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# Fishing Vessel Risk and Safety Analysis: A Bibliometric Analysis, Clusters Review and Future Research Directions

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**Abstract:** This study conducts a bibliometric analysis to evaluate the current research landscape and identify future directions in fishing vessel safety. Using the Scopus database, 285 relevant documents were collected and analyzed using the Biblioshiny app version 4.1 in the bibliometrix R package and VOSviewer version 1.6.20. The analysis generated an authors' collaboration network, a three-field plot, and a keyword Thematic map, which were used for citation analysis, while VOSviewer was utilized to build networks between journals, articles, affiliations, countries, and keywords, enabling bibliographic coupling. The results identified four primary research clusters: *Accident/Risk Analysis*, *Human Errors*, *Stability*, and *Operation*. A detailed review of selected studies within these clusters was conducted, focusing on accident and risk factors, analytical methods, their strengths and weaknesses, and potential improvements. Based on these findings, a discussion was provided on future research directions in fishing vessel safety. The results suggest that future research should prioritize the integration of advanced technologies, enhancement of real-time monitoring capabilities, and promotion of international collaboration to ensure the safety of fishermen in hazardous environments.

**Keywords:** fishing vessel; safety; risk analysis; risk assessment; accident analysis; stability; human error; bibliometric; bibliographic; literature review

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**Citation:** Lee, S.H.; Kim, H.; Kwon, S. Fishing Vessel Risk and Safety Analysis: A Bibliometric Analysis, Clusters Review and Future Research Directions. *Appl. Sci.* **2024**, *14*, 10439. https://doi.org/10.3390/app142210439

Academic Editors: Grzegorz Karoń, Igal Shohet, Ayeley Tchangani, Andrea Maternová, Andrej Dávid, Nermin Hasanspahic and Lucia Švábová

Received: 2 October 2024
Revised: 6 November 2024
Accepted: 7 November 2024
Published: 13 November 2024

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## 1. Introduction

### 1.1. Background

Capture fisheries are of paramount importance to numerous coastal communities around the world, playing a key role in promoting local economic development, generating employment, and ensuring food security. Currently, it is estimated that over 39 million individuals are engaged in this sector globally. Additionally, the seafood trade has emerged as one of the most dynamic industries, with approximately 38% of global fish production involved in international commerce (FAO et al., 2020 [1]). Over the years, the significance of fisheries has continued to rise, with fish production, including aquaculture and capture fisheries, witnessing steady growth—from 19 million tons in the 1950s to 97 million in 1997, and further increasing to 178 million tons by 2020. This rising production underscores the growing importance of fisheries in the global economy and food systems (ILO, 2024 [2]).

However, fishing remains one of the most dangerous occupations, with a high fatality rate of approximately 80 deaths per 100,000 fishers (Wang et al., 2023 [3]). This high mortality rate highlights the critical need to address the safety and health of fishers. Efforts to establish international safety regulations for the fishing sector have been ongoing for decades, but the diverse range of vessel sizes, fishing practices, regions, and countries poses significant challenges to developing universal safety standards that can be applied across the board.

Fishing vessel accidents arise from a variety of risk factors, which can be broadly classified into natural, human, mechanical, and design-related causes. Natural factors

include rough seas and severe weather conditions, while human factors often involve errors, fatigue, or negligence. Mechanical issues, such as equipment failure or malfunction, also pose significant risks. Design-related factors, such as inadequate vessel principal particulars or designs that violate regulatory standards, further contribute to the likelihood of accidents. These various risk factors can result in injuries, casualties, vessel damage, and even capsizing, leading to both personal and economic losses. As a result, there has been increasing attention on research aimed at analyzing these risk factors and developing methodologies for accident prevention.

### 1.2. International Efforts

From the past, international organizations, such as the Food and Agriculture Organization of the United Nations (FAO), the International Maritime Organization (IMO), and the International Labour Organization (ILO), have been involved in developing regulations to improve safety of fishing vessels at sea. The need for fishing vessel safety was first recognized by the FAO in the 1950s. In the 1960s, the organizations collaborated to create the *Code of Safety for Fishermen and Fishing Vessels*, with Part A addressing basic health and safety practices in 1968, and Part B outlining construction and equipment standards for vessels over 24 m in 1974. This initiative was followed by the completion of the *Voluntary Guidelines for the Design and Equipment of Small Fishing Vessels* in 1982. In 1993, the adoption of the Torremolinos International Convention for the Safety of Fishing Vessels prompted a review of these safety standards. Consequently, the IMO, in cooperation with the FAO and ILO, undertook a thorough revision of both the Code and the Voluntary Guidelines. These revised texts were approved by the IMO's Maritime Safety Committee (MSC) in 2004 and subsequently endorsed by both the FAO and ILO in 2005. In 2012, the International Maritime Organization (IMO) adopted the International Convention on Standards of Training, Certification and Watchkeeping for Fishing Vessel Personnel (STCW-F) Convention, strengthening training and certification standards for crew on fishing vessels over 24 m. Additionally, in 2012, the Cape Town Agreement was introduced, setting minimum global safety standards for the construction and operation of vessels of the same size. Most of the regulations currently being enforced, including both initiatives, apply to fishing vessels over 24 m in length. Recognizing the need for more comprehensive regulations, particularly for smaller vessels, the ILO introduced the Work in Fishing Convention (C188) in 2007. This convention established minimum requirements for working conditions aboard all fishing vessels, covering areas such as medical certification, crew accommodations, and occupational safety. Most of the regulations that are being enforced to date, including both initiatives, apply to fishing vessels over 24 m in length (IMO, 2014 [4]).

However, a significant proportion of fishing vessel accidents involve small vessels under 12 m in length, which are particularly vulnerable to rough weather. Their open decks and low stability further increase the risk of accidents (Santiago Caamaño et al., 2019 [5]; Gudmundsson, 2013 [6]). In 2010, the IMO, FAO, and ILO jointly developed the *Safety Recommendations for Decked Fishing Vessels of Less than 12 Meters in Length and Undecked Fishing Vessels* to address the accidents associated with small vessels. These recommendations, which cover vessel design, equipment, crew training, and safety management, remain voluntary guidelines rather than binding international regulations, leaving enforcement primarily to national authorities (IMO, 2014 [4]).

Efforts to establish international regulations for fishing vessel safety continue, but the diversity in vessel types, fishing practices, and regional conditions makes it challenging to create comprehensive regulations that can apply universally. As a result, developing a one-size-fits-all framework for fishing vessel safety remains a complex task.

### 1.3. Research Objective

As mentioned earlier, efforts to enhance fishing vessel safety are ongoing, but considering the multitude of factors and circumstances involved remains a challenge. Nevertheless,

numerous studies have been conducted to prevent fishing vessel accidents, each employing different methods to analyze risks and propose preventive strategies.

The purpose of this study is to review research trends and future directions in fishing vessel safety and risk analysis related to accidents occurring across various vessel types and environmental conditions. Using the bibliometric method, referred to as "bibliometric analysis", this study aims to explore research trends in the field of fishing vessel safety, and identify influential authors, publications, institutions, and countries. Furthermore, through keyword clustering of frequently mentioned terms, the research themes are categorized based on the risk factors and methodologies associated with fishing vessel accidents. Each theme's analytical methods and their strengths and weaknesses are reviewed to provide a comprehensive understanding. The ultimate goal is to present recent ideas and propose future research directions in fishing vessel safety based on the findings from the detailed review of each cluster.

The structure of this study is as follows: Section 2 introduces the Research methodology, Section 3 presents the Analysis of Bibliometric and Bibliographic Data, Section 4 provides the Results: Review of Research Clusters, Section 5 discusses the Discussion: Future Work, and Section 6 concludes.

## 2. Research Methodology

### 2.1. Bibliometric Analysis

Within this research, a bibliometric analysis was conducted to examine the risk factors and preventive measures related to fishing vessel safety. The foundation for structured research programs in bibliometrics was laid in the early 1960s with the development of the science citation index (Garfield, 1955 [7]) and the citation network analysis (Price, 1965 [8]). The bibliometric method analyzes various data related to publications, researchers, and institutions within a specific academic field to identify research trends, collaboration networks, and knowledge structures. This method involves examining citation relationships between papers, co-authorship networks, and research keywords, creating a visual representation of the intellectual development and flow within the field. Through this analysis, key research topics and collaboration patterns among researchers are identified, and the evolution and trends of the research area can be explored.

In this study, the bibliometric analysis was performed through five steps as shown in Figure 1:

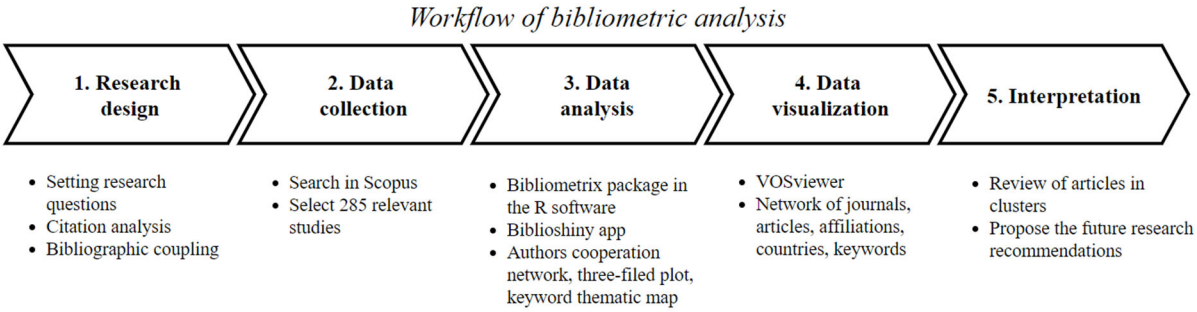


**Figure 1.** Workflow of bibliometric analysis in this study.

### 2.2. Research Design

In the research design phase, it is crucial for the researchers to clearly define the specific research questions they aim to address. This is the first step in determining the direction of the study, as the research questions will guide the selection of appropriate bibliometric methods. For example, if the goal is to identify which researchers or papers have had the greatest impact in a particular field, 'Citation analysis' is used. To analyze the intellectual structure of a specific field, 'Co-citation analysis' or 'Bibliographic coupling' are chosen. In this phase, the research field or set of papers to be analyzed is also determined,

along with the specific time period or geographic region to be studied (Zupic and Čater, 2015 [9]).

In this study, citation analysis was selected to observe trends in fishing vessel safety research, as well as to identify influential papers, journals, authors, institutions, and countries. As part of the network analysis, a three-field plot for journal, keyword, and country was derived. Additionally, bibliographic coupling was chosen to cluster keywords related to fishing vessel safety.

### 2.3. Data Collection

In the data collection phase, relevant research papers are retrieved based on the defined research questions. The data are sourced from bibliographic databases such as Web of Science, Scopus, and Google Scholar. Researchers filter and select papers of interest using search terms, keywords, journal names, and other criteria. Bibliographic information, such as the paper's title, author, citation count, reference list, journal name, keywords, and abstract, is collected, along with citation data, which is essential for bibliographic coupling or co-citation analysis. In this phase, it is important to establish clear parameters for data collection to define the scope of the analysis accurately.

For this work, bibliometric data were collected in September 2024 using Scopus, and Boolean syntax was utilized to create query strings, as shown in Table 1, to select relevant academic literature. The final query string included hazard-related keywords (hazard* OR safe* OR risk* OR accident* OR error*) and analysis-related keywords (analys* OR manage* OR assess* OR method* OR probab* OR factor* OR stud*) within the title, abstract, and keyword fields. To exclude biology-related papers, terms such as (bio* OR bird* OR hunt* OR animal*) were omitted. Furthermore, to specifically focus on fishing vessels, terms like (fishing AND (vessel* OR ship* OR boat* OR fleet*)) were included in the title. As a result, a total of 312 publications were identified, of which 27 were non-English papers. This study chose to include only English-language publications, as it was determined that the non-English papers would not significantly impact the overall trends of the final results. Consequently, a total of 285 papers related to fishing vessel safety were selected for the analysis. The results consist of 197 articles, 78 conference papers, 5 chapters, 4 reviews, and 1 book.

**Table 1.** Literature search in Scopus.

| Step | Advanced Query in Scopus | No. of Articles |
|---|---|---|
| 1 | TITLE-ABS-KEY (fishing* AND vessel*) | 8425 |
| 2 | TITLE-ABS-KEY ((fishing* AND (vessel* OR fleet* OR boat*))) | 14,012 |
| 3 | TITLE-ABS-KEY ((fishing* AND (vessel* OR fleet* OR boat*)) AND (risk*)) | 1212 |
| 4 | TITLE-ABS-KEY ((fishing* AND (vessel* OR fleet* OR boat*)) AND (risk* OR accident*)) | 1509 |
| 5 | TITLE-ABS-KEY ((fishing AND (vessel* OR fleet* OR boat*)) AND (risk* OR accident*) AND (management* OR assessment*)) | 810 |
| 6 | (TITLE-ABS-KEY ((hazard* OR safe* OR risk* OR accident* OR error*)) AND TITLE (fishing AND (vessel* OR ship* OR boat* OR fleet*))) | 414 |
| 7 | (TITLE-ABS-KEY ((hazard* OR safe* OR risk* OR accident* OR error*)) AND TITLE-ABS-KEY ((analys* OR method*)) AND TITLE (fishing AND (vessel* OR ship* OR boat* OR fleet*))) | 266 |
| 8 | (TITLE-ABS-KEY ((hazard* OR safe* OR risk* OR accident* OR error*)) AND TITLE-ABS-KEY ((analys* OR manage* OR assess* OR method* OR probab* OR factor* OR stud*)) AND TITLE (fishing AND (vessel* OR ship* OR boat* OR fleet*))) | 358 |

**Table 1.** *Cont.*

| Step | Advanced Query in Scopus | No. of Articles |
|---|---|---|
| 9 | (TITLE-ABS-KEY((hazard* OR safe* OR risk* OR accident* OR error*) AND NOT (bio* OR bird* OR hunt* OR animal*)) AND TITLE-ABS-KEY ((analys* OR manage* OR assess* OR method* OR probab* OR factor* OR stud*)) AND TITLE (fishing AND (vessel* OR ship* OR boat* OR fleet*))) | 312 |
| 10 | (TITLE-ABS-KEY((hazard* OR safe* OR risk* OR accident* OR error*) AND NOT (bio* OR bird* OR hunt* OR animal*)) AND TITLE-ABS-KEY ((analys* OR manage* OR assess* OR method* OR probab* OR factor* OR stud*)) AND TITLE (fishing AND (vessel* OR ship* OR boat* OR fleet*))) AND (LIMIT-TO (LANGUAGE, "English")) | 285 |

### 2.4. Data Analysis

In this phase, the collected data were analyzed using various bibliometric techniques to identify relationships within the data. Several software tools have been developed for bibliometric analysis, including Bibexcel (Persson et al., 2009 [9]), CiteSpace (Chen, 2006 [10]), and the Science of Science (Sci2) tool (Sci2 Team, 2009 [11]).

For this study, the bibliometrix package in the R software (Aria and Cuccurullo, 2017 [12]) was used. It is built in R, an open-source language, and is preferred for its statistical algorithms, numerical methods, and data visualization features. Additionally, the Biblioshiny app version 4.1, included in the bibliometrix package, was utilized to perform bibliometric analysis without the need for coding. Through this app, an analysis of the authors' cooperation network, a three-field plot, and keyword clustering was conducted.

### 2.5. Data Visualization

In the visualization phase, a science map is generated based on the analysed data. This map visually represents papers, authors, and keywords in the form of a network, allowing for a comprehensive view of the structure and key trends within the research field. For instance, co-author analysis illustrates the collaboration network among researchers, while co-citation analysis reveals the extent to which specific research topics or authors are interconnected. This visualization helps to identify major clusters, key researchers, and the relationships between different areas of the research field more easily. Visualization software, such as Pajek and VOSviewer, is commonly used for this purpose.

In this study, VOSviewer version 1.6.20 was used to visualize networks of journals, articles, affiliations, countries, and keywords. Each network symbol was color-coded by year, allowing the identification of both the influence and the periods of active research.

### 2.6. Interpretation

Finally, in the interpretation phase, the visualized science maps and analysis results are used to interpret trends and major topics within the research field. This step helps reveal key figures, influential papers, and the connections between research topics, while also identifying gaps or emerging areas of research. Based on the interpretation, future research directions are proposed, offering practical recommendations for researchers (Zupic and Čater, 2015 [13]).

In the current study, the results obtained from Biblioshiny app version 4.1 and VOSviewer version 1.6.20 were used to analyze trends in fishing vessel safety research and to categorize similar research topics into clusters. Each cluster was reviewed in terms of accident analysis methods and the preventive measures proposed. Through this analysis, the strengths and weaknesses of different interpretation methods were examined, and suggestions for future research directions were provided.

## 3. Results I—Analysis of Bibliometric and Bibliographic Data

### *3.1. Documents by Year*

The trend analysis shows that the number of publications related to fishing vessel safety has steadily increased over the years. Figure 2 illustrates the distribution of documents by year, with a noticeable rise in publications over the past decade. This increase reflects growing attention to fishing vessel safety and risk management. In addition, although the number of studies in 2024 is currently lower than in 2023 as of September 2024, the trendline suggests that the number of related studies is expected to continue increasing.

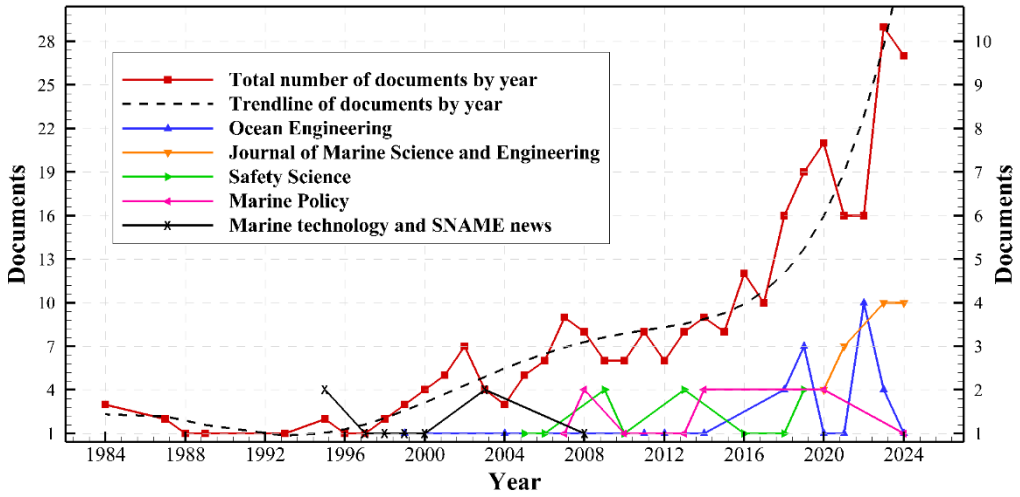


**Figure 2.** Number of annual literary works related to fishing vessel safety.

### *3.2. Sources (Journals)*

In terms of publication sources, several journals have emerged as major contributors to the field of fishing vessel safety research. Figure 3 shows a network visualization of the most relevant journals using VOSviewer, where the size of each symbol is proportional to the number of published articles. The color of each symbol represents the average publication year of the respective journals, indicating the timeline of research development. The interconnectivity among most sources suggests that research papers on fishing vessel safety are closely referenced and interrelated, reflecting the collaborative feature of this field. Additionally, the presence of conference proceedings in the network indicates that academic presentations are also significant in this research domain. Notably, these include proceedings from the *IOP (Institute of Physics)* conferences, which focus on science and engineering fields, and the *OMAE (International Conference on Ocean, Offshore and Arctic Engineering*), which emphasizes marine, offshore, and Arctic engineering. This presence suggests that research on fishing vessel safety is being actively disseminated and discussed in both journal and conference settings.

The analysis indicates that *Ocean Engineering* has the highest concentration of related articles. As shown in Figure 4, this journal has published a total of 19 articles, making it the leading source in the field. This is followed by the *Journal of Marine Science and Engineering (JMSE)*, *Safety Science*, and *Marine Policy*, with 13, 11, and 10 articles, respectively, indicating that these journals are also significant contributors to research on fishing vessel safety. The color of the symbols of Figure 3 suggests that these sources have published relatively recent articles, reflecting the publication trend shown in Figure 2. Notably, all *JMSE* publications were produced after 2020. Meanwhile, *Marine Technology and SNAME News*, published by the Society of Naval Architects and Marine Engineers (SNAME), was an active contributor to fishing vessel safety research in earlier years but, as illustrated in Figure 2, has not published any relevant articles since 2008. This journal primarily focuses on research and industry trends related to marine technology and naval engineering.

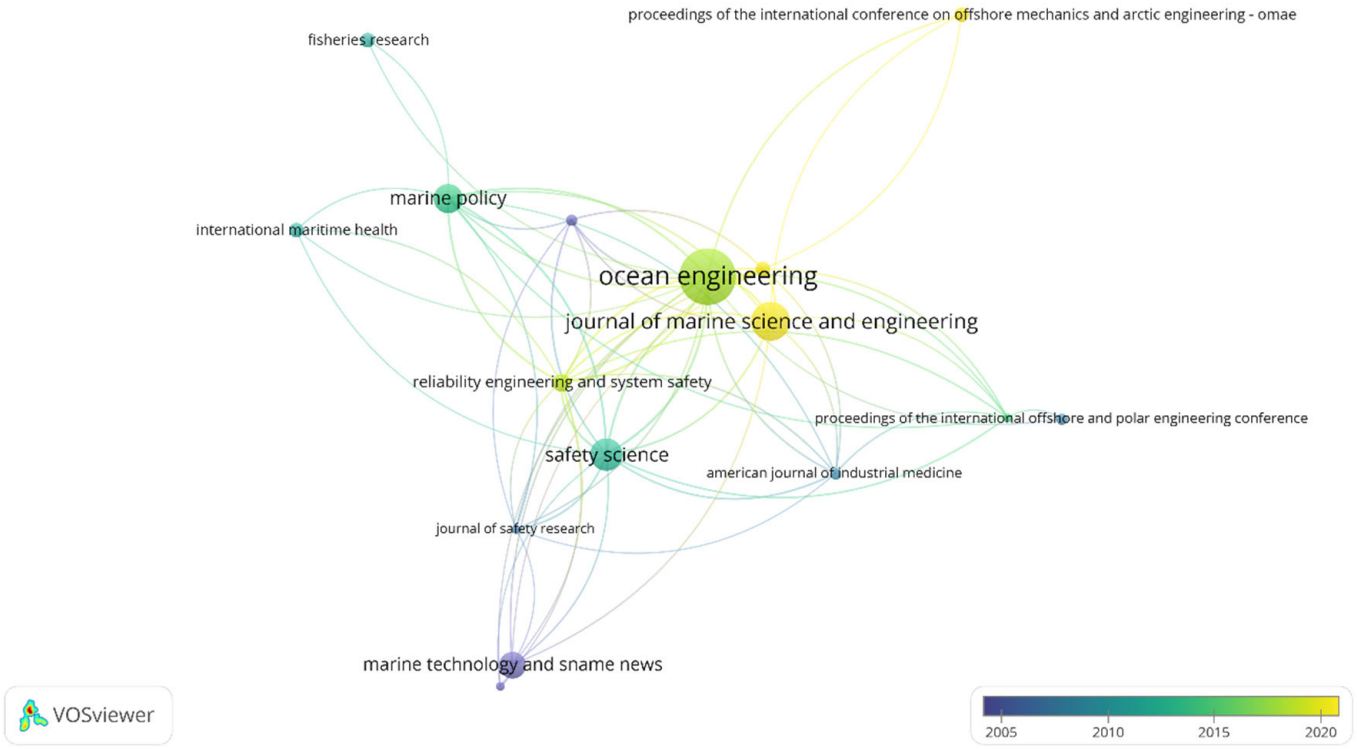


**Figure 3.** Journal co-citation network related to fishing vessel safety.

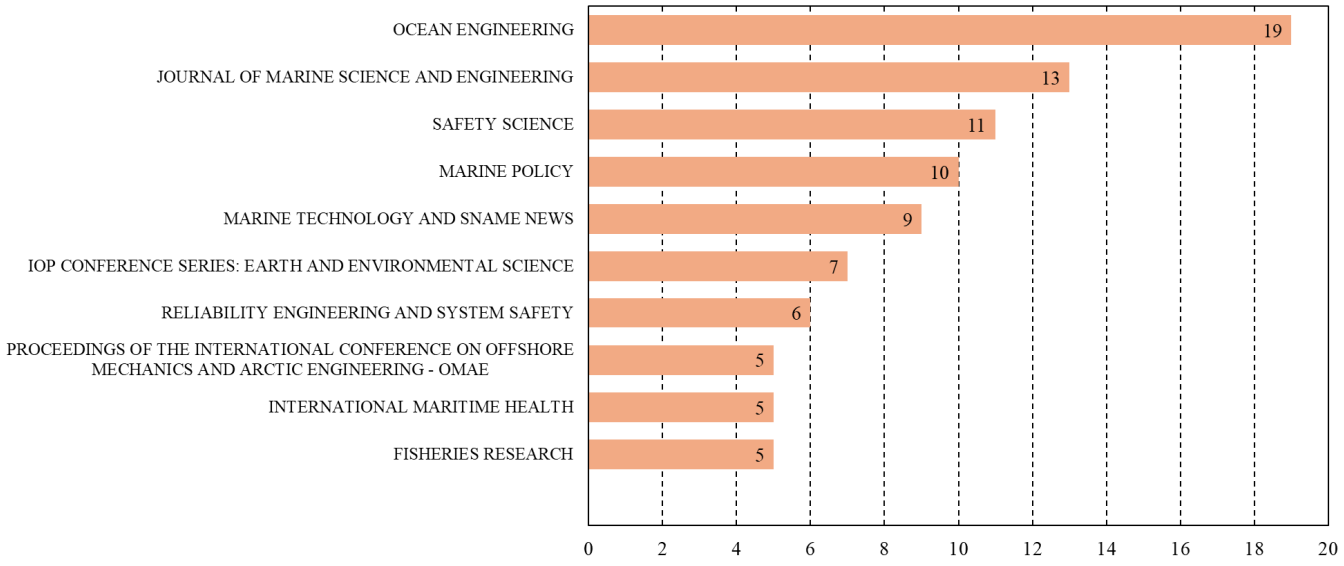


**Figure 4.** Number of documents by journal related to fishing vessel safety.

### *3.3. Ranking of Articles by Citation*

An important metric for identifying influential research is the citation count. Among the sample of literature, Table 2 presents the top 10 articles ranked by citation count. The most cited paper is the study by Certa et al. (2017) [14], with a total of 137 citations, making it the most influential work in terms of citation frequency. This paper also has the highest average annual citation rate, indicating its continued relevance and impact in the field.

**Table 2.** Raking of articles by number of citations.

| No | Article | Theme | TC | TC/Y |
|---|---|---|---|---|
| **1** | Certa et al., 2017 [14] | **Safety assessment techniques** | 137 | 17.13 |
| **2** | Bastardie et al., 2010 [15] | Fisheries management | 124 | 8.27 |
| **3** | Wang et al., 2005 [16] | **Risk assessment and accident analysis** | 88 | 4.4 |
| **4** | Jin and Thunberg, 2005 [17] | **Risk assessment and accident analysis** | 85 | 4.25 |
| **5** | Jin et al., 2001 [18] | **Risk assessment and accident analysis** | 69 | 2.88 |
| **6** | Utne, 2009 [19] | Sustainability of fishing vessel designs | 68 | 4.25 |
| **7** | Uğurlu et al., 2020 [20] | **Risk assessment and accident analysis** | 64 | 12.8 |
| **8** | Bye and Lamvik, 2007 [21] | **Accident analysis** | 64 | 3.56 |
| **9** | Basurko et al., 2013 [22] | Energy consumption | 63 | 5.25 |
| **10** | Jin, 2014 [23] | **Accident analysis** | 57 | 5.18 |

TC: Total citations, TC/Y: Total citations per year.

Meanwhile, in addition to citation count, the network of documents obtained through VOSviewer was also considered, as shown in Figure 5, where the size of each symbol is proportional to the number of citations. Upon examining the network distribution, it is apparent that the paper by Certa et al. (2017) [14] has relatively fewer connection points. Furthermore, the study by Bastardie et al. (2010) [15], which is ranked second in terms of citation count, does not appear in Figure 5. This can be explained by the themes of the articles in Table 2, as the majority of the 285 articles selected for this study focus on accident analysis related to fishing vessels. Therefore, studies falling outside this theme tend to have fewer connections. In particular, papers such as Wang et al. (2005) [16], Jin and Thunberg (2005) [17], and Uğurlu et al. (2020) [20], which are centered around themes like risk assessment and accident analysis, have relatively lower total citation counts but show more connections in the network. Thus, the most recent and well-connected study in this field appears to be the work by Uğurlu (2020) [20].

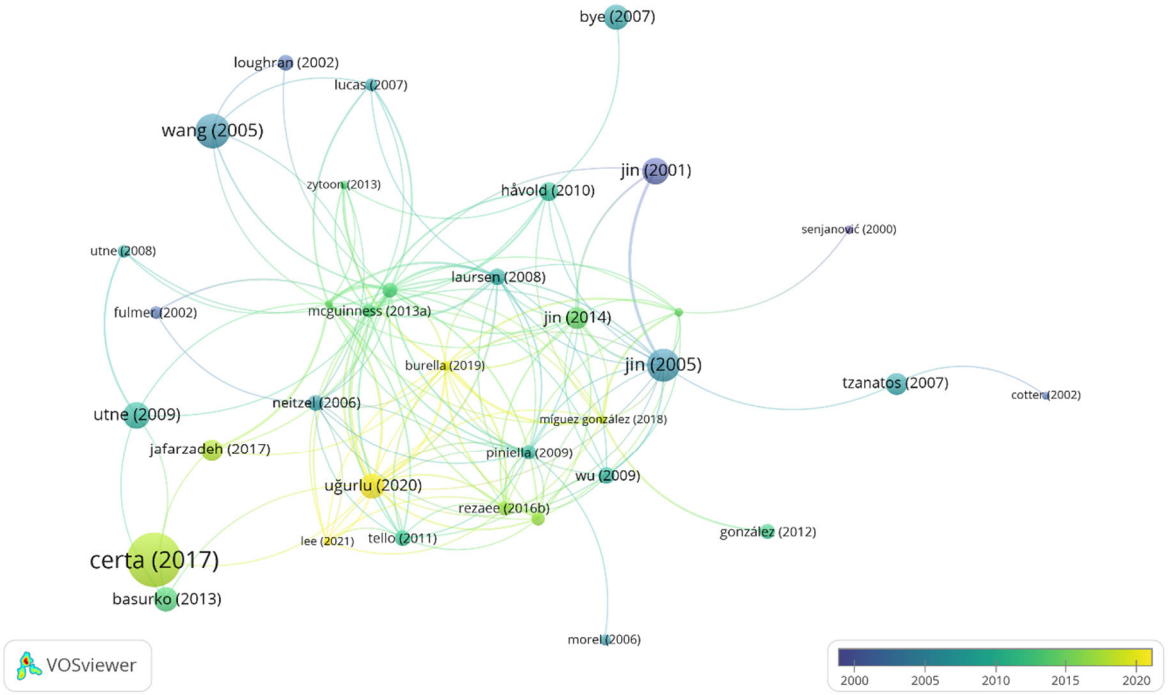


**Figure 5.** Article collaboration network related to fishing vessel safety.

This shows that, to identify the most influential research within a specific field, it is essential to consider not only the total citation count but also the connectivity with other papers in the same research area. Evaluating the network connections with other studies

helps determine how well the themes align within the field and indicates the study's relevance and influence beyond raw citation numbers.

### 3.4. Documents by Author

This study identified the most active researchers in the field of fishing vessel safety by analyzing the top authors who have published the highest number of related papers. A list of the top ten authors based on the number of publications (NP), total citations (TC), and the year of their first published paper (PY start) was compiled, as shown in Table 3. Additionally, to further evaluate the academic impact and research performance of these authors, h-index, g-index, and m-index were compared, which reflect the citation count, contribution, and consistent influence, respectively. By utilizing these indices, the impact of each researcher's work on the academic community and the significance of maintaining steady research contributions over time were assessed.

**Table 3.** Raking of authors by number of publications.

| Author | h-Index | g-Index | m-Index | TC | NP | PY Start |
|---|---|---|---|---|---|---|
| Wang, J. | 5 | 9 | 0.208 | 266 | 9 | 2001 |
| Utne, I.B. | 6 | 8 | 0.353 | 254 | 8 | 2008 |
| Pillay, A. | 4 | 8 | 0.167 | 202 | 8 | 2001 |
| Bose, N. | 4 | 6 | 1.000 | 69 | 6 | 2021 |
| Khan, F. | 4 | 6 | 1.000 | 69 | 6 | 2021 |
| Obeng, F. | 4 | 6 | 1.000 | 69 | 6 | 2021 |
| Sanli, E. | 4 | 6 | 1.000 | 69 | 6 | 2021 |
| Kim, S.H. | 2 | 2 | 0.500 | 8 | 6 | 2021 |
| Domeh, V. | 4 | 5 | 1.000 | 65 | 5 | 2021 |
| Loughran, C.G. | 3 | 5 | 0.125 | 137 | 5 | 2001 |

The author with the highest number of citations and publications is Wang, J., with a total of nine papers and 266 citations. However, considering the m-index, which takes into account that the first paper was published in 2001, it appears that active research in this field has not been sustained in recent years. The starting years of the first publications of the top 10 authors show that the research groups can be categorized into those who began their work in the early 2000s and those who entered the field more recently. At the same time, when examining research activity through the m-index, it can be inferred that there is a distinction between earlier and more recent research groups in terms of sustained research productivity.

To examine the relationships among authors in addition to the quantitative results, a network analysis of the authors was conducted using Biblioshiny, as illustrated in Figure 6. The analysis was performed through the collaboration network feature in Biblioshiny, using the walktrap clustering algorithm and association for normalization. A total of 50 nodes were used, with a minimum of three edges applied. Through the network analysis, several research clusters were identified, and a clear distinction between earlier and more recent research groups was observed. Specifically, among the top 10 authors listed in Table 3, Wang, J. and Pillay, A. from Liverpool John Moores University and Loughran, C.G. from the Maritime and Coastguard Agency have a history of co-authoring multiple papers, which is clearly reflected in Figure 6. Additionally, a relatively recent research group was formed by Bose, N., Khan, F., Obeng, F., Sanli, E., and Domeh, V. Except for Khan, F., who is affiliated with Texas A and M University, the remaining authors are associated with Memorial University of Newfoundland, Canada. Such research groups can thus be distinguished, while other clusters include Utne, I.B. from the Norges Teknisk-Naturvitenskapelige Universitet (NTNU), who shows a high h-index and continues to

be active in the field. Meanwhile, Kim, S.H. from Pukyong National University in South Korea is also part of a cluster with other authors from the same institution. As a result, these findings highlight the presence of distinct research groups and collaborative patterns within the field, providing insight into both historical and emerging research networks.

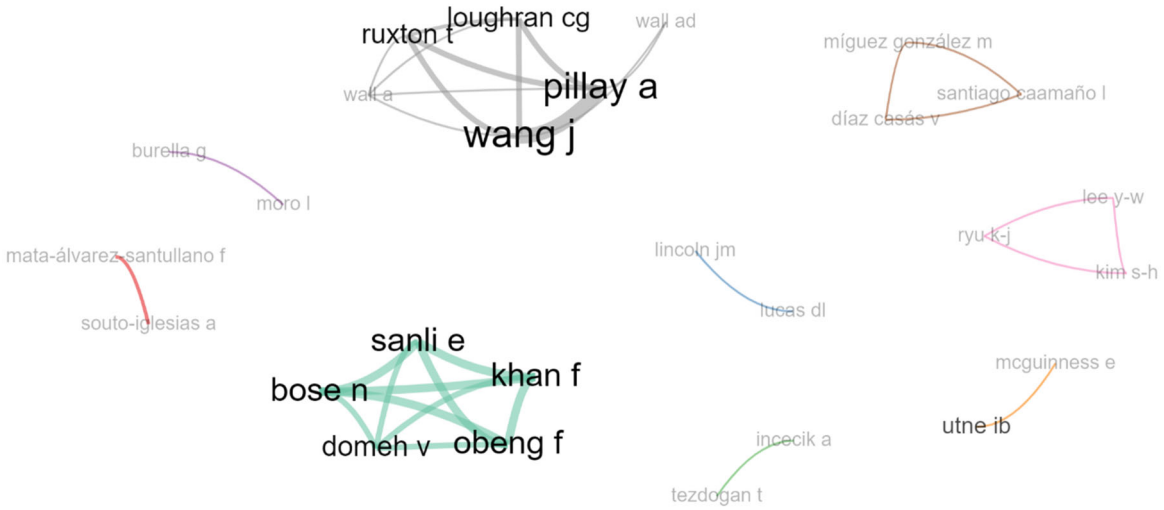


**Figure 6.** Authors collaboration network related to fishing vessel safety.

### *3.5. Affiliations by Number of Publications*

The affiliations with the highest number of publications are presented in Figure 7. The NTNU has the largest number of publications with 15 papers, followed by the Memorial University of Newfoundland in Canada with 13 papers. Next in line are Institut Teknologi Sepuluh Nopember (ITS) in Indonesia, SINTEF Ocean in Norway, and Liverpool John Moores University in the United Kingdom.

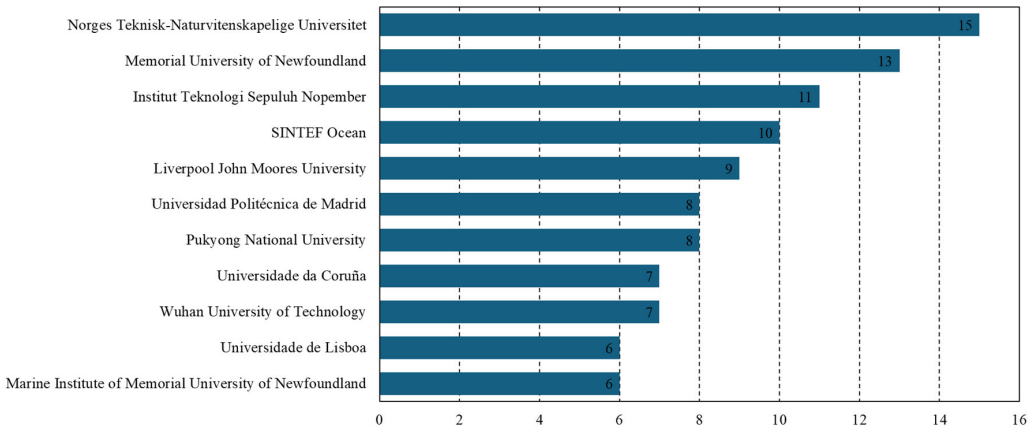


**Figure 7.** Number of documents depending on affiliations.

The reason these institutions actively conduct research on fishing vessel safety is due to the unique environmental and economic characteristics of the regions, where maritime and fishing activities are highly prevalent. As a result, there is a strong demand for research in areas such as marine safety, vessel design, and maritime risk management, leading to the establishment of various research projects centered around marine-related departments at these universities and affiliations.

A detailed review of the three institutions with the highest number of publications provides further insights. NTNU has maintained international research collaborations on marine accident analysis, risk management, vessel stability, and safety systems, resulting in numerous publications on fishing vessel safety. The Memorial University of Newfoundland, located in the Newfoundland region of Canada, is situated in an area where fisheries and

marine industries are critical to the local economy. The harsh maritime environment of the region poses significant challenges for vessel stability and safety, making these key research topics. The Fisheries and Marine Institute, in particular, is a research center focused on marine safety, vessel design, stability analysis, maritime risk assessment, and risk mitigation strategies, with a strong emphasis on fishing vessel safety. ITS, located in Indonesia, is based in the world's largest archipelago nation, where the fishing industry is a vital economic sector. The safe operation and management of small-scale fishing vessels are crucial issues in this region, and ITS has been actively conducting various studies to address these challenges. The institution has established a strong research foundation in marine engineering and vessel design, and much of its research is focused on preventing fishing vessel accidents and enhancing safety along the Indonesian coastlines and inland waters.

The relationships between research institutions were visualized using VOSviewer, as illustrated in Figure 8. The network diagram reveals the dominant role of institutions such as NTNU in advancing research on fishing vessel safety. These institutions have been central to collaborative efforts across countries and disciplines. Most of the institutions are organically connected, with a significant presence of the key institutions previously identified as having a high number of publications. Through the symbols used in the network, it is observed that Liverpool John Moores University predominantly published papers in earlier periods, while the University of Strathclyde, Pukyong National University, and Shanghai Maritime University are identified as institutions that have recently contributed to the field. However, as the timeline in the legend is set from 2012, it can be inferred that all the institutions are still actively engaged in research up to the present.

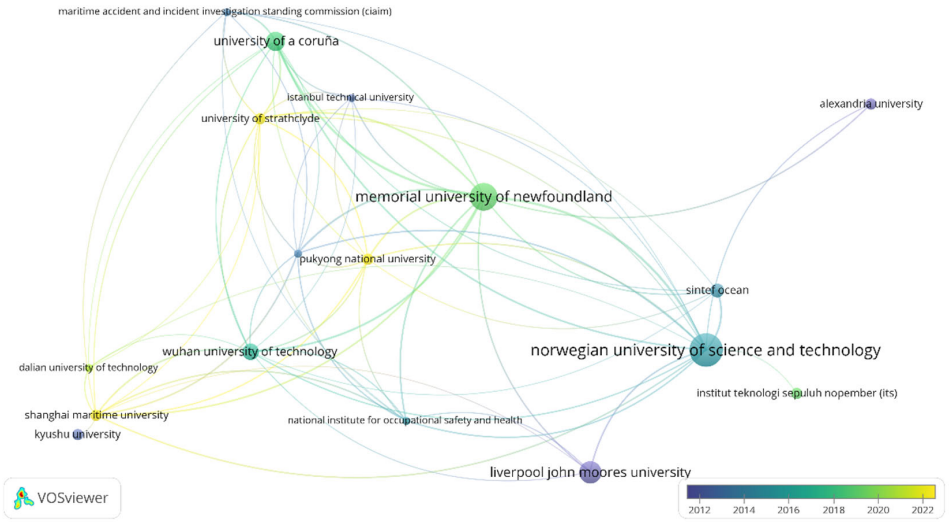


**Figure 8.** Affiliation collaboration network related to fishing vessel safety.

### *3.6. Ranking of Countries by Document*

The global distribution of research is illustrated in Figure 9, which ranks countries by the number of documents they have contributed. China has the highest number of publications with 33 papers, followed by Indonesia with 31, the United Kingdom and the United States with 29 each, Spain and Norway with 27 each, and South Korea with 25. All of the top 10 countries listed are those where fisheries are highly active, which aligns with the findings from the institutional analysis.

For instance, China is the world's largest producer of fisheries, with both small-scale and large-scale fisheries actively conducted in inland and coastal waters. The high accident rates and complex maritime environments make fishing vessel safety research essential. Similarly, Indonesia, where fisheries play a vital role in the economy, faces a high risk of fishing vessel accidents due to diverse marine conditions and inadequate safety infrastructure, highlighting the need for extensive research. The United States engages in fishing activities across various regions, including the Atlantic, Pacific, Arctic, and Gulf of

Mexico, and has developed robust databases and analytical frameworks for fishing vessel safety. The United Kingdom, with its long maritime history and fishing tradition, has consistently conducted research on maritime safety. Strong legal regulations and policies for marine safety and accident prevention have further driven research in this area.

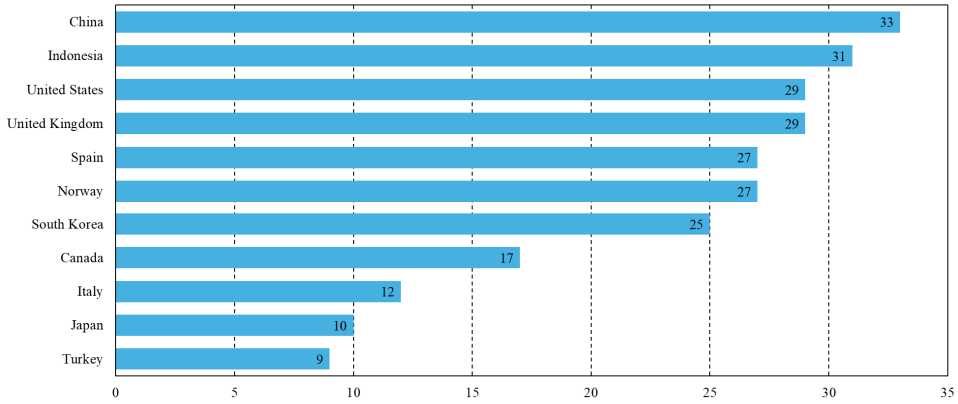


**Figure 9.** Number of documents depending on country.

In conclusion, these countries are actively engaged in fishing vessel safety research because fisheries significantly impact their economies and societies. The unique maritime environments and high accident rates have made fishing vessel safety a central research topic, and major research institutions in these nations are making substantial academic contributions to address these issues.

The network of countries was visualized using VOSviewer, as shown in Figure 10, which highlights the prominent presence of fishing-oriented nations. China, Indonesia, and South Korea are among the countries where relatively recent papers have been published. Similar to the institutional analysis, the timeline is set to post-2010, indicating that most countries continue to actively engage in research up to the present.

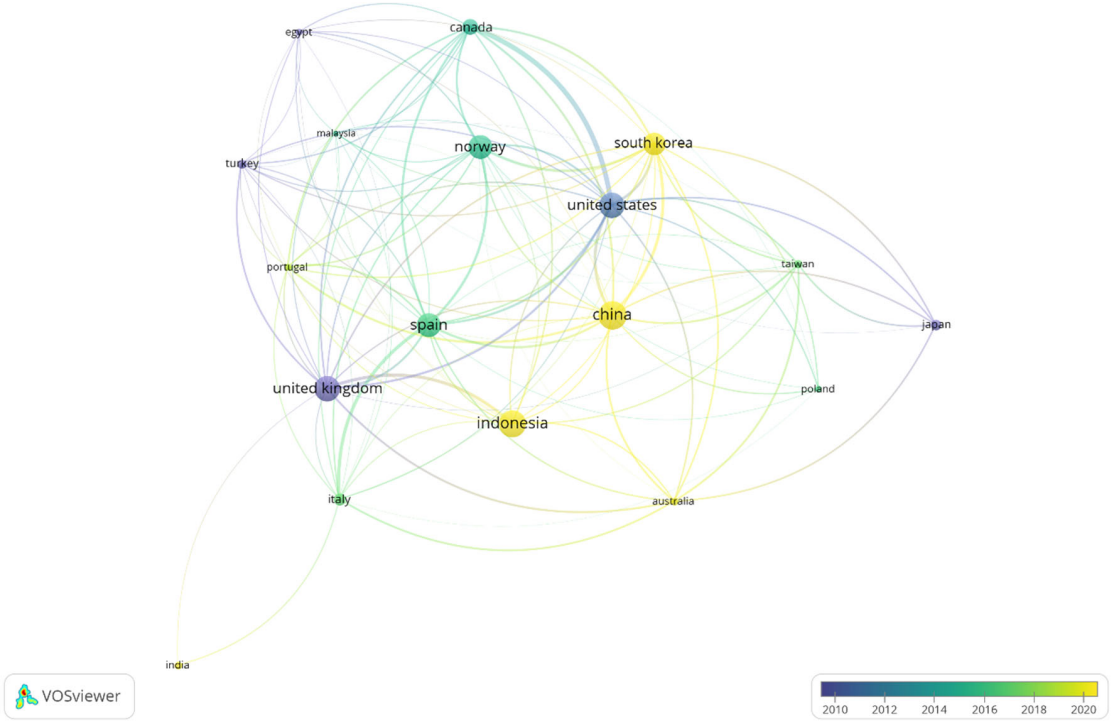


**Figure 10.** Country collaboration network related to fishing vessel safety.

### *3.7. Three-Field-Plot*

A three-field plot was generated using Biblioshiny to visualize the relationship between sources, keywords, and countries. The three-field plot visually connects three main research elements, allowing for an understanding of the relationships between them. Additionally, the frequency of connections between the elements is represented as weighted links, which are illustrated by the thickness of the lines. As shown in Figure 11, this plot highlights the interconnectedness of key journals, frequently used keywords, and the countries contributing most to fishing vessel safety research.

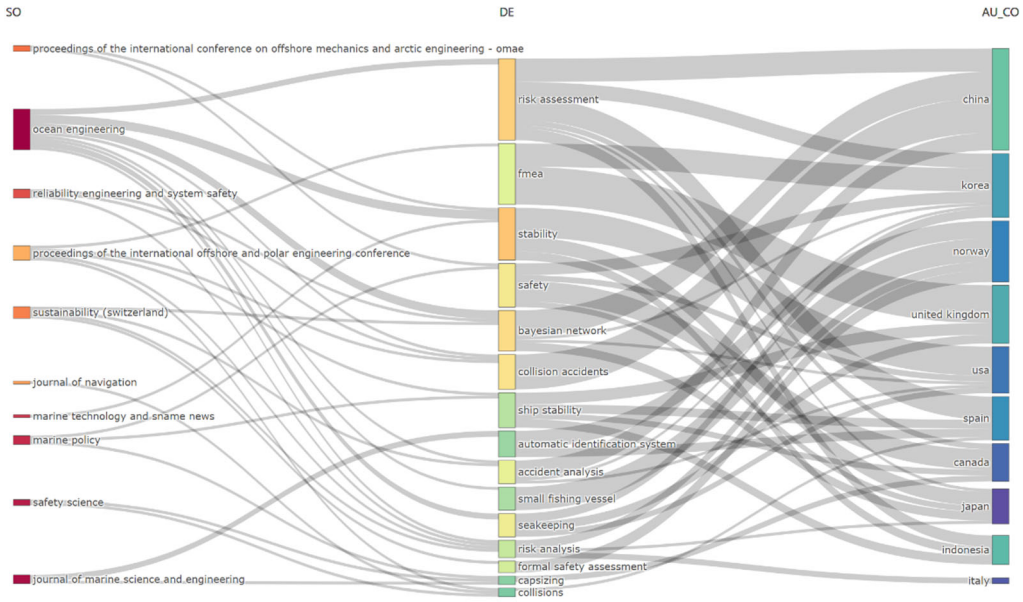


**Figure 11.** Three-fields plot connecting journal outlets, keywords, and countries.

It can be observed that many connections link the major journals previously identified to a variety of keywords, and *Ocean Engineering*, in particular, is linked to most of the fishing vessel safety-related keywords presented in this study. Notably, the *OMAE* proceedings and *Sustainability* are closely associated with keywords such as "accidents" and "risk analysis", indicating that many studies published in these sources are focused on accident analysis. Most of the countries identified earlier are included in the current plot, showing that keywords related to "risk assessment", "risk analysis", "stability", and "collisions" are actively being researched across different countries. Among them, China, South Korea, Norway, and the United Kingdom have made significant contributions to research associated with these key topics.

### *3.8. Keyword Clustering*

Keyword clustering was performed to identify major themes within the research about the safety of the fishing vessels. As shown in Figure 12, a Thematic map was generated in Biblioshiny to classify the keywords based on their relevance and development, illustrating their relative positions and relationships. In this map, Motor themes are topics with both high academic importance and strong internal development, indicating that they are well-established and play a central role in the research field. Niche themes are topics that are highly developed internally but have low connectivity to other themes. These topics are often considered as specialized fields, representing very specific areas. Basic themes are foundational or cross-cutting topics that often serve as a basis for research or can be applied across multiple fields. Emerging or declining themes are topics that are either in the process of emerging or in decline, indicating that they may require further research to fully develop. It is important to note that the positions of these themes on the map are indicative but not absolute in significance.

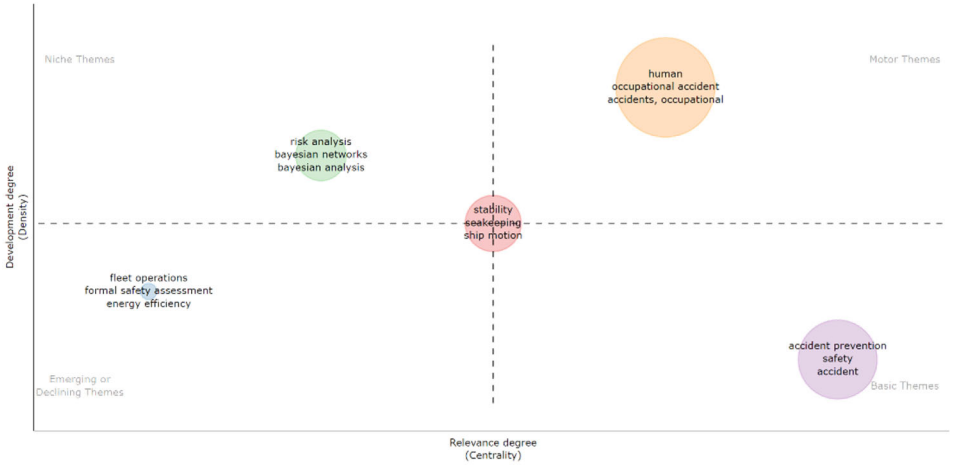


**Figure 12.** Thematic map of keywords related to fishing vessel safety.

As a result, clusters related to "accident prevention" can be seen as basic themes, while research on topics such as "human" and "stability" are actively progressing, indicating their ongoing importance in the field. Furthermore, topics such as "fleet operations" appear to be emerging themes, reflecting recent trends in addressing environmental issues and advancing autonomous navigation. "Risk analysis" although not particularly strong, is categorized as a niche theme, suggesting that it is a specialized cluster focused on the analysis of accidents.

In addition to the Thematic map, VOSviewer was utilized to create a network combining both Scopus-indexed keywords and author-provided keywords, as shown in Figure 13. The keywords were grouped into four main clusters: "risk assessment", "human", "stability", and "fleet operations". This classification closely aligns with the findings from the Thematic map, indicating a consistent pattern in the core themes and ongoing research trends in the field.

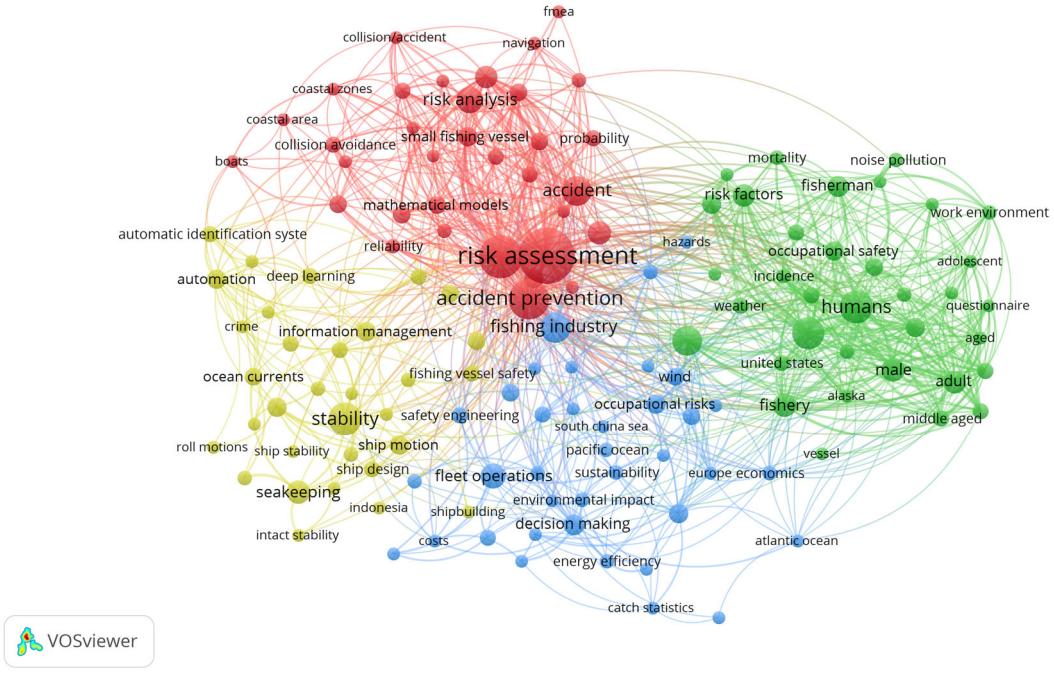


**Figure 13.** Network of keywords related to fishing vessel safety.

The keywords included in the risk assessment cluster consist of terms such as "accident prevention", "accidents", "risk factor", and "Bayesian networks". This suggests

that studies focusing on analyzing the causes of accidents occurring on fishing vessels, developing methodologies for categorizing these accidents, and researching strategies to prevent potential risk factors are closely interrelated. Based on this observation, this study categorizes these related topics into a single research cluster named *Risk/Accident Analysis*. This area corresponds to both the niche and basic themes in the Thematic map, indicating that it represents a specialized yet foundational field of research.

Next, a group of keywords centered around human factors can be observed, which includes terms such as "aged", "occupational health", "injury", and "statistics". While all accidents on fishing vessels inherently involve human elements, this cluster specifically focuses on the impact of accidents on individuals and the role of human error as derived from accident case studies. This area pertains to the motor themes, suggesting that it is a highly active and central research field. Consequently, this area has been established as a distinct research cluster under the theme *Human Factor*.

The third cluster is comprised of research focused on vessel stability. Unlike analyzing accident causes or calculating probabilities, stability can be calculated physically using established metrics. Reflecting this characteristic, the cluster includes keywords such as "seakeeping", "stability analysis", "loading condition", and "automation". This indicates that studies are being conducted on evaluating vessel maneuverability and stability, as well as developing automated methods for calculating these factors. Therefore, a *Stability* cluster was formed to encompass studies related to the evaluation methods for fishing vessel stability.

The fourth cluster is *Operation*. This cluster includes keywords such as "fleet operations", "decision making", "regression analysis", and "sustainability", which encompass topics related to the efficient operation of vessels and, more recently, autonomous navigation. However, this study focuses specifically on fishing vessel accidents and aims to review topics centered on autonomous navigation, particularly algorithms for collision risk warning and collision avoidance during vessel operations.

The safety clusters related to fishing vessels can exhibit similar trends to those observed in merchant ships, considering that both fall under the broader category of marine vessels. For example, Cao et al. (2023) [24] conducted a bibliometric analysis on marine accidents, comparing various methods of accident analysis. However, this study focuses specifically on accident analysis involving fishing vessels, which have distinct risks compared to merchant ships. Fishing vessels are more vulnerable to weather conditions and external disturbances and operate under diverse loading conditions, which can lead to a wide range of situations. Additionally, compared to merchant ships, fishing vessels generally have fewer safety systems in place and rely more on human decision-making during emergency situations. Therefore, ensuring the safety of fishing vessels requires immediate responses while taking various conditions into account, reflecting a unique and demanding environment. From this perspective, although there may be similarities with merchant ship clusters, the clusters presented in this study are primarily focused on the specific characteristics and analysis related to fishing vessels.

## 4. Results II—Review of Research Clusters

This section aims to analyze and review the research directions of studies related to fishing vessel safety identified through keyword clustering. Representative studies within each cluster were selected and reviewed to provide an in-depth understanding. Among the studies categorized, particular emphasis was placed on observing research related to accident and risk analysis, as well as prevention strategies. Through the cluster review, the study examines which types of accidents were analyzed, the methodologies used for accident analysis, and the approaches proposed for accident prevention. Additionally, the strengths and limitations of these studies are discussed to ultimately propose strategic directions for future research.

### *4.1. Selection of Papers by Cluster*

Papers were chosen as shown in Table 4. In this study, particular emphasis was placed on the analysis of accidents and risks, which were the primary focus of the review. As a result, a relatively higher proportion of studies related to accident analysis, risk assessment, and prevention strategies for fishing vessel safety were included in the categorized research. To select representative papers for each cluster, 145 sample studies were extracted from the initial pool of 285 studies using the Thematic map generated in Section 3.8 of Biblioshiny. For the selected cluster-specific papers, the top 15 papers were reviewed for each cluster based on a scoring system that considered the year of publication and the number of citations. Papers that did not align well with the primary themes were excluded. Additionally, influential documents, relevant titles, and works by prominent authors that were not initially included in the Thematic map were also incorporated into the appropriate clusters. Ultimately, a total of 37 papers were finalized and categorized into their respective clusters, as illustrated in Table 4.

**Table 4.** Articles within a cluster, classified according to criteria.

| **Cluster 1** *Risk/Accident Analysis* | | **Cluster 2** *Human Factor* | **Cluster 3** *Stability* | **Cluster 4** *Operation* |
|---|---|---|---|---|
| **Sub-Cluster 1** *Accident Analysis* | **Sub-Cluster 2** *Risk Analysis* | | | |
| Jin and Thunberg (2005) [17] | Piniella and Fernández-Engo (2009) [25] | Bye and Lamvik (2007) [21] | Tello et al. (2011) [26] | Zhu et al. (2019) [27] |
| Wang et al. (2005) [16] | Certa et al. (2017) [14] | Sønvisen (2017) [28] | González et al. (2012) [29] | Lee et al. (2021) [30] |
| McGuinness et al. (2013) [31] | Núñez Sánchez and Pérez Rojas (2017) [32] | Burella et al. (2019) [33] | Míguez González and Bullan (2018) [34] | Shanthi et al. (2022) [35] |
| Jin (2014) [23] | Domeh et al. (2022) [36] | Domeh et al. (2021) [37] | Santiago Caamaño et al. (2018) [38] | Jung et al. (2023) [39] |
| Rezaee et al. (2016) [40] | Kimera and Nangolo (2022) [41] | Lee et al. (2024) [42] | Liu et al. (2019) [43] | Park et al. (2023) [44] |
| Uğurlu et al. (2020) [20] | Domeh et al. (2023) [45] | Wang et al. (2024) [46] | Santiago Caamaño et al. (2019) [5] | Ramesh and Ramesh (2023) [47] |
| Irvana et al. (2020) [48] | Obeng et al. (2024) [49] | Zhang et al. (2024) [50] | Szozda and Krata (2022) [51] | Yoo et al. (2024) [52] |
| Case and Lucas (2020) [53] | Siahaan et al. (2024) [54] | | Domeh et al. (2023) [55] | |
| Wang et al. (2023) [3] | | | Iqbal et al. (2023) [56] | |
| Yang et al. (2023) [57] | | | | |
| Kim et al. (2023) [58] | | | | |
| Kim et al. (2024) [59] | | | | |

### *4.2. Cluster 1: Risk/Accident Analysis*

The first cluster consists of papers related to risk analysis and accident analysis, which focus on identifying the root causes of fishing vessel accidents and proposing methodologies for accident prevention. This cluster is divided into two sub-clusters: accident analysis, which focuses on analyzing causes through accident cases, and risk analysis/risk assessment, which aims to predict future accidents through risk evaluation.

#### 4.2.1. Sub-Cluster 1: Accident Analysis

Accident analysis has been a long-standing research area, primarily utilizing statistical data, such as accident records, to identify the causes of accidents and analyze their correlation with external factors. Depending on the regions investigated, accident characteristics can vary significantly, and each study employs different methodologies to conduct the analysis. The period of the analysed accidents, countries/regions, data sources, and analysis methods considered by the study authors who performed the accident analysis

are listed in Table 5. The accident cases considered here are those included in the reviewed literature, which cover only a limited number of regions. Fishing vessel accidents are more likely to occur in vulnerable areas where infrastructure is weak. Therefore, a more detailed examination of various regions will be necessary in future research.

**Table 5.** Accident year, region, source, and accident analysis method applied to the accident analysis.

| Article | Accident Analysis Period | Country/ Region | Accident Data Source | Accident Analysis Method |
|---|---|---|---|---|
| Jin and Thunberg (2005) [17] | 1971–2000 | United States/Northeastern | ■ Coast Guard's Marine Information for Safety and Law Enforcement (MISLE)<br>■ National Marine Fisheries Service (NMFS) | ■ Logit Regression Model |
| Jin (2014) [23] | 2001–2008 | United States/Northeastern | ■ MISLE<br>■ NMFS | ■ Ordered Probit Model |
| Wang et al. (2005) [16] | 1992–1999 | United Kingdom | ■ Marine Accident Investigation Branch (MAIB) | ■ Statistical Analysis |
| McGuinness et al. (2013) [31] | 1990–2011 | Norway | ■ Staten Havarikommi sjon for Transport (SHT)<br>■ Norwegian Maritime Directorate<br>■ Norwegian Labour and Welfare Administration (NAV)<br>■ SINTEF Fisheries and Aquaculture | ■ Statistical Analysis |
| Rezaee et al. (2016) [40] | 2005–2010 | Canada | ■ Canadian Coast Guard (CCG)<br>■ Department of National Defense<br>■ Fisheries and Oceans Canada (DFO) | ■ Negative Binomial Regression<br>■ Zero-Inflated Negative Binomial Regression (ZNBR)<br>■ Fractional Logit Regression (FLR)<br>■ Random Parameters Negative Binomial Regression |
| Ugurlu et al. (2020) [20] | 2009–2018 | Global | ■ Global Integrated Shipping Information System (GISIS)<br>■ MAIB<br>■ European Maritime Safety Agency (EMSA)<br>■ Australian Transport Safety Bureau (ATSB)<br>■ Transportation Safety Board of Canada (TSB) | ■ Bayesian Network (BN)<br>■ Chi-square Test |
| Case and Lucas (2020) [53] | 2010–2015 | United States/Alaska | ■ Commercial Fishing Incident Database (CFID) managed by the National Institute for Occupational Safety and Health (NIOSH)<br>■ MISLE | ■ Logistic Regression<br>■ Multivariable Model |
| Irvana et al. (2020) [48] | 2000–2010 | Indonesia | ■ Indonesian Maritime Accident Records | ■ Formal Safety Assessment (FSA) |
| Yang et al. (2023) [57] | 2016–2020 | China/Shandong and Zhejiang | ■ Maritime Safety Administration (MSA) of China | ■ Statistical Analysis<br>■ Kernel Density Estimation (KDE)<br>■ Kepler.gl Visualization |
| Wang et al. (2023) [3] | 2018–2022 | China | ■ Fishery Mutual Insurance Association (FMIA) | ■ Random Forest (RF)<br>■ Tree-Augmented Naive Bayes (TAN)<br>■ Sensitivity analysis |
| Kim et al. (2023) [58] | 2016–2020 | South Korea | ■ National Federation of Fisheries Cooperatives (NFFC) | ■ BN<br>■ FSA |
| Kim et al. (2024) [59] | 2018–2022 | South Korea | ■ Korea Maritime Safety Tribunal (KMST)<br>■ Ministry of Oceans and Fisheries (MOF)<br>■ Korean Statistical Information Service (KOSIS) | ■ FTA<br>■ Statistical Analysis<br>■ Skill-Rule-Knowledge (SRK) Model<br>■ Slip-Lapse-Mistake-Violation (SLMV) Model |

Jin and Thunberg (2005) [17] analyzed fishing vessel accidents to identify key variables affecting accident probability, such as daily maximum wind speed, vessel size, season, catch volume, and vessel location. Using a logit regression model, they highlighted the impact of weather conditions, fishing location, and vessel size on accident probability, emphasizing the importance of an accident probability model for accident prevention. While this method allowed the consideration of various factors in determining accident occurrence, it faced challenges in handling non-linear data and accurately determining the specific effects of each variable. In a subsequent study, Jin (2014) [23] analyzed fishing vessel accidents using an Ordered Probit Model, which categorizes the severity of vessel damage and crew injury into levels such as minor, moderate, and severe. This model effectively calculates non-linear effects and probabilities but can be challenging to interpret and may struggle to account for interactions between variables. Therefore, incorporating

an extended model, like Multinomial Logistic Regression, which includes interaction terms, could address these limitations.

Similarly, there are cases where regression analysis was performed. Rezaee et al. (2016) [40] applied multiple regression models, including Negative Binomial Regression, Zero-Inflated Negative Binomial Regression (ZNBR), and Fractional Logit Regression (FLR), to analyze accident occurrence rates and identify key contributing factors. Their results revealed that wind speed, ice presence, and pressure changes were the most influential factors. While these models are effective for handling diverse data characteristics and simultaneously analyzing accident probability and frequency, the study suggested that hierarchical or multi-level modeling could offer a more refined approach by reducing data complexity. Case and Lucas (2020) [53] employed a case-control research design, analyzing the relationship between risk factors and large-scale disaster events, like capsizing and sinking. Logistic regression was used to evaluate the odds of disaster occurrence, and a multivariable model was applied to analyze the simultaneous impact of all variables. The methodology demonstrated its ability to generate meaningful results even from relatively small sample sizes but faced challenges in controlling for certain variables, potentially leading to bias. To address this, the study recommended controlling for confounding factors such as weather conditions and sea states.

Statistical research based on accident data has also been conducted. Wang et al. (2005) [16] used frequency analysis by accident type and statistical analysis by cause to evaluate the main causes of accidents and the contribution of each type. Their findings indicated that inadequate vessel maintenance, equipment failure, navigational errors, and lack of proper navigation equipment were primary causes of accidents. Given that machinery damage accounted for the majority of accidents, they recommended strengthening vessel maintenance programs and implementing additional management measures to prevent mechanical failures. McGuinness et al. (2013) [31] also employed the statistical method using Incident Rate per 10,000-man years to assess accident severity and mortality rates, representing the fatal accident rate relative to the total workforce in the fishing industry. They found that vessel disasters, such as capsizing, sinking, and grounding, accounted for the highest proportion of fatalities, while man-overboard incidents were also significant. The study highlighted that small coastal vessels have a particularly high accident risk and emphasized the importance of effective safety policies and preventive measures. An example of the latest techniques being applied to statistical analysis, Yang et al. (2023) [57] employed statistical analysis and spatial distribution visualization using the Kernel Density Estimation (KDE) method to identify areas with a high concentration of collision incidents. This approach, based on actual data, provides an objective basis for analysis and is advantageous for visual interpretation. However, it heavily relies on data accuracy, making it challenging to discern the exact causes and timing of incidents. To address these limitations, integrating this method with Geographic Information System (GIS) technology can enable a clearer visual representation of distribution and risk levels.

There is also a study using the evaluation methods of the IMO. Irvana et al. (2020) [48] used the Formal Safety Assessment (FSA) methodology, which involves risk analysis and cost-benefit assessment to examine various risk control options. Accident types were categorized into vessel foundering, falling overboard, mechanical failure, grounding, flooding, collision, fire, capsizing, and other accidents. According to FSA, the study followed these steps: (1) Hazard Identification: defining scenarios, (2) Risk Assessment: calculating accident risk levels, (3) Risk Control Options Selection: identifying risk control alternatives, (4) Cost–Benefit Analysis: evaluating the effectiveness of risk control measures, and (5) Recommendations for Decision-Making: proposing strategies to minimize accidents. FSA offers a systematic and comprehensive approach but is highly dependent on data accuracy and requires significant time and resources. To address these limitations, the study recommended simplified FSA procedures or approaches that reduce uncertainties associated with human error.

Research on analyzing accidents using Bayesian Networks (BN) is on the rise. Uğurlu et al. (2020) [20] analyzed accidents using BN modeling, followed by Chi-square independence testing. The BN approach constructs a hierarchical network that models accident causes, environmental factors, and potential risks, allowing for a precise analysis of the conditional probability of accident occurrence. The Chi-square test was then applied to examine the statistical relationship between accident types and various factors, such as vessel type, vessel length, vessel age, and operation conditions. This comprehensive approach enabled the study to determine the main causes and severity levels of fishing vessel accidents, particularly critical factors influencing capsizing and collision incidents. Despite its strengths, the study suggested incorporating automation processes to enhance modeling efficiency. Kim et al. (2023) [58] quantitatively categorized accidents and identified major risk factors using BN and FSA methodologies. They found that the most common accident types were slips/falls, collisions, and entrapments, and highlighted that implementing safety checklists (CL) and protective equipment (PE) played a crucial role in reducing accident rates. While these methods allowed for probabilistic analysis and accurate identification of accident causes, they do not account for causal relationships between variables, making real-world application challenging. Therefore, causal inference techniques and sensitivity analysis were recommended to improve the interpretation of variable relationships.

Additionally, in recent years, there has been an increasing trend of integrating various analytical methods to complement the previously mentioned approaches. Wang et al. (2023) [3] employed the Random Forest (RF) method and a BN model to analyze fishing vessel accidents, identify Risk Influential Factors (RIF), and establish a predictive model for assessing accident risk. Using the Tree-Augmented Naive Bayes (TAN) approach, which considers dependencies between variables, they built a network to represent interrelationships among variables. Sensitivity analysis indicated that power, ship length, gross tonnage, and operational type were the most influential factors. By employing RF, BN, and TAN methods, the study complemented the shortcomings of each model, demonstrating an effective approach for analyzing large datasets. Kim et al. (2024) [59] applied Fault Tree Analysis (FTA) to model collision accidents and systematically analyzed accident causes. To classify human errors, they utilized the Skill-Rule-Knowledge (SRK) and Slip-Lapse-Mistake-Violation (SLMV) models to analyze human errors in collisions and occupational accidents. While these models are useful for systematically understanding accident causes and decision-making patterns, they have limitations in addressing interactions between human and environmental factors. Thus, strategies for collecting precise and diverse data are needed, and combining FTA with BN could provide a more comprehensive approach to analyzing mutual influences between variables.

#### 4.2.2. Sub-Cluster 2: Risk Analysis

Risk analysis or risk assessment is similar to accident analysis; however, it fundamentally focuses on analyzing accident factors to proactively control risks and proposes measures or strategies to prevent accidents based on these factors.

To identify or evaluate risk factors, tools such as checklists or FSA can be utilized. Piniella and Fernandez-Engo (2009) [25] aimed to develop a checklist-based safety management tool. The proposed checklist was designed to systematically manage accident risk factors that commonly occur in fishing vessel work environments by categorizing them into detailed components. It includes checklists for safety equipment, fire prevention, work environment, and fishing operations, with response options of “Yes”, “No”, and “NA”. Through a survey, the tool facilitates risk estimation to implement appropriate preventive measures based on the risk levels (e.g., minor, medium, severe). Although the checklist is a practical tool that allows crew members to systematically assess risk factors and conduct self-inspections, regular training and education are necessary to address potential subjectivity in user responses. Meanwhile, Núñez and Pérez (2017) [32] introduced the FSA based on the Goal-Based Safety Level Approach (GBS-SLA) to systematically manage the accident risks of small fishing vessels (less than 24 m in length) and establish effective accident

prevention measures. The Goal-Based Standards (GBS) focuses on setting outcome-based goals that can be flexibly applied to different nations, vessels, and situations. The GBS-SLA approach extends the GBS concept by quantitatively setting and managing safety levels. Through the combined use of FSA and GBS-SLA, this study was able to systematically analyze various accident risk factors and establish clearer and more precise safety measures. As a result, a total of 22 risk control options (RCOs) were derived based on FSA and prioritized against existing safety regulations. Among these, the implementation of safety education programs and the enhancement of safety-related equipment on fishing vessels were evaluated as the most effective risk control measures. The GBS-SLA approach allows for flexible application of safety regulations, contributing significantly to the establishment of consistent maritime policies at the national, regional, and international levels. Moreover, this approach enables designers, regulatory authorities, and shipowners to share common goals and establish a framework for continuously evaluating and improving the effectiveness of regulations. However, since the various safety measures proposed in the study are primarily focused on a regulatory approach, they may encounter difficulties in being practically applied to the actual operational environment of fishing vessels. Therefore, a review should be conducted to ensure that these measures are suitable for the specific working conditions and regional contexts before implementation.

Furthermore, the BN, which has been widely used in accident analysis, is also effectively utilized for risk assessment. To identify the risks of small fishing vessels, Obeng et al. (2024) [49] developed a method that combines BN and Dempster-Shafer Theory (DST) to incorporate uncertainty and effectively evaluate RCOs to prevent accidents proactively. The research methodology involved literature reviews, accident report analyses, and expert opinion collection to identify RCOs, which were then applied to the BN and DST models to assess the impact of risk reduction strategies. The study demonstrated that the proposed framework could quantitatively evaluate the major risk factors during vessel operations and reduce the probability of accidents by up to 62.5% when appropriate RCOs are implemented. This approach has the advantage of optimizing accident prevention strategies by quantitatively assessing the cost-effectiveness of each control option. However, it is recommended that the framework be validated through real-world scenario implementation. Additionally, continuous monitoring and updates are essential from a risk management perspective to ensure its long-term effectiveness.

Domeh et al. (2023) [45] developed a Risk Awareness (RAw) tool designed to systematically monitor and prevent potential hazards encountered in the harsh environments of small fishing vessels (SFVs). The primary objective was to identify accident risk factors faced by crew members during vessel operations and provide situational awareness (SA) information that enables proactive responses, thereby reducing the likelihood of accidents. To achieve this, a risk analysis technique based on the BN model was applied to categorize risk factors into technical, environmental, and human-related elements, and to quantitatively assess the impact of each factor on accident occurrence. Additionally, to address the subjectivity and inconsistency that may arise during the construction of Conditional Probability Tables (CPTs) in BN, the study introduced predefined probability scales to minimize expert opinion variability and enhance the model's reliability. The results demonstrated that the proposed RAw tool enables crew members to track potential hazards in real-time and implement appropriate preventive measures based on SA information. However, BN-based models are complex to build and require further examination to ensure their applicability across diverse vessel types and operating environments. Thus, the study suggests simplifying the model construction process to improve its practicality and robustness.

Meanwhile, among the causes of risk, mechanical failures can cause major accidents. Therefore, reliability assessment of machines can be considered a type of safety assessment. In industries where safety and reliability are important, Failure Mode, Effects, and Criticality Analysis (FMECA) is a commonly used method to identify potential system failures in advance and implement preventive measures. FMECA is a systematic risk analysis

technique that identifies potential failure modes, assesses the impact of each failure, and prioritizes them accordingly. Through this process, the primary goal is to prioritize critical failure modes and enhance the system's reliability and safety. Certa et al. (2017) [14] proposed a failure analysis based on the DST to address the uncertainties and subjective judgments in the conventional FMECA approach. In the traditional FMECA method, the Risk Priority Number (RPN) does not adequately handle uncertain expert opinions and faces issues with the equal weighting of the parameters: Occurrence, Severity, and Detection. To overcome these limitations, the study utilized DST to convert ambiguous or interval-valued expert opinions into Belief and Plausibility distributions, thus deriving the priority of risk factors. This method was applied to the propulsion system of fishing vessels in the Sicilian region, identifying a total of 28 failure modes and analyzing the risk levels of each. The results showed that the most critical failure mode was the pumping failure of the gear-inverter oil pump, and the DST-based FMECA approach could more effectively account for uncertainties compared to the traditional RPN method. While this approach enables more reliable analysis, it can lead to a rapid increase in computational complexity in large-scale systems, resulting in constraints on time and resources.

Another study proposed a method to evaluate the reliability of mechanical devices. Domeh et al. (2022) [36] aimed to develop a Risk-Based Maintenance (RBM) strategy for the Main Propulsion System (MPS) of fishing vessels. To address the issue that traditional preventive and condition-based maintenance approaches are not suitable due to high costs and operational disruptions, the study proposed a model that combines the Goal-Directed Risk Identification Technique (Goal-DRIT) with an Object-Oriented Bayesian Network (OOBN) to identify critical failure components of the MPS and optimize the maintenance intervals. The results showed that this methodology achieved a 24.78% cost reduction compared to conventional maintenance strategies, demonstrating its contribution to improving operational efficiency for fishing vessels. The proposed approach effectively incorporates uncertainty to optimize maintenance planning and provides reliable analysis by considering interactions between risk factors. However, there is a limitation in that the computational burden increases significantly when applied to large-scale systems. This issue is similar to the challenges highlighted by Certa et al. (2017) [14]. To address this, the study suggests that simplifying the model and developing automated tools are necessary to improve analytical efficiency.

### *4.3. Cluster 2: Human Factors*

In any field, the impact of human factors can be reflected in accidents. Stroeve et al. (2023) [60] systematically analyzed human factors involved in accidents in aviation and maritime sectors, demonstrating that classification and structuring of these human factors can contribute to accident prevention. When focusing on human-centered safety and accidents on fishing vessels, it is evident that various factors can influence human behavior, such as human error, perceived risk, organizational and social factors, and working environment. This cluster includes studies that analyze and research the resulting damages and accidents, and this section aims to review related research on this topic.

Human behavior can be a crucial factor when analyzing the causes of accidents, as individuals act based on their psychological state and perception. Additionally, their behavior is significantly influenced by organizational, social, and cultural factors. The study by Bye and Lamvik (2007) [21] aimed to analyze accident risks on small fishing vessels and offshore service vessels in the Norwegian maritime industry, evaluating the impact of risk perception on accident behaviors. Through the analysis of accident statistics, surveys, interviews, and field observations, the relationship between risk perception and risk behaviors was comprehensively assessed. The study found a significant discrepancy between the official risk estimates and the crew's subjective risk perception on both fishing and service vessels. In particular, crew members on small fishing vessels tended to underestimate the perceived risk despite high objective risk levels, which appeared as part of their risk-avoidance and coping strategies during work. This phenomenon was influenced

by the working environment and cultural factors, indicating that risk perception might not be a reliable indicator of the organizational safety level.

Sønvisen et al. (2017) [28] analyzed the working environment and health conditions of Norwegian fishing vessel crews, investigating the primary accident causes and risk factors in the working environment. The study collected data from 830 full-time fishermen through phone surveys and evaluated the relationship between various occupational risk exposures and health conditions using Relative Risk (RR) analysis. The results showed that coastal fishermen were exposed to higher risks due to climatic, ergonomic, and work-processing conditions, leading to more musculoskeletal problems and a higher rate of sickness absence. The study concluded that long-term health promotion programs and the adoption of safety technologies are needed to improve the working environment for fishermen. Although the study systematically analyzed risk perceptions and health conditions under various working conditions, it had limitations due to the subjective biases inherent in survey-based research. The suggested improvement was to conduct a comprehensive research approach that includes field observations for an objective risk assessment, thereby developing tailored health promotion strategies.

Domeh et al. (2021) [37] used the OOBN technique to analyze the causes and risk factors of man-overboard (MOB) incidents on small fishing vessels and derive risk control measures. The study quantitatively evaluated MOB scenarios and identified risk factors through literature reviews, accident report analysis, and expert opinions. The OOBN model was used to assess the dependencies and interactions between these factors, with key risk factors identified as the lack of safety gear, working under the influence of alcohol, and working near low guardrails. The proposed model quantitatively predicts accident probabilities and evaluates risk control options based on the results. However, more scenarios need to be considered to account for diverse situations, and empirical validation in various fishing environments would be necessary to complement the model.

There has been growing research on Human Factors, which deals with the impact of human behavior, cognitive abilities, and psychological and physical limitations on system performance and safety, particularly in system design. Lee et al. (2024) [42] identified cognitive errors and working environment conditions as the main causes of accidents in small fishing vessels in Korea. The Cognitive Reliability and Error Analysis Method (CREAM) was used to predict Human Error Probability (HEP), and risk assessment was conducted by combining the Fuzzy Set Theory (FST) with a BN to reflect uncertain working conditions and human cognitive factors. This approach aims to estimate accident probabilities for each scenario and predict human errors that may occur during real-time operations. The results showed that the probability of accidents increased significantly under high fatigue and insufficient working hours, with falling accidents and being caught in equipment identified as the highest risk factors. This method provided high predictive reliability even under uncertain conditions. However, the analysis covered only a limited range of conditions, suggesting that continuous research and data accumulation would improve model accuracy.

Wang et al. (2024) [46] specifically analyzed Human and Organizational Factors (HOFs) in collision accidents on fishing vessels. The HFACS-BN model was applied, with HFACS (Human Factors Analysis and Classification System) classifying human factors into four hierarchical structures and BN used to quantitatively analyze the relationships between factors. This model used data from 443 collision accidents in China between 2013 and 2023 to identify human and organizational factors and employed CPT and sensitivity analysis to determine accident pathways. The most influential factor was identified as Unsafe Acts, such as improper collision avoidance maneuvers. The study suggested that fishery management agencies and maritime safety authorities should prioritize regulatory compliance, strengthen training, and improve safety management systems to prevent collisions. The HFACS-BN model enables systematic analysis of complex human and organizational factors, making it effective for developing accident prevention strategies. However, as the model is based on specific regional data, it may have limitations when

applied to other waters or countries. The study suggested collecting diverse regional data to tailor the model to local characteristics and incorporating fishing methods and environmental factors into additional analyses.

Collision accidents between merchant ships and fishing vessels are mainly caused by human factors (76.1%) and system/equipment failures (25.3%). Zhang et al. (2024) [50] applied the HFACS model to systematically categorize various human factors and used complex network theory to analyze the propagation mechanisms of accident causes. The model aimed to identify major risk factors for collision accidents between merchant and fishing vessels (CAMF) in Chinese waters and develop effective accident prevention strategies. The results indicated that specific risk factors (e.g., non-compliance with collision avoidance rules, inattentiveness during work) played a crucial role in accident occurrences. However, HFACS primarily focuses on human factors, addressing technical and environmental factors to a lesser extent, indicating the need for multidimensional analytical approaches.

In addition, research evaluating fishermen's exposure to hazards exists, providing foundational data for analyzing accident causes. Burella et al. (2019) [33] addressed noise exposure issues on small fishing vessels in Newfoundland and Labrador, evaluating noise sources and hazardous noise levels within vessels. Real-time noise levels were measured across various locations during seven fishing operations, with most primary areas exceeding recommended noise levels. The study recommended implementing noise control measures in vessel design and operational environments, such as installing noise barriers, applying soundproofing to engines and auxiliary machinery, and encouraging the use of hearing protection devices by crew members.

### *4.4. Cluster 3: Stability*

The term "stability" refers to the ability of a vessel, including fishing boats, to maintain its restoring force, which prevents capsizing. Unlike the approaches that analyze the causes of safety accidents, stability can be calculated by reflecting the ship's main particulars and loading conditions. Studies related to fishing vessel stability can be categorized into two primary approaches: numerical calculation methods employed during the design phase and real-time stability monitoring assessment techniques used for operational safety.

The literature related to stability considered in this study is summarized in Table 6, along with the methods for stability analysis and their pros and cons. A detailed description of each study is as follows:

**Table 6.** Methods, pros, and cons of analyzing the stability of fishing vessels by article.

| Author(s) | Stability Analysis Method | Analysis Technique | Evaluation Metrics | Advantages | Limitations |
|---|---|---|---|---|---|
| Tello et al. (2011) [26] | ■ Strip theory<br>■ Potential flow theory<br>■ Short-term sea state analysis | ■ Computing motion responses<br>■ Frequency-domain analysis<br>■ Harmonic motion analysis<br>■ Probabilistic method | ■ Motion criteria<br>■ Derived criteria<br>■ Operability index | ■ Relatively simple<br>■ Accurate prediction of vessel behavior | ■ Does not account for complex real-world interactions<br>■ Require accurate input |
| Domeh et al. (2023) [55] | ■ Loss of Stability (LoS) risk assessment using quantitative risk analysis (QRA) | ■ Bayesian Networks<br>■ De Morgan gates | ■ LoS probability<br>■ Risk visualization | ■ Precise risk prediction<br>■ Useful for adding new risk factors | ■ Model building and maintenance can be challenging<br>■ High dependency on data quality |
| Míguez González et al. (2012) [29] | ■ SKIPPER system | ■ Stability and equilibrium calculation algorithms (In software) | ■ Stability parameters (e.g., GZ curves, trim, draft) | ■ User-friendly and visual risk indicator | ■ Limited dynamic stability scenario evaluation |
| Iqbal et al. (2023) [56] | ■ Operability assessment | ■ ShipX VERES Software<br>■ Potential theory | ■ RMS roll<br>■ RMS pitch<br>■ Percentage operability (PO)<br>■ Operability robustness index (ORI) | ■ Identifies vessel vulnerability under various conditions<br>■ The two methods are complementary | ■ May not capture complex nonlinear interactions |

**Table 6.** *Cont.*

| Author(s) | Stability Analysis Method | Analysis Technique | Evaluation Metrics | Advantages | Limitations |
| --- | --- | --- | --- | --- | --- |
| Santiago Caamaño et al. (2018, 2019) [5,38] | ■ Real-time stability assessment system | ■ Fast Fourier Transform (FFT)<br>■ Hilbert-Huang Transform (HHT)<br>■ Error propagation analysis | ■ Natural roll frequency<br>■ GM | ■ Possible to consist autonomous and real-time safety alerts | ■ Does not handle various wave effects (e.g., wave direction) |
| Míguez González and Bulian (2018) [34] | ■ 1-DOF models<br>■ 6-DOF blended code | ■ Mathematical calculation<br>■ Comparing with various results | ■ Roll motion<br>■ Parametric roll resonance<br>■ Large motions in beam sea | ■ High accuracy for 6-DOF<br>■ Quick evaluations for 1-DOF<br>■ Reasonable data in design stage | ■ 1-DOF lacks reliability<br>■ 6-DOF is costly<br>■ Inadequate for real-time monitoring |
| Liu et al. (2019) [43] | ■ Computational Fluid Dynamics (CFD) | ■ Case study | ■ Roll motion (Roll reduction via bilge keel optimization) | ■ Various cases can be reviewed without actual production | ■ Verification of the results is necessary |
| Szozda and Krata (2022) [51] | ■ Second Generation Intact Stability Criteria (SGISC)<br>■ Level 1 and Level 2 criteria | ■ Historical accidents analysis<br>■ Check the criteria | ■ Vulnerability assessment (surf-riding, broaching probability) | ■ Handles multiple stability modes<br>■ Assessment of dynamic stability failure modes (surf-riding, broaching) | ■ Potential false positives for safe vessels<br>■ Consumes a lot of time and computational resources |

Numerical studies include theoretical formulas and computer simulations such as Computational Fluid Dynamics (CFD), which have continuously evolved from past to present. Tello et al. (2011) [26] conducted a study to evaluate the seakeeping performance of fishing vessels in irregular waves and to identify the main factors that limit the operability of vessels under various sea conditions. The study predicted the short-term responses of the vessels using the transfer functions for heave and sway motions along with the Pierson–Moskowitz spectrum. Additionally, the motion responses of each vessel were analyzed based on Salvesen's strip theory, and the results were compared against various criteria to evaluate the operational limits of the vessels. The slender body theory, which allows a 6-DOF (Degrees of Freedom) analysis, enables comprehensive assessment of ship movements and provides quick evaluations under multiple conditions. However, because this theory may not fully account for complex physical factors that can occur in real ocean environments, verification of the results is necessary to ensure accuracy. Míguez and Bulian (2018) [34] used a 6-DOF nonlinear model and a 1-DOF roll model to predict the roll response of fishing vessels and evaluate their dynamic stability. The 6-DOF model provides high accuracy by precisely simulating wave–ship interactions, but its high computational complexity and cost limit its practical use in the design phase. In contrast, the 1-DOF model, though less reliable due to its simplified approach, allows for quick and cost-effective evaluations, making it suitable for initial design stages. The study found that the prediction differences between the two models were minimal under moderate wave heights, but discrepancies increased as wave heights grew, with the 6-DOF model yielding more precise results. To improve this approach, the study suggests enhancing the nonlinear effects in the 1-DOF model and developing hybrid models that can more accurately capture the dynamic interactions between waves and hull structures. Additionally, integrating real-time weather data to reflect complex operational conditions is recommended to increase the reliability of stability assessments for practical applications.

Liu et al. (2019) [43] employed CFD to design and optimize bilge keels for traditional fishing vessels, achieving up to an 11.78% reduction in roll motion. However, installing bilge keels may lead to increased hydrodynamic resistance, highlighting the need for an optimal design that minimizes this drawback. While CFD studies allow for extensive case analyses, validation processes must accompany these results to ensure reliability and accuracy. Szozda and Krata (2022) [51] evaluated the dynamic stability of fishing vessels using the Second Generation Intact Stability Criteria (SGISC) and analyzed the vulnerability of vessels to surf-riding and broaching phenomena. In this study, the authors applied SGISC's Level 1 and Level 2 assessment methods, where Level 1 uses simple

formulas for preliminary risk evaluation, and Level 2 employs complex physics-based models for detailed analysis. While this approach has the advantage of reflecting a variety of external factors, there is a potential risk of false positives, where safe vessels may not meet the regulatory standards. Thus, further validation and refinement of the criteria are needed to ensure precision and practical applicability.

Secondly, stability monitoring primarily utilizes scenarios or measured data to evaluate stability, and the results from these assessments can serve as foundational data for future real-time monitoring applications. González et al. (2012) [29] proposes a user-friendly fishing vessel stability assessment system specifically designed for small and medium-sized vessels, addressing the limitations of conventional stability evaluation methods. The system, named SKIPPER, offers an intuitive interface for accurately evaluating a vessel's stability by considering various loading conditions, dynamic seawater conditions, and vessel specifications. By utilizing detailed hull form data and hydrostatic characteristics, the software calculates the equilibrium and stability parameters of the ship, such as the righting lever (GZ) curves, trim, and draft. The system features a visual risk level indicator using color codes ranging from green (safe) to black (high risk) to provide immediate feedback on the vessel's stability status. Additionally, the system incorporates IMO regulatory criteria and dynamic stability phenomena, like parametric rolling and loss of stability in following seas, to comprehensively assess safety. Despite its strengths, the system currently has limitations in addressing complex dynamic stability scenarios and combined environmental effects, such as wind and waves, which are common in real-world operations. Future improvements should focus on enhancing the dynamic stability assessment, integrating real-time meteorological data, and providing additional crew training modules to optimize system usability and accuracy. Santiago Caamaño et al. (2018, 2019) [5,38] proposed a real-time stability assessment system that estimates the natural roll frequency of a vessel using frequency analysis techniques, such as Fast Fourier transform (FFT) and Hilbert-Huang Transform (HHT), and calculates the metacentric height (GM) based on this value to monitor the transverse stability of fishing vessels in real-time. This system operates autonomously without the need for manual input from the crew and has the advantage of visually alerting the crew to the ship's safety status. However, it does not fully account for external wave effects and nonlinear dynamic interactions, which limits its reliability under complex sea conditions. Future research should focus on integrating hybrid models that incorporate more complex sea conditions and real-time weather data to improve the accuracy of dynamic stability assessments.

Domeh et al. (2023) [55] proposed a quantitative risk analysis (QRA) approach to assess the risk of Loss of Stability (LoS) in small fishing vessels by integrating BN with De Morgan gates to develop a comprehensive LoS risk assessment tool. The tool quantitatively evaluates the likelihood of various risk factors and predicts the probability of LoS occurrence, while also providing visual alerts to communicate risk levels intuitively. This approach offers the advantage of precise risk prediction and simplified data management through De Morgan gates, which streamline the complexity of conditional probability tables. However, the methodology has certain limitations, such as data dependency, and the inability to incorporate real-time dynamic environmental changes, which could reduce its reliability under varying sea conditions. To address these limitations, the authors suggest integrating real-time weather data, enhancing the tool's user interface for ease of use, and developing hybrid models that can better capture nonlinear sea state interactions. Implementing these improvements would increase the tool's practical applicability, making it more effective for real-world vessel stability management. Iqbal et al. (2023) [56] proposed a stability risk assessment methodology using the Operability Robustness Index (ORI) and Percentage Operability (PO) to analyze the operability of traditional small fishing vessels in Indonesia under various loading conditions. In this study, the ship's Response Amplitude Operator (RAO) was calculated using the VERES software, and RMS roll and pitch motions were used as primary stability criteria to assess the vessel's operability in different sea conditions. This approach allows for an accurate identification of the vessel's vulnerabil-

ity under different loading and environmental conditions. However, a limitation of this methodology is that it may not fully capture complex sea conditions and nonlinear effects, which could reduce the reliability of predictions. To improve this assessment approach, it is recommended to enhance the model by incorporating more detailed nonlinear analyses and integrating real-time weather data to increase evaluation accuracy.

### 4.5. Cluster 4: Operation

The proper operation of fishing vessels implies navigating efficiently and safely. However, accidents or safety issues during fishing operations can result in harm to personnel or damage to vessels due to collisions. Potential causes of accidents include fishermen's misjudgments and internal system errors, making it crucial not only to prevent such accidents but also detect them in advance. To ensure the safety of fishermen during navigation, numerous studies have focused on monitoring the activities of both fishermen and their vessels. These studies help detect illegal fishing activities or support effective search and rescue (SAR) operations during accidents. For example, Zhu et al. (2019) [27] analyzed the drift characteristics of fishing vessels in Chinese coastal waters under different wind conditions and developed a model to support SAR operations. The study used the AP98 leeway model and a drift dynamics model to compare and analyze two approaches, predicting drift trajectories and search areas during marine accidents. The AP98 model estimates leeway coefficients based on experimental data to accurately predict the drift speed and direction of vessels under various wind conditions, utilizing Lagrangian particle tracking and the Monte Carlo method for trajectory simulation. The results showed that the AP98 model provided higher accuracy compared to the drift dynamics model, especially when the Probability of Positive Crosswind (POPC) was considered. Although the AP98 model is effective for predicting drift in various conditions, it needs to incorporate external factors such as currents to improve accuracy.

Similarly, Jung et al. (2023) [39] compared the accuracy of Global navigation satellite system (GNSS) data stored in V-pass and Automatic identification system (AIS) terminals on fishing boats against Differential Global Positioning System (DGPS)-corrected data from Electronic Chart Display and Information System (ECDIS) to assess the reliability of these systems for emergency response and accident investigation. The study revealed that V-pass terminals, which transmit data every 30 s, exhibited positional errors of up to 41 m in certain scenarios, especially during sharp turns. This finding was visually and quantitatively verified using a Ship Collision Reproduction System, highlighting discrepancies between navigation devices and emphasizing the need for improved positional accuracy in SAR operations. Likewise, Park et al. (2023) [44] investigated the reliability of V-pass data for the timely rescue of fishing vessels, identifying transmission delays of up to 7 min, which resulted in critical data gaps during emergencies. To mitigate these issues, the study suggested refining V-pass transmission protocols and adopting a shorter data-saving interval to ensure precise tracking during SAR missions.

Regarding the monitoring of vessels engaging in risky behavior, Shanthi et al. (2022) [35] utilized AIS data to analyze vessel movements and identify abnormal behaviors, such as illegal fishing, cross-border activities, and unexpected route changes. The study employed an Automatic Tracking System (ATS) to periodically collect AIS data and detect deviations from normal operational patterns. Identified anomalies were integrated into international maritime monitoring systems, like Global Fishing Watch (GFW), to accurately locate illegal vessels and support rapid responses from marine protection agencies. In a similar context, Ramesh and Ramesh (2023) [47] proposed a system to monitor fishing vessel activities in the Indian region using MIMO (Multiple Input Multiple Output) technology and database management, enabling real-time monitoring and rapid alerts. However, the study pointed out that intentional communication disruptions on vessels pose a challenge, necessitating the development of redundant communication pathways to ensure continuous monitoring.

As autonomous vessels are being actively developed, collision avoidance and warning algorithms are also being researched for application to fishing vessels. For example,

Yoo et al. (2023) [52] developed a trajectory prediction model for fishing vessels using an Attention-Based Bidirectional Gated Recurrent Unit (BiGRU) to enhance short- to medium-term trajectory predictions, supporting collision avoidance for autonomous ships. The model was structured using a sequence-to-sequence (Seq2Seq) architecture with an attention mechanism, resulting in a 7–12% improvement in prediction accuracy compared to conventional Gated recurrent unit (GRU) and Long short-term memory (LSTM) models. This model has the potential to enhance collision avoidance capabilities for autonomous ships; however, further refinement with diverse datasets is necessary to increase robustness and generalizability.

Additionally, research on collision warning systems has predominantly focused on merchant ships, with ongoing development occurring. Lee et al. (2021) [30] implemented a collision warning algorithm that utilized metrics, such as Distance to Closest Point of Approach (DCPA), Time to Closest Point of Approach (TCPA), and a modified Potential Assessment of Risk (PARK) model, to evaluate collision risks. The algorithm was validated through real-ship tests under various scenarios based on the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), effectively identifying high-risk areas using millimeter-wave communication for real-time updates. While it successfully detected hazardous zones, the study highlighted that excessive alarms led to operator desensitization. Therefore, refining the algorithm to reduce false alarms and improve real-time data integration is recommended.

However, further examination is necessary to determine whether such avoidance algorithms are appropriate for fishing vessels. Fishing vessels often operate at much higher speeds compared to merchant ships, and collision avoidance is frequently based on the captain's judgment rather than strict adherence to regulations. Additionally, encounters not only between merchant ships and fishing vessels but also between fishing vessels themselves can be more complex and challenging to manage. Therefore, a collision avoidance algorithm designed for fishing vessels must take these specific characteristics into account.

## 5. Discussion: Future Work

Through the review of selected literature, fishing vessel safety studies have been categorized into distinct clusters. Considering the safety analysis methods related to fishing vessel accidents, the following key directions for future research are proposed.

### *5.1. Development of Advanced Data-Driven Predictive Models*

Conventional statistical methods have limitations in accurately capturing nonlinear factors and complex environmental interactions. In particular, a key point is how to take into account the high variability of fishing vessels, including factors such as operating areas, weather conditions, types of fishing activities, the condition of the crew, and loading status. Consequently, there has been a growing trend in research utilizing advanced algorithms, such as BN, machine learning, and RF, to improve the predictive accuracy of fishing vessel accidents. Studies employing BN have demonstrated the capability to analyze various accident scenarios and risk factors, enabling quantitative assessments (Uğurlu et al., 2020 [20]; Kim et al., 2023 [58]; Wang et al., 2023 [3]; Obeng et al., 2024 [49]; Domeh et al., 2021, 2023 [37,45]; Wang et al., 2024 [46]; Lee et al., 2024 [42]). In particular, recent studies have integrated algorithms, such as RF, DST, and Chi-square tests, alongside BN. These methods are employed for variable selection, handling uncertain conditions, and qualitative relationship analysis, thereby complementing the limitations of BN and enhancing its applicability (Wang et al., 2023 [3]; Obeng et al., 2024 [49]; Uğurlu et al., 2020 [20]).

Future research should aim to establish a balance between quantitative and qualitative analyses through approaches such as BN or methods capable of quantifying accident risk. However, this process is often complex, involving high initial configuration costs and computational overhead. Integrating artificial intelligence (AI) technologies, such as machine learning or automated processes, can potentially overcome the static characteristics of con-

ventional models, enabling real-time risk prediction. Moreover, employing hybrid models based on deep learning can significantly enhance predictive performance by automatically learning the nonlinear relationships between variables. For instance, combining BN with tree-based models, such as Gradient Boosting Decision Trees (GBDT), can facilitate visual analysis of nonlinear interactions between variables, which aids in identifying key causes of accidents and understanding complex interdependencies (Anghel et al., 2018 [61]).

Additionally, sensitivity analysis and Shapley values can be used to quantitatively evaluate the impact of each risk factor on accident probability, thereby enhancing model transparency and providing decision-makers with more reliable insights (Song et al., 2016 [62]). Consequently, this approach enables the detection of hidden risk factors that may not be identifiable through traditional BN and facilitates the integration of diverse environmental data to better predict accident occurrence and improve overall risk assessment. This approach will be helpful in addressing the diverse situations encountered by fishing vessels.

### *5.2. Development of Real-Time Monitoring Systems*

For fishing vessels, it is crucial to quickly monitor the current situation due to the constantly changing stability during operations and the high-speed nature of their navigation. Establishing a real-time safety monitoring system that integrates real-time meteorological data, vessel conditions, and location information could significantly enhance risk awareness and help prevent accidents. Several foundational studies on real-time safety assessments have been conducted, as noted in previous research. If real-time data can be further integrated into meteorological warning systems, vessel stability assessments, and autonomous navigation, accident prevention could be achieved with higher precision through more refined data (Yang et al., 2023 [57]; Piniella and Fernández-Engo, 2009 [25]; Domeh et al., 2023 [55]; Obeng et al., 2024 [49]; Zhang et al., 2024 [50]; Burella et al., 2019 [33]; González et al., 2012 [29]; Santiago Caamaño et al., 2019 [5]; Shanthi et al., 2022 [35]; Jung et al., 2023 [39]; Park et al., 2023 [44]).

To achieve this, advanced technologies must be employed. First, Internet of Things (IoT) sensors are crucial for real-time data collection. Various sensors installed on fishing vessels (e.g., GPS, speedometers, meteorological sensors, and engine status monitoring sensors) can monitor the vessel's location, speed, direction, mechanical condition, and weather conditions, providing real-time information. Additionally, by utilizing sensor network technology, data from each sensor can be transmitted to a central system, integrated in real-time, and reflected in the monitoring system. In commercial vessels, intelligent ship collision risk assessment using video data has been attempted by Ding et al. (2024) [63], and there is a need to evaluate the feasibility of this approach for fishing vessels as well. Second, a reliable network is essential. Since terrestrial communications, such as LTE or 5G. are often unavailable in marine environments, real-time data transmission is challenging. Therefore, satellite communication systems, like Iridium and Inmarsat, can be employed to enable real-time data exchange even when vessels are operating far offshore (Kerczewski et al., 2008 [64]).

However, the integration of these technologies into fishing vessels poses challenges, as many of these vessels are aging and high-end sensors are likely to be costly. Therefore, government-level support or the development of cost-effective and efficient technologies is necessary to successfully implement these systems on fishing vessels.

### *5.3. Implementation of Human Factors and Decision Support Systems*

Although human and organizational factors are critical to the safety of fishing vessels, they are often overlooked or only partially integrated into existing safety analysis models. As mentioned earlier, human factors can vary significantly depending on the country, region, and individual, making it quite challenging to effectively account for such diversity. Consequently, efforts to analyze human errors along with technical and environmental factors are increasing, utilizing methods such as CREAM, Fuzzy Logic, SRK, and HFACS (Wang et al., 2024 [46]; Lee et al., 2024 [42]; Zhang et al., 2024 [50]; Kim et al., 2024 [59]).

Beyond these, advanced models, like STAMP (Systems-Theoretic Accident Model and Processes) and FRAM (Functional Resonance Analysis Method), are crucial for in-depth analysis and assessment of accident factors (Zhang et al., 2022 [65]; Patriarca et al., 2020 [66]).

Moreover, due to the diverse cultural and operational characteristics inherent in the fishing industry, models that account for such variability are essential. For this purpose, investigations tailored to specific cultural contexts are needed. While surveys and interviews are commonly used, they can be influenced by interviewer bias. Additionally, conducting such research requires a considerable amount of time and expense. Thus, developing more objective and efficient tools, such as standardized checklists, should be considered to ensure comprehensive and unbiased assessments.

### *5.4. Strengthening Policies and Regulations, and Promoting International Standardization*

As mentioned in the introduction, the regulation of fishing vessel safety is managed independently by various agencies and countries, leading to overlap and inefficiencies. Although international organizations. such as IMO, ILO, and FAO. have collaborated to introduce policies and regulations, there remains a lack of comprehensive guidelines for small-scale fishing vessels. To address this issue, it is necessary to promote data sharing and research collaboration among countries, and continuous attention from individual nations is crucial for achieving international standardization. Encouraging as many countries as possible to participate in international agreements and introducing diverse policies are essential steps toward enhancing the effectiveness of safety regulations.

## 6. Conclusions

This study conducted a bibliometric analysis by reviewing the current state and future research directions related to fishing vessel safety, utilizing relevant literature. For data collection, the Scopus database was used, and Boolean syntax was employed to create the query strings. As a result, 285 relevant documents were identified, and a bibliometric analysis was performed using the Biblioshiny app from the bibliometrix package in R software, along with VOSviewer. Biblioshiny was used to generate an authors' cooperation network, three-field plot, and keyword Thematic map, which were used for citation analysis. VOSviewer was used to create networks between journals, articles, affiliations, countries, and keywords, through which bibliographic coupling was performed.

Research on fishing vessel safety has been steadily increasing. The journal with the highest number of publications was *Ocean Engineering*. The most cited paper was Certa et al. (2017) [14]; however, despite its high citation count, it was found to have fewer or no connections in the network plot due to its lower relevance to the themes of the 285 documents considered. The author with the most publications was Wang, J., with nine papers. Wang's network plot showed clustering with co-authors who conducted research around the same period. The characteristic author clusters were divided into two groups: those who started research in the early 2000s and those who began after 2020. The institution with the highest number of publications was NTNU, and the country with the most publications was China. The institutions and countries contributing to fishing vessel safety research were primarily those with active fishing industries. Using the three-field plot, the relationships between journals, keywords, and countries were observed, revealing that *Ocean Engineering* hosted a wide variety of topics. It was also confirmed that most countries covered diverse topics related to fishing vessel safety.

Through bibliographic coupling, the keywords of the 285 documents were grouped into four main clusters: *Accident/Risk Analysis*, *Human errors*, *Stability*, and *Operation*. These clusters represented different aspects of accidents and prevention measures, categorized based on situations and technology. Moreover, *Accident/Risk analysis* was further subdivided into *Accident analysis* and *Risk analysis* depending on whether the focus was on analyzing past incidents or studying factors for accident prevention. To perform a detailed review of the selected literature, 148 documents categorized in the Thematic map were prioritized based on publication year and citation count for the initial screening. Additionally, other

documents not included in the Thematic map were evaluated for their relevance based on the titles and the prominence of the authors. Through this process, 37 documents were finally selected for a detailed review within each cluster.

The first cluster, *Accident/Risk Analysis*, can be divided into two subcategories: *Accident Analysis* and *Risk Analysis*. *Accident analysis* focuses on investigating the causes of fishing vessel accidents that have occurred worldwide and proposes safety measures based on these findings. This subcategory mainly uses statistical methods or BN to quantitatively estimate the probability of accidents and incorporates qualitative factors through approaches like FTA and FSA. In contrast, *Risk Analysis* is more prevention-oriented, focusing on defining risk factors and calculating the probability of accidents. Strategies such as risk selection using checklists and RBM are commonly employed. Techniques like RAw tools and FMEA are used to predict accident likelihood. The second cluster, *Human Factors*, addresses the impact of human error in maritime accidents, with a focus on analyzing the diverse factors contributing to human error. Various models are proposed to assess these influencing factors. Additionally, understanding human factors requires an analysis of less quantifiable elements, such as national, regional, and cultural characteristics. The third cluster, *Stability*, primarily deals with evaluating and comparing different stability assessment methods. Due to the dynamic nature of stability influenced by irregular operational conditions on fishing vessels, the studies in this cluster suggest mathematical calculations, real-time evaluation, and methodologies for hazard warning. The final cluster covers *Operation*, focusing on strategies to prevent collision accidents and avoid entry into hazardous areas through location tracking technologies. With the recent advancements in autonomous navigation technologies, research on algorithms for collision avoidance is also increasing.

After conducting detailed reviews by cluster and considering the strengths and weaknesses of the methods proposed in the surveyed literature, future directions were suggested for advancing research in fishing vessel safety. Future research on fishing vessel safety should focus on incorporating emerging technologies into existing safety methodologies. This integration will not only enhance the accessibility of these methods for researchers but also facilitate the development of solutions that can be easily and efficiently implemented by a broader range of fishermen. As fishing vessel accidents are caused by various factors and occur under diverse circumstances, real-time monitoring is essential to enable immediate responses to these dynamic situations. Furthermore, with the continued advancement of the fishing industry, ongoing research and the development of international regulations and agreements are necessary to ensure the safety of fishermen working in hazardous environments.

**Author Contributions:** Conceptualization, S.H.L. and H.K.; Methodology, S.H.L. and H.K.; Investigation, S.K.; Resources, S.H.L. and S.K.; Data curation, S.H.L. and H.K.; Writing—original draft, S.H.L.; Writing—review & editing, H.K. and S.K.; Visualization, S.H.L.; Supervision, H.K.; Funding acquisition, S.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by Korea Institude of Marine Science and Technology Promotion (KIMST) Funded by the Ministry of Oceans and Fisheries (RS-2022-KS221571).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Nomenclature

**Acronyms**

| | |
|---|---|
| AI | Artificial intelligence |
| AIS | Automatic identification system |
| ATS | Automatic Tracking System |
| ATSB | Australian Transport Safety Bureau |
| BiGRU | Attention-Based Bidirectional Gated Recurrent Unit |
| BN | Bayesian Network |
| CAMF | Collision accidents between merchant and fishing vessels |
| CCG | Canadian Coast Guard |
| CFID | Commercial Fishing Incident Database |
| CL | Checklists |
| COLREGs | Convention on the International Regulations for Preventing Collisions at Sea |
| CPT | Conditional Probability Table |
| CPT | Conditional Probability Tables |
| CREAM | Cognitive Reliability and Error Analysis Method |
| DCPA | Distance to Closest Point of Approach |
| DFO | Fisheries and Oceans Canada |
| DGPS | Differential Global Positioning System |
| DOF | Degrees of Freedom |
| DST | Dempster-Shafer Theory |
| ECDIS | Electronic Chart Display and Information System |
| EMSA | European Maritime Safety Agency |
| FAO | Food and Agriculture Organization |
| FFT | Fast Fourier transform |
| FLR | Fractional Logit Regression |
| FMECA | Failure Mode, Effects, and Criticality Analysis |
| FMIA | Fishery Mutual Insurance Association |
| FRAM | Functional Resonance Analysis Method |
| FSA | Formal Safety Assessment |
| FST | Fuzzy Set Theory |
| GBDT | Gradient Boosting Decision Trees |
| GBS | Goal-Based Standards |
| GBS-SLA | Goal-Based Safety Level Approach |
| GFW | Global Fishing Watch |
| GIS | Geographic Information System |
| GISIS | Global Integrated Shipping Information System |
| GNSS | Global navigation satellite system |
| Goal-DRIT | Goal-Directed Risk Identification Technique |
| GRU | Gated recurrent units |
| GZ | Righting lever |
| HEP | Human Error Probability |
| HFACS | Human Factors Analysis and Classification System |
| HHT | Hilbert-Huang Transform |
| HOFs | Human and Organizational Factors |
| ILO | International Labour Organization |
| IMO | International Maritime Organization |
| IOP | Institute of Physics |
| IoT | Internet of Things |
| ITS | Institut Teknologi Sepuluh Nopember |
| JMSE | Journal of Marine Science and Engineering |
| KDE | Kernel Density Estimation |
| KMST | Korea Maritime Safety Tribunal |
| KOSIS | Korean Statistical Information Service |
| LoS | Loss of Stability |
| LSTM | Long short-term memory |
| MAIB | Marine Accident Investigation Branch |
| MIMO | Multiple Input Multiple Output |
| MISLE | Coast Guard's Marine Information for Safety and Law Enforcement |
| MOB | Man overboard |
| MOF | Ministry of Oceans and Fisheries |
| MPS | Main Propulsion System |
| MSA | Maritime Safety Administration |
| MSC | Maritime Safety Committee |
| MSC | Maritime Safety Committee |
| NAV | Norwegian Labour and Welfare Administration |
| NFFC | National Federation of Fisheries Cooperatives |
| NIOSH | National Institute for Occupational Safety and Health |
| NMFS | National Marine Fisheries Service |
| NP | Number of publications |
| NTNU | Norges Teknisk-Naturvitenskapelige Universitet |
| OMAE | International Conference on Ocean, Offshore and Arctic Engineering |
| OOBN | Object-Oriented Bayesian Network |
| ORI | Operability Robustness Index |
| PARK | Potential assessment of risk |
| PE | Protective equipment |
| PO | Percentage Operability |
| POPC | Probability of Positive Crosswind |
| PY start | Year of their first published paper |
| QRA | Quantitative risk analysis |
| RAO | Response Amplitude Operator |
| RBM | Risk-Based Maintenance |
| RCOs | Risk control options |
| RF | Random Forest |
| RIF | Risk Influential Factors |
| RPN | Risk Priority Number |
| RR | Relative Risk |
| SA | Situational awareness |
| SAR | Search and rescue |
| Sci2 | Science of Science |
| Seq2Seq | Sequence-to-sequence |
| SFVs | Small fishing vessels |
| SGISC | Second Generation Intact Stability Criteria |
| SHT | Staten Havarikommi sjon for Transport |
| SLMV | Slip-Lapse-Mistake-Violation |
| SNAME | Society of Naval Architects and Marine Engineers |
| SRK | Skill-Rule-Knowledge |
| STCW-F | International Convention on Standards of Training, Certification, and Watchkeeping for Fishing Vessel Personnel |
| TAN | Tree-Augmented Naive Bayes |
| TAN | Tree-Augmented Naive Bayes |
| TC | Total citations |
| TCPA | Time to Closest Point of Approach |
| TSB | Transportation Safety Board of Canada |
| ZNBR | Zero-Inflated Negative Binomial Regression |

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