Analysing Environmental Conditions and Human Factors in Marine Casualties in the Black Sea Using HFACS-PV and Similarity Mapping Technique

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Abstract

The Black Sea is a waterway characterized by adverse weather and sea conditions. Despite collaborations aimed at ensuring navigational safety, serious marine accidents continue to occur in the area. This study aims to identify human and organizational factors (HOFs) specific to the region that emerge in marine accidents. In this context, the focus was on factors contributing to common accident types, such as groundings and sinkings, occurring in the Black Sea 2019-2024. To identify contributing factors, a modified Human Factors Analysis and Classification System was employed. Network analysis using VOSviewer was conducted to reveal relationships among contributing factors. The results showed that, in addition to frequently cited factors like adverse weather, sea conditions, and limited manoeuvring space, Black Sea-specific factors such as inland/river-type ships and aging/worn hull structures play a significant role in the occurrence of accidents. The most common accident sequence for groundings and sinkings in the region was defined as a chain of events starting with engine failure, followed by drifting and grounding, and ultimately resulting in hull failure and sinking. This study contributes to a deeper understanding of HOFs specific to marine accidents in the Black Sea, providing a useful foundation for future research and risk management strategies.

Keywords: *Accident Analysis; HFACS-PV; Black Sea; Marine Accidents; Maritime Safety; VOSviewer*

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Abstract

The Black Sea is a waterway characterized by adverse weather and sea conditions. Despite collaborations aimed at ensuring navigational safety, serious marine accidents continue to occur in the area. This study aims to identify human and organizational factors (HOFs) specific to the region that emerge in marine accidents. In this context, the focus was on factors contributing to common accident types, such as groundings and sinkings, occurring in the Black Sea 2019-2024. To identify contributing factors, modified Human Factors Analysis and Classification System was employed. Network analysis using VOSviewer was conducted to reveal relationships among contributing factors. The results showed that, in addition to frequently cited factors like adverse weather, sea conditions, and limited manoeuvring space, Black Sea-specific factors such as inland/river-type ships and aging/worn hull structures play a significant role in the occurrence of accidents. The most common accident sequence for groundings and sinkings in the region was defined as a chain of events starting with engine failure, followed by drifting and grounding, and ultimately resulting in hull failure and sinking. This study contributes to a deeper understanding of HOFs specific to marine accidents in the Black Sea, providing a useful foundation for future research and risk management strategies.

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1. Introduction

Maritime transportation is essential for a sustainable global economy, over 80% of international trade volume is transported by sea, with this rate being even higher for many developing countries (Fratila et al., 2021). The Black Sea has an important role in global maritime trade, establishing the link between Europe, Asia, and the Middle East. This can be considered as evidence to the significance of maritime corridors like the Black Sea in facilitating worldwide maritime logistics and trade flows.

The Black Sea region presents a high level of maritime risk due to harsh and unpredictable weather conditions. In particular, the frequent storms, heavy rainfall, and strong winds during the winter months significantly disrupt maritime traffic and increase the number of accidents (Novac et al., 2021; Uğurlu et al., 2020). Between 2019 and 2024, numerous maritime accidents in the Black Sea were caused by severe weather. In 2019, the Panama-flagged MV Volgo-Balt 214 sank, resulting in 6 fatalities, and the MV Volgo-Balt 179 also sank, causing 2 deaths. In 2021, the MV Arvin broke apart and sank during a storm, leading to three fatalities. The year 2023 was particularly eventful, with multiple accidents including the sinking of the MV Kafkametler in Ereğli (1 fatality), the grounding and structural failure of the MV Pallada, the grounding of the FR Pearl off Hopa, and the grounding of the Blue Shark near Anapa due to engine failure. In 2024, the sinking of the MV Mohammed Z (3 missing) and the breaking apart of the Volgoneft 212 in the Kerch Strait highlighted the continuing risks in the region. These incidents demonstrate both the prevalence of sinking and grounding accidents in the Black Sea and the severe consequences associated with each type.

Continuous occurrence of accidents highlights both the severity of environmental conditions and the structural challenges faced by maritime operations in the region. The number of sheltered anchorage areas where ships can avoid storms is limited, and most of the existing sites are exposed to severe weather. This situation places vessels at direct risk, particularly during sudden weather changes. Although accidents specific to the Black Sea have not been examined in every study, the literature widely recognizes that maritime accidents threaten trade continuity, environmental safety, and human life (Huang et al., 2023; Rata and Rusu, 2019; Uğurlu et al., 2020). Therefore, a detailed analysis of regional accident reports to understand the patterns and consequences of accidents is critically important for preventing the recurrence of similar events.

The analysis of human and organizational factors (HOFs) plays a critical role in the prevention of maritime accidents. These factors include human error, organizational culture, decision-making processes, and communication problems, all of which help to explain the underlying and preventable causes of accidents (Yıldırım et al., 2019; Yildiz et al., 2021; Wu et al., 2022; Wang et al., 2023; Jovanović et al., 2024). Although regulations set by international authorities such as the International Maritime Organization (IMO) provide the basic framework for ship operations, these rules can vary across countries and directly influence the decisions of both crews and organizations (Cao et al., 2023; Kapoor et al., 2023; Kaptan et al., 2021). Such differences, together with weaknesses in inspection mechanisms, can create gaps in safety practices and increase the risk of accidents (Fedi et al., 2024; Ma et al., 2024a; Sarıalioğlu et al., 2020; Yildiz et al., 2021; Youssef et al., 2023).

Maritime accidents often occur as a result of the interaction between unsafe behaviours and operational conditions. Human-related actions such as rule violations, decision-making errors, lack of skills, and perceptual mistakes, when combined with fatigue, stress, and communication problems among bridge teams, can pave the way for accidents (Bowo et al., 2024; Hebbar et al., 2023; Ma et al., 2024b; Meng et al., 2024). However, for these behaviours to result in accidents, operational pressures are usually also present. Environmental factors such as adverse weather, challenging navigational environments, and deficiencies in port or Vessel Traffic Service (VTS) infrastructure reduce the quality of operators' decisions and increase the likelihood of errors (Ma et al., 2024c; Uğurlu et al., 2020; Crestelo Moreno et al., 2023; Demirci et al., 2023; Zhang et al., 2023; Palbar et al., 2024). In this context, a strong safety culture and continuous risk assessment play a critical role in improving maritime safety by strengthening the system's resilience against errors.

This study aims to analyse the human and organizational factors that contributed to grounding and sinking accidents in the Black Sea between 2019 and 2024. In this context, recent accident reports were examined within the framework of the Human Factors Analysis and Classification System (HFACS), and the relationships among factors were explored through both qualitative and network-based analyses. The study contributes to the literature by applying the HFACS-PV approach, an improved version of the traditional HFACS model that integrates operational conditions. It also distinguishes itself methodologically by using VOSviewer, software commonly employed in bibliometric analyses, in a novel way to identify and visualize causal relationships in maritime accidents. Furthermore, by focusing on operational risks that have been insufficiently studied, such as the operation of river-type vessels under open-sea conditions, the study addresses empirical gaps in the literature. Through this holistic approach, the research provides a deeper understanding of the dynamics of maritime accidents in the Black Sea and develops policy recommendations to support improvements in maritime safety.

2. Literature on Marine Accidents in the Black Sea Context

Maritime accidents are a widespread and complex issue in the field of maritime safety and have been examined from different perspectives in many studies (Uğurlu et al., 2020; Yıldırım et al., 2019; Song et al., 2025). Regional and environmental conditions, human and organizational factors, and advanced modeling techniques emerge as key themes in accident analysis (Wu et al., 2022; Ma et al., 2024d, Baskan et al., 2025). In the case of the Black Sea, the interaction of these multi-layered factors is critically important for a better understanding of the causes of maritime accidents in the region.

Studies on the causes and impacts of maritime accidents in the Black Sea show that high traffic density, adverse weather conditions, and human errors are the primary and secondary causes of accidents in the region (Stingheru et al., 2018). Research focusing on accidents along the Romanian coast has examined their environmental consequences and response processes, emphasizing that compliance with international regulations and effective emergency management play a critical role in reducing the impacts of accidents (Novac et al., 2019). A comprehensive analysis by Uğurlu et al. (2020), using Geographic Information Systems (GIS) and Bayesian networks, identified high accident density in certain coastal areas of the Black Sea and highlighted risk factors such as the use of inland vessels in open-sea conditions. In addition, Novac et al. (2021) analysed the *Queen Hind* accident using the Swiss Cheese Model, evaluating both the causes of the accident and the effectiveness of rescue operations. From an environmental perspective, Nedelcu and Rusu (2022) examined the toxic impacts of oil spills along the Romanian coast and their socio-economic consequences, noting a decline in such incidents due to increased environmental awareness and regulatory compliance. Similarly, Huang et al. (2023) analysed maritime accidents in the Mediterranean and the Black Sea based on variables such as vessel age, tonnage, and type, showing that older and medium-tonnage general cargo ships carry higher risks. A more recent study by Atodiresei et al. (2025) simulated the dynamics of oil spills and coastal pollution risk along the Romanian Black Sea coast using the General NOAA Operational Modeling Environment (GNOME) and Automated Data Inquiry for Oil Spills (ADIOS2) models. Collectively, these studies demonstrate the multidimensional nature of maritime accidents in the Black Sea and highlight the need for complex analyses addressing both accident prevention and the management of environmental impacts.

Various methodological approaches have been developed in the literature to analyse the causes of maritime accidents. To reduce uncertainties, particularly in high-risk operations, hybrid models that integrate Bow-Tie cause-effect relationships with fuzzy logic have become increasingly common (Ay, 2025; Ma et al., 2024d). Such models allow for a systematic evaluation of the interactions between factors such as human error, technical failures, and organizational weaknesses using Bayesian networks and importance ranking analyses. In the context of navigational accidents, studies combining Fault Tree Analysis (FTA), Event Tree Analysis (ETA), and consistency-based methods have identified poor lookout practices, adverse weather conditions, and COLREG violations as prominent risks (Aslan et al., 2024). On the other hand, for a holistic analysis of complex system accidents, research integrating the Systems-Theoretic Accident Model and Processes (STAMP) with multi-criteria decision-making methods has highlighted the dominant role of human and organizational factors (Ceylan et al., 2025). Studies directly addressing the role of human error are also present in the literature. Human reliability analysis methods, such as the Human Error Assessment and Reduction Technique (HEART), contribute to decision support by classifying error-inducing conditions within the 4M framework (Bowo et al., 2024). While all these models make significant contributions to identifying and prioritizing accident-causing factors, the literature frequently emphasizes that they should be complemented with comprehensive taxonomic frameworks such as HFACS, which link human and organizational errors to higher-level system components (Uğurlu et al., 2020).

In the analysis of maritime accidents, the HFACS framework, which enables the systematic classification of human and organizational factors, is widely used in the maritime field. Yıldırım et al. (2019) examined collision and grounding accidents using the HFACS structure and found that decision errors, deficiencies in resource management, and communication problems were prominent, while the role of human factors varied depending on accident type. Reviewing the evolution of the HFACS method, Kaptan et al. (2021) noted that it has also been applied in non-maritime sectors and that the HFACS-PV model, which considers operational conditions as a separate level, provides greater flexibility. Nasur et al. (2025) combined HFACS-MA with the Functional Resonance Analysis Method (FRAM) to develop more effective safety strategies for both manned and autonomous vessels in port operations and emergency situations. Yıldız et al. (2024) integrated HFACS-PV with Bayesian Networks in their analysis of accidents in the Istanbul Strait, creating a decision-support system capable of real-time risk prediction. Similarly, Guo et al. (2025) analysed 343 collision accidents using the HFACS-SCA model, identifying organizational deficiencies as the primary causal factors and unsafe actions as the main outcome factors. This study also applied the Bayesian Probability-Decision Making Trial and Evaluation Laboratory (BP-DEMATEL) method to establish causal relationships among accident factors, highlighting “unsafe speed” and “deficiencies in the safety management system” as the most critical elements. Collectively, these studies demonstrate that by integrating different versions of HFACS with complementary methods, accidents can be analysed holistically not only in terms of human error but also within their organizational and environmental context (Jovanović et al., 2024; Loughney et al., 2024).

The causes of maritime accidents, regardless of which taxonomy or classification system is used, often emerge within a complex and multi-layered network of relationships. For this reason, systematically modelling the contributing factors and quantitatively analysing their causal links has gained increasing importance in the literature. This trend, which began with Bayesian networks, has now expanded to include complex network theory, graph neural networks, and knowledge extraction-based models. Zhang et al. (2025) constructed a directed and weighted accident network using risk factors extracted from 320 ship collision reports and introduced an innovative method to calculate the risk level of each node by considering cascading effects. Gan et al. (2025) transformed textual data into graph data and developed a deep learning model called the Mutual Information-based Deep Graph Convolutional Network (MIDG-GCN) to predict causes in maritime traffic accidents, achieving high accuracy in ranking predicted causes. Similarly, Huang et al. (2025) analysed hazardous materials transportation accidents using a knowledge extraction process based on Bidirectional Encoder Representations from Transformers (BERT), Bidirectional Long Short-Term Memory (BiLSTM), and Conditional Random Fields (CRF), constructing a network model that reflects the evolutionary nature of accidents. Collectively, these studies demonstrate that network-based approaches, which evaluate not only human factors but also technical and environmental components together with their interactions, are becoming increasingly widespread and effective in understanding and preventing maritime accidents.

Although recent years have seen an increase in serious maritime accidents such as groundings and sinkings in the Black Sea, empirical analyses specific to this region remain noticeably limited. A review of the existing literature shows that most studies focus either on environmental pollution dispersion (Nedelcu and Rusu, 2022; Atodiresei et al., 2025) or on single case studies (Novac et al., 2021), without employing holistic approaches capable of uncovering the systematic cause-effect relationships behind accidents. Three main gaps are particularly evident. First, there are limited studies analysing accident reports from the 2019-2024 period with a comprehensive taxonomy such as HFACS-PV, which has the capacity to classify human and organizational factors in detail. Second, risk factors unique to the Black Sea, such as the operation of river-type vessels in open-sea conditions under inland standards cannot be adequately classified under the traditional HFACS category of "unsafe acts" (Uğurlu et al., 2020). Third, while the VOSviewer software has often been used for bibliometric analyses (Yurt and Şakar, 2023) or to visualize themes in accident prevention (Cao et al., 2023), it has not yet been applied to systematically analyse causal structures in maritime accidents.

This study introduces a two-layered analytical approach that differs from traditional HFACS applications in maritime safety by integrating the HFACS-PV framework with the VOSviewer software. HFACS-PV provides a systematic classification of human and organizational factors, while VOSviewer enables the visualization of co-occurrence and interactions among these factors. Compared with other causal analysis methods, HFACS-PV allows for more detailed classification of latent conditions and active failures, whereas VOSviewer visually maps the patterns of their co-existence. This integrated use goes beyond conventional cause-effect categorizations and helps identify structural patterns across clusters of factors. Moreover, HFACS-PV and VOSviewer offer greater ease of application in the causal analysis of maritime accidents. Another key advantage is HFACS-PV's ability to examine sector-specific adaptations and operational conditions as a separate level. Therefore, the proposed approach contributes a multi-layered causality perspective to the theoretical literature while also providing practitioners with a practical tool that supports decision-making and offers an at-a-glance understanding of accident structures.

3. Methodology

Extracting HOFs from casualty reports is an important but a challenging task due to their complex interactions in the accident formation and underlying (hidden) nature. There are structured qualitative analysis tools required to be used to extract the causes and causal factors in a complete and free from flaw manner. HFACS is based on Reason's Swiss Cheese Model (Reason, 1990), and it is a systems approach to human factors in accidents (Wiegmann and Shappell, 1997). The Swiss Cheese Model illustrates how consecutive layers of defence can fail, leading to accidents. HFACS builds on this by offering a detailed classification within its framework, allowing the analysis of contributing factors in accidents. HFACS is including four main levels: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. Shappell and Wiegmann originally developed this method aiming to accurately identify and categorize human factors in aviation accidents, which has since proven to be a reliable and applicable taxonomy for analysing HOFs across various sectors including the maritime one (Olsen, 2011; Uğurlu et al., 2018; Zhan et al., 2017). Therefore, this study applies HFACS-PV to analyse marine accidents in the Black Sea. The HFACS structure used in the study is presented in Figure 1. The fundamental difference of the HFACS-PV structure from other HFACS structures and human factor analysis approaches in accidents is its examination of operational conditions as a separate level. Operational conditions refer to the environmental conditions to which ships are exposed while navigating, anchoring, manoeuvring, loading, unloading, etc. These conditions are divided into internal (such as main engine failure, steering failure, bow thruster failure and old vessel structure) and external conditions (such as the presence of shallows in the area, strong currents, wind, heavy traffic and type of navigation). These factors are structurally distinct from the human and organizational factors located under other levels of HFACS and play a complementary role in the occurrence of marine accidents by completing unsafe acts (Yildiz et al., 2021).

Figure 1. The HFACS-PV structure used in the study (Yildiz et al., 2021)

In line with the study's objective, data on two of the most common and severe types of accidents in the Black Sea, groundings and sinkings, were selected and collected as a first step. All countries bordering the Black Sea are members of the International Maritime Organization (IMO) and are therefore obligated to report very serious marine accidents. The incidents analysed in this study are classified as very serious accidents and are documented in the Global Integrated Shipping Information System (GISIS) database. The focus was placed on accidents occurring between 2019 and 2024, with priority given to official reports that provide detailed information on human and organizational factors. The final dataset consists of 20 very serious marine accidents (12 groundings and 8 sinkings) that occurred in the Black Sea between 2019 and 2024. Accident investigation reports were collected from the maritime safety investigation databases of the coastal countries (i.e., Romania, Bulgaria and Georgia), IMO GISIS, European Marine Casualty Information Platform (EMCIP), and the casualty database of the Transport Safety Investigation Center of Türkiye (EMSA, 2024; GISIS, 2024; TSIC, 2024). In step 2, by examining the existing databases, the study’s database was constructed using Microsoft Excel. This database includes information such as the type of accident, type of ship, ship size, year of construction, accident location, and the date and time of the accident. Although the data used in this study were collected from various sources, all datasets were organized in accordance with international standards, such as those of the IMO and EMCIP, ensuring comparability. In addition to the accident metadata, accident reports were also included in the dataset. For the classification of the age of vessels, ships aged 15 years or older were considered. This threshold was established based on multiple sources. Notably, the Enhanced

Survey Program (ESP) Code mandates additional survey applications for ships aged 15 years and above (IMO, 2011). Furthermore, the annual report of the Black Sea MoU indicates that Port State Control inspections are predominantly focused on ships in this age group (BSMoU, 2024). Accordingly, vessels classified as 15 years or older were categorized as "old vessels," given their higher risk profile. The obtained dataset makes it simpler to analyse and understand the accidents. This study did not rely on a statistical analysis based on dataset size (e.g., regression and correlation). Instead, it aimed to identify the patterns of accident occurrences and the relationships among the factors influencing these patterns. A hybrid methodological approach was adopted, employing both quantitative and qualitative analysis techniques to conduct an in-depth examination. Therefore, the study should be considered a focused analysis, intended to provide critical insights into 20 recently reported accidents. The sample was carefully selected according to predefined inclusion criteria. To ensure the relevance of the results, only cases that occurred in the Black Sea between 2019 and 2024, classified as "very serious accidents" under the IMO GISIS system, and that contained detailed information on human and organizational factors in their reports were included in the analysis. Due to these selection criteria, the dataset was limited to 20 accidents. However, the aim of the study is not to produce quantitative or statistical generalizations, but to conduct in-depth pattern analyses based on the case studies. This methodological choice is consistent with the qualitative comparative analysis approach, which is widely applied in maritime accident research using small but information-rich datasets. Then, in step 3, utilizing the HFACS-PV structure the causes and causal factors of accidents were extracted (Uğurlu et al., 2018). Proficiency in the structure and content of the HFACS model is critical for accurate coding within the framework. A lack of comprehensive knowledge about the model may lead to inconsistencies and errors in the analysis results. The data used in this study were analyzed by a team of five experts with at least five years of academic experience in maritime safety, accident investigation, and human and organizational factors (HOFs), as well as professional seafaring backgrounds. This approach was designed to enhance the reliability and consistency of the findings. All of the experts have have experieece in human factor studies, particularly on HFACS-PV. In addition, two of them have served as researchers or consultants in accident investigation projects conducted for the IMO and national authorities.

During the analysis, each expert independently reviewed the accident reports and identified the causes and contributing factors for each case. To ensure reliability in the coding process, a model calibration was first carried out using five sample cases. At this stage, the

HFACS-PV structural levels were thoroughly discussed, definitions were clarified, and interpretation criteria were standardized. Coding consistency across all accidents was then checked through group discussions, where any conflicting codes were reviewed and resolved by consensus. The coding process followed a standardized codebook that included decision trees and operational definitions for each HFACS-PV level, which all experts used (Yildiz et al., 2021). This procedure strengthened the objectivity and replicability of the study. Then, in step 4, the group gathered to investigate the main events triggering the accidents and the relationships between causal factors within the framework of the HFACS-PV structure, to reach the consensus regarding the occurrence of each accident. As a result, using the HFACS-PV framework, the patterns and trends in HOFs related to the marine accidents that occurred in the Black Sea were revealed. In step 5, network analysis is conducted using VOSviewer, a tool developed by (Van Eck and Waltman, 2010), to examine the interactions among the factors identified in the HFACS-PV framework (Abdullah, 2021; Cao et al., 2023; Yurt and Şakar, 2023). This framework is critical for understanding how different HOFs interact in marine accident formation in the Black Sea. VOSviewer is specifically used to create visual network maps that visually indicate these relationships and interactions, extracted from accident data analysis. This visualization is essential for showing critical interactions that contributed to accident occurrences and understanding the broader context. The VOSviewer software has the capability to analyse co-occurrence relationships between authors, keywords, terms, and similar elements by processing data files downloaded from academic databases such as Web of Science and Scopus. However, the data used in this study consists of accident reports obtained from accident databases rather than academic databases. Since these reports are not in a format that can be processed directly by VOSviewer software, an alternative method has been developed for analysing this data. In this context, reports compiled from accident databases were analysed by experts based on the HFACS-PV framework, and the results obtained were converted into an Excel-based data format readable by VOSviewer. This enabled the creation of a network map visualizing the relationships between causal factors underlying maritime accidents in the Black Sea, with co-occurrences between factors systematically examined. This method expands the application scope of traditional bibliometric analysis tools, offering a new perspective for quantitative data analysis in accident investigations. In step 6, to highlight the re-occurring and different results a comparison has been made to the studies in the literature focusing on the accidents that occurred in the Black Sea. In step 7, to provide insights into the evolution of accident locations and spatial patterns, the distribution of maritime accidents in the Black Sea was thoroughly analysed using point maps and density maps. Drawing on the study by Uğurlu et al. (2020), accident data from 2003-2018 were compared with accidents from 2019-2024, and differences in density were identified. For this purpose, the dataset was divided into three sub-periods: 2003-2010, 2011-2018, and 2019-2024. Only grounding and sinking accidents were included in the analysis. Finally in step 8, recommendations have been identified and presented to raise awareness and to prevent future occurrences. The flow diagram of the methodology is presented in Figure 2.

Figure 2. Methodology flow chart of the study

4. Results and Discussions

This study presents an analysis of the organizational, operational, and human factors that contribute to marine accidents, specifically grounding and sinking incidents in the Black Sea. By utilizing the HFACS-PV framework, the research reveals how underlying organizational deficiencies, such as inadequate safety management and poor emergency preparedness, play a pivotal role in accident occurrence. Moreover, operational challenges, including adverse weather conditions and the use of aging or unsuitable vessels, were identified as significant contributing factors. The study underlines how addressing key issues in maritime safety can improve accident prevention and enhance overall resilience. It also highlights the impact of these findings on the industry and suggests ways to strengthen organizational structures and operational practices.

Organizational influences represent the initial stage of latent failures contributing to marine accidents. They encompass organizational flaws underlying these incidents. Organizational influences include factors related to human/equipment resource management, organizational climate, and organizational processes. Resource management involves aspects such as lack of familiarity with ship machinery, electronic navigational aids, vessel manoeuvring characteristics, emergency management, bridge resource management, and risk assessments prior to navigation and anchoring, as well as inappropriate personnel assignments. Organizational climate covers issues like time pressure exerted by the company on its fleet, weak safety culture within the company and its staff, and unsafe fleet management and supervision by the company. Mismanagement of navigational operations, inappropriate company navigation policies, and the absence of risk assessments for departure, navigation, and anchoring operations fall under organizational processes. Figure 3 and the related HFACS diagrams list all deficiencies associated with grounding and sinking accidents, organized by each HFACS level, based on previous studies (Uğurlu et al., 2018; Uğurlu et al., 2020; Kaptan et al., 2021; Yildiz et al., 2021). The deficiencies specific to grounding and sinking accidents in the Black Sea are highlighted in red in these figures. Figure 3 illustrates the factors at the Organizational influences level in grounding and sinking accidents in the Black Sea, marked in red.

Figure 3. Organizational-level factors contributing to the occurrence of grounding and sinking accidents

Unsafe supervision is the second stage of latent failures contributing to marine accidents. Unsafe supervision includes inadequate oversight and improperly planned operations. Inadequate oversight covers deficiencies in testing and checks of bridge navigation aids, the engine control panel, monitoring voyage planning for seaworthiness, and company inspections. Improperly planned operations include nonconformities in voyage planning and anchoring. Figure 4 highlights, in red, the factors at the unsafe supervision level for grounding and sinking accidents in the Black Sea.

Figure 4. Factors at the unsafe supervision level contributing to grounding and sinking accidents

Preconditions for unsafe acts include factors that lead individuals to perform unsafe acts. These preconditions represent the final stage before the occurrence of unsafe acts. They include substandard team members and technological and interface failures. The bridge team, from the master to the helmsman (including the pilot), and the engine room team, from the chief engineer to the oiler, are all part of this team. Safe navigation or manoeuvring is only possible when there is cohesion and communication among team members. Therefore, in accident analysis, the inadequate conditions and practices of all crew members present on the vessel at the time, not just the master, should be considered (Yildiz et al., 2021). Figure 5 highlights, in red, the factors at the Preconditions for unsafe acts level in grounding and sinking accidents in the Black Sea. These include situational awareness deficiencies among bridge crew members, poor bridge resource management, and gaps in communication and coordination both within the vessel and between the vessel and the company.

Figure 5. Factors at the preconditions for unsafe acts level contributing to grounding and sinking accidents

Unsafe acts are the visible face of accidents and are the actions that directly trigger an accident. Unsafe acts fall into two subcategories: errors and violations. Errors are unintended behaviours that occur during otherwise correctly executed actions and hinder success. Violations involve deliberate disregard of rules and regulations (Shappell and Wiegmann, 2000; Wiegmann et al., 2005). Errors include mistakes in emergency management, incorrect or delayed manoeuvres, selecting an improper anchoring area, failure to identify grounding risks, and failure to detect water ingress in the vessel. Violations include using the vessel beyond its design limits and neglecting pre-operational checks mandated by company procedures. Figure 6 highlights, in red, the factors at the Unsafe acts level in grounding and sinking accidents in the Black Sea.

Figure 6. Factors at the unsafe acts level contributing to grounding and sinking accidents

Operational conditions play a complementary role in the occurrence of accidents by combining with unsafe acts. They were divided into internal and external operational conditions. Internal operational conditions are related to the ship's structure, including factors that influence vessel movement and can be partially controlled by operators. External operational conditions include natural conditions and external factors unrelated to the vessel's structure and unaffected by human input or intervention. Adverse weather and sea conditions, along with limited manoeuvring space, fall under external operational conditions. Factors such as machinery failure, power loss, inland/river-type vessels, and older/worn vessel structures (age ≥ 15 years) constitute internal operational conditions. Figure 7 highlights, in red, the factors at the Operational Conditions level in grounding and sinking accidents in the Black Sea.

Figure 7. Factors at the Operational Conditions level contributing to grounding and sinking accidents

The findings reveal that organizational influences are the most critical factor among HFACS-PV levels in Black Sea maritime accidents, contributing to 34.7% of grounding accidents and 37.2% of sinking accidents. Operational conditions also played a substantial role, representing 32% of groundings (22.7% internal, 9.3% external) and 28.9% of sinkings (13.2% internal, 15.7% external). In comparison, unsafe acts had a relatively lower impact, accounting for 17.1% of groundings (10.2% errors, 6.9% violations) and 16.5% of sinkings (9.1% errors, 7.4% violations) (Figure 8).

Figure 8. Distribution of accident causal factors under HFACS-PV main levels

A network analysis was conducted using VOSviewer to examine the relationships between causal factors in grounding and sinking accidents in the Black Sea. The analysis identified operational conditions and organizational influences as the most frequently encountered factors in these accidents. Adverse weather and sea conditions, inland/river-type vessels, older/worn vessel structures (age ≥ 15), and limited manoeuvring space were the most common operational conditions. Within organizational influences, lack of familiarity with emergency management and weak safety culture among company and personnel were prominent factors (Figure 9). The abbreviations used in the VOSviewer analysis are presented in Table 1.

Table 1. Abbreviations used in the VOSviewer application

Figure 9. Network of relationships among HOFs in accidents occurring in the Black Sea

In the study, 90% of the accidents examined involved a combination of adverse weather and sea conditions and factors related to river or inland waterway-type vessels. Additionally, 80% of the accidents were found to involve four simultaneous operational conditions: adverse weather and sea conditions, river/inland waterway-type vessels, aging/worn ships and vessel structures (age ≥15 years), and limited manoeuvring space (Figure 9). Furthermore, a lack of familiarity with emergency management and a weak safety culture among companies and personnel were present in 55% of the accidents. In 50% of the accidents, both weak safety culture among companies and personnel and a lack of familiarity with electronic navigation devices were observed, indicating a strong relationship among these factors (Figure 9).

It was found that, in accidents occurring in the Black Sea, there was a close relationship between the preconditions for unsafe acts and the unsafe acts themselves, as categorized by HFACS-PV (Figure 10).

Figure 10. Heat map of HOFs in accidents in the Black Sea

In recent years, grounding accidents in the Black Sea have become more concentrated, with the average time of occurrence identified as the last quarter of 2023. When these grounding incidents were examined, the most common operational conditions were river/inland waterway-type vessels, adverse weather and sea conditions, and limited manoeuvring space. Regarding unsafe acts, the most frequently encountered factors were operating the ship beyond its design limits and failing to detect the risk of grounding. In terms of preconditions, the most common issues were poor bridge resource management, lack of onboard communication and coordination, and the bridge crew's lack of situational awareness. For unsafe supervision, factors such as inadequate voyage planning, insufficient internal review of the voyage plan, and failure to test and check bridge navigation aids stood out. Organizational influences most frequently included a lack of familiarity with emergency management, weak safety culture among the company and crew, and insufficient familiarity with bridge resource management practices (Figure 11).

Figure 11. Relationship between grounding accidents and HOFs in the Black Sea

The average time of occurrence for sinking accidents in the Black Sea was identified as mid-2022. When examining these sinking accidents, the most common operational conditions were adverse weather and sea conditions, river/inland waterway-type vessels, and aging/worn ships and vessel structures (age ≥15). In terms of unsafe acts, the most frequently encountered factors included operating the ship beyond its design limits, inadequate company procedures and pre-operation checks, and failure to detect water ingress. The most common precondition was poor bridge resource management, while key factors for unsafe supervision included deficiencies in company oversight, voyage planning, and lack of internal review of the voyage plan. In terms of organizational conditions, the most frequently observed issues were a lack of familiarity with emergency management, a weak safety culture among the company and crew, and inadequate risk assessment (during departure, navigation and anchoring) (Figure 12).

Figure 12. Relationship between sinking accidents and HOFs in the Black Sea

Overall, the most frequently observed factors in grounding accidents include adverse weather and sea conditions, river/inland waterway-type vessels, limited manoeuvring space, lack of familiarity with emergency management, aging/worn ships and vessel structures, and a weak safety culture (Figure 11). For sinking accidents, the main factors were adverse weather and sea conditions, river/inland waterway-type vessels, aging/worn ships and vessel structures, and limited manoeuvring space (Figure 12). The most common accident pattern for grounding and sinking incidents in the Black Sea was identified as a chain of events starting with engine failure (main engine, auxiliary engines, or rudder), leading to drifting and grounding, and eventually resulting in hull failure and sinking (Figure 13). Engine failures were observed in 70% of the accidents, causing 60% of the affected ships to lose control and drift, with 60% of these cases ending in grounding. Ultimately, 45% of accidents that began with engine failure ended in sinking. Importantly, the use of river-type vessels not designed for open seas significantly contributed to accidents in the Black Sea. This issue is exacerbated when vessels over 15 years old (even if only halfway through their expected lifespan) experience metal fatigue and hull failure under adverse weather conditions. These findings highlight the high risk associated with operating ships beyond their design limits.

Figure 13. Most prevalent accident formation pattern in the Black Sea (N= 20)

In this study, various factors influencing accidents from 20 different grounding and sinking accident reports were compared with the findings of similar studies in the literature that examined accidents in the Black Sea (Table 2). Factors that showed at least four or more similarities with this study were considered frequent contributors to accidents. On the other hand, elements not found in other studies were regarded as unique and specific findings of this research.

The findings provide important insights for preventing marine accidents and improving safety measures. Under the level of Organizational influences, the most commonly observed issues were identified as lack of familiarity with ship machinery, electronic navigation devices, and manoeuvring characteristics, inappropriate crew assignments, and non-compliance with navigation regulations (e.g., weather conditions, permitted navigation areas). Overall, lack of familiarity with ship equipment, incorrect crew assignments, and navigation-related non-compliance were highlighted as the most common issues. The study by Kaptan et al. (2021), which discussed modifications to the HFACS framework, emphasized that lack of familiarity was a prevalent factor in all modified HFACS structures. Similarly, inappropriate personnel assignments and navigation non-compliance were frequently identified in HFACS-based studies (Uğurlu et al., 2018). This study clearly shows that regardless of the models used, research findings consistently point to lack of familiarity, inappropriate crew assignments, and navigation non-compliance as critical factors in ship accidents (Table 2).

Table 2. Comparison of the literature findings and this study

Under the organizational influences level, a specific accident factor highlighted by this study, not found in other research, is the lack of familiarity with pre-voyage and anchoring risk assessments. Factors impacting accidents under the unsafe supervision level were also identified as unique findings that are rarely discussed in the literature. These factors include insufficient testing and checking of bridge navigation devices and engine control panels, voyage planning, and anchoring (Table 2). These elements can be seen as early indicators of risk assessment deficiencies within the organizational influences level (e.g., risk assessment checklist items). Therefore, these rare factors should be considered as part of a comprehensive approach under risk assessment. In maritime practices, risk assessment not only measures the current level of safety but also aims to minimize the likelihood of accidents by eliminating contributing factors (Kim et al., 2011). The study by Melnyk and Onyshchenko (2022) showed that giving sufficient attention to risk assessments led to significant reductions in accident rates. Although the literature clearly emphasizes the impact of risk assessment deficiencies on marine accidents, the fact that these deficiencies are either insufficiently addressed or differently interpreted as accident-causing factors in various models suggests a gap in accident modelling. In this context, accident models could be reviewed to integrate risk assessment processes as an essential system component.

In the Preconditions for unsafe acts level, the most commonly identified factors contributing to accidents were lack of situational awareness (bridge team) and lack of communication and coordination (within the ship). The lack of situational awareness among the bridge team is closely related to the frequent issue of unfamiliarity with bridge equipment under the Organizational influences level. Ensuring situational awareness is not possible during bridge operations conducted with unfamiliar equipment and incomplete information. This relationship supports the internal consistency of the study's findings across these categories. Additionally, communication issues within the ship were also common accident contributors. Research has shown that communication errors often stem from misunderstandings and avoiding interactions between individuals (McCallum et al., 2000; Tonoğlu et al., 2022). These findings clearly demonstrate that improving communication and coordination within the ship can play a critical role in preventing accidents (Table 2).

In the unsafe acts level, the most frequently contributing factors to accidents were identified as incorrect/inadequate emergency management, improper/delayed manoeuvring, and failure to detect the risk of grounding. Manoeuvring errors and the failure to recognize the risk of grounding can be linked to deficiencies in bridge team management, as previously mentioned. Additionally, incorrect/inadequate emergency management is one of the common factors highlighted in studies using the HFACS model (Kaptan et al., 2021). These findings, which are also frequently noted in similar studies in the literature, emphasize the critical role of crew training and proper crew selection in preventing accidents (Table 2).

In the operational conditions level, the most frequently contributing factors to accidents were identified as adverse weather and sea conditions, limited manoeuvring space (coastal area), engine failure, and aging ship/worn hull and structure (age ≥ 15). Among these, adverse weather conditions and limited manoeuvring space are classified as external factors. Although planning is done to minimize these external impacts during navigation, it is not possible to completely eliminate them (Uğurlu et al., 2020). Many studies have shown that these external factors contribute to marine accidents (Chen et al., 2022; Hu and Park, 2020). Additionally, factors such as engine failure and aging ships are internal operational conditions affecting accidents. Unlike external factors, these internal issues can be controlled with preventive measures such as regular maintenance and repair, replacement of outdated equipment, and monitoring the thickness of the ship's hull plates (Wang et al., 2021; Yildiz et al., 2021) (Table 2).

In summary, this study reveals that the most prominent contributors to grounding and sinking accidents in the Black Sea region are deficiencies in situational awareness and communication within the bridge team, along with improper manoeuvring and inadequate emergency management. Through the HFACS-PV framework, the study identifies organizational-level weaknesses, particularly related to insufficient risk assessment practices and unfamiliarity with bridge equipment. Unlike prior studies, this research provides a multi-layered analysis that connects unsafe acts, preconditions, and organizational influences, demonstrating a clearer causal chain. It also highlights often-overlooked areas such as anchorage inspections and voyage planning. These findings emphasize the necessity for targeted crew training, improved communication protocols, and systematic risk assessments to reduce marine accidents. The study thus contributes both empirically and methodologically to maritime safety research by refining the application of HFACS in regional accident analysis.

This study demonstrated the application of the HFACS model from a more comprehensive perspective compared to other accident research findings related to the Black Sea region. It explicitly highlights deficiencies in risk assessment processes at the organizational influences level and their impact on accidents. Specific factors, such as voyage planning and anchorage inspections, have been identified, drawing attention to these often-overlooked areas. The study's internal consistency emphasizes connections among contributing factors, shedding light on root causes that are frequently neglected in the literature. Furthermore, the limited scope and sample sizes of previous studies, often confined to specific regions (e.g., accidents in Romania) or single-case analyses, may explain the comparatively smaller number of findings. The multi-layered structure of the HFACS model addresses a critical gap in the existing research by integrating risk assessment processes into accident analysis.

The spatial distribution of maritime accidents in the Black Sea was comprehensively analysed using point maps and density maps. The evaluation, covering the period 2003-2024, was presented in five sub-figures based on accident types and their temporal distributions. The point distribution map shows in detail the geographical locations of grounding (n=34) and sinking (n=32) accidents in the region (Figure 14). The overall point distribution indicates clear clusters of both accident types near the northern entrance of the Istanbul Strait, around the Kerch Strait, in the approach areas to Novorossiysk Port, and around Varna Port in Bulgaria.

The density map, based on the spatial proximity and recurrence of accidents, shows high concentration values particularly in river mouths, port entrances, and areas with heavy maritime traffic where the safe navigation space is limited. In these regions, under adverse weather and sea conditions, the likelihood of accidents increases significantly, especially for older vessels; in the best-case scenario, such ships experience structural damage or engine failure leading to grounding. Other findings of the study support this observation. The entrance to the Istanbul Strait, the Kerch Strait, and the approaches to Novorossiysk emerge as the three main hotspots of accidents, while the number of accidents around Varna Port is also high but spatially more dispersed, resulting in lower density values (Figure 15).

Using the study by Uğurlu et al. (2020) as a reference, accident data from 2003-2018 were compared with those from 2019-2024, and differences in density were mapped. For this purpose, the dataset was divided into three sub-periods. The density analyses show that there were notable changes in the spatial distribution of accidents in the Black Sea between 2003 and 2024 (Figure 16). In the first period (2003-2010, n=24), accidents were concentrated mainly at the entrance of the Istanbul Strait, the approaches to Novorossiysk Port, the Kerch Strait, and the southern coast of the Crimean Peninsula. In the second period (2011-2018, n=22), new clusters appeared off Ereğli, Zonguldak, and Samsun, while the number of accidents in the Kerch Strait declined significantly. This shift may be linked to port investments, changes in trade routes, and political-economic developments in the region. In the third period (2019-2024), accident density remained high around the Istanbul Strait, Ereğli, Sinop, and the Kerch Strait, whereas the clusters off Zonguldak and Samsun decreased. Overall, when the three periods are considered together, it is evident that the main high-risk areas have largely remained stable over time, but new clusters have emerged, while some regions show a decline in density due to safety measures.

Finally, the spatial distribution of maritime accidents in the Black Sea was analysed using point maps and density maps. The evaluation, covering the years 2003-2024, was presented through five sub-figures based on accident types and their temporal distributions. The point distribution map shows in detail the geographical locations of grounding (n=34) and sinking (n=32) cases in the region (Figure 14). The overall point distribution indicates clear clusters of both accident types near the northern entrance of the Istanbul Strait, around the Kerch Strait, in the approach areas to Novorossiysk Port, and in the Varna Port region of Bulgaria.

Figure 14. Point distribution map of accidents in Black Sea between 2003-2024 by accident type ($n_{Grounding}$=34, $n_{Sinking}$=32)

The density map, based on the proximity and frequency of accidents, shows high concentrations particularly in river mouths, port entrances, and areas of heavy maritime traffic where safe navigation space is limited. In these areas, under severe weather and sea conditions, accidents become almost inevitable for older vessels. In the best-case scenario, such ships suffer structural deformation or engine failure, resulting in grounding. The overall findings of the study support this conclusion. The entrance to the Istanbul Strait, the Kerch Strait, and the approaches to Novorossiysk stand out as the three main hotspots where accidents are most concentrated. Although the number of accidents around Varna Port in Bulgaria is relatively high, the wider spatial distribution of cases has resulted in lower density compared with the three main hotspots (Figure 15).

Figure 15. Density map of accidents in Black Sea between 2003-2024 (N=66)

In this study, accident data from earlier years (2003-2018) and more recent years (2019-2024) were mapped using the approach of Uğurlu et al. (2020), and differences in density between the two periods were identified. For this purpose, the dataset was divided into three sub-periods: 2003-2010, 2011-2018, and 2019-2024. Only grounding and sinking accidents were included in the analysis. The density analyses indicate clear changes in the spatial distribution of maritime accidents in the Black Sea between 2003 and 2024 (Figure 16). In the first period (2003-2010, 24 accidents), accidents were mainly concentrated at the entrance of the Istanbul Strait, the approaches to Novorossiysk Port, the Kerch Strait, and the southern coast of the Crimean Peninsula. In the second period (2011-2018, 22 accidents), new clusters appeared along the coasts of Ereğli, Zonguldak, and Samsun, while the number of cases in the Kerch Strait showed a remarkable decrease. This shift may be related to port investments in the region and changes in trade routes linked to political and economic developments.

In the 2019-2024 period, accident density remained high around the Istanbul Strait, Ereğli, Sinop, and the Kerch Strait, while a decline in density was observed off the coasts of Zonguldak and Samsun. When the three periods are considered together, it becomes clear that high-risk areas have largely remained stable over the long term, but new clusters have emerged over time, and in some regions accident density has decreased due to the implementation of safety measures (Figure 16).

Figure 16. Density map of accidents in Black Sea: 16a. 2003-2010 Period, 16b. 2011-2018 Period, 16c. 2019-2024 Period

The spatial analysis conducted in this study not only confirmed the existing causes of accidents but also clearly identified the geographic areas where risks are concentrated. The findings indicate that policies and operational measures for accident prevention should be developed in a more targeted manner. In particular, in narrow waterways, port approaches, and the high-density areas identified in this study, it is important to strengthen the use of AI-assisted traffic management systems through continuous data flow from existing AIS stations and buoys, to develop decision-support software integrated into electronic chart systems, and to enforce mandatory pilotage services. In addition, in busy port approach areas, enforcing speed limits as mandatory rather than recommendatory, and redesigning approach routes, drift zones, and anchorage areas could help reduce risks. For accidents occurring in open seas, measures such as suspending the voyages of river-type vessels in adverse weather or providing route optimization support from ports could be considered. Moreover, since a significant proportion of grounding and sinking cases involve older vessels, policies that encourage fleet renewal and regulate ship age limits may play a critical role in improving regional maritime safety. Finally, it should be considered that the Black Sea coastal states establish a “Black Sea Safety Agency” or a similar joint framework to standardize the content and language of reports as well as the causal factor classification systems used in accident investigations. Such an initiative would allow lessons from past accidents to be learned more comprehensively and help prevent future possible accidents.

5. Conclusion

In order to contribute to the ongoing discussions on maritime safety in the Black Sea, this study aimed to analyse recent marine accidents that occurred in the Black Sea, employing HFACS-PV to identify the HOFs involving in these accidents. The results have underscored the significant role of adverse weather conditions, hull failures, and equipment malfunctions, particularly in high-traffic coastal areas. Notably, the widespread use of river-type ships (designed with particular design criteria and design limits), which are ill-suited for open sea conditions, has been identified as a critical factor in the occurrence pattern of these accidents. The concepts of river-type vessels and inland waters have already been defined by Türk Loydu, one of the International Association of Classification Societies (IACS) members in the Black Sea region. These vessels are not designed for open-sea operations; however, they continue to operate in open-sea areas such as the Black Sea. It is well-documented that most river-type vessels in the Black Sea originate from the Volga-Don River, accessing the Black Sea via the Sea of Azov and the Kerch Strait. Additionally, the average age of river-type vessels in the region significantly exceeds 15 years. It is imperative that classification societies and authorities formally classify these vessels as river-type/inland water vessels and restrict their access to open seas. To achieve this, the countries in the region, followed by the international community, may consider urgently implementing necessary regulatory measures. Furthermore, strict enforcement of these regulations by all stakeholder countries is of critical importance to ensure maritime safety in the region.

The study findings revealed a complex interaction of factors leading to marine accidents in the Black Sea, with machinery failures often setting off a chain of events that result in grounding and ultimately hull failure and sinking. This pattern not only emphasizes the criticality of ship machinery maintenance but also highlights the dangers of operating ships beyond their design limits, especially in adverse environmental conditions.

Furthermore, the analysis through the HFACS-PV framework has illuminated key organizational and supervisory shortcomings, such as inadequate risk assessment and emergency management, which exacerbate the risk of accidents. The persistence of these issues, despite regulatory advancements and technological improvements in navigation, suggests a disconnect between policy implementation and actual practice on the ground. In this context, Port State Control (PSC) inspections could be revised to go beyond merely auditing documentation and the existence of procedures. Adjustments to PSC checklists could focus on more comprehensively evaluating the competencies and knowledge of crew members regarding the implementation of these procedures.

Finally, it is worth noting that the presence of multiple coastal states around the Black Sea, differences in the primary languages used by crew members, and the absence of a dedicated maritime safety agency for the Black Sea have complicated the data collection process. Although reports are prepared in accordance with the IMO Casualty Investigation Code, the level of detail and format of these reports vary depending on the practices of the investigating authorities. This issue should be comprehensively addressed by the Black Sea coastal states, either through the establishment of a Black Sea Maritime Safety Agency or by adopting a joint protocol to ensure consistency and effectiveness.

The findings of this study offer practical implications for improving navigation safety and maritime safety management systems. For instance, the identification of situational awareness and communication failures as key contributors to accidents can inform the development of enhanced bridge team training programs, with a stronger emphasis on equipment familiarization and real-time coordination under stress. The observed link between organizational-level risk assessment deficiencies and operational mishaps suggests a need for revising safety management systems (SMS) to include more robust voyage planning and anchorage inspection protocols. Furthermore, the HFACS-based analysis framework used in this study can serve as a diagnostic tool for maritime authorities and policy makers to systematically evaluate root causes of incidents, prioritize interventions, and design evidence-based regulations. Integrating these findings into policy processes would support more targeted investments in crew training, ship maintenance standards, and digital navigation systems, ultimately fostering a more proactive maritime safety culture.

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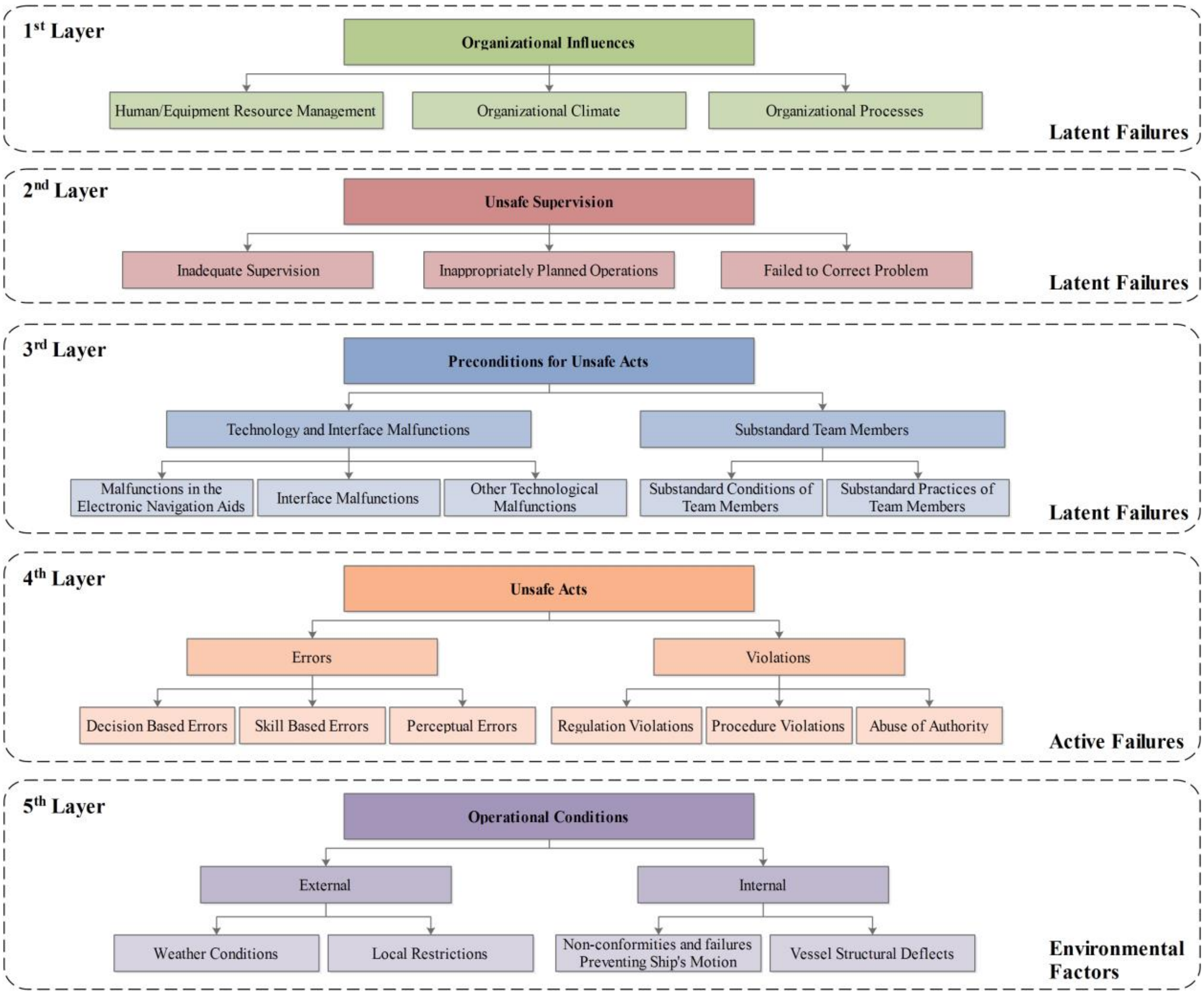


Figure 1. The HFACS-PV structure used in the study (Yildiz et al., 2021)

Step 1. Data collection

Grounding and sinking accidents in the Black Sea between 2019-2024 were gathered from various sources including maritime safety investigation databases, media reports, and interviews.

Step 2. Data cleaning and preparation for the analysis

The data were systematically organized in a Microsoft Excel database, recording details such as accident type, ship type, ship size, year of construction, location of the accident, and the date and time it occurred.

Step 3. Extracting the HOFs using the HFACS-PV structure

An expert group consisting of five individuals, each with substantial experience in maritime safety and investigation, conducted independent analyses of the accident data to identify underlying causes and contributing factors.

Step 4. Focus group discussion to reach consensus

Following individual analyses, the expert group gathered to discuss the findings. This discussion aimed to explore the interconnections between identified causal factors and to achieve consensus on the factors contributing to each accident.

Step 5. Network analysis and HFACS-PV factors' mapping using VOSviewer

Network analysis was conducted via VOSviewer to examine the interactions among the variables identified in the HFACS-PV. Visual network maps were created that illustrate the relationships among the HOFs.

Step 6. Comparison of results of the study with the literature

Comparison were made to highlight the re-occurring and different results vis a vis the studies in the literature focusing on the accidents occurred in the Black Sea.

Step 7. Spatial density analysis of accidents between 2003-2024 and comparison

Analysis of spatial distribution and density evolution of accident-prone areas in Black Sea for accidents occurred between 2003-2024.

Step 8. Results and recommendations

From the consensus and analysis of the VOSviewer maps, patterns and trends in HOFs influencing the accidents were identified, recommendations were made aiming to enhance maritime safety and mitigate future incidents.

Figure 2. Methodology flow chart of the study

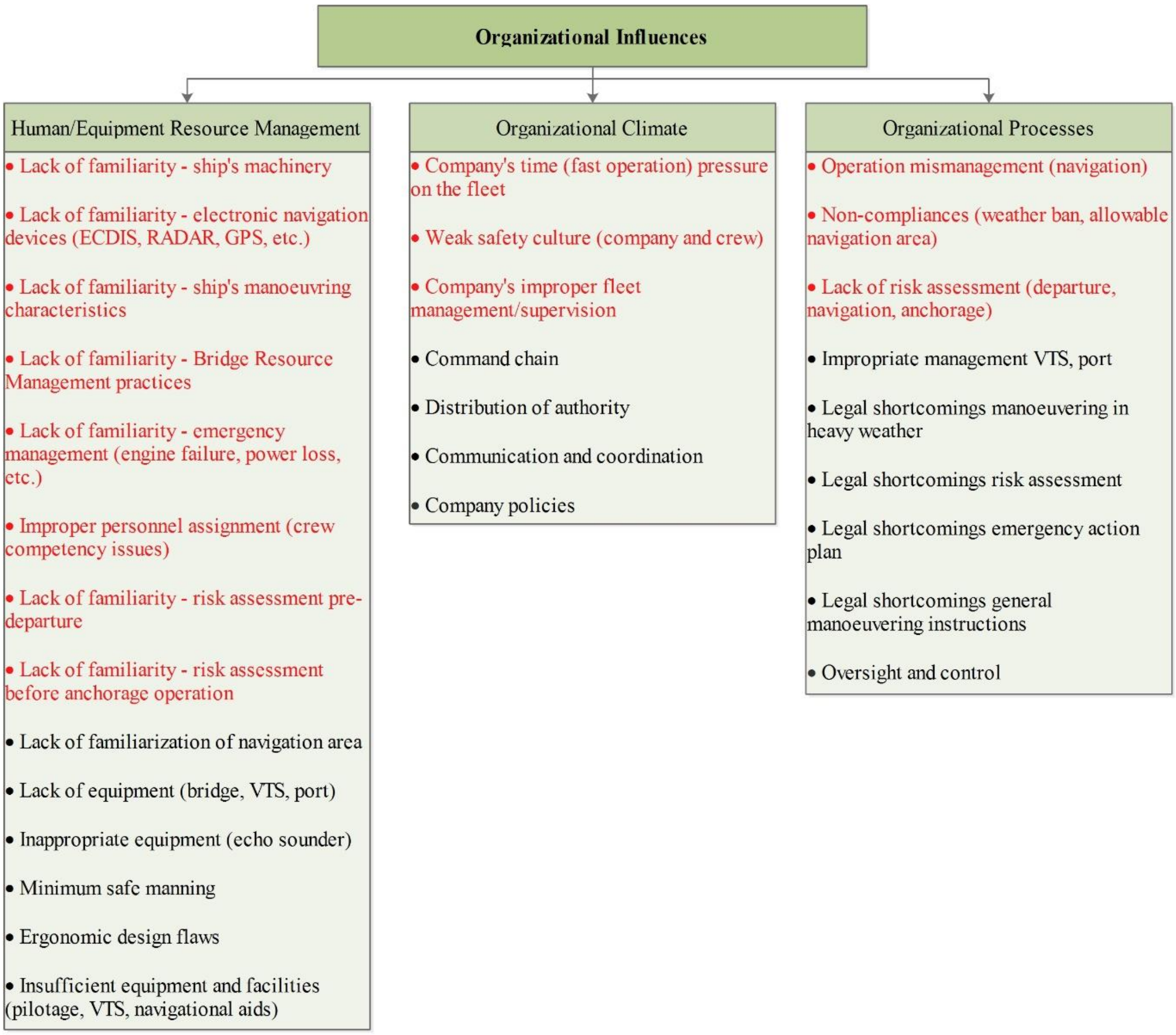


Figure 3. Organizational-level factors contributing to the occurrence of grounding and sinking accidents

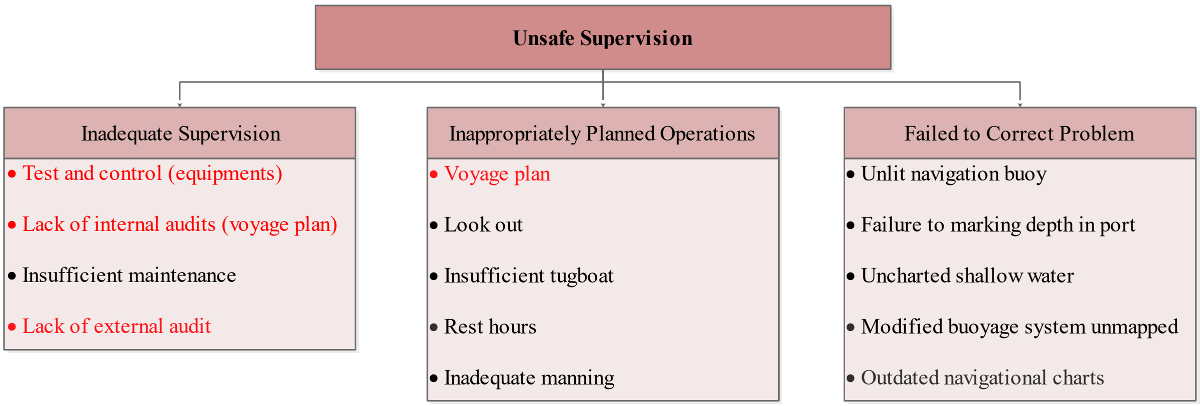


Figure 4. Factors at the unsafe supervision level contributing to grounding and sinking accidents

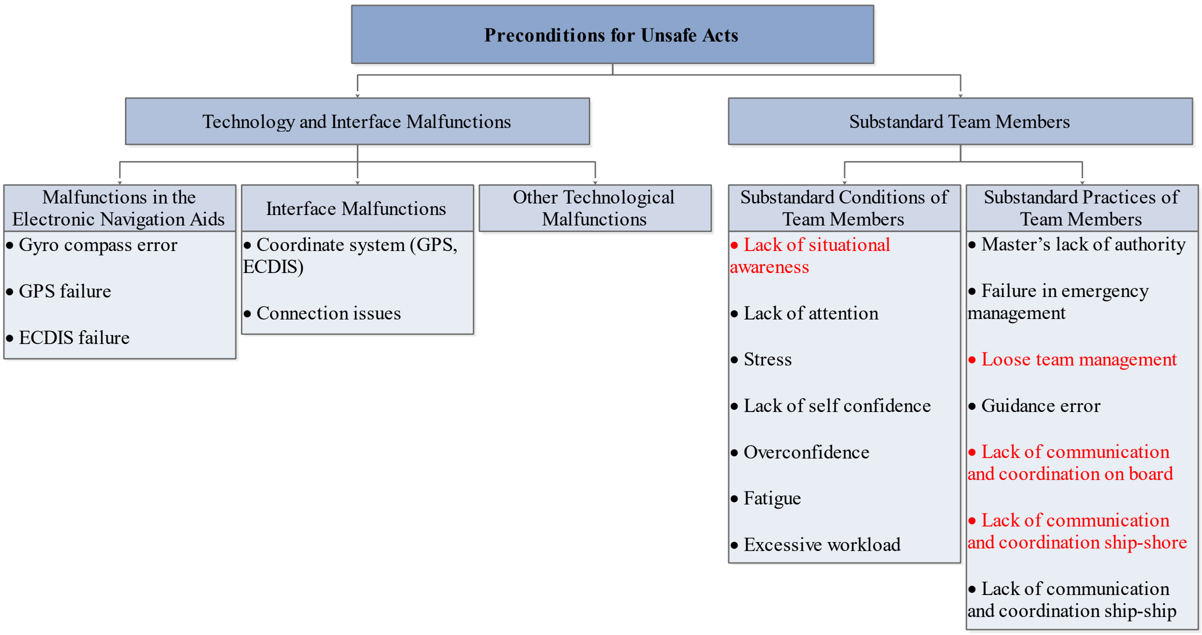


Figure 5. Factors at the preconditions for unsafe acts level contributing to grounding and sinking accidents

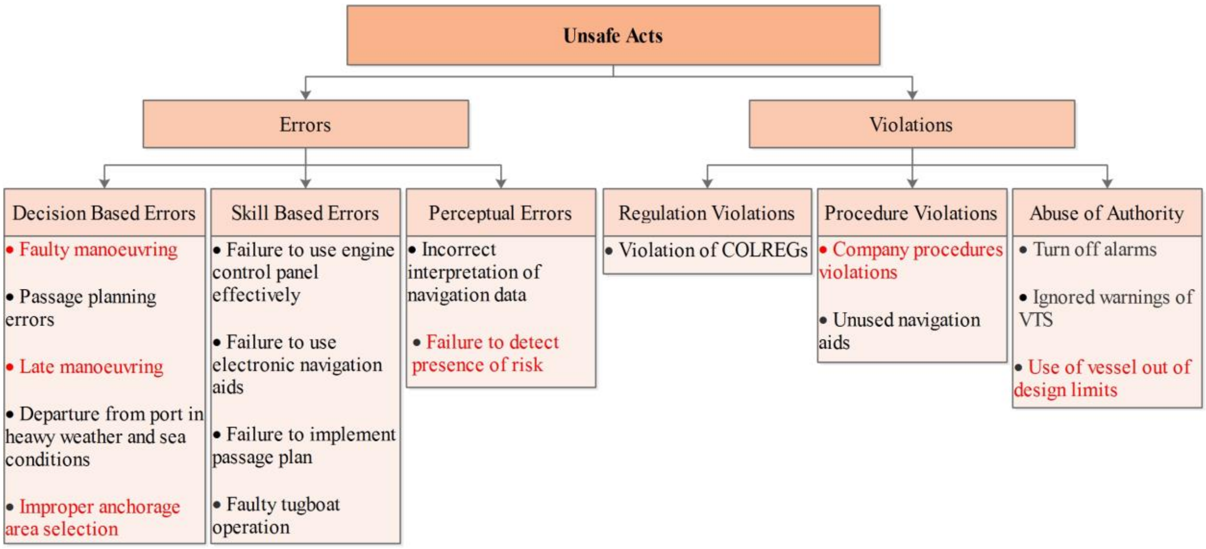


Figure 6. Factors at the unsafe acts level contributing to grounding and sinking accidents

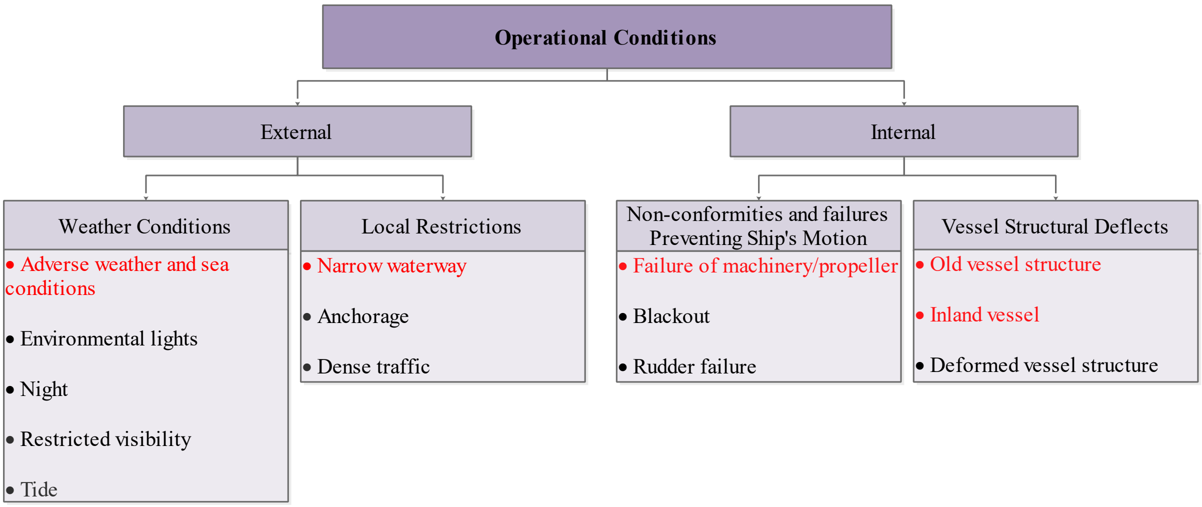


Figure 7. Factors at the Operational Conditions level contributing to grounding and sinking accidents

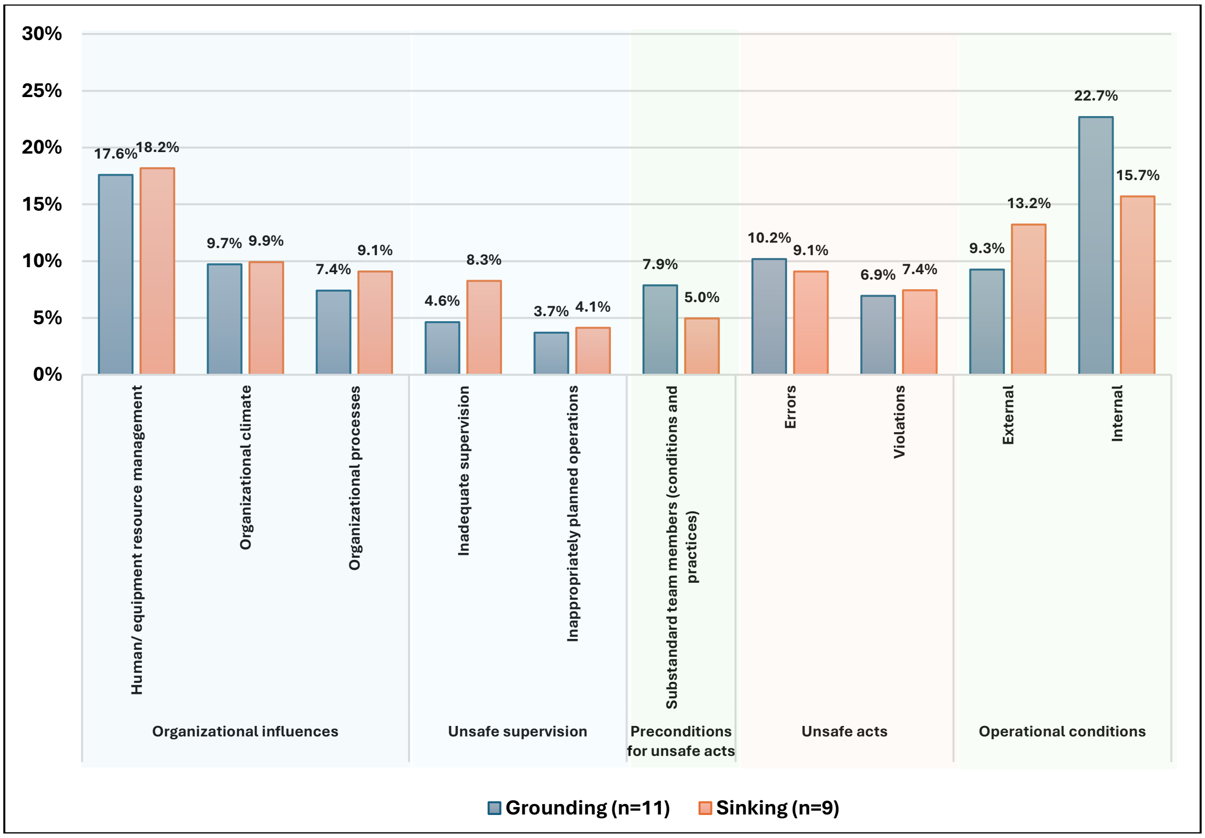


Figure 8. Distribution of accident causal factors under HFACS-PV main levels

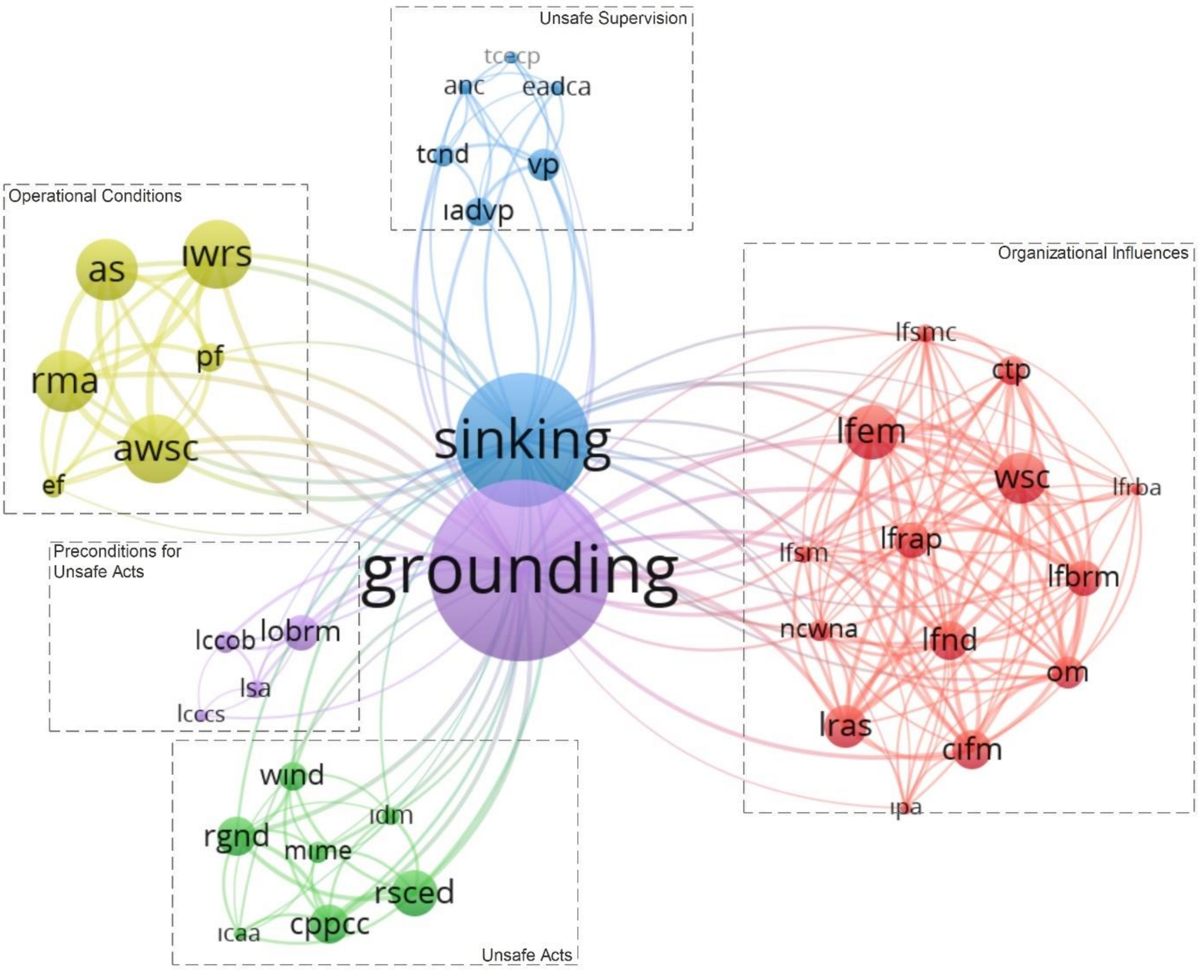


Figure 9. Network of relationships among HOFs in accidents in the Black Sea

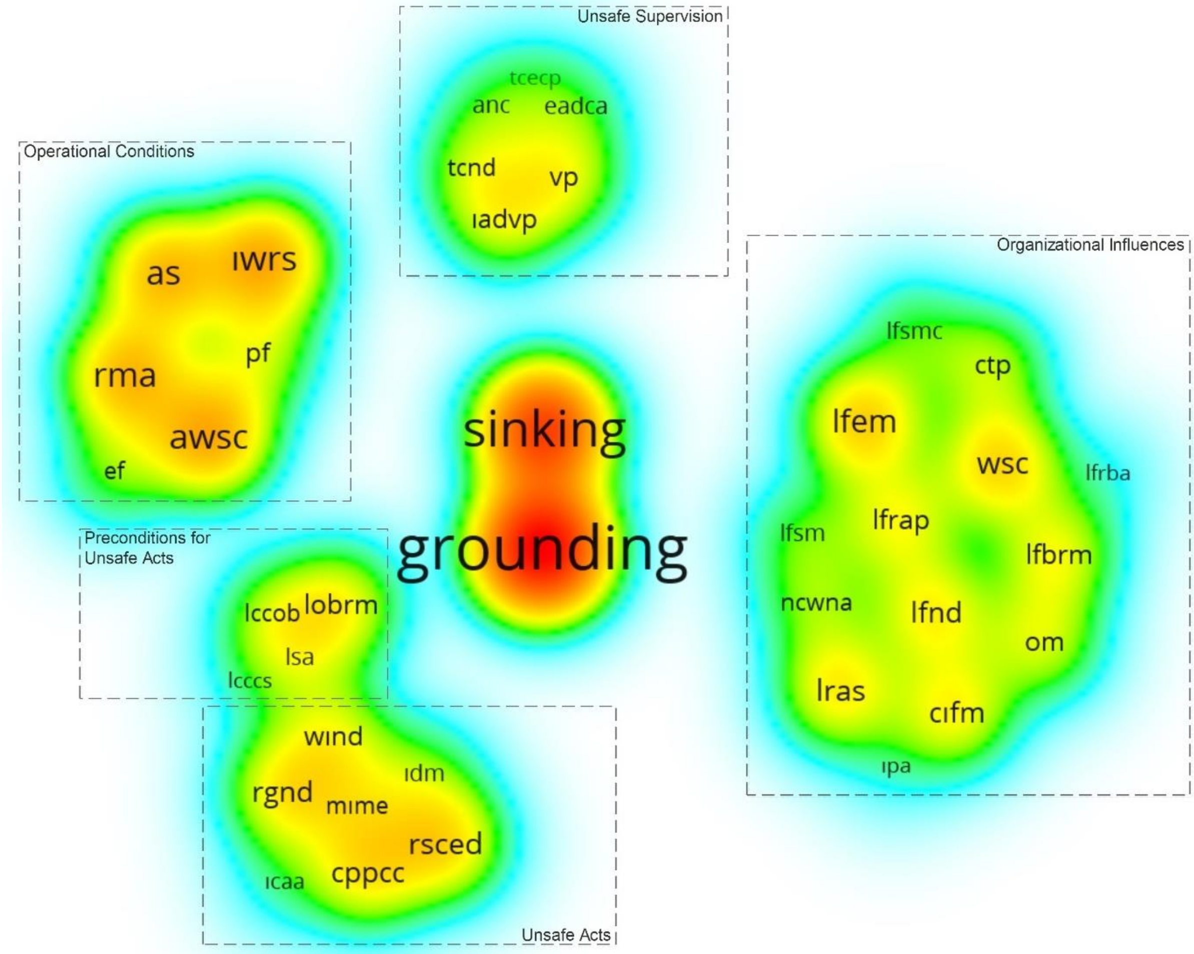


Figure 10. Heat map of HOFs in accidents in the Black Sea

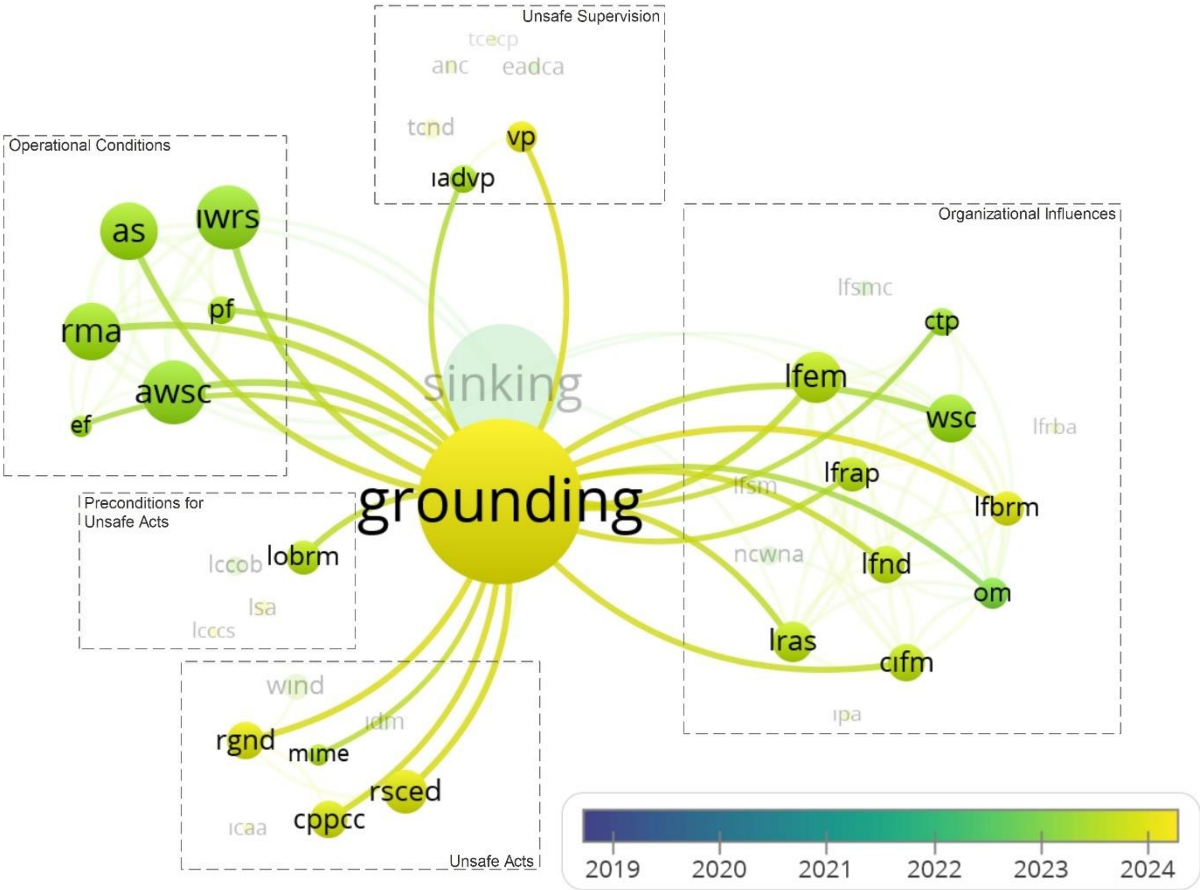


Figure 11. Relationship between grounding accidents and HOFs in the Black Sea

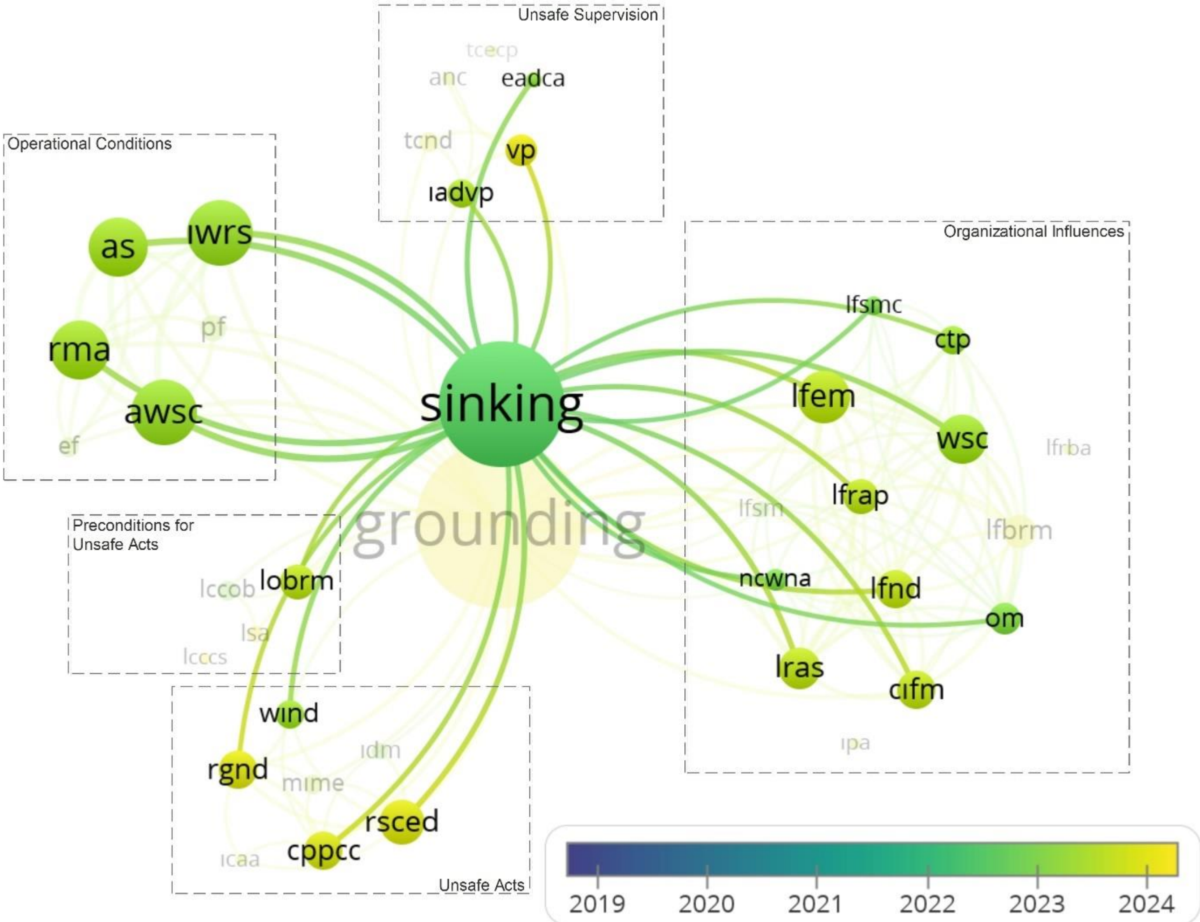
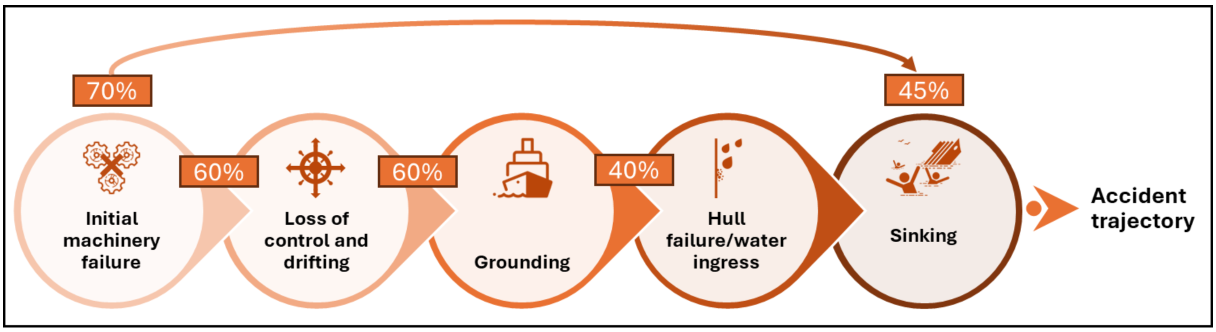


Figure 12. Relationship between sinking accidents and HOFs in the Black Sea



*Due to multiple initial event occurrence in an accident (i.e., grounding and a hull failure in the same accident), the total percentage is more than 100%.

Figure 13. Most prevalent accident formation pattern in the Black Sea (N = 20)

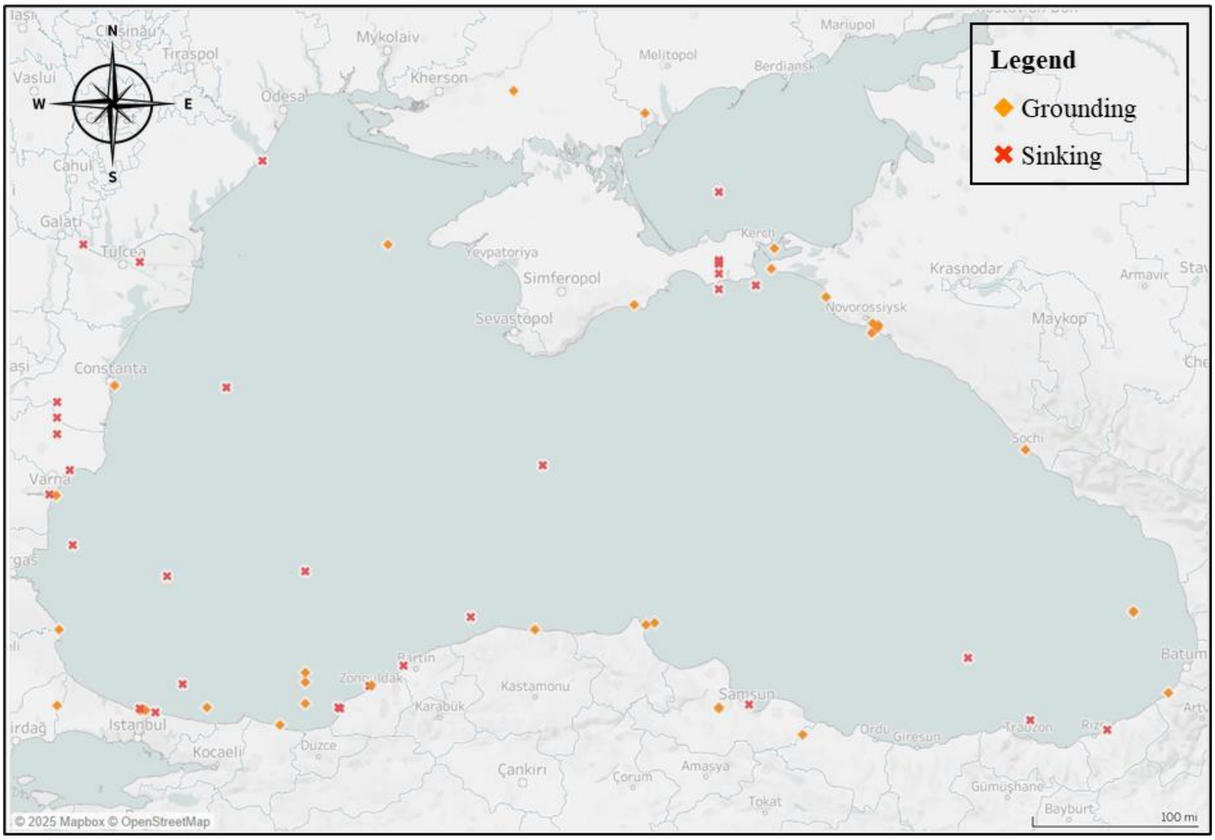


Figure 14. Point distribution map of accidents occurred in Black Sea between 2003-2024 by accident type ($n_{Grounding}$=34, $n_{Sinking}$=32)

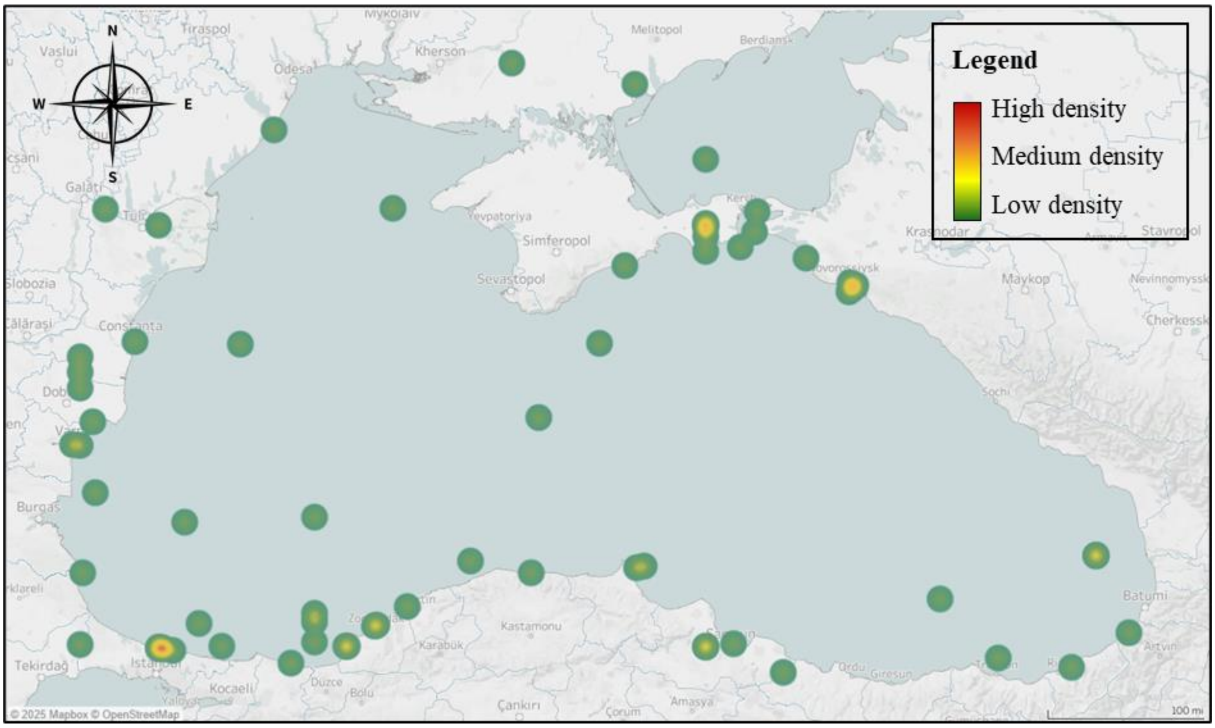


Figure 15. Density map of accidents in Black Sea between 2003-2024 (N=66)

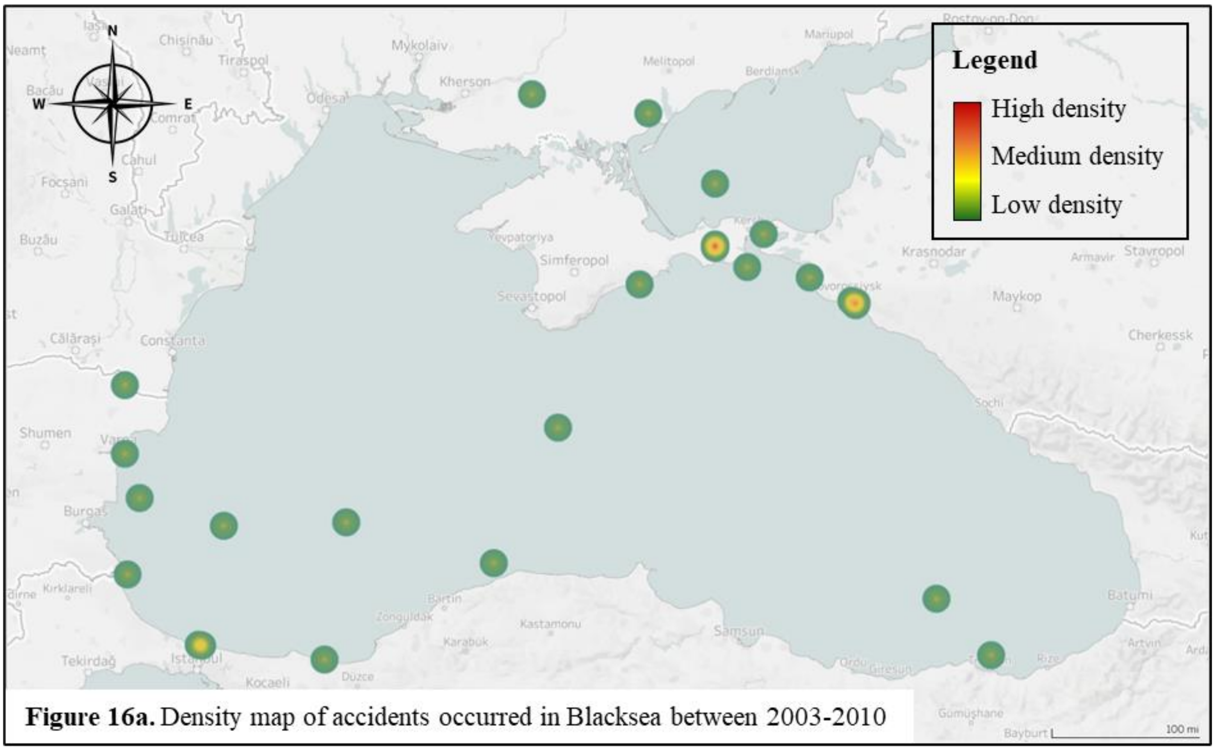


Figure 16a. Density map of accidents occurred in Blacksea between 2003-2010

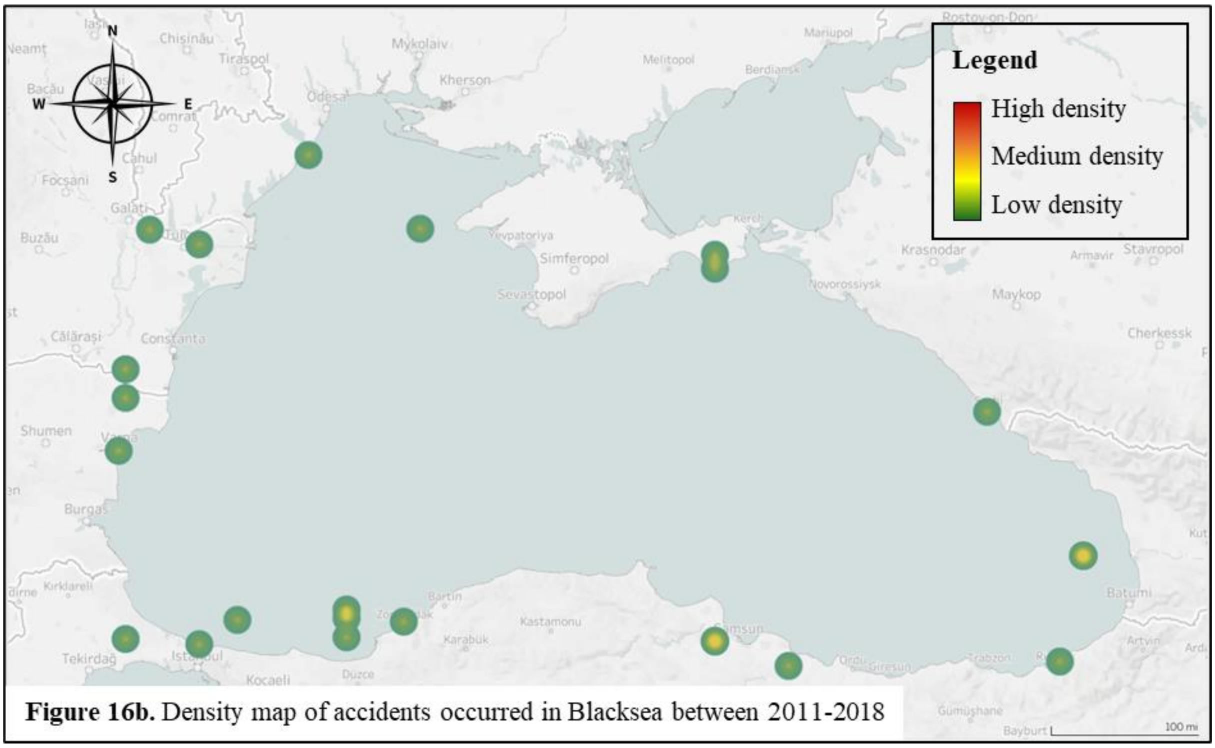


Figure 16b. Density map of accidents occurred in Blacksea between 2011-2018

Figure 16. Density map of accidents in Black Sea: 16a. 2003-2010 Period, 16b. 2011-2018 Period, 16c. 2019-2024 Period

Table 1. Abbreviations used in the VOSviewer application

Tiers	Factors	Abbreviation
Organizational influences	Lack of familiarity - ship's machinery	lfsm
	Lack of familiarity - electronic navigation devices (ECDIS, RADAR, GPS, etc.)	lfnd
	Lack of familiarity - ship's manoeuvring characteristics	lfsmc
	Lack of familiarity - Bridge Resource Management practices	lfbrm
	Lack of familiarity - emergency management (engine failure, power loss, etc.)	lfem
	Improper personnel assignment (crew competency issues)	ipa
	Lack of familiarity - risk assessment pre-departure	lfrap
	Lack of familiarity - risk assessment before anchorage operation	lfrba
	Company's time (fast operation) pressure on the fleet	ctp
	Weak safety culture (company and crew)	wsc
	Company's improper fleet management/supervision	cifm
	Operation mismanagement (navigation)	om
	Non-compliances (weather ban, allowable navigation area)	ncwna
	Lack of risk assessment (departure, navigation, anchorage)	lras
Unsafe supervision	Test and control - bridge navigation devices (ECDIS, RADAR, Echo Sounder, etc.)	tcnd
	Test and control - engine control panel	tcecp
	Internal audit deficiency - voyage plan (seaworthiness)	iadvp
	External audit deficiency - company audits (seaworthiness)	eadca
	Voyage plan	vp
	Anchorage	anc
Preconditions for unsafe acts	Lack of situational awareness (bridge team members)	lsa
	Loose Bridge Resource Management (BRM)	lobrm
	Lack of communication and coordination (on board)	lccob
	Lack of communication and coordination (ship-company)	lcccs
Unsafe acts	Mis/improper management of emergency	mime
	Incorrect/delayed manoeuvre	idm
	Incorrect choice of anchorage area (anchor dragging)	icaa
	Risk of grounding not detected	rgnd
	Water ingress not detected (flooding, risk of sinking)	wind
	Regulation - use of ship in condition of exceeding design limits	rsced
	Company procedures - preoperational checks and controls (departure, navigation and anchorage)	cppcc
Operational conditions	Adverse weather and sea conditions	awsc
	Restricted manoeuvring area (coastal area)	rma
	Engine failure	ef
	Power failure	pf
	Inland waterway/river ship	iwrs
	Aged ship/worn hull, and ship structure (age ≥ 15)	as

Table 2. Comparison of the literature findings and this study

Tiers	Factors	RA1	RA2	RA3	RA4	RA5	RA6
Organizational influences	Lack of familiarity - ship's machinery	✓		✓		✓	✓
	Lack of familiarity - electronic navigation devices (ECDIS, RADAR, GPS, etc.)	✓				✓	✓
	Lack of familiarity - ship's manoeuvring characteristics		✓			✓	✓
	Lack of familiarity - Bridge Resource Management practices			✓		✓	✓
	Lack of familiarity - emergency management (engine failure, power loss, etc.)						✓
	Improper personnel assignment (crew competency issues)	✓		✓		✓	✓
	Lack of familiarity - risk assessment pre-departure						
	Lack of familiarity - risk assessment before anchorage operation						
	Company's time (fast operation) pressure on the fleet						✓
	Weak safety culture (company and crew)						
	Company's improper fleet management/supervision						✓
	Operation mismanagement (navigation)						
	Non-compliances (weather ban, allowable navigation area)		✓			✓	✓
	Lack of risk assessment (departure, navigation and anchorage)			✓			
Unsafe supervision	Test and control - bridge navigation devices (ECDIS, RADAR, Echo Sounder, etc.)						
	Test and control - engine control panel						
	Internal audit deficiency - voyage plan (seaworthiness)						✓
	External audit deficiency - company audits (seaworthiness)						✓
	Voyage plan						
	Anchorage						
Preconditions for unsafe acts	Lack of situational awareness (bridge team members)	✓		✓		✓	✓
	Loose Bridge Resource Management (BRM)			✓			✓
	Lack of communication and coordination (on board)			✓		✓	✓
	Lack of communication and coordination (ship-company)			✓			✓
Unsafe acts	Mis/improper management of emergency	✓	✓				✓
	Incorrect/delayed manoeuvre		✓	✓			✓
	Incorrect choice of anchorage area (anchor dragging)						✓
	Risk of grounding not detected			✓		✓	✓
	Water ingress not detected (flooding, risk of sinking)						
	Regulation - use of ship in condition of exceeding design limits			✓			✓
	Company procedures - preoperational checks and controls (departure, navigation, anchorage)				✓		
Operational conditions	Adverse weather and sea conditions		✓			✓	✓
	Restricted manoeuvring area (coastal area)		✓		✓	✓	
	Engine failure				✓	✓	✓
	Power failure						✓
	Inland waterway/river ship						✓
	Aged ship/worn hull, and ship structure (age ≥ 15)				✓	✓	✓

RA1: Nedelcu and Rusu, 2022; RA2: Novac et al., 2019; RA3: Novac et al., 2021; RA4: Huang et al., 2023; RA5: Stingheru et al., 2018; RA6: Ugurlu et al., 2020.