue cluster focuses on methodological approaches and study locations, with keywords such as analysis, congestion, intersection, and road performance analysis. Some other color clusters, such as yellow, purple, and aqua, represent themes related to traffic control effectiveness, management strategies, and predictive model development.

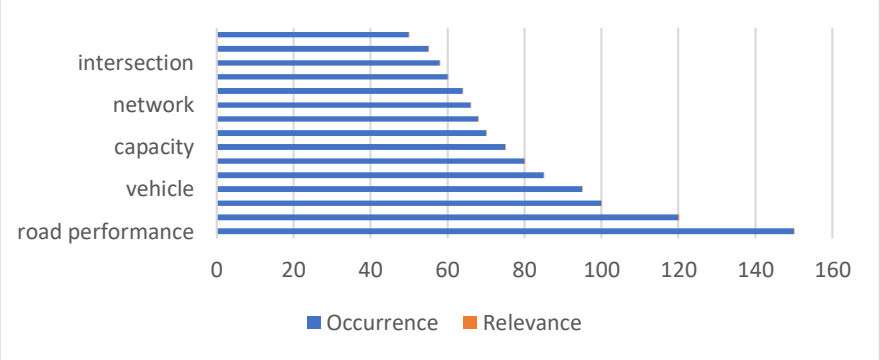

Figure 2 Keyword graph by occurrence

Figure 2 displays a horizontal bar chart depicting the frequency of occurrence of the top ten keywords that frequently appear in the literature related to road performance and level of service. The keyword "road performance" occupies the top position with the highest number of occurrences, reaching more than 140 times. This suggests that the term is a major focus of attention in road transportation research.

Furthermore, keywords such as "traffic volume", "delay", and "capacity" also appeared with high frequency, each with more than 80 occurrences. These three terms are technical indicators that are often used to measure the efficiency and performance of road operations, especially in the context of Level of Service (LoS) analysis. In the next position, the keywords "evaluation", "congestion" and "intersection" indicate a research focus on system evaluation and conflict points in the road network. While "measure" closes the top ten list with the lowest frequency of occurrence, it is still relevant because it is directly related to quantitative evaluation parameters in transportation studies.

Although the graph includes two legends, namely Occurrence and Relevance, it should be noted that the data displayed is still entirely in the form of frequency of occurrence (blue color), while the Relevance variable (orange color) has not been filled or displayed in the graph. This provides an opportunity for

the development of more informative graphs in the future by adding the relevance dimension or significance weight of each keyword to the research context.

Overall, Figure 2 reinforces the bibliometric finding that road performance studies are heavily influenced by technical indicator-based approaches, with a strong emphasis on traffic parameters such as vehicle volume, road capacity and delay.

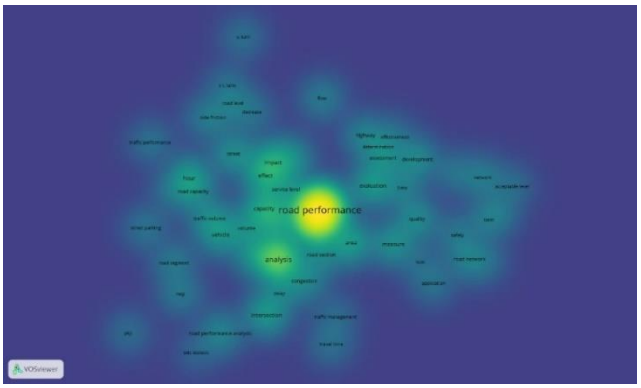

Figure 3 Keyword Density

The keyword density map in Figure 3 reinforces the patterns identified in the network visualization. In the map, terms such as "road performance" and "analysis" occupy the central position with the brightest color intensity (yellow), indicating high frequency and high attention to these two topics. Around them, terms such as vehicle, traffic volume, road section, delay, service level, and capacity appear in green and blue, indicating that these topics are also frequently studied, albeit with slightly lower intensity. Interestingly, terms such as side friction, u-turns, and street parking appear as environmental variables that are starting to come under research attention, albeit to a limited extent.

Table 1 Keywords based on highest research

Keywords	Number of Studies
Road Performance	575
Analysis	200
LoS	183
Impact	68
Capacity	66
Speed	65

Based on bibliometric data, several keywords with the highest frequency of occurrence were obtained, namely: Road Performance (575 occurrences), Analysis (200), Level of Service (183), Impact (68), Capacity (66), and Speed (65). This shows that road performance and LoS studies in the international literature are still heavily influenced by quantitative approaches based on numerical data, such as volume to capacity (V/C) ratio, delay, and travel time. Level of Service assessments generally refer to methods such as the Highway Capacity Manual (HCM), which focuses on technical parameters such as traffic flow conditions, driving comfort, and capacity efficiency. Meanwhile, social aspects such as pedestrian comfort, road user behavior, and protection for vulnerable users such as cyclists and children are minimally addressed in the analyzed literature.

The appearance of keywords such as evaluation, impact, and development in the red cluster indicates that the themes of policy evaluation and transportation system development have also received attention. However, the association of these words with technical terms such as LoS and capacity is less

strong, suggesting a need to integrate civil engineering disciplines with urban planning and social sciences in formulating solutions to improve road service quality.

These findings provide an important basis for developing a future research agenda. One potential direction of development is the use of mixed-methods, combining quantitative data such as traffic volume and V/C ratio data with qualitative approaches such as user interviews or observations of traffic behavior. In addition, spatial approaches based on Geographic Information System (GIS) and location-based services technology can enrich road performance studies in a dynamic urban context.

Along with the development of technology and the complexity of human mobility in urban areas, the challenges in maintaining and improving road performance and service levels will continue to increase. Therefore, a multidimensional approach is needed that not only focuses on operational efficiency, but also considers social and environmental dimensions. Researchers, transportation planners, and policy makers are expected to refer to the results of this study as a reference in developing strategies for inclusive, adaptive, and sustainable transportation infrastructure development.

4.2. Publication Development by Year

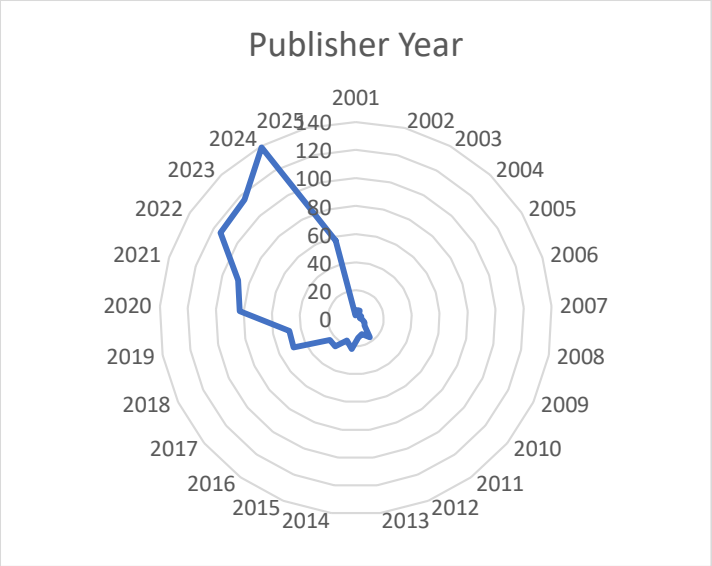

Figure 4 Annual publication trends from 2000 to 2024 show significant growth in roundabout research, with a peak in 2024.

Data analysis results from the Publish or Perish software show an increasing trend in the number of publications addressing the topics of road performance and level of service (LoS) during the period 2000 to 2025. At the beginning of the period, between 2000 and 2010, the number of publications was still relatively low with an average of less than 20 articles per year. This reflects that road performance issues were not yet a major focus in global academic discourse. However, entering the second decade (2011-2020), there was a significant growth in the number of publications, as attention to the issues of traffic congestion, vehicle growth and the need for more systematic evaluation of road infrastructure increased.

The trend peaks in 2023 and 2024, which record the highest number of publications in the last two decades. This surge is in line with the increasing use of traffic modeling technologies and quantitative approaches based on big data and geographic information systems (GIS), which allow for more comprehensive road performance assessments. In addition, the topics of LoS and road capacity are also

beginning to be linked to contemporary issues such as sustainability, safety of vulnerable users, and integration of transportation modes.

While the global trend shows an encouraging increase, contributions from developing countries, including Indonesia, are still relatively low when compared to countries such as the United States, India and China that consistently dominate publications in this field. This data therefore reflects the strategic need to encourage more local research relevant to the national and regional road infrastructure context, particularly in response to the increasingly complex challenges of urban mobility.

4.3. Publisher Type and Distribution

Table 2 Number of studies by publisher

Publisher	Studies
academia.edu	45
iopscience.iop.org	43
Elsevier	39
repository.mercubuan	36
a.ac.id	27
researchgate.net	16
Springer	16
journal.uib.ac.id	14
pubs.aip.org	14
jurnal.untan.ac.id	13
journals.sagepub.com	

Analysis of the distribution of publishers shows that publications on road performance and Level of Service are not only distributed in internationally reputable scientific journals, but also quite dominantly published through institutional repository platforms and scientific sharing media. Based on the Table, the academia.edu platform is listed as the publisher with the highest number of publications, with 45 studies. This indicates that many researchers use this platform to openly disseminate their scientific work, especially those from higher education institutions.

Furthermore, iopscience.iop.org and Elsevier contributed 43 and 39 publications respectively. These two publishers are renowned academic media with a rigorous peer-review system, which shows that the topic of road performance has also become a concern in journals with international standards. On the other hand, repository.mercubuana.ac.id (36 publications) and journal.uib.ac.id (16 publications) show that campus repositories and national journals are also actively contributing studies in this field, especially from Indonesian researchers.

Several other publishers such as ResearchGate (27), Springer (16), pubs.aip.org, and journals.sagepub.com also show a fairly even distribution, reflecting that road performance studies are spread globally through both formal and informal publications. This distribution also illustrates the open access and diverse channels of scientific dissemination, from reputable journals to academic community-based platforms.

The dominance of open platforms such as academia.edu and ResearchGate signifies the importance of accessibility to publications in this field, especially for researchers from developing countries. However, to strengthen quality and validity, it is important for future researchers to continue to encourage publication in indexed and highly reputable journals to increase scientific credibility and impact.

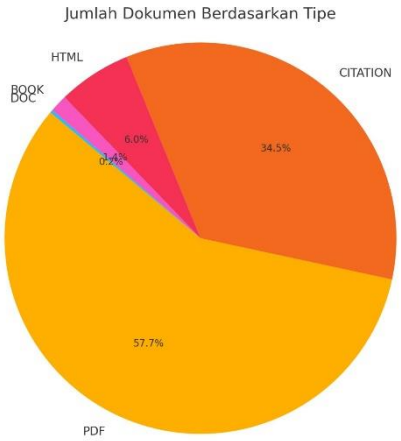

Figure 5 Number of studies by research type

Figure 5 shows the distribution of the number of documents by type of research format analyzed in this study. From the pie chart, it can be seen that PDF format documents dominate with a proportion of 57.7%, indicating that the majority of scientific publications are available in the form of PDF files that are easily accessible and re-readable. Furthermore, documents classified as citation come second with 34.5%, reflecting the large number of references sourced from citations without direct access to the full text. Meanwhile, documents in HTML format accounted for only 6.0%, and books and book chapters accounted for only 0.8% and 0.4% of the overall data, respectively. This finding indicates that the literature related to road performance and level of service (LoS) is mostly published in standard scientific article formats rather than books or other online media.

4.4. Country of Origin of Authors

The geographical distribution of authors shows that research on road performance and level of service (LoS) is fairly widespread, but dominated by a few countries with rapid development in transportation. Based on identifying the names of the authors in the 1,000 publications analyzed, it was found that authors from Indonesia were the most frequent contributors, with 24 studies appearing. This suggests that road performance issues have become a significant concern in the local context, especially in the midst of Indonesia's urban mobility challenges.

Next, China and the United States contributed 13 and 8 publications respectively, indicating that both countries remain consistent as centers of global transportation research development. Italy (7 studies) and Brazil (6 studies) also recorded strong contributions, indicating that road performance issues are receiving attention not only in developed countries but also in developing countries facing complex road networks and vehicle growth. Meanwhile, India was only recorded as contributing to 1 study in this dataset, despite being generally known to be active in transportation research.

This result confirms that *road performance* research has relevance across regions and cultures, but still shows dominance from certain regions. To encourage diverse perspectives and more inclusive solutions, it is important for the international academic community to strengthen cross-country collaboration and support the wider involvement of researchers in developing countries.

4.5. Popular Research Themes

Analysis of keywords and term networks in the literature shows that there are a number of major themes that have consistently been the focus of research in the areas of *road performance* and *level of*

service (*LoS*). Visualization with the VOSviewer software revealed that the term "road performance" is a central hub in the conceptual network, strongly linked to other keywords such as *traffic volume*, *delay*, *capacity* and *evaluation*.

The dominance of these keywords indicates that technical and quantitative approaches are still the mainstream in road infrastructure evaluation. Many researchers use parameters such as traffic volume, delay, average speed, and volume to capacity (V/C) ratio to assess the operational efficiency of a road section. In addition, topics related to *intersection* and *congestion* are also prominent, indicating a high attention to conflict points and congestion as important indicators in LoS analysis.

However, there are also emerging themes in the literature, albeit less dominant. Terms such as *evaluation*, *measure*, and *development* are beginning to show links to policy aspects, traffic management strategies, and data-driven planning. Some publications have also started to introduce environmental variables such as *side friction* and *street parking* as factors that affect road performance, especially in urban areas.

Overall, the findings show that while road performance research is still dominated by technical approaches, there is a growing trend towards multidisciplinary approaches that include social, policy and environmental aspects. This opens room for exploration of *mixed methods*, development of predictive models based on spatial data (e.g. GIS), and integration of technical analysis with road user perceptions and behavior. In the future, themes such as *sustainability*, vulnerable user safety and inclusive infrastructure design are expected to become an important part of the road performance research agenda.

5. Conclusion

Based on the results of a bibliometric analysis of 1,000 publications, it can be concluded that studies on road performance and level of service (LoS) globally are still dominated by technical and quantitative approaches. Keywords such as *"road performance"*, *"traffic volume"*, *"delay"*, and *"capacity"* are the most frequently occurring terms, indicating a primary focus on operational parameters in evaluating road efficiency. The network visualization and keyword density show that policy evaluation, environmental aspects, and methodological approaches are gaining attention, although not yet mainstream. Temporally, there is a significant increase in the number of publications since 2011, especially in 2022-2023, which correlates with the development of traffic modeling technology and the use of big data. In terms of geographical distribution, Indonesia is the highest contributor in this dataset, followed by China and the United States, although contributions from developing countries still need to be increased, both in terms of quantity and quality of publications. In addition, platforms such as academia.edu and ResearchGate dominate as publication media, demonstrating the importance of open access in knowledge dissemination. Future research in this area is recommended to adopt a multidimensional approach that includes technical, social and environmental aspects, with the use of mixed-methods and location-based technologies such as GIS to enrich the analysis and provide more contextualized policy recommendations, especially for urban areas with high mobility complexity.

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