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Contents

Developments and research directions for collision avoidance in mixed navigation environment for MASS: A systematic literature review with bibliometric analysis.

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المستخلص

تُعزز تكامل التقنيات المتقدمة والعمليات التي تعتمد على تلقائية نقل البيانات وذلك في ظل الثورة الصناعة الرابعة، حيث أهمية الاتصالات بين السفن والبنية التحتية البحرية، وخصوصًا مع ظهور السفن البحرية السطحية الذاتية الحركة (MASS) .يوجد بعض الدراسات الحالية التي تعمقت في قوانين منع التصادم البحري (COLREG) وسفن الملاحة الذاتية، وتقييم المخاطر للملاحة البحرية لـMASS ،و لحصر و تحليل بعض هذه الدراسات، تم عمل مراجعة شاملة ونظامية للأدبيات وتحليل ببليومتري للدراسات الأكاديمية التي تتناول منع التصادم MASS داخل البيئات الملاحية المختلطة، تهدف هذه المراجعة إلى تقديم نظرة عامة موجزة عن التقدم الذي تحقق في البحوث الأكاديمية المتعلقة بالتحديات المرتبطة بـ MASS وسلامة الملاحة في البيئات الملاحية المختلطة. باستخدام مقاييس وأدوات تحليل لفهم مواضيع البحوث الأكاديمية، والتحديات الأساسية، والاتجاهات في هذا المجال. عن طريق استخدام *(PRISMA)*، بما في ذلك الكلمات الرئيسية في قاعدة بيانات *SCOPUS*. أظهرت النتائج أن الصين والنرويج وبولندا وكوريا الجنوبية هي الدول الرائدة في الأبحاث المتعلقة بالموضوع، استنادًا إلى العدد المُرْوَّج للمؤلفين. بالإضافة إلى ذلك، ظهرت مجلة Ocean Engineering ومجلة IFAC-Papers Online كأبرز المجلات للمنشورات في هذا الموضوع. من خلال الأدبيات المحللة، تم تحديد بعض المقترحات للبحوث المستقبلية.

ABSTRACT:

The integration of advanced technologies, data-driven processes, and automation under the Industry 4.0 revolution is fostering increased connectivity among ships and maritime infrastructures, particularly with the emergence of Maritime Autonomous Surface Ships (MASS) and the imperative for safe navigation. Despite existing studies delving into collision regulations (COLREG), autonomous navigation, and risk assessment for MASS navigation, a comprehensive systematic literature review and bibliometric analysis of academic research studies addressing collision avoidance in the context of MASS within mixed navigational environments has, to our knowledge, not been undertaken. This review aims to provide a concise overview of academic research advancements concerning the challenges associated with MASS and the safety of navigation in mixed navigational environments. To achieve this objective, we conducted a bibliometric analysis of pertinent studies, utilizing metrics and analysis tools to discern academic

research topics, primary challenges, and directions in this domain. Our approach adhered to the principles outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) for systematic literature reviews, incorporating tailored keywords in a Scopus search. The results revealed that China, Norway, Poland, and South Korea are the leading countries in MASS collision avoidance, based on the weighted number of authors. Additionally, Ocean Engineering and the Journal of IFAC-Papers Online emerged as the principal journals for publications on this topic. Through the analyzed literature, specific challenges were identified, paving the way for suggested avenues for future research.

Keywords: MASS, Collision Avoidance, Autonomous Navigation, Bibliometric Analysis, PRISMA

2- INTRODUCTION

Continuous technological innovation continues to enhance various facets of human existence. The advent of the Fourth Industrial Revolution (Industry 4.0) has notably strengthened the connectivity among ships, onboard systems, and associated infrastructure (Issa et al., 2022). Within the maritime industry, there is a discernible trend toward incorporating smart systems, particularly in safety-critical areas where artificially intelligent agents are poised to manage collision avoidance and grounding prevention autonomously (Jadhav et al., 2023a). This shift yields several advantages, including enhanced control over the functioning of marine systems, improved precision in monitoring their health, and more effective collaboration between ship and shore personnel. Moreover, it facilitates compliance with emission regulations and propels maritime operations towards greater automation, potentially involving crewless ships (Issa et al., 2022). Despite the ongoing emphasis on Maritime Education and Training and the enhancement of sensor capabilities, groundings and collisions continue to account for a significant proportion of marine accidents. In many instances, collisions result from human errors, leading to consequences ranging from moderate to severe and exerting a substantial impact on both the marine environment and life at sea (Martelli et al., 2023). Research indicates that human error remains a prominent factor in such incidents. Consequently, the maritime industry consistently explores novel autonomy approaches to address and mitigate this persisting issue (Jadhav et al., 2023b).

MASS have garnered substantial attention in recent years, primarily due to their appealing economic advantages and the potential to enhance safety. A key feature of MASS lies in its ability to leverage perception information, thereby replacing Officers on Watch (OOW) and enabling the implementation of varied navigation decisions through expert and intelligent systems (Wang et al., 2022). The introduction of unmanned or minimally manned autonomous ships contributes to reducing the exposure of individuals to risks at sea. Even in cases where autonomous navigation does not directly decrease the number of accidents, it signifies an enhancement in overall safety at sea (de Vos et al., 2021). Moreover, researchers tackle different aspects of research regarding collision avoidance for instance, (C.-C. Chou et al., 2022) presented an innovative model for objectively and quantitatively forecasting navigational risks associated with MASS. In a

complementary vein, (Li, 2023) developed a decision-making model tailored for collision avoidance (CA) involving numerous target ships (TSs). This model is grounded in the principles of ship collision avoidance geometry and the distinctive characteristics of collision avoidance among multiple target ships at sea. Meanwhile, (Liu et al., 2023) conducted a comprehensive review of current research on scene generation methods, with a specific focus on testing ship collision avoidance. The analysis encompasses simulation methods for collision avoidance models and algorithms, drawing insights from both domestic and international research. Furthermore, (Huang and van Gelder, 2020) provided an extensive overview of collision prevention techniques, centering on the fundamental processes of determining evasive solutions, namely motion prediction, conflict detection, and conflict resolution. On a different note, (Zhao and Roh, 2019) proposed an efficient method to address multi-ship collision avoidance challenges using the Deep Reinforcement Learning (DRL) algorithm. This method directly maps encountered ship states to an own ship's steering commands in terms of rudder angle using the Deep Neural Network (DNN). Lastly, (Wu et al., 2019) introduced a fuzzy logic-based approach for ship-bridge collision alerts, considering ship particulars, bridge parameters, and the natural environment.

(Zhou et al., 2024) presented a method for parametric modeling of encounter scenarios for ship avoidance testing in inland waterways, which is employed to automatically generate inland waterway ship encounter scenarios. (Guan et al., 2024) proposed an intelligent navigation approach leveraging PRM (Probabilistic Roadmap) and PPO (Proximal Policy Optimization) algorithms to enhance autonomous navigation and decision-making for collision avoidance in (MASS). (Cui et al., 2024) delved into the interactive collision avoidance challenges arising in mixed navigation scenarios involving both autonomous and manned ships, with the objective of ensuring efficient collision avoidance and safe navigation. The authors advocated for a multi-agent interactive ship dynamic game collision avoidance decision-making method. Within this framework, dynamic game theory is employed to portray individual ships as participants with independent decision-making capabilities, with course alterations representing strategic actions aimed at optimizing safety and socio-economic considerations. (Wang et al., 2024) examined a collision avoidance system tailored for autonomous ships navigating through intricate encounter scenarios, such as congested ports. This system integrates various sensors for object detection and environmental perception. To assist autonomous ships in handling complex and dynamic scenarios, a collision map is generated to depict encounter scenarios, serving as input for a deep reinforcement learning (DRL) model.

These studies aimed at understanding the general MASS collision avoidance challenges in mixed environments, researchers strived to solve different challenges using different techniques and algorithms. Risk assessment models have been proposed, as decision-making systems, fuzzy logic algorithms, and reinforcing deep learning techniques like artificial neural networks. None of the currently available review studies implemented a comprehensive analysis and a thorough bibliometric analysis of the research studies published on the topic of MASS Collision Avoidance. There is a need for a review that would offer a succinct description of the progress in the rising

topic of collision avoidance, summarize the current state of knowledge with a focus on the scientific methods, and distill the findings provided in the various research papers with a focus on the future research and known methodological challenges. The aim of this review is therefore to attempt to answer the following Research Questions (RQs) related to MASS collision avoidance research:

RQ1: What are the primary countries, authors, cluster topics, and relevant journals based on scientific publications' bibliometric analysis?

RQ2: What methodological challenges are reported in these studies and what future research directions do they lead to?

The RQ1 aims at identifying the achieved progress in the topic of autonomous ship navigation in different countries, journals, and established networks of cooperation, RQ2 at the known challenges and potential future research in the area. In this way, a brief description of the progress in collision avoidance of MASS in mixed navigation challenges and future research directions can be realized which is of great support for novel and experienced researchers in the field.

This paper is structured as follows. First, the literature review and bibliometric analysis methodology are presented. Then the investigated research questions are answered using the presented methodology. The paper's limitations are also provided. Finally, we summarize the main review findings in the conclusions section.

3- METHODOLOGY

The review methodology employed in this article adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Liberati et al., 2009), a structured approach for conducting systematic literature reviews. While there are various techniques available for literature reviews, we chose PRISMA due to its widespread use, systematic nature, and user-friendly methodology. In this study, we tailored the PRISMA methodology to address the research questions outlined in the introduction section. The information flow, guided by the PRISMA methodology, is depicted in **Figure 1**, with detailed steps elucidated in the subsequent sections. The same figure also provides information on the number of identified publications and the final selection process.

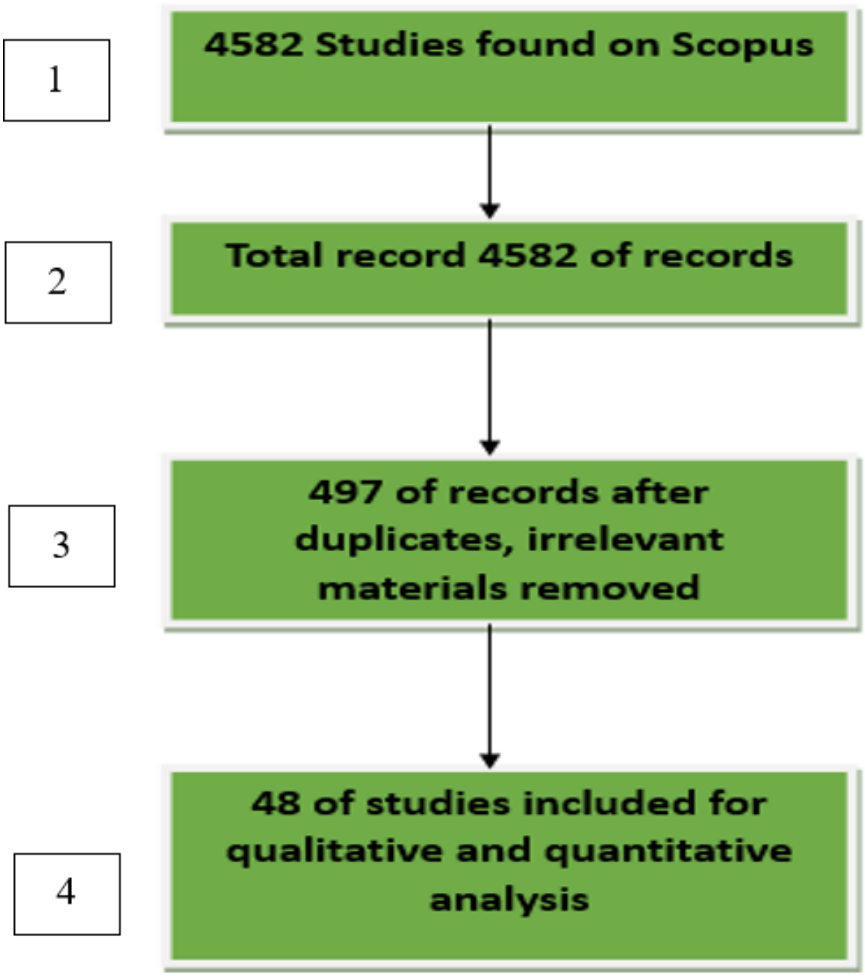

Figure 1: The flow of information through the different phases of systematic literature review. (numbers as of Dec 2023)

Step 1: Identification of research studies

Scopus is used as search engine to find relevant studies. Google Scholar was not used because the results it provided included many publications of low quality, ones that weren't peer-reviewed or were intended for a broader audience rather than an academic one, which is what we were specifically looking for. This decision was made to ensure the focus on scholarly and peer-reviewed sources in our research. Also, identification for the relevant publications in a series of journal publishers is not conducted as the returned results were overwhelmingly large in number including many irrelevant publications, Therefore, by using Scopus we ensured broader coverage. By using the term "Autonomous ships" 4582 entries were received in response, For the identification process generic keywords as below were used as a topic filter for the main keyword:

1. Collision avoidance
2. Autonomous navigation
3. MASS

Autonomous ships are used as a keyword in combination with other keywords during identification as the observant results, although largely similar, included some additional valuable references. Also, it was noticed that the first two keywords collision avoidance and autonomous navigation contributed to the identification of the most research studies that were included in this analysis, So, when the additional keyword MASS was used, a significant number of additional studies was identified. However, very few research studies were additionally included for the collision of MASS in a mixed navigation environment, considering these similar search results, we did not perform research in Scopus for additional keywords that could be additionally considered.

Step 2: Screening of research studies

The screening process aimed to narrow down the number of identified publications for a more in-depth analysis of the most pertinent ones. This involved reviewing the title, abstract, and if needed, a brief overview of the content. The focus was on determining if the research study investigated Collision avoidance of MASS with manned vessels in mixed navigation environments. Additionally, duplicate references were identified and removed during this step. Books were intentionally excluded from the analysis due to their tendency to provide review opinions, limited accessibility, and heavy reliance on findings from previously published conference papers and journal articles. To facilitate further filtration and data analysis using bibliometric methods, the search results were exported to a CSV file. Following the screening, a significant number of initially identified research studies were excluded. Unfortunately, a few relevant studies were inaccessible and had to be excluded as well.

Step 3: Suitability assessment of research studies

In evaluating research studies for suitability, Thorough analysis to the screened studies is conducted and the most fitting ones are chosen for further examination. specific criteria are determined for this, considering where the study was published (whether it was in a reputable journal), the importance of its content (like practical implications and if it showed innovative results), and the reliability of its research methods and results (checking for a meaningful and logical approach and conclusions). To assess journal publications, Scimago's journal ranking is used, and only a few Scopus-indexed journal publications were excluded to ensure we focused on high-quality research. Conference papers were not excluded altogether, as valuable contributions are found in the review. For assessing conference papers, the same criteria are applied. In this step, most of the screened research studies is considered in the analysis to gather diverse perspectives and have enough material to answer our research questions and conduct bibliometric analysis.

Step 4: Included research studies analysis

In the final stage, Bibliometric analysis for the chosen and qualified studies is employed. These particular research studies were exclusively utilized to address the research questions, and the detailed analysis process is outlined in the following sections.

To assess the impact of each country, specific scores/metrics in our analysis of the included research studies are utilized. These metrics encompassed the total number of authors included across all papers, weighted by the overall publication count of the 48 publications. In this analysis,

if an author from a particular country contributed to multiple papers (x times), their contribution was considered x times. The affiliation of each author at the time of publishing, as indicated in the paper, was considered for the analysis, not their actual nationality. In cases of double affiliation, only the first affiliation is counted. Microsoft Excel facilitated this analysis. Additionally, we explored the most prevalent journals covering topics related to MASS collision avoidance, using the number of published articles as a metric, without considering citation counts. Our analysis focused on Scopus-indexed references and top journals, aligned with the Scimago ranking used for eligibility assessment. We employed bibliometric analysis using the open-source software VOS viewer for keywords and term analyses.

For term analysis, we employed the full counting method, which tallies the occurrences of a term in the articles and accord more weight to frequently mentioned keywords.

This marks the final, so far significant, contribution of this article. The identification of challenges involved a thorough examination of the introduction, methodology rationale, and limitations/discussion sections within the inspected publications. To pinpoint directions for future research, the selected studies are analyzed, with particular attention to the discussion, conclusions, and future research sections.

5- Results and Discussion

Figure 2 presents the leading research countries based on the considered metrics, specifically the total weighted number of authors. The legends for the top 10 countries are also provided within the same figure. Notably, countries such as China, Norway, Poland, and South Korea emerge as the primary contributors, as indicated by the metric of the total weighted number of authors in the selected papers. Among the top 10 identified countries, the first four, comprising China, Norway, Poland, and South Korea, account for the majority of contributions to research in MASS collision avoidance, representing 60% of the selected Scopus-indexed publications. This distribution closely aligns with the Pareto principle, suggesting that a substantial portion of the final output (60%) is derived from a smaller percentage of the total input (30%) involving these four countries (Wicksteed and Pareto, 1906). Additionally, it is noteworthy that the majority of researchers referenced, consistently publishing in Scopus-indexed sources, are situated in Europe, with the exception of China and South Korea.

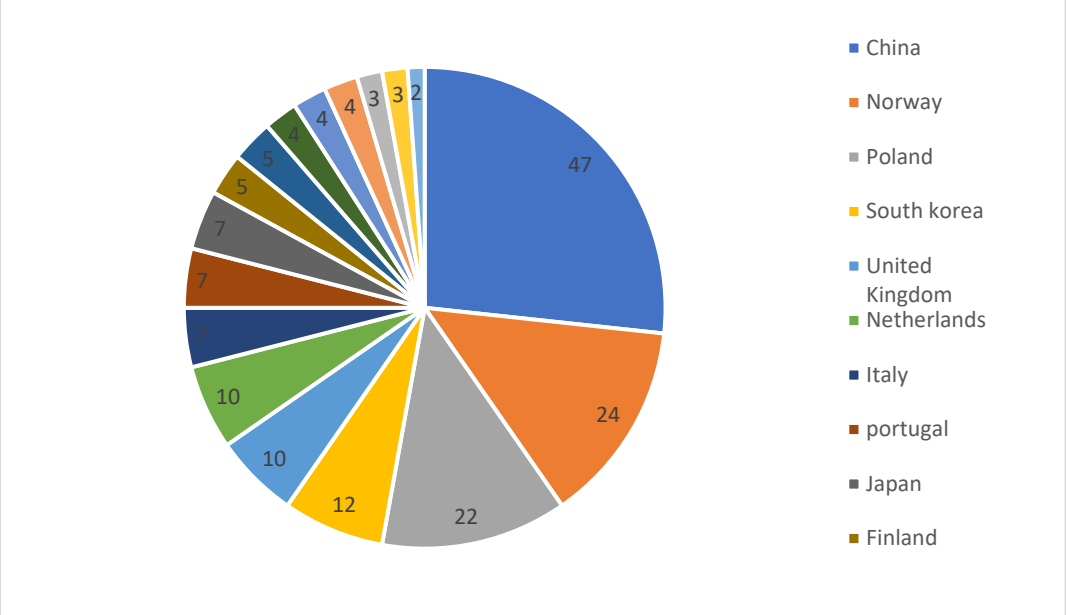

Figure 2: The total weighted number of authors for top countries.

Table 1 shows the top authors with their affiliations and their number of publications. it is noted that China and specially Wuhan University has the top authors publishing in the Topic of MASS collision avoidance which support the finding of the top countries. Moreover, it has been appeared from the number of publications that this topic is a new arising topic under development and needs more attention in the research field.

Table 1: Top Authors with their affiliations

Author	Affiliation	Number of publications
Guedes Soares C.	Universidade de Lisboa, Lisbon, Portugal	3
Lazarowska A.	Gdynia Maritime University, Poland	3
Perera L.P.	University of Lisbon, Portugal	3
Arshad M.R.	Universiti Sains Malaysia (USM), Malaysia	2
Chen P.	Wuhan University of Technology, China	2
Chu X.	Wuhan University of Technology, China	2
Cristofaro A.	University of Camerino, Italy	2
Perez T.	Queensland University of Technology, Australia	2
Mei J.H.	Hebei University, China	2
Zaccone R.	Polytechnic School of Genoa University, Italy	2

Figure 3 presents the most prevalent journals based on the number of selected Scopus-indexed publications focusing on MASS collision avoidance. Notably, Ocean Engineering emerged as the primary journal accommodating a significant number of articles considered in this review. Following closely is the Journal of IFAC-Papers Online, while several other journals, including WMU Journal of Maritime Affairs, Safety Science, and Sustainability (Switzerland), also reported publications on MASS collision avoidance. The figure underscores that authors exhibit a preference for publishing across a diverse array of journals, possibly indicative of the absence of highly specialized journals dedicated to MASS. Given the novelty of the topic, such diversity in journal selection should not come as a surprise.

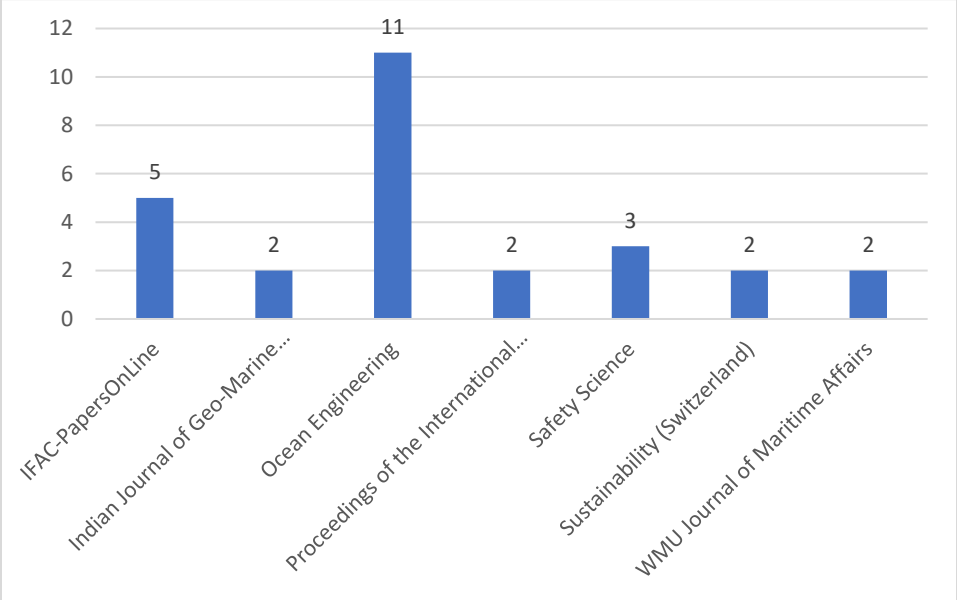

Figure 3: The journals with the most articles related to MASS collision Avoidance

Figure 4 and **Figure 5** display the outcomes of the bibliometric analysis conducted using VOSviewer. These figures illustrate the results of the co-occurrence of terms analysis and Author Keywords Analysis, respectively. The full counting method, as opposed to the binary counting method, was employed to assign greater weight to keywords occurring more frequently. In the first analysis, a total of 1296 keywords were identified, and subsequent filtration resulted in the selection of 26 keywords, each with a minimum of 7 occurrences. For Author Keyword analysis, 155 words were identified, and after filtration, 17 keywords were chosen, each with at least 2 occurrences. The term analysis reveals connections between terms (keywords) that commonly occur together. In addition to evident terms such as "autonomous ship," "MASS," and "collision avoidance," other frequently appearing terms encompass "algorithm," "path planning," "decision support," "hazard," "risk," "situation awareness," "cybersecurity," and "reliability." A closer examination of the keyword analysis suggests that researchers frequently deliberated on methodology, approaches, and risk assessment. There is a notable emphasis on addressing issues related to uncertainty, risk evaluation, situation awareness, and the applicability of different methods.

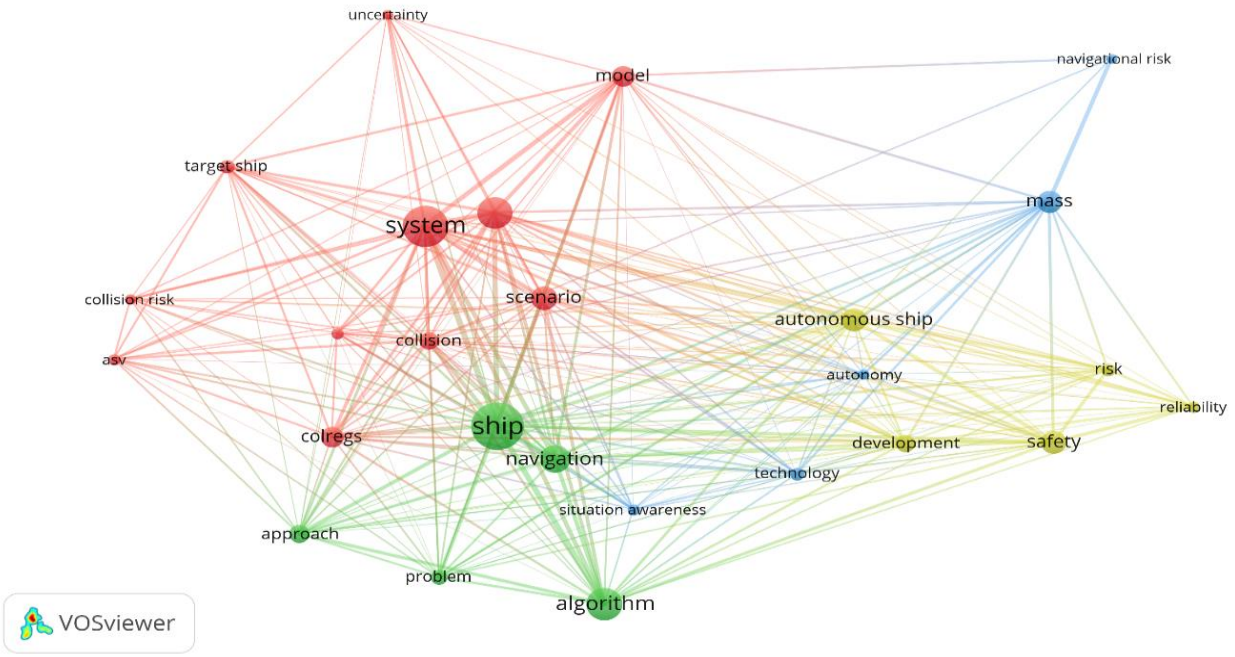

Figure 4: Term analysis map using full counting method, including 26 out of 1296 keywords.

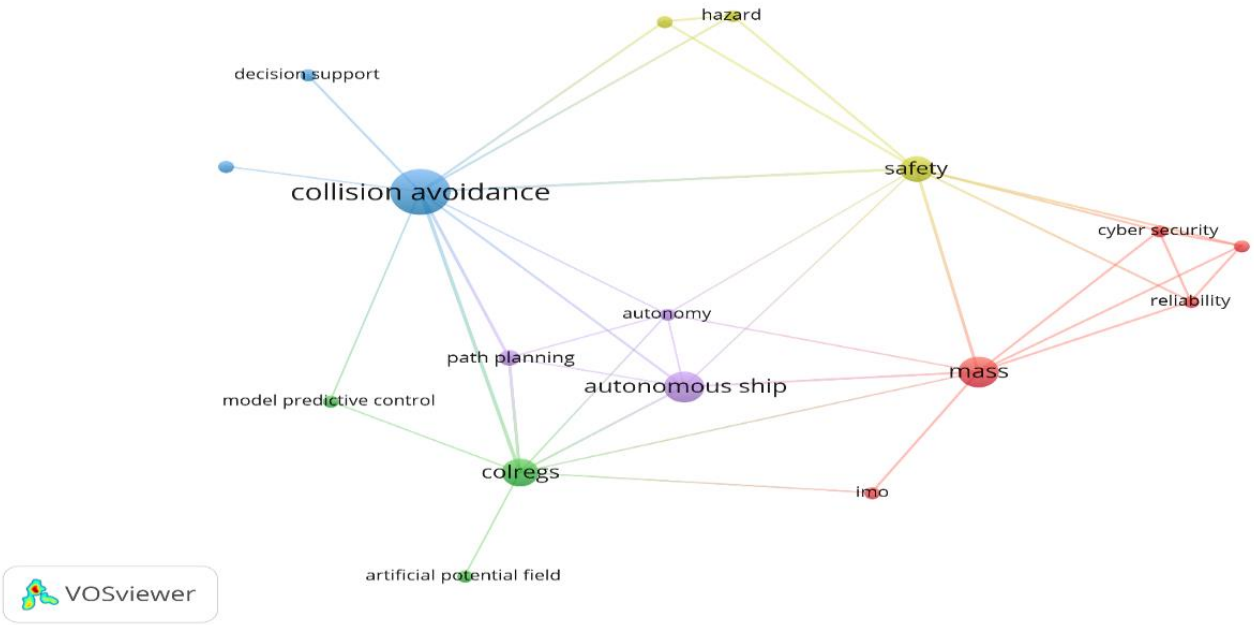

Figure 5: Author Keywords analysis using full counting method, including 17 out of 155 keywords.

Future Research Recommendations

Based on the investigated papers several challenges and research directions and topics were identified. (Papageorgiou et al., 2022) determined 2 considerations into the current scheme of research related to MASS collision avoidance which are: the overall maneuverability capabilities of a target, and the maneuverability restrictions imposed by the geographical properties of the area surrounding the target vessel. (Huang et al., 2020) claimed that the boundaries of the predicted trajectories need further studies, better risk assessment methods are expected and Collision resolution needs more studies in safety validations and extreme conditions for different methods. (C. C. Chou et al., 2022) proposed that in order to reduce efficiently the navigational risk of MASS, future researches must integrate efficiently the path planning algorithms, data sensors, navigational equipment on board and the whole COLREGs.

5- Conclusion

This article conducts a systematic literature review and bibliometric analysis of research studies in Scopus related to MASS collision avoidance. The bibliometric analysis aids in identifying leading countries, prevalent journals, and researchers (RQ1). Additionally, an examination of the analyzed papers reveals research challenges and sets directions for future research (RQ2). Consequently, the article succinctly summarizes advancements in MASS collision avoidance through academic publications. Key findings include:

- China, Norway, Poland, and South Korea demonstrate the highest contributions based on the number of Scopus-indexed publications, with Europe leading in authors with two or more articles.
- Ocean Engineering and the Journal of IFAC-Papers Online boast the highest publication numbers.
- The annual scientific publications on MASS collision avoidance exhibit a consistent upward trend, accompanied by an increase in research topics' diversity and employed methodologies since 2019.
- Several research directions have been identified.

The results from the bibliometric analysis offer valuable insights for policymakers, shedding light on research groups, collaborations, and the direction of research. This information can inform decisions regarding future investments in research. The identified research studies, methodological challenges, and proposed research directions serve as a foundation for conducting focused and innovative research in this domain.

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