

Application and Prospect of Simulation Software in Ocean Engineering Field based on Bibliometric Analysis

Rongjie Cai*

Guangdong Ocean University, Saint-Petersburg Institute for Shipbuilding & Marine Technology, Zhanjiang 524088, Guangdong, China

*13559208936@stu.gdou.edu.cn

Abstract

This study employs bibliometric analysis to evaluate the application and development trend of simulation software in the field of ocean engineering from 2004 to 2024. The analysis covers 1176 articles, involving software applications in platform design, corrosion analysis, education, and other aspects. The results show significant advancements in simulation technology, playing a crucial role in education reform, environmental protection, and engineering optimization. Global collaboration network analysis reveals the dominant positions of countries such as China and the United States. In the future, simulation software will face challenges such as improving accuracy and handling massive data, providing direction for technological innovation.

Keywords

Ocean Engineering; Simulation Software; Bibliometric Analysis; Technological Progress; Global Collaboration.

1. Introduction

Ocean engineering is a comprehensive technical field involving the development, utilization, and protection of the marine environment. With the advancement of computer technology, simulation software has become an indispensable tool in this field. Recent studies have shown that simulation technology exhibits great potential in platform design, education reform, material analysis, and other areas. However, integrating different simulation tools to adapt to complex environments remains a challenge. This study explores the current status, challenges, and development trends of simulation software in ocean engineering through bibliometric analysis, providing guidance for technological innovation.

2. Development History of Ocean Engineering Simulation Software

2.1 Early Development

The early development of ocean engineering simulation software reflects the complexity and multidisciplinary nature of the field. Hardware-in-the-loop technology provided an effective means for system testing, while global outsourcing influenced software development patterns. Simulation software played a crucial role in the design of ocean energy devices, extreme programming practices, and ecological research. Discrete event simulation and environmental flow assessment demonstrated their application value in various fields. As the offshore oil and gas industry developed, the importance of simulation software in improving efficiency and safety became increasingly prominent. In the future, simulation technology will continue to drive the sustainable development of ocean engineering[1-5].

2.2 Major Ocean Engineering Simulation Software and Their Evolution

The development of ocean engineering simulation software reflects the constantly changing industry demands. Abaqus and ANSYS, as general-purpose finite element software, excel in structural analysis and fluid dynamics. OrcaFlex focuses on the hydrodynamic analysis of offshore slender structures. SACS is widely used in offshore structural design. MOSES excels in floating body stability and offshore installation. HydroStar plays a crucial role in ship wave resistance research. OpenFOAM and STAR-CCM+ provide open-source and commercial solutions for complex fluid dynamics problems. The continuous development of these software drives the advancement of ocean engineering technology.

2.3 Technological Progress and Innovation

The development of ocean engineering simulation software stems from technological progress and innovation. Enhanced computing capabilities and improved numerical algorithms have driven revolutionary changes in simulation technology. ANSYS AQWA focuses on hydrodynamic analysis, Abaqus Aqua excels in complex structural analysis, and Fluent stands out in the CFD field. OpenFOAM provides a flexible simulation environment as an open-source tool, while STAR-CCM+ introduces advanced turbulence models and mesh technology[6-9]. The development of these software reflects the demand for more accurate and efficient simulation tools in the ocean engineering field, driving industry technological progress.

2.4 Case Studies and Application Examples

Ocean engineering simulation software is widely used in research and engineering design. Digital twin technology improves system efficiency and predictive capabilities. Neural networks like PyEff-U-Net are used for real-time stress field prediction, which is significant for structural health monitoring. Structural optimization techniques improve device performance and reliability. High-performance computing displays enormous potential in handling complex models. OpenFOAM is used to simulate ocean platform fluid dynamics and ship design. STAR-CCM+ is applied to ship optimization and ocean renewable energy device development. Fluent is used to analyze offshore drilling platforms and ship performance. In the future, simulation software will increasingly integrate digital twin, artificial intelligence, and high-performance computing technologies to enhance predictive and problem-solving capabilities[10-16]. Strengthening international cooperation and interdisciplinary research will further drive innovation and application.

3. Methods

3.1 Data Source and Retrieval

This study retrieved literature data from the Web of Science (WOS) using the Science Citation Index Expanded (SCIE) and Social Sciences Citation Index (SSCI). The retrieval time span was from January 1, 2004, to March 1, 2024, with the literature type limited to articles and reviews, and the language set to English. The retrieval strategy employed specific keyword combinations, including various simulation software names and "ocean engineering". This ensured that the retrieval results were highly relevant to the research topic. The retrieval results were exported and saved in plain text format from the Web of Science, preparing for subsequent analysis. This comprehensive and precise literature retrieval method provided a reliable data foundation for the research, helping to gain an in-depth understanding of the development trends of ocean engineering simulation software[17].

3.2 Data Collection and Processing

This study downloaded 1176 articles that met the screening criteria from the WoSCC on March 1, 2024. Choosing a fixed date for retrieval helped reduce errors caused by database updates, ensuring that the data reflected the research landscape of a specific period. The study used R software version 4.2.1 and the "bibliometrix package 4.0.1" for bibliometric analysis and data collection. After data import, a systematic integrity check and cleaning were performed to ensure analysis quality[18]. Key information such as title, author, and year was imported into Microsoft Office Excel (2019 version)

for storage. Figure 1 shows the flow diagram of the executed procedures for bibliometric review, clearly presenting the steps from data collection to analysis. This rigorous data processing method laid a solid foundation for subsequent in-depth analysis.

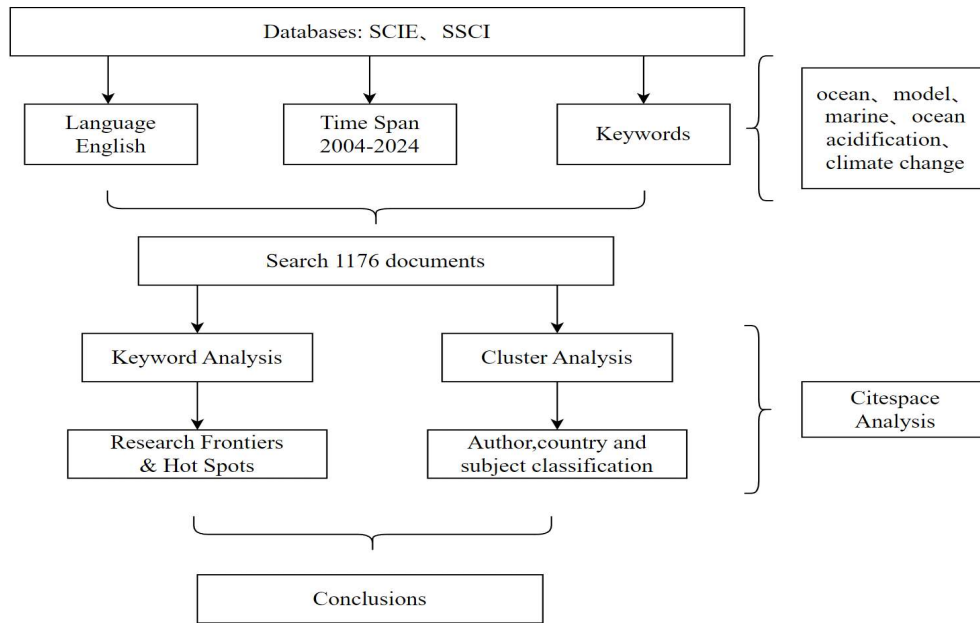


Figure 1. The flow diagram of the executed procedures for bibliometric review

3.3 Bibliometric Analysis

In bibliometric analysis, scientific mapping and visualization analysis play a crucial role in intuitively displaying research results. To this end, the research team employed multiple software tools for in-depth analysis. R software was used to statistically analyze the number of publications by authors, organizations, and countries. Excel software accurately calculated the annual publication ratio, total citations, and average citations. Citespace (version 6.1.R6) performed citation visualization analysis, revealing the intrinsic connections of scientific literature, and displaying research hotspots and evolution trends. VOSviewer (version 1.6.18) was used to construct and view bibliometric maps, analyzing bibliometric networks. Through these tools, the study successfully constructed a visualized coupling network of journals, countries, co-authors, and keywords, identified citation burst data, and drew visualized maps[19-23]. This multi-software combination method provided powerful support for comprehensively and deeply understanding the trends and hotspots of the research field.

4. Results

4.1 Distribution of Literature

The retrieval strategy obtained 1176 articles that met the conditions, published from 2004 to 2024. As shown in Figure 2, the number of articles presents two growth stages: slow growth from 2000 to 2016 and a significant increase from 2017 to 2023. The most articles were published in 2023, with 185 articles and a total of 6333 citations. Figure 2 shows the distribution trend of publication years and citation years. According to WOS statistics, the top 10 most cited articles are shown in Figure 3. Among them, Mirjalili, S (2017), Duarte, CM (2013), and Faramarzi, A (2020) were cited 2872, 1157, and 1109 times, respectively, ranking in the top three[24]. These highly cited articles reflect the important research results and hot topics in the field, providing important references for subsequent research.

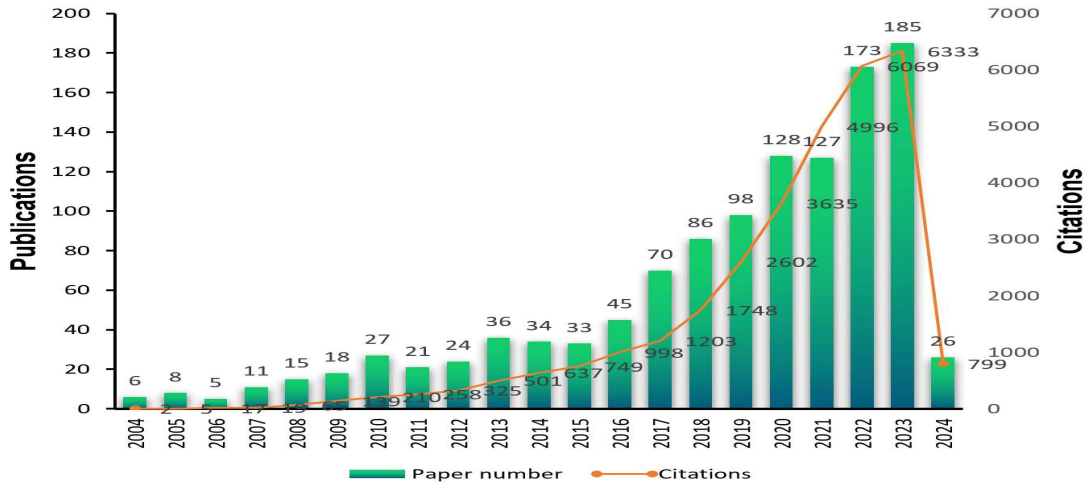


Figure 2. Distribution trend of publication years and citation years

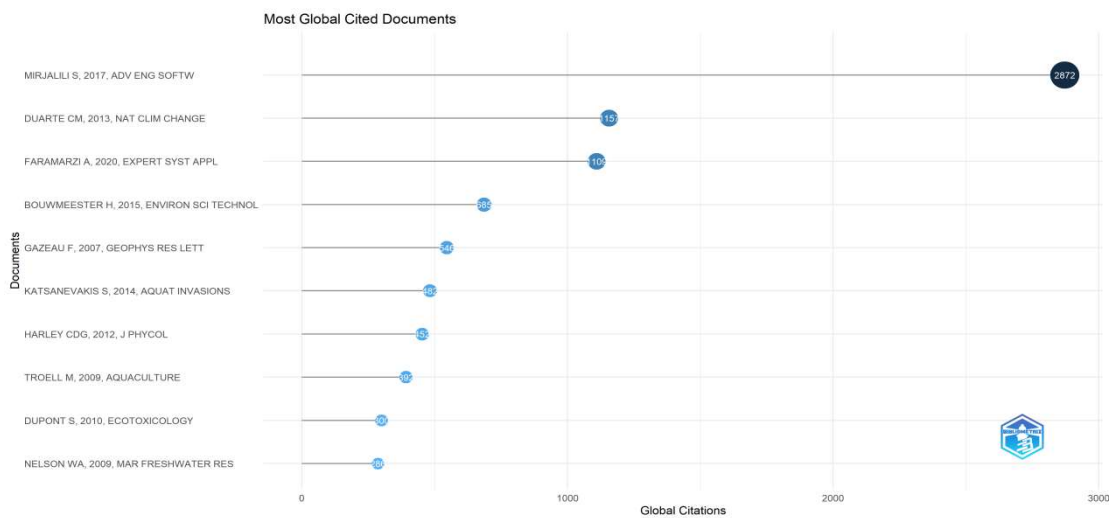


Figure 3. Top 10 most cited articles

4.2 Visualization Analysis of Keyword Co-occurrence

The keywords of an article can represent the theme and main viewpoints of the article. By constructing a graph of repeated occurrences of keywords, we can describe the research hotspots and trends in this field. Using VOSviewer to perform a visual analysis of keywords that appear 10 times or more, we obtained 111 keywords. The top five most frequently used keywords are "ocean", "model", "marine", "ocean acidification", and "climate change". The keywords are divided into four color groups, representing different clusters. Most of the keywords appeared relatively late (after 2017), and the average appearance time of the top five most frequently used keywords is around 2019. Some early keywords have not been used in recent years, while the emergence of new keywords such as "coastal infrastructure", "machine learning", and "eco-engineering" represents new research directions. Simulation software plays an important role in ocean engineering research, and its development trend is reflected in the changes of keywords[25-31]. The keyword "ocean model" is associated with the application of ocean dynamics simulation software such as ROMS and COHERENS. The keyword "climate change" is related to the use of OAPS software, which is used to simulate the long-term impact of climate change on ocean systems. The growth of the keyword "coastal infrastructure" reflects the importance of structural simulation software such as ANSYS and ABAQUS in coastal construction planning. The emergence of the keyword "machine learning" reflects the application of AI tools such as TensorFlow and PyTorch in optimizing design and predicting system behavior. The keyword "eco-engineering" reflects the increasing use of ecosystem

modeling software such as EwE in evaluating the impact of human activities and designing sustainable solutions.

4.3 Journal Analysis

This study drew a visualization map of the participating journals (Figures 4), where the size of the circle represents the number of published articles. The top three journals with the most published articles on ocean-related simulation software are Ocean Engineering, Journal of Marine Science and Engineering, and Frontiers in Marine Science, showing significant influence. The participating journals are mostly specialized ocean science journals, which frequently cite each other but have weaker citation relationships with other journals. These journals play an important role in promoting different simulation tools[32-34]. Ocean Engineering often publishes fluid dynamics simulation research using CFD software such as Star-CCM+ or OpenFOAM. Journal of Marine Science and Engineering focuses on introducing the application of structural analysis and design tools such as ANSYS or Abaqus. Frontiers in Marine Science tends to publish research on environmental impact assessment using ecological modeling software such as AquaSim or EcoWin. The citation relationships between journals indicate that simulation software-related articles have a professional focus. Although there are cross-journal citations, articles on specialized tools such as ocean dynamics simulation, structural stress analysis, or ecosystem modeling are mostly published in renowned specialized journals in their respective fields. This trend suggests that journals may form informal alliances with specific simulation software, providing a reference for researchers to choose publication channels[35].

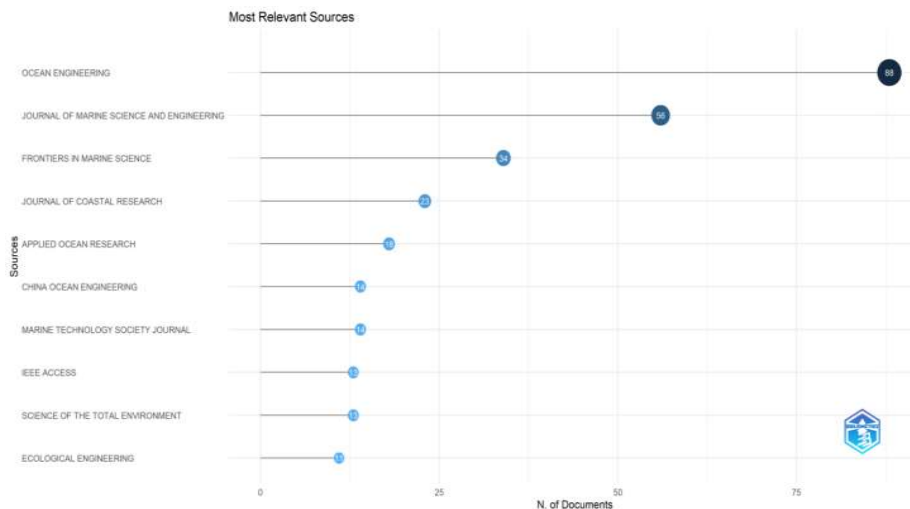


Figure 4. Top 10 most relevant journals

4.4 National Collaboration Analysis

This study conducted a visualization network analysis of the 79 countries involved in the 1176 papers (Figures 5). China had the most publications (446 papers, 5570 citations), followed by the United States (268 papers, 12518 citations), the United Kingdom (156 papers, 4604 citations), and Australia (106 papers, 8471 citations). The United States and Australia had higher average citation rates, indicating a larger number of high-quality articles[36-37]. Collaboration was mainly concentrated around China and the United States, with developed countries at the center. Most countries had multiple international collaborations, but collaboration between other countries was relatively weak. China was active in ocean engineering simulation technology research, particularly in the application of CFD, with a high citation rate. The United States focused on advanced simulation technologies, such as high-fidelity models combined with machine learning, with software like STAR-CCM+ and ANSYS Fluent frequently appearing in international collaborations. The United Kingdom had significant achievements in ocean ecosystem simulation (e.g., EwE software), while

Australia excelled in ocean renewable energy simulation (e.g., WEC models). The international collaboration network analysis showed that developed countries were leading the development of ocean engineering simulation software, with multiple countries collaborating on software development and application innovation. Meanwhile, developing countries showed growth potential in specific simulation software applications, particularly in environmental protection and ocean resource management.

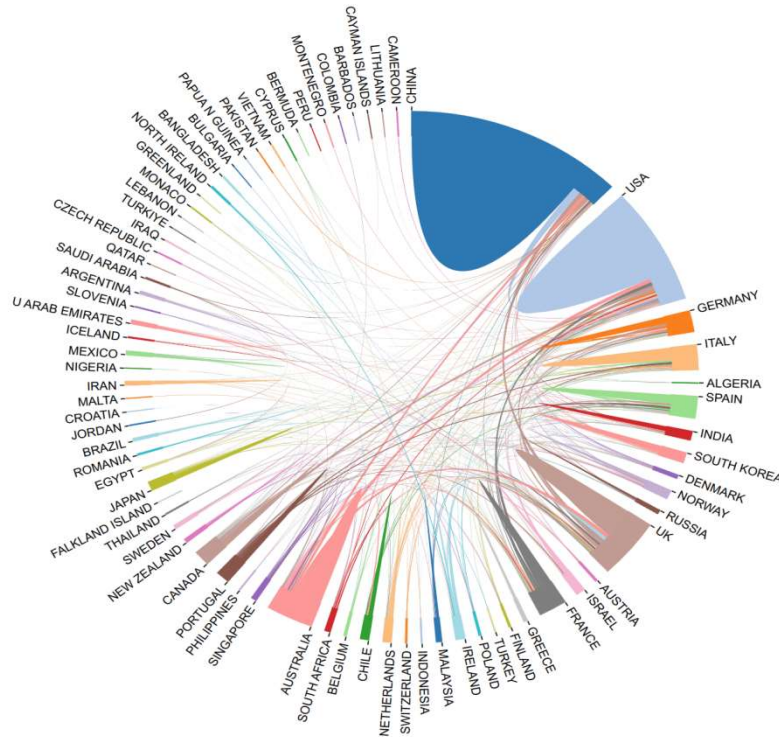


Figure 5. Chord diagram of national collaboration

4.5 Research Hotspots and Development Trends Analysis

The impact of environmental changes on ocean engineering is becoming increasingly significant, as reflected by the sudden increase in citations of keywords such as "climate change", "sea level rise", and "ocean sprawl". Simulation software needs to simulate the impact of climate change on ocean structures, including the threats of temperature fluctuations and sea level rise to coastal infrastructure. Software such as HSP and Coastal Simulation Models is becoming increasingly accurate and complex in addressing these issues, evolving from simple hydrodynamic models to comprehensive climate models that can predict the long-term impact of sea level rise. Biodiversity and ecosystem services are receiving increasing attention, with keywords such as "biodiversity", "ecosystem services", and "habitats" highlighting the need for software that can simulate natural environments and biological communities. Tools such as EMS and BioVeL have made breakthroughs in simulating ecosystem dynamics, enabling the comprehensive consideration of multiple pressure factors. The emergence of keywords such as "machine learning", "optimization", and "numerical simulation" indicates that ocean engineering simulation software is trending towards intelligence[38]. The application of MLAs in software such as Ansys and OpenFOAM has improved the accuracy and efficiency of simulations. Meanwhile, the strengths of different simulation software are becoming increasingly apparent, such as Abaqus in structural analysis and Star-CCM+ in fluid dynamics, prompting researchers to consider the specific functions and simulation intensity of software when making choices. As shown in Figure 6.

Top 25 Keywords with the Strongest Citation Bursts

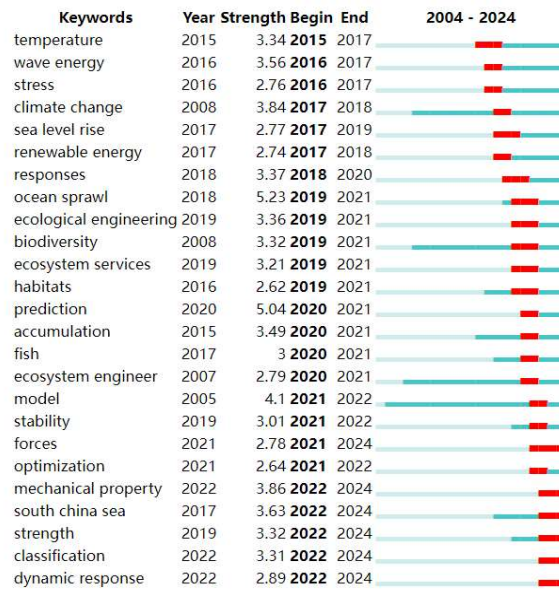


Figure 6. Research frontier analysis diagram

4.6 Organizational Analysis

We performed a network visualization analysis of the institutions involved in publishing articles using VOSViewer software. We set the minimum collaboration frequency to 5 times and constructed a collaborative relationship between 120 organizations. Among them, there are more collaborations with Ocean University of China, Chinese Academy of Sciences, and University of Essex, and most of them are comprehensive universities. Most institutions maintain a stable group collaborative research pattern, and there are fewer collaborations between transnational organizations[39]. Figure 7 shows the top 10 most relevant institutions, which are not limited to the institutions of the first author and corresponding author. The institution with the most publications is the French National Center for Scientific Research (72 articles), followed by the University of California in the United States (50 articles) and the Chinese Academy of Sciences (39 articles).

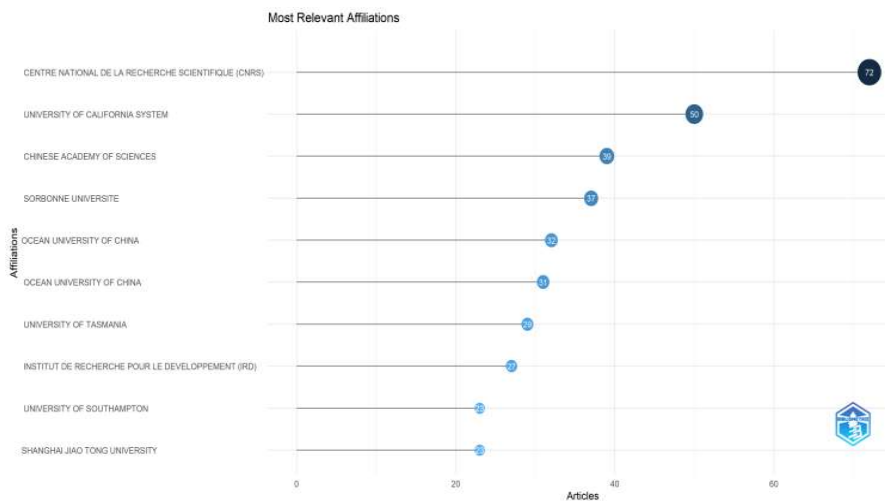


Figure 7. Top 10 most relevant institutions

4.7 Author Analysis

Through data calculation, we constructed a co-authorship network of authors who have published more than 3 papers and have close collaborations, involving 110 authors. It can be seen that the

collaborations between authors are mainly in the form of groups, and these authors mainly collaborate with each other within institutions, with relatively few cross-institutional collaborations. Figure 8 shows the top 10 most relevant authors, most of whom are researchers in the field of ocean science. These authors have participated in publishing relatively few papers, with most having fewer than 10 papers[40]. The author who has made the greatest contribution is Professor FIRTH LB, who has participated in publishing 13 papers.

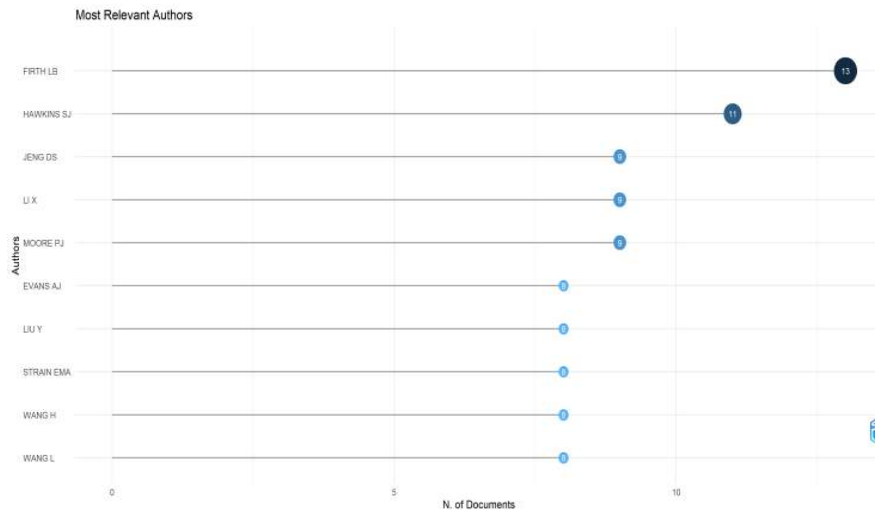


Figure 8. Top 10 most relevant authors

5. Conclusion

This study explores the application and development prospects of simulation software in the field of ocean engineering based on bibliometric analysis. The results show that the application of simulation software in ocean engineering has increased significantly in recent years, with technological advancements and expanding application ranges covering multiple aspects, from gear box temperature field simulation to complex ocean structure corrosion fatigue simulation. Global cooperation and knowledge sharing have played an important role in promoting the development of simulation software, particularly in the collaborative research efforts of countries such as China, the United States, European nations, and Australia. In the future, with the development of computer technology, artificial intelligence, and big data, simulation software is expected to achieve a qualitative leap in performance and application scope. However, issues such as handling massive data, ensuring the accuracy and reliability of simulation results, and improving software user-friendliness and interoperability remain key concerns that require attention in future research.

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