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Applications of HFACS in maritime accident research: a systematic review and bibliometric analysis

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The Human Factors Analysis and Classification System (HFACS) is increasingly used and modified in maritime accident research. This study is a systematic review of the use of HFACS in maritime research. Bibliometric patterns in Web of Science (WoS) and Scopus are investigated. The study used a combination of systematic review, content analysis and bibliometric mapping according to the PRISMA 2020 guidelines. The final datasets of WoS and Scopus included 60 studies each, of which 55 were common to both databases, resulting in a total of 65 unique eligible studies. The results show a recent growth in maritime HFACS research, mainly concentrated in China and Türkiye. HFACS is still in widespread use, but a number of maritime-specific adaptations have been proposed and HFACS has been combined with probabilistic, system-oriented and data-driven methods. Analyzing the ten most-cited and ten database-specific studies identified causal factors at different HFACS levels and mitigation measures addressing operational and organizational issues. The citation-network structures of WoS and Scopus were different, but the frequently occurring keywords and highly cited publications and authors were similar. In general, the results show that maritime HFACS research has progressed beyond accident classification by the use of adapted frameworks and complementary analytical methods.

KEYWORDS
HFACS, HFACS maritime, maritime accidents, systematic review, bibliometric analysis

1 Introduction

Maritime transport is the largest share of international trade and enables the intercontinental transport of almost every type of product (Kaluza et al., 2010). Thanks to its high transport capacity and economies of scale, it is considered one of the most cost-effective transportation modes in the global supply chain (UNCTAD, 2024; Stopford, 2008). This increase in world trade volume is leading to the growth of maritime transport and an increase in ship traffic at sea (Kosowska-Stamirowska, 2020). Despite advances in ship design, navigation technologies, and safety regulations, maritime accidents remain a significant safety issue in the maritime sector (Guo et al., 2025). These accidents not only

result in loss of life and property damage but also lead to operational disruptions, environmental pollution, and adverse impacts on marine ecosystems (European Maritime Safety Agency-EMSA, 2024).

Maritime accidents can occur for many reasons, including the interaction between technical, environmental, operational, and human factors (Dominguez-Péry et al., 2021). Although technology reduces risks arising from devices and equipment, the human factor remains a component of maritime accidents (Ward and Nathan-Roberts, 2021). Seafarers' decision-making processes, adherence to procedures, fatigue, and situational awareness directly affect human and ship safety (Wu et al., 2022). Therefore, revealing the impact of the human factor in accidents is considered one of the fundamental priorities of research aimed at improving maritime safety (Sánchez-Beaskoetxea et al., 2021). Human errors often do not occur in isolation; rather, they result from the interaction of organizational practices, socio-technical systems, and individual and cognitive factors (Dominguez-Péry et al., 2021). This situation highlights the need for systematic analytical methods that can assess human factors from a multifaceted perspective, rather than relying entirely on traditional accident investigation approaches. Among these methods, the Human Factors Analysis and Classification System (HFACS) has emerged as a widely used framework for systematically analyzing human factors in accidents (Shappell et al., 2006). HFACS, developed from Reason's Swiss Cheese Model, examines human error across multiple levels, including unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences (Kaptan et al., 2021; Wiegmann and Shappell, 2017b). The systematic and hierarchical nature of the HFACS classification structure has allowed the framework to be adapted to different operational contexts (Chauvin et al., 2013; Wiegmann and Shappell, 2017a). Several modified HFACS frameworks have been used in maritime studies, such as HFACS-Ground for grounding accidents (Mazaheri et al., 2015), HFACS-Coll for collision accidents (Chauvin et al., 2013), HFACS-PV for passenger vessel accidents (Uğurlu et al., 2018), HFACS-MA for maritime accidents (Chen et al., 2013) and HFACS-SIBCI for collision accidents between assisted ships and icebreakers in ice-covered waters (Zhang et al., 2019). Moreover, HFACS has been combined with approaches such as Bayesian Networks, DEMATEL, AHP, and fuzzy logic to model the relationships among classified factors, identify cause-effect relationships, and evaluate their relative importance (Hsieh et al., 2018; Ma et al., 2022; Uğurlu et al., 2020). Scopus-indexed more recent studies also show that maritime HFACS research has been diversified through both domain-specific adaptations and applications to different accident contexts. Higher-level organizational and supervisory factors have been identified in very serious maritime accidents using a modified HFACS framework (Batalden and Sydnes, 2017). HFACS has been applied to collision and grounding accidents with electronic navigation devices (Kaptan and Uğurlu, 2022) and the HFACS-PV framework has been applied to grounding and collision/contact accidents in the English Channel (Loughney et al., 2022). HFACS-FV was constructed by Zohorsky and Handley (2022) to examine commercial fishing vessel accidents and coding reliability was examined by several independent raters. A recent example of the application of HFACS in the shipping domain is the analysis of ship grounding (Wang et al., 2023), large datasets of maritime accidents (Maternová and Materna, 2023), container vessel accidents with the NASA-HFACS framework (Singh and Totakura, 2024) and cargo-related operations on oil tankers with HFACS-MA (Krivokapić and Hasanspahić, 2025). Together, these studies suggest that the maritime use of HFACS is moving away from a single generic taxonomy toward accident-, vessel- and operation-specific implementations. A parallel methodological development is the increasing use of HFACS as the structuring layer of quantitative, probabilistic and system-oriented models. An early contribution combined HFACS with Bayesian Networks and fuzzy AHP to quantify the contribution of human and organizational factors (Wang et al., 2010). In subsequent studies, HFACS has also been combined with Structural Equation Modeling to evaluate the causal relationships between the levels of the human-factors hierarchy (Hu et al., 2019) and with information-flow theory to study the change of navigation risk (Ren et al., 2021). This trend has accelerated in recent years. Xi et al. (2025) used accident-report text mining and structural equation modeling to explain the formation of unsafe acts of ship officers. Shi et al. (2025) integrated the Dynamic Bayesian Network with the HFACS-based ship-fire taxonomy. Waskito et al. (2026) integrated STPA, HFACS and Bayesian Networks to link system hazards, human-error classifications and probabilistic risk analysis. Sunardi et al. (2026) used HFACS-MA combined with CASMET and STAMP for the analysis of passenger-ship sinking and capsizing accidents. Zhang et al. (2026) employed HFACS causes as features of machine learning to predict the types of maritime accidents. The studies show that HFACS is increasingly being used not only as an accident classification tool but also as a standardized feature and causal-structure framework for predictive and system-level analysis. This interpretation of methodological evolution is also supported by the broader HFACS literature. Hulme et al. (2019) reviewed peer-reviewed HFACS applications in safety-critical domains and found that more than 60% of the reviewed studies used a modified form of HFACS and identified maritime transport as one of the main application areas. The additional Scopus evidence considered in the present review is therefore consistent with a wider trajectory in which HFACS taxonomies are progressively adapted, integrated with complementary analytical techniques, and used to represent interacting latent and active failures. Although the number of HFACS-based maritime studies has grown in recent years, current studies are scattered in terms of accident types, research topics and methodological approaches. In addition, the adaptation of HFACS to different maritime contexts and the combination of different analytical methods have contributed to the methodological diversity of the field. However, systematic reviews on the development of HFACS in maritime research, the application areas, the different forms of use, the integration with hybrid methods, and the bibliometric trends are still limited. Therefore, a systematic compilation of the existing literature is needed to reveal the general structure and development of HFACS usage in the maritime field.

This study is a systematic literature review of the applications of HFACS in maritime research based on PRISMA 2020 guidelines. Complementary bibliographic sources were used to improve the database coverage and to allow cross-database comparison: Web of

Science (WoS) and Scopus. The WoS dataset was the main dataset for the original bibliometric and content analyses. The Scopus dataset was analyzed separately to identify overlapping and additional studies and to compare publication, author, country, and source patterns. The selected studies were analyzed in terms of trends in number of publications over time, geographical distribution, research topics, HFACS applications and methods in combination with HFACS. Additionally, the bibliometric structure of the literature was assessed through keyword analysis, author citation analysis, and document citation analysis. The aim of this study is therefore to provide a comprehensive overview across different databases of the evolution of the use of HFACS in maritime research over time, its main application areas and methodological trends.

2 Methodology

The present study followed the PRISMA 2020 guidelines (Page et al., 2021) for systematic and comprehensive literature review, as illustrated in Figure 1. In addition, the review design includes bibliometric mapping with the bibliometric mapping approach of Van Eck and Waltman (2010), content analysis, and cross-database comparison. The aim of this study is to systematically review the academic studies conducted with the Human Factors Analysis and Classification System (HFACS) and its related approaches in the maritime industry in a methodological and thematic way. The procedure of this study is as follows: (1) define research questions, (2) select databases, (3) determine keywords and develop search strategy, (4) define inclusion and exclusion criteria, (5) classify studies for analysis, and (6) compare the WoS findings with the complementary Scopus dataset.

2.1 Defining the research questions

We retrieved articles related to the selected field from both the Web of Science (WoS) and Scopus databases and selected the articles most relevant to the topic. The process started by defining the research questions (RQ). Against this background, the formulation of research questions is the backbone of this review study. The research questions identified for this study are as follows:

RQ1: What HFACS frameworks and maritime-specific adaptations have been applied across maritime research contexts, and how do their applications differ?

RQ2: Which analytical methods have been integrated with HFACS in maritime research, and for what analytical purposes have these combinations been used?

RQ3: What methodological approaches, causal factors, HFACS levels, and mitigation strategies are reported in the ten most-cited maritime HFACS studies?

RQ4: What types of maritime accidents are most studied and what are the research areas?

RQ5: How has the annual publication output of maritime HFACS research evolved over time?

RQ6: What bibliometric structures emerge from keyword co-occurrence, document citation, and author citation analyses, and to what extent are these structures consistent or database-specific across WoS and Scopus?

RQ7: What is the geographical location of HFACS applications in the maritime sector?

2.2 Database selection

The literature search was performed in WoS and Scopus to increase the bibliographic coverage and to provide a multi-database base for cross-database robustness evaluation. WoS was selected because of its long-standing use, broad coverage of scholarly publications and highly cited articles, and compatibility with bibliometric mapping tools such as VOSviewer (Li et al., 2018; Birkle et al., 2020; Maddi and Baudoin, 2022). Scopus was added as a complementary multidisciplinary indexing source to check whether the main patterns observed in the WoS data were robust to the choice of database and to find relevant maritime HFACS studies not included in the WoS screening set. For the sake of comparability, the results from WoS and Scopus were analyzed separately before comparing across databases. The original WoS bibliometric indicators were used in their original form and not pooled.

2.3 Keyword selection and search strategy

The search strategy was designed to identify studies that explicitly use HFACS in the maritime domain. Equivalent search concepts were employed for both databases with database-specific field syntax. In the Web of Science search, TS=("HFACS" AND "Maritime") was used in the Topic field and in the Scopus search TITLE-ABS-KEY("HFACS" AND "Maritime") was used. Related maritime HFACS adaptations (i.e., HFACS-MA, HFACS-PV, HFACS-SIBCI, and HFACS-FV) were identified during screening and full-text assessment. The databases were analyzed separately, and records were matched by title to determine overlap between databases and Scopus-only records.

Preliminary searches in both Web of Science (WoS) and Scopus were used to compare alternative descriptors related to maritime issues and identify the formulation that provided the broadest coverage before the final search strategy was determined. Using WoS, with the same restriction to the document type of Article, the search strings "HFACS" AND "Maritime" resulted in 105 articles, while "HFACS" AND "Ship", "HFACS" AND "Shipping" and "HFACS" AND "Marine" resulted in 95, 78 and 57 articles respectively. The search strategy "HFACS" AND "Maritime" in Scopus resulted in 64 articles, "HFACS" AND "Ship" resulted in 51 articles, "HFACS" AND "Shipping" resulted in 20 articles, and "HFACS" AND "Marine" resulted in 41 articles. The review of the retrieved records showed that the studies identified by these alternative maritime-related descriptors were also included in the "HFACS" AND "Maritime" search in both databases. Therefore, "HFACS" AND "Maritime" was the main search combination intentionally chosen, as it offered the broadest coverage of the tested formulations, while maintaining the studies retrieved by the other descriptors. Thus, rather than expanding the final query with a combination of many highly overlapping maritime descriptors, we kept the "HFACS" AND "Maritime" formulation to maximize the population coverage of the study. These initial search-term comparisons were conducted to determine the most appropriate search terminology and should not be confused with the record numbers

outlined later in the PRISMA-based identification and screening process, which describe the formal search, database-specific filtering, and eligibility procedures.

For sensitivity analysis, additional searches were performed in both databases using the full term "Human Factors Analysis and Classification System" and "Maritime." The results of full-name searches in the pre-specified scope were compared to the results of acronym searches to determine the extent to which the main search strategy captured the relevant literature.

The formal searches in both Web of Science (WoS) and Scopus were finalized on 4 August 2026. Thus, this review includes all articles obtained from the two databases that fulfill the pre-specified eligibility criteria up to and including 4 August 2026.

2.4 Inclusion and exclusion criteria

The literature search was conducted in both databases using the terms "HFACS" and "Maritime" with the field syntax specific to each database. The initial WoS search resulted in 124 records. After filtering by document type and index, 105 records remained, of which 39 were excluded during title/abstract screening, leaving 66 for full-text eligibility assessment. Six additional records were excluded as out of the review scope, leaving a final WoS dataset of 60 studies. An independent search of Scopus retrieved 91 records. The same inclusion criteria were applied to the Scopus records, and the final Scopus dataset included 60 studies. The last two datasets were retained separately for database-specific bibliometric analyses.

Cross-database title matching of the two final 60-study datasets yielded 55 studies common to both databases, 5 studies unique to WoS, and 5 studies unique to Scopus. The resulting combined cross-database evidence base comprised 65 unique eligible studies. The ten database-specific studies were evaluated separately to determine if the database coverage affected the research contexts, HFACS adaptations, causal factors, and mitigation recommendations found. The design avoided pooling of database-specific citation metrics, but allowed direct assessment of the robustness of the substantive findings across WoS and Scopus.

2.5 Data extraction and study selection

Eligibility was assessed in a sequential manner at title/abstract and full-text levels. Studies had to be related to HFACS or a maritime-specific adaptation of HFACS and within the framework of maritime safety, accidents, operations or human factors. Records outside this scope were excluded. We extracted bibliographic information, the HFACS framework or an adaptation, the maritime context, the analytical method, the main causal factors, the HFACS levels, and the reported mitigation methods. Two review authors independently screened titles/abstracts and full texts, with any disagreements resolved through discussion and consensus. A thesaurus was used in VOSviewer for standardization of synonymous terms, spelling variations, singular/plural forms and acronym/full-name variations for bibliometric mapping. The analysis was based on complete enumeration. The minimum occurrence threshold for keywords was 2 and the minimum document citation threshold was 1 citation. For the author citation analysis, the minimum number of documents per author was set at one, and the minimum citation threshold was set at 75. We excluded documents with more than 25 authors from the analysis. WoS and Scopus were subjected to the same procedures and thresholds for direct comparability.

2.6 Article classification and analysis

The final datasets from WoS and Scopus were analyzed as two parallel, analytically separate corpora. The same procedures and thresholds in VOSviewer were used for each database to perform keyword co-occurrence, document citation, and author citation analyses. The WoS dataset was also classified by publication year, country, HFACS framework/adaptation, context of accident/research, and analytical method. A separate bibliometric comparison was performed with the Scopus dataset, which was also used to assess whether database-specific studies altered the substantive interpretation. Following overlap matching, the five WoS-only and five Scopus-only studies were compared in terms of research context, HFACS adaptation, causal factors, HFACS levels, and mitigation recommendations. The differences in indexing coverage and citation metrics between WoS and Scopus precluded pooling of database-specific citation counts and Total Link Strength values.

3 Results

3.1 Web of Science results

Based on the research questions and keyword search in the Web of Science (WoS) database, a total of 124 records were found and 60 articles were selected for analysis based on the inclusion and exclusion criteria. First, a keyword analysis was conducted using VOSviewer, followed by author citation and co-citation analyses. The analysis involved the distribution of studies by year, types of maritime accidents and research areas covered in the studies, distribution of HFACS models used, analytical methods integrated with HFACS and topics of most cited articles.

Because "HFACS" was itself an inclusion/search term, its high occurrence in the keyword network is partly expected by design and should not, by itself, be interpreted as evidence of intellectual influence or conceptual centrality. Citation-based indicators and network link structures are therefore interpreted separately.

Keyword analysis using VOSviewer identified the intensity of the keywords used. Prior to the analysis, synonymous terms, spelling variants, singular/plural forms, and acronym/full-name variants were standardized using a VOSviewer thesaurus file. Full counting was applied, and the minimum occurrence threshold was set at two. Of the 179 author keywords identified, 33 met the threshold and were included in the network analysis. The results show that "HFACS" had the highest occurrence in the network with 33 occurrences and a Total Link Strength (TLS) of 62 (Table 1). "Human factors" was the next most frequent keyword (22 occurrences, TLS = 51), followed by "Maritime accidents" (21 occurrences, TLS = 45) and "Maritime safety" (13 occurrences, TLS = 33). These results indicate that HFACS has mainly been used in studies

TABLE 1 Frequency and total link strength of the ten most frequently occurring keywords.

No.	Keywords	Occurrences	Total link strength
1	HFACS	33	62
2	Human factors	22	51
3	Maritime accidents	21	45
4	Maritime safety	13	33
5	Bayesian network	9	18
6	Accident analysis	7	18
7	Human error	6	12
8	Collision accidents	3	9
9	Data-driven BN	3	8
10	Maritime autonomous surface ships (MASS)	3	7

addressing human factors, maritime safety, and maritime accident analysis.

Figure 2 shows the association of the HFACS node with the keywords "Human factors", "Maritime safety", "Maritime accidents", "Bayesian networks", and "Human error". Among these, "Bayesian networks" also shows connections with HFACS in the keyword network. The network also shows a number of distinct clusters of research. The clusters include keywords related to maritime accidents and human factors, accident analysis and investigation, Bayesian networks, maritime safety, and collision accidents. The co-occurrence of HFACS with methodological keywords such as "Bayesian networks", "data-driven BN", and "machine learning" also indicates the presence of studies integrating HFACS with quantitative and data-driven analytical approaches.

Table 1 shows the top 10 most used keywords. The keywords indicate that the HFACS methodology generally focuses on the human factor in maritime accidents and is used with hybrid models such as Bayesian Networks (Li et al., 2023; Liu et al., 2026; Sanal et al., 2026). These findings also show the main subject and methodological trends represented in the reviewed literature.

Document Citation Analysis is one of the bibliometric methods used to identify the most influential publications in a research field and the citation relationships among them (Arslan, 2022). In this analysis, the nodes represent articles, while the size of each node indicates the number of citations received by the corresponding article. The links between the articles represent citation relationships. The proximity and density of connections between the nodes indicate that the studies have developed together in the literature and contributed to similar research areas (Kang, 2023). For the document citation analysis, the minimum citation threshold was set at one. Of the 60 documents, 53 met this threshold and were included in the analysis.

As shown in Figure 3, the network consists of several research clusters with connections to each other. Chauvin et al. (2013), located at the center of the network, is the largest node and the most highly cited publication in the dataset. As shown in Table 2, this study has the highest citation count, with 465 citations and a Total Link Strength (TLS) value of 33. This means that the study is one of the main references for the application of HFACS in the analysis of maritime accidents (Table 2). The green cluster is mainly formed around Chauvin et al. (2013) and is connected to studies such as Çelik and Cebi (2009); Hu et al. (2019); Liu et al. (2019), and

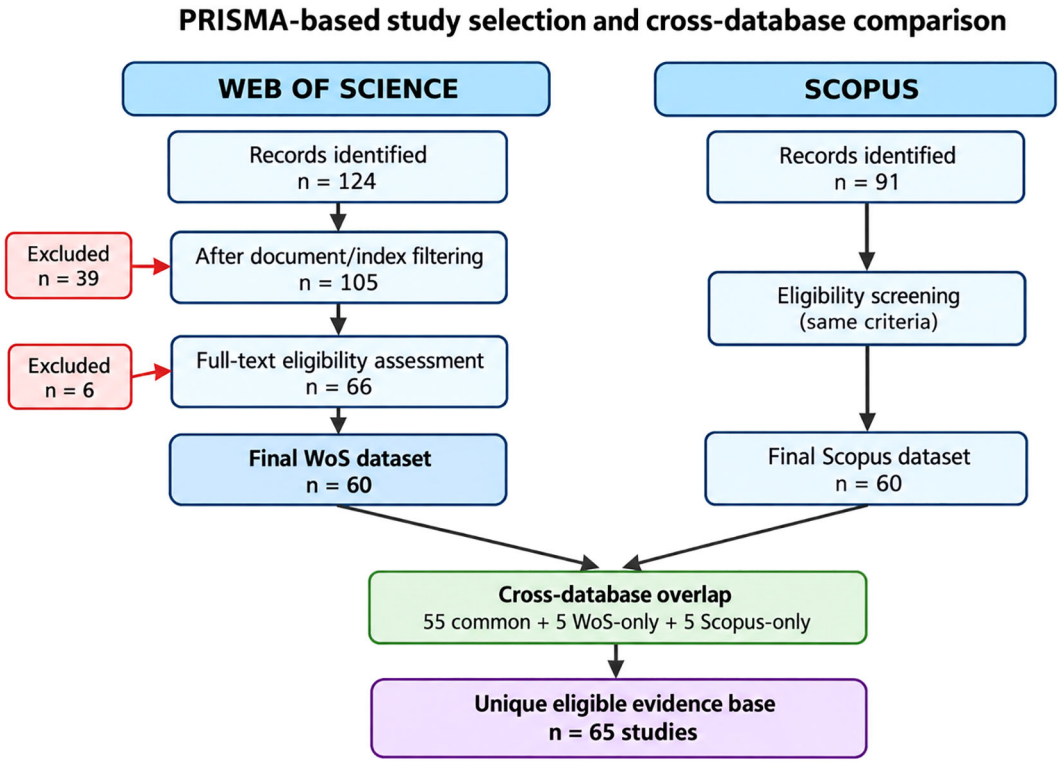

FIGURE 1
PRISMA flow diagram of the study selection process.

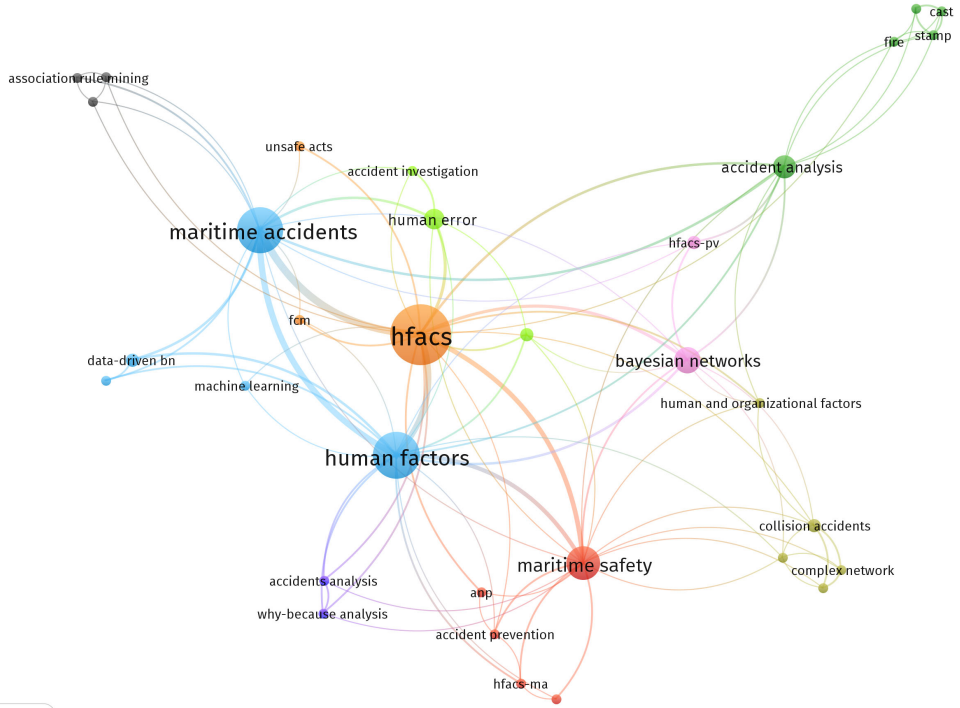

FIGURE 2
Keyword analysis.

Maternová and Materna (2023). Specifically, the second most highly cited publication is Çelik and Cebi (2009), with 242 citations and a TLS value of 28. It is also one of the first studies to apply an analytical HFACS approach to maritime accidents.

The purple cluster is largely centered on Chen et al. (2013). This study has 219 citations and a TLS value of 28, introduced the HFACS-MA (HFACS-Maritime Accidents) model and was important in the development of maritime-specific HFACS applications. The studies of

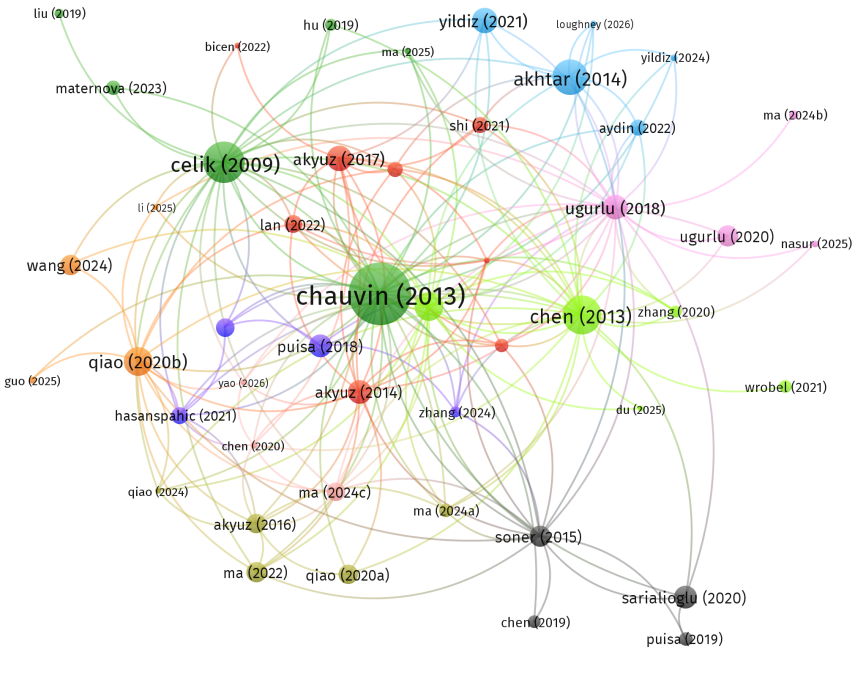

FIGURE 3
Document citation analysis.

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TABLE 2 Top 10 most cited publications on HFACS in maritime research.

No.	Documents	Citation	Total link strength
1	Chauvin, C., Lardjane, S., Morel, G., Clostermann, J. P., Langard, B. (2013). Human and organizational factors in maritime accidents: Analysis of collisions at sea using the HFACS. *Accident Analysis & Prevention*, *59*, 26-37.	465	33
2	Çelik, M. and Cebi, S. (2009). Analytical HFACS for investigating human errors in shipping accidents. *Accident Analysis & Prevention*, *41*(1), 66-75.	242	28
3	Chen, S. T., Wall, A., Davies, P., Yang, Z., Wang, J., Chou, Y. H. (2013). A Human and Organisational Factors (HOFs) analysis method for marine casualties using HFACS-Maritime Accidents (HFACS-MA). *Safety science*, *60*, 105-114.	219	28
4	Akhtar, M. J. and Utne, I. B. (2014). Human fatigue's effect on the risk of maritime groundings–A Bayesian Network modeling approach. *Safety science*, *62*, 427-440.	190	10
5	Yıldırım, U., Başar, E. and Uğurlu, Ö. (2019). Assessment of collisions and grounding accidents with human factors analysis and classification system (HFACS) and statistical methods. *Safety Science*, *119*, 412-425.	140	24
6	Qiao, W., Liu, Y., Ma, X. and Liu, Y. (2020b). Human factors analysis for maritime accidents based on a dynamic fuzzy Bayesian network. *Risk analysis*, *40*(5), 957-980.	140	16
7	Schröder-Hinrichs, J. U., Baldauf, M. and Ghirxi, K. T. (2011). Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. *Accident Analysis & Prevention*, *43*(3), 1187-1196.	122	20
8	Akyüz, E. (2017). A marine accident analyzing model to evaluate potential operational causes in cargo ships. *Safety science*, *92*, 17-25.	112	12
9	Yildiz, S., Uğurlu, Ö., Wang, J. and Loughney, S. (2021). Application of the HFACS-PV approach for identification of human and organizational factors (HOFs) influencing marine accidents. *Reliability Engineering & System Safety*, *208*, 107395.	112	6
10	Uğurlu, Ö., Yıldız, S., Loughney, S. and Wang, J. (2018). Modified human factor analysis and classification system for passenger vessel accidents (HFACS-PV). *Ocean Engineering*, *161*, 47-61.	106	25

Uğurlu et al. (2018) and Yildiz et al. (2021) are very relevant to this cluster, contributing to the literature by developing the HFACS-PV model and applying it to accidents in passenger ships. Other clusters of application-oriented studies are also present on the map. Akhtar and Utne (2014), with 190 citations, is one of the important early studies that integrated HFACS with a Bayesian Network model. Qiao et al. (2020b) combined HFACS with a dynamic fuzzy Bayesian Network approach and showed that the method can also be used for more advanced risk analyses. In addition, the studies by Schröder-Hinrichs et al. (2011) and Akyüz (2017) are important references in the literature due to their applications to engine room fires and operational accidents on cargo ships, respectively. The citation network

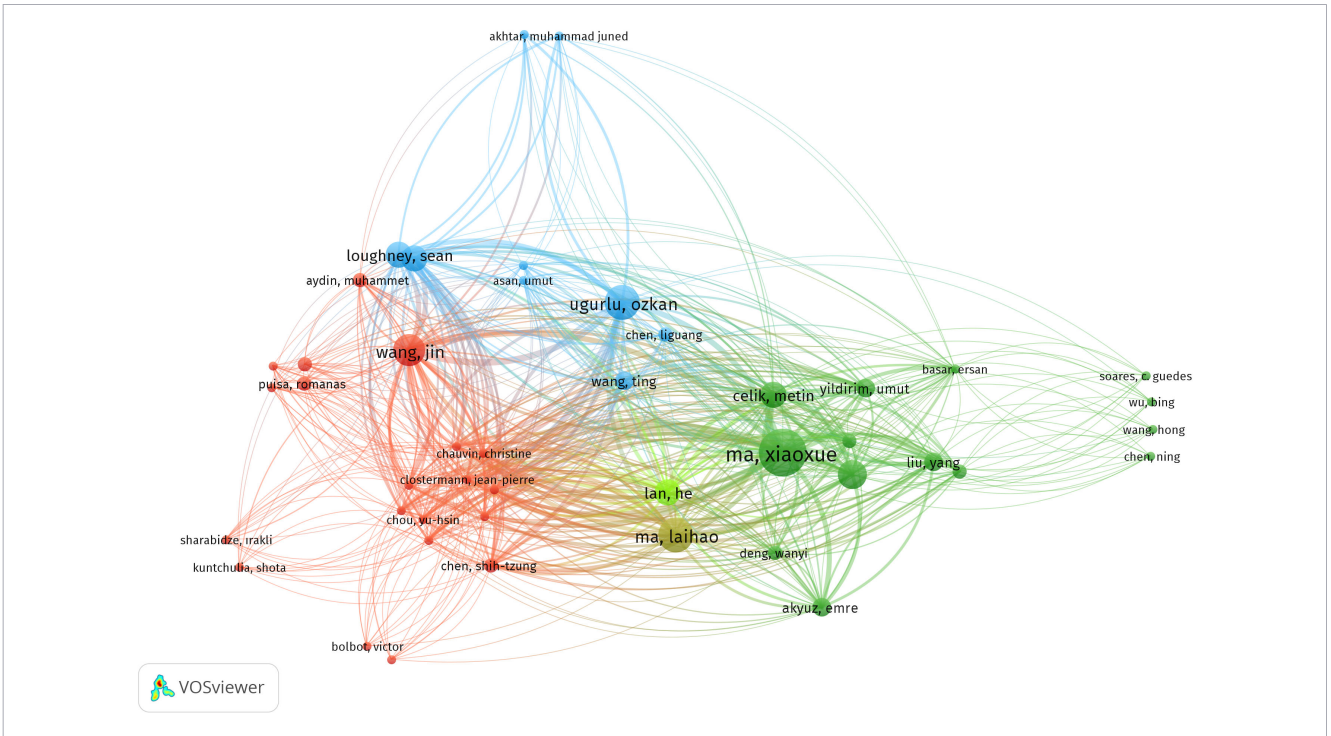

FIGURE 4
Author citation analysis.

presented in Figure 3 also captures the broader body of research applying the Human Factors Analysis and Classification System (HFACS) in the maritime domain, as represented by studies such as Puisa et al. (2018), Chen (2020), Hasanspahić et al. (2021), Wróbel et al. (2021), Lan et al. (2022), Nasur et al. (2025), and Loughney et al. (2026).

Author citation analysis is one of the bibliometric methods used to identify highly cited researchers in a particular research field and the citation relationships between them (Ulukök, 2022). In Figure 4, the nodes represent researchers, the size of the nodes shows the total number of citations received by the authors, and the links show the citation relationships between the researchers. The clusters shown in different colors represent groups of researchers with stronger citation relationships within the network (Zupic and Čater, 2015). For the author citation analysis, the minimum number of documents per author was set at one and the minimum citation threshold was set at 75. Documents with more than 25 authors were excluded from the analysis. Of the 141 authors, 48 met the specified thresholds and were included in the network.

Figure 4 and Table 3 show that HFACS-based maritime research includes several highly cited and well-connected researchers. The researcher with the highest number of citations in the network is Wang Jin, with 7 publications, 637 citations, and a TLS value of 202. Özkan Uğurlu has 8 publications and 613 citations, with a TLS value of 219. Ma Xiaoxue has the highest number of publications among these researchers, with 13 publications, 587 citations, and a TLS value of 251. Metin Çelik is also among the highly cited researchers in the network, with 5 publications, 514 citations, and a TLS value of 174.

The map shows that the red cluster mainly includes Wang Jin and several researchers associated with Chauvin et al. (2013), including Christine Chauvin, Jean-Pierre Clostermann, Salim Lardjane, and Gael Morel. The blue cluster includes Özkan Uğurlu and Sean Loughney, whereas the green cluster includes Ma Xiaoxue, Metin Çelik, Umut Yıldırım, Liu Yang, and Emre Akyüz. Ma Laihao and Lan He form another closely connected group near the center of the network. In contrast, researchers located toward the outer parts of the map generally have fewer citation connections. Overall, the network consists of several interconnected groups of researchers. Among them, Wang Jin, Özkan Uğurlu, Ma Xiaoxue, and Metin Çelik are notable for their high citation counts and relatively high Total Link Strength values.

TABLE 3 Top 10 most cited authors in HFACS maritime research.

Rank	Author	Documents	Citations	Total link strength
1	Wang, Jin	7	637	202
2	Uğurlu, Özkan	8	613	219
3	Ma, Xiaoxue	13	587	251
4	Çelik, Metin	5	514	174
5	Chauvin, Christine	1	465	81
6	Clostermann, Jean-Pierre	1	465	81
7	Langard, Benoit	1	465	81
8	Lardjane, Salim	1	465	81
9	Morel, Gael	1	465	81
10	Qiao, Weiliang	6	343	135

Figure 5: Publications distribution by year using the HFACS method in the maritime field. Publication activity was rather limited between 2009 and 2018 and the use of HFACS in the maritime literature was not yet widespread in this period. Conversely, a clear increase began in 2019. There were some fluctuations in the following years, but in general the number of publications was higher than in the previous period. The largest number was in 2024 with 9 publications, followed by 7 publications in 2025 and 8 publications in 2026 in the examined period. This shows a recent increase in HFACS-related maritime research. To summarize, the results show that HFACS was first applied in the maritime field to a limited extent only, but its application has increased in more studies, especially after 2019.

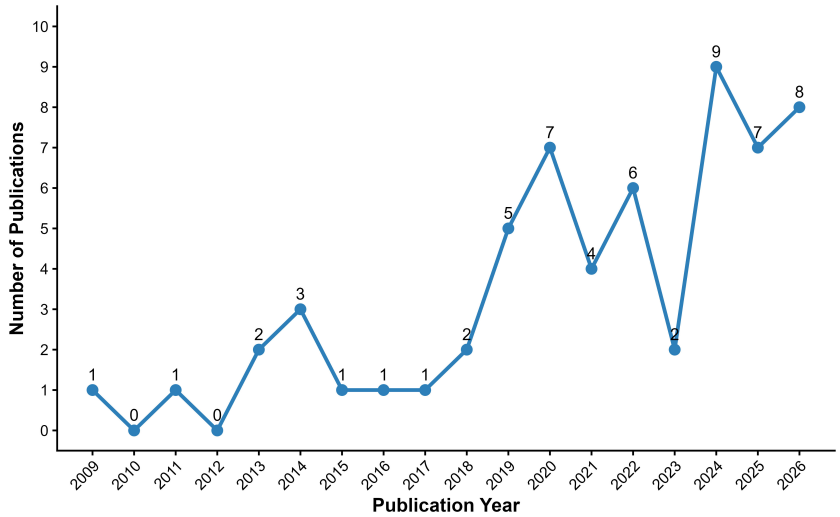

FIGURE 5
Distribution of HFACS publications in the maritime field by year.

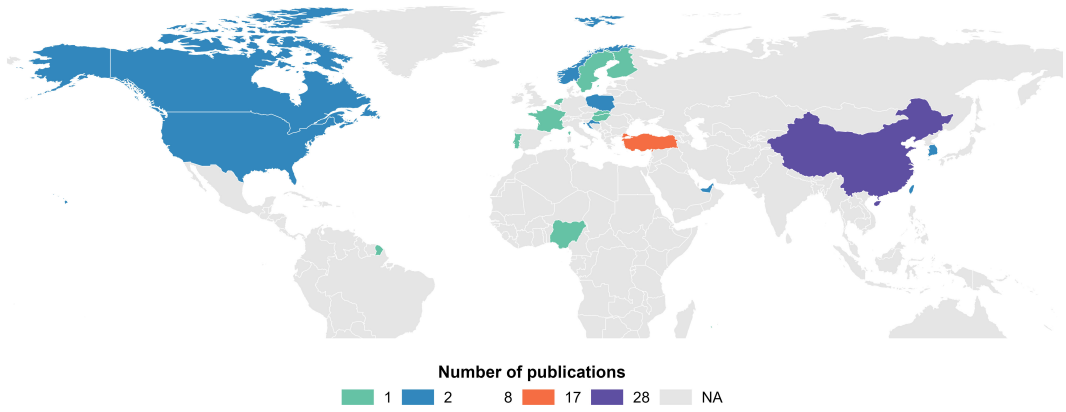

FIGURE 6
Geographical distribution of publications included in the systematic review. Colors indicate the number of publications by country.

Figure 6. Geographical distribution of studies using HFACS in the maritime field. Results indicate that the publications are not equally distributed among the countries and are mainly concentrated in China and Türkiye. China has the highest contribution of 28 publications followed by Türkiye with 17 publications. The number of publications from other countries is restricted to one or two studies. The presence of countries from different continents on the map shows that HFACS has been used in maritime research in different geographical regions. However, the literature is geographically concentrated, with a primary focus on China and Türkiye.

Figure 7. Distribution of HFACS model and adaptations used in the reviewed studies. The results indicate that the original HFACS model was the most used approach (n=28). Among the models adapted to the maritime field, HFACS-MA is the most popular with 9 studies, followed by HFACS-GT and Improved HFACS with 7 studies each. HFACS-PV was used in 3 studies, while more specific adaptations such as HFACS-Coll, HFACS-YA, HFACS-TCO, HFACS-RC, HFACS-MASS and HFACS-MSS were each used in 1 study. This distribution shows that the original HFACS structure still dominates the approach in maritime research. Concurrently, various versions of HFACS have been created and applied to the study of different types of accidents and operational contexts.

The most common hybrid method with HFACS is Bayesian Network (BN) with 17 studies, followed by Association Rule Mining (ARM) with 7 studies. Why-Because Analysis (WBA), Analytic Network Process (ANP), HEART, Complex Network Analysis (CNA) and Evidential Reasoning (ER) were used in 2 studies each. Additionally, other quantitative, systemic, and decision support techniques, including AHP, Fuzzy AHP, DEMATEL, Fuzzy Cognitive Mapping (FCM), SPAR-H, Bowtie, FRAM, Structural Equation Modeling (SEM), System Dynamics (SD), and Gray Relational Analysis (GRA), were less frequently employed in the literature. The distribution indicates that the integration of HFACS with probabilistic modeling and data mining approaches is more common in the literature, but a wide range of methods has also been used.

Table 4 presents the main causal factors, their corresponding HFACS levels, and the mitigation strategies reported in the ten most-cited studies. Rather than presenting all 60 studies in detail, the table focuses on the most-cited publications to provide a concise overview of the topics, methodological approaches, causal factors, and mitigation strategies addressed in widely cited HFACS-based

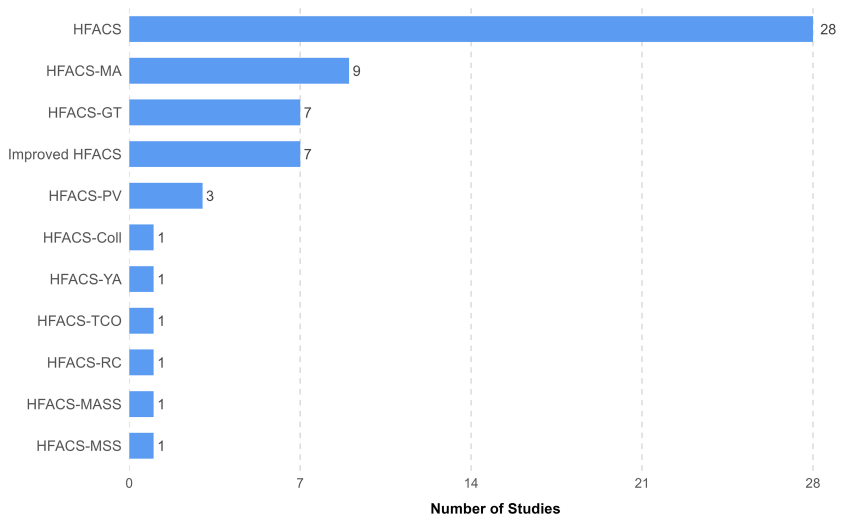

FIGURE 7
Distribution of HFACS frameworks used in maritime studies.

maritime research. The remaining studies were retained in the overall systematic and bibliometric analyses.

The factors identified across these studies varied in both their nature and HFACS level. Chauvin et al. (2013) associated decision errors with Unsafe Acts, while Uğurlu et al. (2018) reported regulation violations at the same level, particularly those involving inappropriate lookout and unsafe speed. Çelik and Cebi (2009) instead pointed to deficiencies in organizational processes related to shipboard maintenance under Organizational Influences. Among the studies addressing Preconditions for Unsafe Acts, Qiao et al. (2020b) reported a lack of understanding of safety-related regulations and laws, Yildiz et al. (2021) identified Substandard Team Members, and Schröder-Hinrichs et al. (2011) reported failed physical barriers. Other studies reported factors across more than one HFACS level. Chen et al. (2013), for example, identified hardware deficiencies together with failures in shore management. Akhtar and Utne (2014) reported factors related to manning, vessel certification, efficiency pressure, and helmsman monitoring. Yıldırım et al. (2019) found different leading factors for the two accident types examined: decision errors in collisions and resource management deficiencies in groundings.

The mitigation measures also varied across the studies. Chauvin et al. (2013) emphasized Bridge Resource Management, whereas Çelik and Cebi (2009) focused on managerial and operational procedures and preventive and corrective actions. Other measures

TABLE 4 Main causal factors, HFACS levels, and mitigation strategies in the ten most-cited studies.

No.	Documents	Method	Topic	Main causal factor(s)	HFACS level	Mitigation strategies
1	Chauvin et al. (2013)	HFACS-Coll	Ship collisions	Decision errors	Unsafe Acts	Strengthening Bridge Resource Management (BRM), particularly during pilotage in restricted waters.
2	Çelik and Cebi (2009)	HFACS+FAHP	Boiler explosion aboard a bulk carrier	Inadequate execution of organizational processes related to shipboard maintenance	Organizational Influences	Redesigning managerial and operational procedures and implementing preventive/corrective actions based on the priority weights of contributing factors.
3	Chen et al. (2013)	HFACS-MA + WBA	Herald of Free Enterprise accident / Ro-Ro capsizing accident	Hardware deficiencies and failures of shore management	Preconditions / Organizational Influences	Not explicitly specified; the analysis emphasizes identifying and addressing deficiencies across multiple HFACS-MA levels.
4	Akhtar and Utne (2014)	HFACS+BN	Fatigue-related risk of maritime grounding	Inadequate manning resources and manning, vessel certification deficiencies, efficiency pressure, and inadequate helmsman monitoring	Organizational Influences / Preconditions of Unsafe States	Adequate manning and watchkeeping arrangements, reduced efficiency pressure, improved helmsman monitoring, and compliance with vessel certification requirements
5	Yıldırım et al. (2019)	HFACS-MA	Collision and grounding accidents	Decision errors (collisions); resource management deficiencies (groundings)	Unsafe Acts / Preconditions for Unsafe Acts	Improved bridge resource management, communication and coordination, watchkeeping discipline, risk assessment, and effective implementation of the ISM system
6	Qiao et al. (2020b)	HFACS + MAMAC + Fuzzy BN	Human factors in sand carrier accidents in China	Lack of understanding of safety-related regulations and laws	Preconditions for Unsafe Acts	Safety training and certification, safety checklists, improved implementation of regulations, and stronger communication and coordination
7	Schröder-Hinrichs et al. (2011)	HFACS-MSS	Engine room fires	Failed physical barriers	Preconditions for Unsafe Acts	Development of specific guidelines for training and investigation practices on human and organizational factors.
8	Akyüz (2017)	HFACS–ANP	Serious gas leak on an LPG carrier ship	Non-compliance with the ship's Safety Management System (SMS)	Unsafe Acts	Redesign of the ship's SMS and increased internal audit frequency to ensure its proper onboard implementation.
9	Yildiz et al. (2021)	HFACS-PV	Grounding accidents on passenger ships	Substandard Team Members	Preconditions for Unsafe Acts	Improved situational awareness, BRM, communication and coordination, safety culture, and consideration of weather and local restrictions in operational planning
10	Uğurlu et al. (2018)	HFACS-PV	Passenger ship collision and contact accidents	Regulation violations, particularly inappropriate lookout (COLREG Rule 5) and unsafe speed (COLREG Rule 6)	Unsafe Acts	Personnel selection and assignment based on professional experience and safety culture, together with improved bridge ergonomics and effective lookout practices.

included adequate manning and watchkeeping arrangements (Akhtar and Utne, 2014), safety training, certification, and better implementation of regulations (Qiao et al., 2020b), guidelines for training and accident investigation (Schröder-Hinrichs et al., 2011), and the redesign and auditing of the Safety Management System (Akyüz, 2017). Yildiz et al. (2021) addressed situational awareness, communication, safety culture, and operational planning, while Uğurlu et al. (2018) focused on personnel selection, bridge ergonomics, and lookout practices. Overall, the ten studies covered different accident and operational contexts, with causal factors occurring at different HFACS levels and mitigation measures generally reflecting the factors identified in each study.

Figure 8 shows the distribution of the reviewed studies by research topic and the types of maritime accidents examined. One-third of the studies (n = 20; 33.3%) focused on more than one type of maritime accident rather than a single accident type. Among the studies focusing on a specific accident type, ship collisions (n = 10; 16.7%) were the most frequently studied. Four studies (6.7%) examined loading and unloading operations, passenger ship accidents, Maritime Autonomous Surface Ship (MASS) accidents, fire and explosion accidents, and grounding accidents. Less frequently studied topics included bulk-carrier accidents, maritime pilotage accidents, and collisions between merchant ships and fishing vessels. One study each examined sinking, man-overboard (MOB), and yacht accidents. The overall distribution indicates that HFACS research applied to the maritime field mainly includes studies on multiple accident types and ship collisions, but the literature is relatively sparse on specific accident and operation types.

3.2 Scopus results

The final Scopus dataset consisted of 60 articles and was analyzed separately following the same bibliometric procedures used for the WoS dataset. This section presents the results of the keyword co-occurrence, document citation, and author citation analyses.

Figure 9 shows the author keyword co-occurrence network for the Scopus dataset. Full counting was used, with a minimum occurrence threshold of two. Of the 168 author keywords identified, 33 met this threshold and were included in the network. The same thesaurus approach used for the WoS dataset was also applied to the Scopus data to standardize synonymous terms, spelling variants, singular and plural forms, and acronym/full-name variants.

HFACS was the most frequent keyword, with 35 occurrences and a Total Link Strength (TLS) of 73. This was followed by maritime accidents (22 occurrences, TLS = 47), human factors (21 occurrences, TLS = 50), maritime safety (16 occurrences, TLS = 40), and Bayesian networks (11 occurrences, TLS = 23). The other keywords in the top ten were human error (8 occurrences, TLS = 17), accident analysis (5 occurrences, TLS = 14), HFACS-PV (4 occurrences, TLS = 8), collision accidents (3 occurrences, TLS = 10), and data-driven BN (3 occurrences, TLS = 8).

Several clusters can be distinguished in the network. HFACS was grouped with human error, accident investigation, error-producing conditions, and why-because analysis. Maritime accidents appeared in another cluster with data-driven BN, machine learning, and operational conditions. The cluster containing maritime safety also included HFACS-MA, accident prevention, accident causation, and ANP. Bayesian networks was grouped with collision accidents, risk factors, complex network, association rules, and accident causes. Another cluster included HFACS-PV, accident analysis, and fire, while association rule mining, grounded theory, and unsafe acts formed part of a separate group. Although these terms were distributed across different clusters, links between the groups were visible through frequently occurring keywords such as HFACS, human factors, maritime accidents, maritime safety, and Bayesian networks.

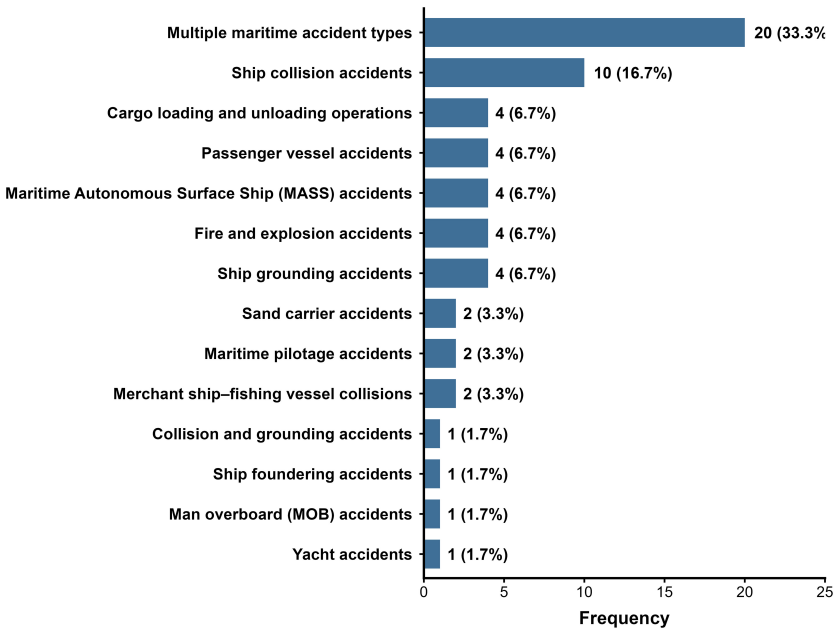

FIGURE 8
Distribution of the included studies by research topic and maritime accident type (n = 60).

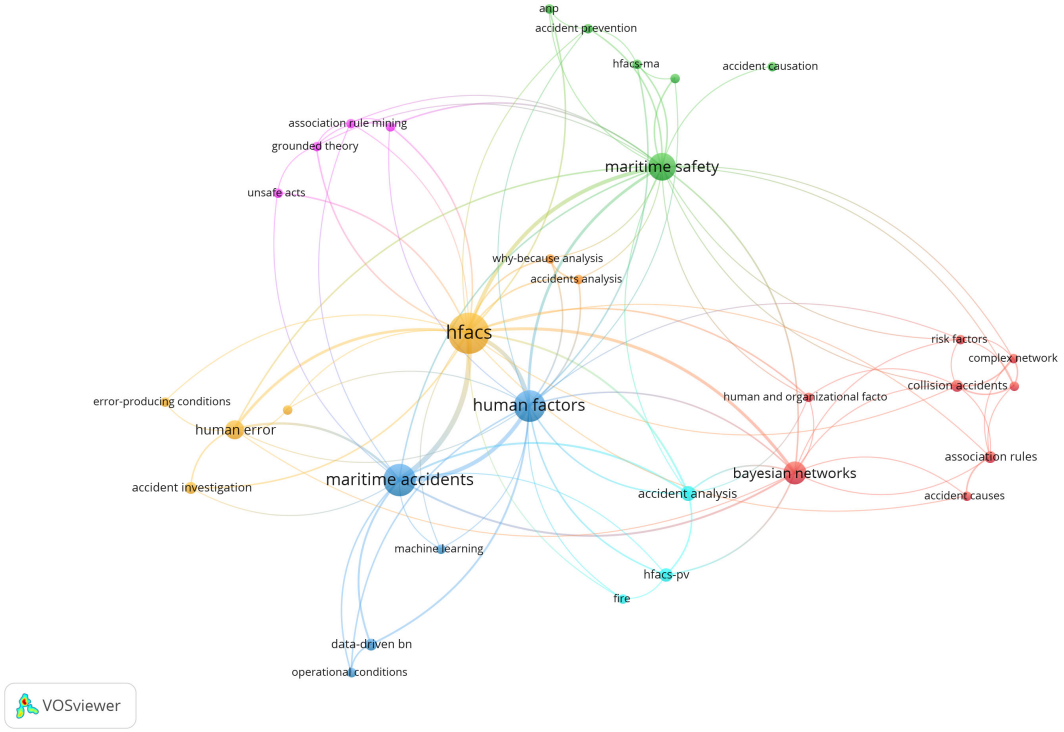

FIGURE 9
Author keyword co-occurrence network based on the Scopus dataset.

Figure 10 shows the document citation network for the Scopus dataset. The minimum citation threshold was set at one, which was met by 50 of the 60 documents. However, only a limited number of direct citation links were found among the publications in the dataset. Akyüz (2017) had the highest number of links, with seven, while Yildiz et al. (2021) had one.

In terms of total Scopus citations, Chauvin et al. (2013) was the most highly cited publication, with 568 citations, followed by Çelik and Cebi (2009) with 304, Chen et al. (2013) with 269, and Akhtar and Utne (2014) with 227. The other publications in the top ten were Qiao et al. (2020a) with 153 citations, Schröder-Hinrichs et al. (2011) with 142, Akyüz (2017) with 136, Uğurlu et al. (2018) with 134, Yildiz et al. (2021) with 129, and Akyüz and Çelik (2014) with 114. Although these publications received relatively high numbers of citations in Scopus, direct citation links among the documents within the 60-study dataset were limited.

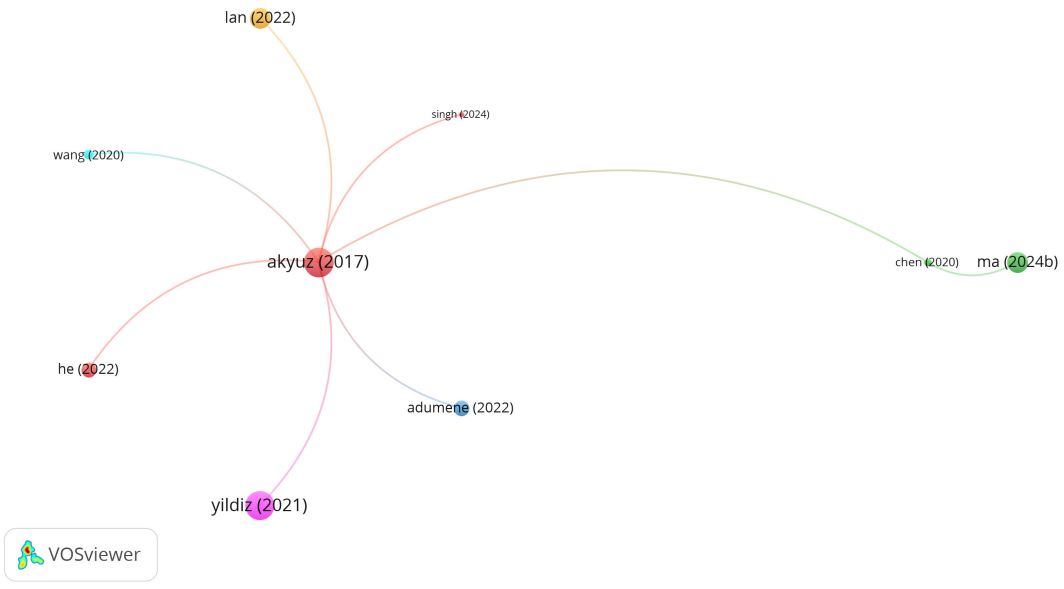

FIGURE 10
Document citation network based on the Scopus dataset.

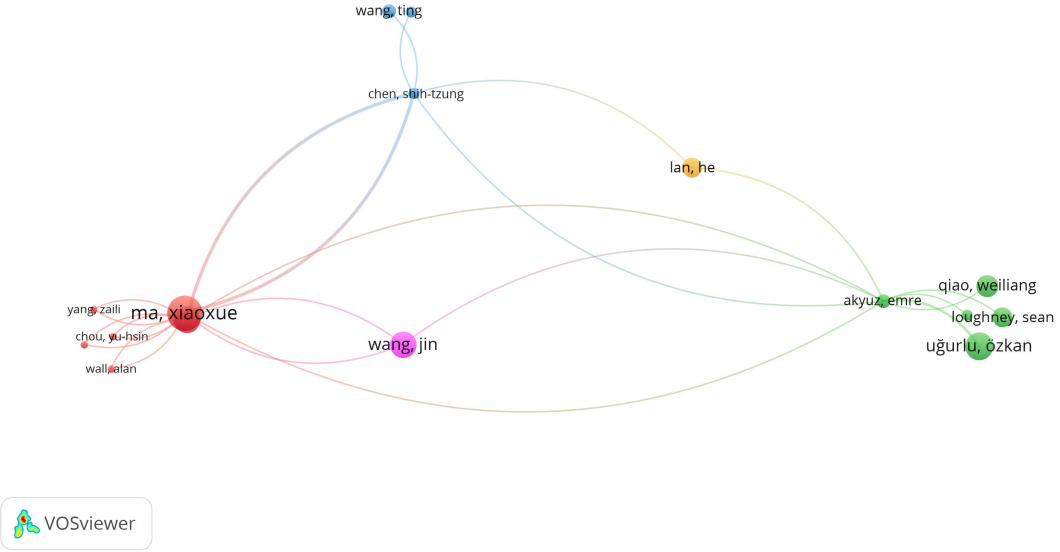

FIGURE 11
Author citation network based on the Scopus dataset.

Figure 11 shows the author citation network for the Scopus dataset. The minimum number of documents per author was set at one, with a minimum citation threshold of 75. Documents with more than 25 authors were excluded. Of the 148 authors identified, 50 met these thresholds and were included in the analysis.

Wang Jin had the highest citation count, with 8 publications and 760 citations. Ma Xiaoxue followed with 13 publications and 620 citations. Christine Chauvin, Jean-Pierre Clostermann, Benoit Langard, Salim Lardjane, and Gaël Morel each had one publication and 568 citations. Özkan Uğurlu had 9 publications and 553 citations, while Metin Çelik had 4 publications and 516 citations and Selçuk Cebi had 2 publications and 387 citations.

The network contained relatively few citation links between authors. In the overall author citation network, Emre Akyüz and Shih-Tzung Chen had the highest Total Link Strength (TLS = 10 each), followed by Ma Xiaoxue and Laihao Ma (TLS = 9 each). Several smaller connected groups can also be seen in the network. Ma Xiaoxue was connected with Yan Zaili, Chou Yu-Hsin, and Alan Wall, while Özkan Uğurlu was connected with Qiao Weiliang, Sean Loughney, and Emre Akyüz. Chen Shih-Tzung and Lan He also had connections with authors in different parts of the network. Overall, the network contained relatively few direct citation links despite the high citation counts of several authors.

3.3 Comparison of Web of Science and Scopus results

The WoS and Scopus datasets were analyzed using the same procedures and thresholds to compare the bibliometric results across the two databases. Table 5 summarizes the results of the keyword co-occurrence, document citation, and author citation analyses for both datasets.

The keyword results were similar in the two datasets. WoS included 179 author keywords and Scopus 168, with 33 keywords meeting the minimum occurrence threshold in each database. Nine of the ten most frequent keywords were shared by both datasets. HFACS ranked first in both WoS (33 occurrences, TLS = 62) and Scopus (35 occurrences, TLS = 73). The only difference in the top ten was MASS in WoS and HFACS-PV in Scopus.

Similar patterns were also found in the citation results. Chauvin et al. (2013) was the most-cited document in both datasets, with 465 citations in WoS and 568 in Scopus. Wang Jin was the most-cited author in both databases, with 637 citations in WoS and 760 in Scopus. The citation networks, however, differed between the two datasets. The WoS document citation network contained more direct links among the publications, while relatively few direct links were found in the Scopus network. This difference was also visible in the author citation networks. Ma Xiaoxue had the highest TLS in WoS (251), whereas Emre Akyüz and Shih-Tzung Chen had the highest TLS in Scopus (10 each). Thus, the two databases showed similar patterns in terms of frequently occurring keywords and highly cited publications and authors, but differed in the structure of their citation networks.

The WoS and Scopus datasets showed substantial overlap. Of the 60 studies included in each database, 55 were common to both, while five studies were unique to the final WoS dataset and five to the final Scopus dataset. Following the bibliometric comparison, these ten database-specific studies were examined separately to assess differences in research context, methodological approach, identified causal factors, HFACS levels, and proposed mitigation measures. The results of this comparison are presented in Table 6.

The ten database-specific studies covered different accident and operational contexts and varied in their application of HFACS. Maritime adaptations, including HFACS-MA, HFACS-Coll, and HFACS-PV, were applied either independently or in combination with methods such as Bayesian Networks, Credal Networks, association-rule mining, STPA, FMEA, and evidential reasoning. Li and Yuen (2025), for example, developed a modified HFACS framework for remote-controlled MASS operations, whereas Canımoğlu et al. (2026) combined HFACS-MA with association-rule mining to examine grounding accidents during marine pilotage.

TABLE 5 Comparison of bibliometric results from the Web of Science and Scopus datasets.

Indicator	Web of Science	Scopus
Final dataset	60 articles	60 articles
Keyword co-occurrence analysis		
Total author keywords	179	168
Minimum occurrence threshold	2	2
Keywords meeting the threshold	33	33
Most frequent keyword	HFACS (33; TLS = 62)	HFACS (35; TLS = 73)
Common keywords in the Top 10	9 of 10	9 of 10
Database-specific keyword in the Top 10	MASS	HFACS-PV
Document citation analysis		
Minimum citation threshold	1	1
Documents meeting the threshold	53 of 60	50 of 60
Most-cited document	Chauvin et al. (2013), 465 citations	Chauvin et al. (2013), 568 citations
Citation links within the dataset	Relatively dense network	Limited direct citation links
Author citation analysis		
Total authors	141	148
Minimum documents per author	1	1
Minimum citation threshold	75	75
Authors meeting the thresholds	48	50
Most-cited author	Wang Jin (637 citations)	Wang Jin (760 citations)
Author(s) with highest TLS	Ma Xiaoxue (TLS = 251)	Emre Akyüz and Shih-Tzung Chen (TLS = 10 each)
Author citation connectivity	Relatively dense network	Relatively sparse network

The same thresholds and bibliometric procedures were applied to both datasets to facilitate comparison. TLS, Total Link Strength.

The causal factors identified across these studies were distributed across different HFACS levels and included navigational and decision errors, communication and resource management deficiencies, cognitive and mental-state factors, and supervisory and organizational deficiencies. Some studies also incorporated technical and environmental conditions into their analyses. The proposed measures accordingly focused on training and competency, communication and coordination, supervision, safety management, regulatory oversight, maintenance, and operational planning (Abuelenin, 2026; Canımoğlu et al., 2026; Chen et al., 2019; Kaptan and Uğurlu, 2022; Li and Yuen, 2025; Singh and Totakura, 2024; Sunardi et al., 2026; Tian et al., 2026; Waskito et al., 2026; Yıldırım et al., 2019).

Despite differences in research context and methodology, the database-specific studies examined causal factors across multiple HFACS levels, from individual actions and preconditions to supervisory and organizational conditions. Given that 55 of the 60 studies were common to both datasets, analyses of publication year, country, research topic, and methodological approach were not repeated for the full Scopus dataset. Instead, the Scopus dataset was used for the bibliometric comparison and to examine the five studies unique to the final Scopus dataset.

4 Discussion

The cross-database findings suggest that maritime HFACS research is both continuous and diversified. In the final WoS and Scopus datasets, HFACS remained the most prominent conceptual framework for structuring human and organizational accident factors, and the same core themes were prominent in keyword networks in both datasets (i.e., human factors, maritime accidents, maritime safety, human error, Bayesian networks). The very high overlap between the databases (55 out of 60 studies) confirms the robustness of the central themes, while the five studies that are unique to each database highlight how database selection can still affect the representation of some specific operational contexts and methodological combinations.

4.1 Framework adaptation and conceptual comparability

The review shows that the original HFACS structure is widely used; however, maritime research has gradually adapted the framework to vessel types, accident mechanisms and operational environments. HFACS-MA, HFACS-PV, HFACS-Coll and other modified structures show the importance of contextualization especially when traditional HFACS categories do not fully capture maritime-specific environmental, technical or operational conditions. At the same time, the proliferation of adaptations poses a comparability problem, as the same causal mechanisms might be attributed to different categories or levels across studies. Future work should, therefore, explicitly report the modifications, keep traceability to the original HFACS taxonomy and clearly distinguish between truly new constructs and context-specific re-labeling of established categories.

4.2 From classification to relational and predictive analysis

A second key finding is the increasing integration of HFACS with quantitative and system-oriented approaches. The most common hybrid approach was Bayesian Networks, but the literature review also identified association-rule mining, fuzzy methods, ANP, evidential reasoning, SEM, STPA/STAMP, and machine-learning approaches. This pattern suggests that HFACS is being increasingly used as a structured representation of causal variables rather than just a retrospective coding taxonomy. Probabilistic and data-driven approaches can model dependencies among HFACS

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TABLE 6 Content characteristics of studies unique to the final WoS and Scopus datasets.

Database	Study	Research/ accident context	Method/ HFACS adaptation	Main causal factor(s)	HFACS level(s)	Mitigation/ recommendation
WoS	Yıldırım et al. (2019)	Collision and grounding accidents; 68 collisions and 189 groundings	HFACS-MA + Chi-square tests + Simple Correspondence Analysis	Collisions: decision errors; groundings: resource management deficiencies; violations prominent in both	Collisions: primarily Unsafe Acts; groundings: primarily Preconditions for Unsafe Acts	Risk assessment; watchkeeping discipline; STCW compliance; communication and coordination; BRM training; effective ISM implementation
WoS	Li and Yuen (2025)	Human factors associated with remote-control failure in Maritime Autonomous Surface Ships (MASS)	Modified HFACS (HFACS-RC) + FMEA + Evidential Reasoning + Rule-Based Bayesian Network; expert survey	Adverse mental states and cognitive limitations, including stress, mental fatigue, information overload, cognitive biases, and automation complacency	Preconditions for Unsafe Acts were particularly important; framework also included Unsafe Acts and Management Influences	Management of psychological and cognitive risks; appropriate work/shift arrangements; operator training and readiness; effective human–machine interfaces; supervisory support; clear operational rules and responsibility allocation
WoS	Abuelenin (2026)	Nine serious marine accidents across fishing, passenger, cargo, offshore, and mixed-use contexts; 2020–2025	HFACS + Bayesian Network + doctrinal legal research + Regulatory Impact Assessment	Weak regulatory enforcement and certification oversight; deficient operational supervision; training deficiencies; jurisdictional fragmentation; weak accountability	All four HFACS levels, with dominant effects at Unsafe Supervision and Organizational Influences	Stronger certification and enforcement; supervisory accountability; competency requirements; regulatory clarity; corrective-action follow-up
WoS	Chen et al. (2019)	Ship collision causation; 20 collision investigation reports + AIS-based case study	HFACS-Coll + Credal Network + expert elicitation + AIS encounter data	Communication failure; inadequate lookout; inadequate crew competency; incorrect situation assessment; improper use of navigational aids; violations; fatigue	Primarily Unsafe Acts and Preconditions for Unsafe Acts	AIS-supported identification of high-risk encounters; targeted management measures; encounter-specific risk controls
WoS	Canımoğlu et al. (2026)	Grounding accidents during marine pilotage; 26 accident reports and 159 contributory factors	HFACS-MA + Apriori Association Rule Mining (HFACS-Apriori)	Ship–marine pilot communication problems; inappropriate passage planning; ineffective use of bridge equipment; port authority resource management; ineffective teamwork	Primarily Preconditions for Unsafe Acts; factors also occurred across External Factors, Organizational Influences, Unsafe Supervision, and Unsafe Acts	Bridge-team training for effective equipment use; improved ship–pilot communication and teamwork; electronic master–pilot information exchange; greater attention to passage planning and exchange/checking of passage plans before pilotage
Scopus	Kaptan and Uğurlu (2022)	Electronic navigation device-related collision and grounding accidents; 153 accident reports	HFACS-PV + frequency analysis	Electronic navigation equipment operating errors; skill-, perception-, and violation-related errors	Unsafe Acts	Periodic equipment training and familiarization; standardized equipment interfaces; control of BNWAS and depth sounder use; improved equipment monitoring
Scopus	Singh and Totakura (2024)	Container-vessel accidents worldwide; 29 accident reports (2010–2021)	NASAFACS + qualitative coding and statistical analysis	Preconditions were the predominant causal category, followed by Acts; decision-making errors prominent within Acts	Preconditions; Acts	Improved cargo securing, declaration, and stowage; decision-making and situational-awareness training; risk assessment; improved procedures and navigational/ weather support
Scopus	Waskito et al. (2026)	Collision, sinking, and fire/explosion accidents in Indonesia; 131 cases	STPA + modified HFACS + Bayesian Network + fuzzy expert judgment	Collision: preconditions; sinking: violations; fire/ explosion: organizational resource management; Unsafe Acts had the highest BN posterior probability	Organizational Influences; Unsafe Supervision; Preconditions of Unsafe Acts; Unsafe Acts	Crew competence and decision-making training; maintenance planning and oversight; stronger safety culture, operational guidelines, and accountability; targeted risk-control measures

(Continued)

TABLE 6 Continued

Database	Study	Research/ accident context	Method/ HFACS adaptation	Main causal factor(s)	HFACS level(s)	Mitigation/ recommendation
Scopus	Tian et al. (2026)	Ship collision accidents along the Zhejiang coast; 213 cases (2016–2023)	HFACS + Apriori Association Rule Mining + Bayesian Network	Neglect of lookout; failure to use navigational aids; inadequate collision assessment; failure to take effective collision-avoidance measures	Unsafe Acts for the four principal factors; analysis covered all four HFACS levels	Targeted risk prevention based on identified causal pathways, particularly lookout and use of navigational aids
Scopus	Sunardi et al. (2026)	Passenger-ship/Ro-Ro sinking and capsizing accidents in Indonesia; 265 cases (2018–2021)	HFACS-MA + CASMET + STAMP; mixed-method content analysis	Adverse weather/ waves/currents; hull breach/water ingress; instability/cargo shift; interaction between technical failures and environmental loading	Multiple HFACS-MA levels integrated with technical, human/ operational, and environmental domains	Maintenance and inspection; watertight integrity and redundancy; condition-based operational limits; CRM/ competency training; loading discipline and safety leadership

factors, identify recurring combinations and facilitate scenario-based risk estimation; however, their outcomes are still sensitive to the quality and consistency of the underlying HFACS coding. Thus, predictive applications demand transparent category definitions, reproducible coding protocols, assessment of interrater reliability where feasible, and sensitivity or validation analyses of the quantitative model built from those categories.

4.3 Multilevel causation and implications for maritime safety

In the ten most-cited studies, HFACS was applied using either standalone or hybrid methodological approaches, the latter combining the framework with probabilistic, fuzzy, statistical, and decision-support techniques to probe causal relationships and prioritize contributing factors.

The synthesis of the content shows that maritime accidents cannot be reduced to unsafe acts only. Decision errors, violations, lookout failures, and equipment-use errors were often observed together with fatigue, communication and teamwork problems, resource-management deficiencies, inadequate supervision, maintenance shortcomings, safety-management weaknesses, and regulatory or organizational conditions in the highly cited and database-specific studies. This multilevel distribution is in line with the basic logic of HFACS: observable operator actions are embedded in larger supervisory and organizational contexts. Accordingly, mitigation should be multilevel as well. BRM and competency training are still important, but evidence supports interventions related to manning and watchkeeping arrangements, bridge and equipment design, passage planning, maintenance, SMS implementation and auditing, supervisory accountability, regulatory enforcement, and organizational safety culture.

4.4 Cross-database robustness, emerging systems, and research gaps

The comparison of WoS and Scopus confirms some interpretations, but also indicates where caution is needed. The two datasets yielded similar top keywords, highly cited documents and authors but different citation-network structures, reflecting database-specific indexing and citation coverage. Geographically, the literature remains concentrated in China and Türkiye, limiting confidence that the patterns observed are transferable unchanged to other regulatory, training, reporting and safety-culture environments. Research also varies by accident type and emerging operations. Remote-control operations, human–automation interaction, and ship–shore coordination are of particular importance because automation does not remove human responsibility but rather reassigns it. Such settings may call for extensions to conventional HFACS categories for remote supervision, automation complacency, information overload, interface design, and distributed decision making.

The ten studies unique to the final databases further demonstrate the value of multi-database review. They introduce combinations with Credal Networks, FMEA, evidential reasoning, STPA, Bayesian Networks, association-rule mining, and CASMET/ STAMP, adding contexts such as remote-controlled MASS, marine pilotage, electronic-navigation-related accidents, container-vessel accidents, Indonesian collision/sinking/fire cases, and passenger-ship capsizing. These studies do not negate the patterns identified in the shared core, but rather add to the breadth of evidence in terms of operation and methodology. Future reviews should continue reporting transparently by database rather than pooling citation indicators. Future primary studies should focus on external validation across countries, vessel types, and accident reporting systems.

4.5 Limitations

A few limitations should be noted. First, the differences in journal coverage, indexing practices and citation counts of WoS and Scopus were considered; for this reason, the bibliometric indicators specific to the databases were analyzed separately, and not pooled. Second, citation-based indicators are time-dependent and may favor older publications. Third, many HFACS studies draw from accident investigation reports, which can constrain the identification of latent organizational and supervisory factors according to their level of detail and reporting conventions. Fourth, HFACS

coding is dependent on researcher judgment, especially when modified taxonomies are used for heterogeneous reports. Fifth, the geographical concentration of the literature and the uneven representation of accident types limit generalizability. Finally, although the same bibliometric thresholds are applied to both databases, network structure is sensitive to author-keyword practices, database metadata, thesaurus decisions, and threshold selection. Transparent coding manuals, inter-rater reliability reporting, sensitivity analyses, wider geographic samples and replication with harmonized datasets should address these limitations.

The selected "HFACS" AND "Maritime" formulation produced the widest and most inclusive retrieval of the tested maritime descriptors in both databases. In response to the concern regarding the use of the acronym "HFACS" rather than the full term "Human Factors Analysis and Classification System," we conducted additional sensitivity searches using the full name of the framework in combination with "Maritime" in both Web of Science and Scopus. In Web of Science, the full-name search retrieved 105 documents, of which 81 were classified as articles. In comparison, the original search using "HFACS" AND "Maritime" retrieved 124 documents, of which 105 were articles; following the predefined eligibility criteria, 60 articles were retained. Cross-checking showed that the studies relevant to the scope of this review identified through the full-name search were encompassed by the acronym-based search. A corresponding sensitivity search in Scopus using the full name together with "Maritime" retrieved 105 documents, of which 81 were articles. Screening showed that many of the additional records were outside the scope of the present review, including studies concerning Parkinson's disease, Vannamei shrimp farming, and general human responses to automation. After application of the same predefined eligibility criteria, cross-checking likewise showed that the records relevant to the scope of this review identified through the full-name search were encompassed by the "HFACS" AND "Maritime" search. Accordingly, the acronym-based formulation was retained as the primary search strategy, not because it simply returned a larger number of records, but because it encompassed the relevant literature identified through the full-name sensitivity search while providing a more focused retrieval for the scope of the review. Using the same primary formulation in WoS and Scopus also ensured methodological consistency across the two databases.

5 Conclusion

This systematic review and bibliometric analysis suggests that maritime HFACS research has evolved from primarily retrospective classification to a broader analytical framework for multilevel, relational and increasingly predictive safety analysis. The final WoS and Scopus datasets each contained 60 studies, with 55 shared studies and 5 unique studies to each database, for a combined evidence base of 65 unique eligible studies. The strong agreement between dominant keywords and top publications suggests that the main structure of the field is robust to the two bibliographical sources. The differences in citation network connectivity and database-specific studies show the advantage of keeping bibliometric results database-specific.

Taken together, the first three research questions reveal that maritime HFACS research is characterized by both context-specific adaptation of the framework and a broadening scope of analytical integration. The ten most-cited studies reveal accident causation involving multiple HFACS levels, linking unsafe acts to preconditions, supervisory lapses, and organizational influences. The corresponding mitigation measures are therefore not limited to individual training, but also include BRM, manning and watchkeeping, bridge and equipment design, maintenance, SMS implementation and auditing, and organizational and regulatory interventions.

The evidence also suggests a dual need for future research resulting from methodological diversification: HFACS needs to be flexible enough to accommodate new maritime contexts, including autonomous and remotely operated systems, but retain enough conceptual standardization for results to be compared and accumulated. Thus, the most useful next step is not to generate further HFACS variants, but to improve transparent taxonomy mapping, coding reliability, external validation, and the integration of HFACS with probabilistic and data-driven models that can be tested on independent accident datasets. The evidence reviewed here supports prevention approaches that consider operator behavior as part of a broader system encompassing supervision, organizational processes, safety management, technology design, and regulatory oversight.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Fİ: Visualization, Writing – original draft, Methodology, Resources, Conceptualization, Writing – review & editing, Data curation. AB: Writing – review & editing, Methodology, Writing – original draft, Resources, Visualization, Conceptualization. ÖD: Visualization, Resources, Data curation, Writing – original draft, Conceptualization, Methodology, Writing – review & editing. İA: Validation, Writing – review & editing, Conceptualization, Supervision, Writing – original draft, Methodology.

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