Application of the HFACS-PV Approach for Identification of Human and Organizational Factors (HOFs) Influencing Marine Accidents

Serdar YILDIZ[a], Özkan UĞURLU[b] Jin WANG[c] and Sean LOUGHNEY[d]

[a]Maritime Transportation and Management Engineering Department, Karadeniz Technical University, Trabzon, Turkey, serdaryildiz@ktu.edu.tr

[b]Maritime Transportation and Management Engineering Department, Ordu University, Ordu, Turkey, ougurlu@odu.edu.tr; ozkanugurlu24@hotmail.com, +905058179839 (Corresponding author)

[c]Liverpool Logistics, Offshore and Marine (LOOM) Research Institute, Faculty of Engineering and Technology, Liverpool John Moores University, Liverpool, UK, J.Wang@ljmu.ac.uk

[d]Liverpool Logistics, Offshore and Marine (LOOM) Research Institute, Faculty of Engineering and Technology, Liverpool John Moores University, Liverpool, UK, S.Loughney@ljmu.ac.uk

ABSTRACT

Shipping is one of the leading modes of transport that has dominated the world economy from past to present. The effectiveness and efficiency of maritime trade is closely related to maritime safety. Providing quality maritime safety is a fundamental requirement for environmentally friendly, sustainable, safe and efficient global trade. Therefore, maritime safety and human factors are frequently studied topics in literature. However, the fact that the human element has a complex socio-technical structure makes it difficult to fully analyse human factors in accidents. That is one of the biggest challenges in preventing and mitigating accidents. This research aims to demonstrate the feasibility of the modified Human Factor Analysis and Classification System for Passenger Vessel collisions (HFACS-PV) for other types of accidents. 51 grounding accidents that occurred in passenger vessels between 1991 and 2017 were analysed by using the HFACS-PV structure. The results show that the HFACS-PV structure created for passenger vessel accidents is compatible with contact, grounding and sinking accidents as well as collisions. Thus, the HFACS-PV structure allows for coherent analysis of marine accidents. Owing to the flexibility if HFACS, it is also possible to combine it with other analytical methods such as Bayesian networks to conduct both qualitative and quantitative analysis.

Keywords: Human factor; HFACS-PV; marine accident; marine safety; accident analysis

1. Introduction

Accidental or unintended events cause loss of life, property damage or environmental pollution. They are not always under the control of individuals [1]. Maritime transportation is a multimodal industry that interacts with many modes of transport and industries [2]. Safety measures are relatively high in this mode of transport compared to other modes of transport [3, 4]. Despite the increasing safety standards and advanced technology, accidents of maritime transport continue to happen [5]. Accidents have a significant impact on the maritime transport sector. The fact that the human factor has a serious impact on the occurrence of marine accidents has led many national and international organizations, including the International Maritime Organization (IMO), to address this issue. Etman and Halawa [6] stated that the annual cost of human error to the maritime industry is approximately $541million [6]. According to EMSA [7] data, there were 20,616 marine accidents between 2011 and 2017. As a result of these accidents, a total of 203 ships sank or became unserviceable, also 6,812 seafarers were injured, and 683 crew killed. Therefore, it is important to investigate human errors and organizational factors underlying marine accidents, and to identify measures to eliminate them [8].

An accident analysis model is an intangible conceptual expression of the formation of an accident. It allows one to reason about how and why the accident occurred [9, 10]. Achieving effective results from accident analyses depends on the correct definition of accident causes, the relationship between them and their effects within the system [11, 12, 13, 14]. There are many methods in the literature that can be used to investigate the effect of human error on marine accidents. All of these methods can be collated into three main groups: consecutive models, epidemiological models and systemic techniques [5, 15, 16]. In consecutive models, accidents are defined as discrete events occurring sequentially and the cause-effect relationship between events is linear [17]. Epidemiological models advocate that accidents occur as a combination of passive and active failures within the system [18]. Systemic techniques are designed to understand the structure and behaviour of complex systems. According to systemic models, accidents occur due to uncontrolled relationships between the components of the system [19]. The choice of the method to be used in accident analysis is as important as the analysis process. It would not be appropriate to analyse a simple marine accident caused by mechanical failures by systemic techniques. In many steps of the analysis, the questions posed to the accident will remain unanswered. Likewise, examining accidents involving human factor by consecutive methods will risk the involuntary neglect of one or more of the human factors. Therefore, it would be appropriate to choose the method according to the complexity of the accident to be analysed and the elements to be investigated [20, 21].

Since human behaviour is not easily predictable and interpretable, it is difficult to investigate the effect of human factor in accidents. Human Factor Analysis and Classification System (HFACS) is an improved hybrid method for human factor analysis and has proven to be highly effective in human factor analysis in many studies [22, 23, 24]. It has a structure that can be adapted to different sectors [25, 26, 27, 28, 29]. In this study, the core structure of HFACS method developed by Wiegmann and Shappell [30] is used for analysis of marine accidents.

2. Human Factor Analysis and Classification System (HFACS)

HFACS based on Reason's Swiss Cheese model was first used by Wiegmann and Shappell [30] for the analysis of aviation accidents. It is a general human error analysis method, and it allows for the investigation of accident occurrences in a hierarchical structure. With this method, it is possible to examine the effects of human factors on accidents and to elaborate the relevant active failures and latent conditions. The most important feature that distinguishes HFACS from other accident analysis methods is its comprehensive taxonomy for the analysis of human and organizational factors [30]. With this taxonomy, human and organizational factors can be easily and accurately extracted in complex events such as accidents [22, 31].

In the classic HFACS structure, the causes of accidents are examined at four levels respectively; organizational influence, unsafe supervision, pre-condition for unsafe act and unsafe act (Figure 1) [29, 32].

Figure 1. Traditional HFACS structure

The main structure of HFACS has been revised over time, taking into account the requirements of the accident type to which it is applied, and has been made compatible with the industry it is applied to. The first revision of the main HFACS structure was made by Shappell and Wiegmann [29]; they added environmental factors to HFACS. In many subsequent studies, environmental factors were examined under the pre-condition for the unsafe act framework with the sub-headings of the physical environment and technological environment. Tvaryanas et al. [27] classified the causes of accidents that occurred on aircraft used by German pilots under this new HFACS structure. They examined 221 accident reports published by German Federal Bureau of Aircraft Accident Investigation in their study. As a result of the study, the compatibility of the HFACS method with airway accidents was measured. In addition, the subjects that should be focused on in-flight training were determined, taking into account the most frequent mistakes made by pilots [27]. Theophilus et al. [27], in their study, introduced the customized HFACS-OGI (Human Factors Analysis and Classification System for the Oil and Gas Industry) model for oil and gas related accidents. In their study, they analysed 11 accident reports that occurred between 1998 and 2012 with the HFACS-OGI method. In the study, the accident causes associated with the oil and gas industry, which are difficult to categorize under the classical HFACS structure, have been successfully classified under the HFACS-OGI [33]. A HFACS-SIBCI (HFACS-Ship-Icebreaker Collision in Ice-covered waters) model was developed, which enables analysis of collision accidents that occur during icebreaker assistance in their studies. The accuracy of the developed HFACS-SIBCI model was proven through the analysis of 17 collision accidents [34]. Schröder-Hinrichs et al. [35] examined the ship engine room fire and explosion accidents with HFACS-MSS (HFACS-Machinery Spaces of Ships) method. In the study, 41 reports were examined and a total of 368 active failures were identified. The aim of the study was to reveal the effect of organizational factors on ship engine room fires and to develop a specialized HFACS structure in order to analyse the human factor in engine room fires. As a result of the study, the latent factors were revised without changing the main HFACS structure, and a modified HFACS framework (HFACS-MSS) was introduced.

Environmental factors have been evaluated as latent factors (under the pre-conditions for unsafe act level) that play a role in the formation of root causes (unsafe act) in many accident studies related to the industry in aviation, railway, road transportation, oil, natural gas and mining [33, 36, 37, 38]. In maritime applications, this is also the case in many modified HFACS structures such as HFACS-MA (HFACS-Marine Accidents) [39], HFACS-ME (HFACS-Helicopter Maintenance Error) [26] and HFACS-MSS [35]. However, Uğurlu et al. [40] have revealed that environmental factors (operational conditions) are not a pre-condition that plays a role in the emergence of unsafe acts but are a complementary factor for unsafe actions to result in an accident. Therefore, they evaluated operational conditions on a separate level as the last level of HFACS. In this study, the modified HFACS (HFACS-PV) structure, outlined by Uğurlu et al. [40], is used for the accident analysis.

3. Scope and Methodology

In this study, the compatibility of the HFACS-PV structure, that was put forward for the analysis of collision-contact accidents on passenger vessels [40], was tested for other accident types, and consists of 3 steps. In the first step, descriptive information was given about the content of the HFACS-PV structure. Thus, the HFACS-PV structure has become easily understandable. In step 2 of the study, the compatibility was tested for 3 different accident categories. These are contact, grounding and sinking. Unlike traditional HFACS structures, HFACS-PV contains 5 levels. When compared to other HFACS structures, the main change in the structure is the environmental factors (operational conditions). Environment is the 5th level of the structure (the last level) and it plays a role in turning unsafe act into an accident. The aim of the study in the second step is to try to explain why the environment should be examined at a last level unlike traditional HFACS structures by illustrative accidents. In the third step, 51 grounding accidents that occurred in passenger vessels between 1991 and 2017 were analysed under the HFACS-PV structure. The flow chart of the study has been presented in Figure 2. In this context, accident reports were obtained from 17 accident investigation institutions (Table 1). In particular, Marine Accident Investigation Branch (MAIB), EMSA and Australian Transport Safety Bureau (ATSB), were examined.

Table 1. List of maritime accident investigation organizations scrutinized in the study

The greatest issue with the extraction and mapping of the Human and Organizational Factors (HOFs), in the HFACS structure, is the varying opinions and thoughts of the different researchers as stated in Olsen’s study [28]. A key reason for this is the different levels of the researchers’ understanding of the HFACS structure. Improving and maintaining consistency regarding researchers’ knowledge of both the individual HOFs and their specific definitions can greatly aid in solving and mitigating this problem. Within this study, the researchers are highly experienced and knowledgeable in both the HFACS structure and the definitions of its HOFs.

In this HOF extraction and mapping process, the researchers individually coded and classified the HOFs, then the results were combined, and all coding was reviewed. It should be noted that all HOF codes were defined from accident reports. The process of discussing each individual HOF code was completed rigorously until a consensus was reached by all participants in the discussions. This methodology allows for considerable care to be taken to ensure that the codes are suitable and as accurate as possible. At this stage of the research 115 different HOFs were mapped under the HFACS-PV framework and thus the analysis of grounding accidents of passenger vessels is completed. Furthermore, in this research, no changes have been made to the HFACS-PV structure. The nonconformities under the HFACS-PV, which were identified by Uğurlu et al. [40], were supplemented by considering the causes of grounding accidents. In other words, new non-conformities (active failures and latent factors) associated with grounding accidents were added to the structure. Thus, the HFACS-PV structure is now compatible with grounding accidents. As a result of the study, the most important active failures, latent factors and operational conditions that have played a role in the occurrence of grounding accidents in passenger vessels, as well as proving the compatibility of the HFACS-PV structure with other accident types have been revealed.

Figure 2. Flow chart of the study

3.1. HFACS-PV

Uğurlu et al. [40] used the classical HFACS method to analyse 70 collision-contact accidents that occurred on passenger vessels. However, they found that traditional HFACS structures are not suitable for the analysis of passenger vessel accidents. Therefore, they proposed a modified Human Factors Analysis and Classification System (HFACS-PV) structure for use in the analysis of the human factor in passenger collision-contact accidents (Figure 3). The HFACS-PV structure includes 5 main levels: Operational Conditions, Unsafe Acts, Pre-conditions for Unsafe Acts, Unsafe Supervision and Organizational Influences. Unlike conventional HFACS, the main change in the structure is the environmental factors (operational conditions) added to the structure. According to the HFACS-PV structure, each marine accident includes at least an operational condition. Operational conditions do not affect the decisions and actions of the operators (unsafe acts). On the contrary, it plays a complementary role in the transformation of unsafe action into an accident. Therefore, environmental factors in the modified HFACS-PV structure have not been examined under the pre-condition for unsafe act. The descriptive information about HFACS levels is given below.

Figure 3. Modified HFACS-PV structure [40]

Operational Condition: It represents the last stage of the formation of a marine accident. Even if all the latent and active inconveniences required for the development of the accident come together, the accident will not occur unless the operational condition exists. For example, there is no possibility of a grounding accident unless the ship is navigating close to shallow waters. Operational conditions are divided into two categories: internal and external conditions. Internal conditions include vessel structural defects and non-conformities preventing ship motion. These are conditions that are partially controlled by operators. External conditions include non-ship factors that are not caused by human contribution or intervention. By using this classification, the effects of weather - sea conditions and local restrictions on marine accidents can be easily interpreted. The factors under the operational conditions are given in Figure 4.

Figure 4. Operational conditions

Unsafe Act: Similar to the traditional HFACS structure, it is divided into 2 sub-categories: errors and violations made by ship crew on board [29]. Errors are unintentional actions [41] and consist of decision-based errors, skill-based errors and perception errors. Skill-based errors are the errors made unconsciously due to lack of knowledge and experience. Decision errors are the result of choices and steps taken to reach a goal [42]. Perception errors are caused by visual, auditory, cognitive or attention problems. This usually happens in a restricted or impaired environment, when sensory inputs are reduced. Violations are behaviours where rules and regulations are intentionally ignored [41]. Unlike the traditional HFACS structure, violations were divided into three sub-categories: rule violations, procedure violations, and abuse of authority [40]. Rule violations can be expressed as deliberate negligence or non-enforcement of legal regulations issued by the IMO, flag states or competent authorities. An example of procedure violations is the violation of berthing and anchoring procedures. Abuses are violations made deliberately by authorized persons. It can be described as the arbitrary use of the authority that is inconsistent with the safety practices or legal regulations. In Figure 5, the HOFs under the structure of unsafe acts are given.

Figure 5. Unsafe acts

Pre-Conditions for Unsafe Act: It has been emphasized by many researchers [22, 23], especially Shappell and Wiegmann [32] that this level is important in accident formation. Unlike other HFACS structures in the literature, this level is divided into two sub-categories: sub-standard team members, and technology and interface malfunctions to ensure compliance with marine accidents [39, 43, 44]. Technology and interface malfunctions pave the way for the formation of decision errors and perceptual errors. In other words, when a technological breakdown occurs, the decision and perception mechanism of the officer on the bridge is directly affected from it. For example, when a synchronization malfunction between Electronic Chart Display and Information System (ECDIS) and Global Positioning System (GPS) occurs, the ship's position may displayed as safe on the ECDIS screen, but it may actually be near risky shallow waters. In the presence of such a situation, an officer who sails with the ECDIS device may think that the ship is in safe waters and accordingly not notice the risk of grounding or contact. This increases the likelihood of an accident. In addition, due to the fact that ship management is carried out as a team work, "Operators" in the traditional structure are called "Team Members" in HFACS-PV. Figure 6 shows the non-conformities under this structure.

Figure 6. Pre-conditions for unsafe act

Unsafe Supervision: It has been examined under three sub-categories: insufficient supervision planned inappropriate operations and failure to correct the known problem. Non-conformities, such as deficiencies in tests and controls, delays in the operation of the planned maintenance system, planned inappropriate operations (e.g. voyage plan and the number of lookout in the shift), etc., are under the structure of unsafe supervision. In Figure 7, the HOFs under the unsafe supervision structure are given.

Figure 7. Unsafe supervision

Organizational Influences: As in other HFACS structures in the literature [22, 39, 44, 45], this level is divided into three sub-categories: resource management, organizational climate and organizational process. Non-conformities related to the personnel and equipment resources, resource management strategies of companies, ship operators, and ports are placed under the Resource Management sub-category. HOFs affecting the performance of the seafarers, such as deficiencies and non-conformities related to the organizational structure, policies and corporate culture, are placed under the Organizational Climate sub-category [39, 46]. The deficiencies and non-conformities in the operational management, such as safety assessments (working/resting hours, time pressure, motivation, shift patterns) and reviews (risk analysis, risk management etc.) are included under the Organizational Process sub-category. The HOFs under organizational influences level are presented in Figure 8. Using the HFACS-PV structure described above, it is possible to examine the occurrence of ship accidents, to identify the active failures and latent factors affecting the accident as a chain of chain events.

Figure 8. Organizational influences

4. Case Studies

4.1. Contact

At this step of the study, a contact accident involving P&OSL Aquitaine was taken as the first case study. The factors that play a role in the occurrence of this case can be listed as follows (Figure 9) [47]:

- Operational conditions: propeller failure (controllable propeller) and restricted manoeuvring area (port).
- Unsafe acts: regulation violation (COLREG rule 6).
- Pre-conditions for unsafe acts: lack of communication (bridge-engine control room), lack of coordination (bridge team members) and over self-confidence (bridge team members).
- Unsafe supervision: inappropriate manoeuvre planning (at port),
- Organizational influences: lack of training and familiarization with bridge navigation equipment, and lack of pre-arrival risk assessment and controls.

Figure 9. HFACS-PV structure of P&OSL Aquitaine accident

This accident occurred as a result of a propeller failure while the P&OSL Aquitaine ship was manoeuvring at an unsafe speed inside the port. The operational conditions of this accident are restricted manoeuvring area (port) and propeller failure (controllable pitch propeller). During the accident, the ship was manoeuvring above the speed limits in the port (speed of the vessel was 13 knots, 3 minutes before the contact). The ship was manoeuvring at an unsafe speed when the propeller failure occurred, and subsequently the ship could not be stopped. In this accident, there is an interaction (conditional relationship) rather than a cause-effect relationship between operational conditions and unsafe acts. As a result of this interaction, the accident occurred. If the ship had been manoeuvring at a speed of 2-3 knots in the port, perhaps the accident would not have occurred, or the consequences would have been lighter. Operational conditions played a complementary role in the occurrence of the accident (Figure 6). Ship accidents are a chain of events. An accident occurs when operational conditions and unsafe acts, which are the last links of the chain, are seen together [40]. Therefore, it would be appropriate to examine all these factors under the operational conditions.

In addition, situations or events under the operational conditions level, include events that are independent of human factor or just partially dependent. The characteristics of the factors under operational conditions are not the same as those of the pre-conditions for unsafe acts. These factors cannot be prevented directly by the ship's crew. Therefore, it is characteristically different from HOFs. It would not be appropriate to examine operational conditions under the pre-conditions for the unsafe acts level.

4.2. Sinking

The Tolstoy accident was investigated in order to reveal the applicability of the HFACS-PV structure in sinking accidents. The accident occurred at the outbound area of the Kerch

Strait on 24/09/2008 [48]. At the time of accident, there were heavy weather and sea conditions at the area. Factors involved in the formation of the Tolstoy accident include (Figure 10):

- Operational conditions: heavy weather and sea conditions, navigating in restricted waters (coastal waters), old vessel structure, inland vessel structure and engine failure.
- Unsafe acts: navigating in stormy weather, inappropriate stability and use of vessel in conditions of exceeding design limits.
- Pre-conditions for unsafe acts: physical fatigue (watch officer), lack of situational awareness, lack of communication (ship to ship) and lack of coordination (bridge team members).
- Unsafe supervision: inappropriate voyage planning, inappropriate cargo operation planning and inappropriate planned maintenance.
- Organizational influences: unqualified crew assignment, minimum safe manning strategy, lack of training, lack of Bridge Resource Management (BRM) training, and lack of oversight (navigation risk assessment and pre-arrival risk assessment).

Figure 10. HFACS-PV structure of Tolstoy accident

Considering the formation of the accident, although all the HOFs in the first 4 levels came together, the accident would not occur. Factors causing unsafe action to result in an accident for this case include: heavy weather and sea conditions, old vessel structure and engine failure (operational conditions). This accident occurred because of engine failure while the ship was navigating in heavy weather and sea conditions beyond the vessel's design limits. This situation proves that operational conditions are essential for the formation of the accident. A sinking accident HFACS-PV case study is presented above as an example. Moreover, Uğurlu et al. [5] analysed 37 sinking accidents in the Black Sea with HFACS-PV, which reinforces the idea that the structure is compatible with sinking accidents.

4.3. Grounding

In order to demonstrate the applicability of the HFACS-PV structure for grounding accidents, the case of tanker vessel Maria M, which occurred in Trubaduren, Sweden on 24/09/2008, was used [49].

The weather was calm and clear in the area where the accident occurred. Factors involved in the formation of grounding of Maria M include (Figure 11):

- Operational conditions: navigating in restricted waters (coastal waters).
- Unsafe acts: faulty manoeuvring (watch officer) and late in intervention (Vessel Traffic Service (VTS) operator inactive in the risky situation).
- Pre-conditions for unsafe acts: lack of communication and coordination (between bridge team members), loose team management, lack of situational awareness (VTS operator), and lack of communication (VTS-Ship).
- Unsafe supervision: inappropriate passage (voyage) planning, inappropriate VTS operation planning.
- Organizational influences: unqualified crew assignment, lack of training and familiarization (navigation equipment) and lack of safety culture.

Figure 11. HFACS-PV structure of Maria M accident

During the accident, the ship was navigating in coastal waters. The accident occurred as a result of the master's faulty manoeuver in shallow waters and the VTS operators did not intervene in the situation. In this accident, operational conditions also played a complementary role in transforming unsafe action into an accident. If there had been no shallow areas in the environment, or if VTS operators had intervened in time, the accident would not have happened. For this reason, it would be appropriate to evaluate the operational conditions as a final stage of the accident formation (complementary element) for grounding accidents.

5. Analysis of Passenger Vessel Grounding Accidents with HFACS-PV

In the previous sections, the number of HOFs under the HFACS-PV structure has been expanded and the compatibility of the structure with other accident types has been demonstrated by three chosen accidents. In this section, the active failures and latent factors of 51 grounding accidents occurring in passenger vessels are classified under HFACS-PV (Tables 2, 3, 4, 5 and 6). The name of the non-conformities detected for each level and their observation frequencies are also shown in Tables 2, 3, 4, 5 and 6. A total of 115 different HOFs were coded under the HFACS-PV structure, and they were observed 382 times in the accident reports (Tables 2-6). The pre-conditions for unsafe acts are the most significant with 25.1% (Table 4) for the occurrence of grounding accidents, followed by unsafe acts (23.3%) (Table 5), operational conditions (22.0%) (Table 6), organizational influences (20.4%) (Table 2) and unsafe supervision (9.2%) (Table 3). Similarly, studies of Xi et al. [44], Chen and Chou [39], Chen et al. [23] and Uğurlu et al. [40] identified and highlighted that pre-conditions for unsafe acts and unsafe acts are frequently observed in accidents. In many studies [23, 35, 44] based on the classical HFACS structure, environmental factors are considered under the pre-conditions for unsafe acts, which is one of the reasons why the pre-conditions for the unsafe acts level have a high degree of importance. When the studies of Celik and Cebi [43], Xi et al. [44], Chauvin et al. [22] and Chen et al. [23] are examined, it is seen that the importance ratio of environmental factors in accidents varies by 15-30%. This situation proves that environmental factors should be considered under a separate level from other levels for a more sensitive approach during the evaluation of HOFs.

When the first sub-categories underneath the main HFACS-PV levels are examined (Figure 12), Substandard Team Members (24.3%), External Conditions (20.7%), Errors (15.2%), Resource Management (15.2%) and Unsafe Supervision (9.2%) appear to be the top five categories in the occurrence of grounding accidents on passenger vessels. The importance of the category Substandard Team Members, which is the most frequent first sub-category in the accidents examined, involving substandard conditions and practices of team members, has been highlighted in many studies [22, 31, 50]. In this context, the conclusion that the Substandard Team Members are an important human factor source in marine accidents is in line with the literature. Substandard Team Members include important nonconformities such as, lack of situational awareness, lack of attention, over-confidence and fatigue. In order to eliminate or reduce marine accidents, these nonconformities should be focused on [5, 35]. As stated in studies of Chen et al. [23], Mazaheri et al. [51] and Graziano et al. [52] the second most important sub-category, weather conditions (wind, heavy seas, *etc.*) and local restrictions (coastal waters, narrow channel *etc.*) under the External Conditions level, must be taken into consideration in the operation planning.

When the HFACS-PV main levels were examined for grounding accidents, it can be seen that 78% of the accidents occurred due to human error [5, 8, 10, 23, 31, 35, 43, 44, 53, 54]. Pre-conditions for unsafe acts (25.1%) and Unsafe acts (23.3%) are the most important levels that should be examined under human error in grounding accidents, followed by operational conditions (22%). The close proximity of the proportions of the levels revealed that environmental factors are at least as important as the other two levels in grounding accidents. Similarly, the effect of environmental conditions on marine accidents has been revealed in other studies in the literature [5, 22, 23, 55, 56, 57].

According to the findings of the study, violations have a share of 8.1% in grounding accidents. In order to prevent violations that play an important role in the occurrence of accidents, it is necessary to focus on the oversight (inspection) and control mechanism. The inspection and control mechanism should be operated effectively by the captain on board, the internal auditor at the company, and port and flag state officials in the countries. Another way to prevent violations is to provide a quality education and safety culture perception. The concept of safety culture is a cultural and social phenomenon that is difficult to acquire later. In order to prevent ship accidents, this phenomenon should be adopted not only individually but socially (ship-company). The study showed that the errors related to BRM are one of the effective pre-conditions (8.6%) in grounding accidents. HOFs such as deficient command chain on board, lack of communication and coordination, and lack of team spirit, are the main bridge team management errors. These non-conformities are the biggest obstacles to effective bridge team management on board, and this finding is also in line with the current literature [55, 58, 59, 60, 61, 62]. Good bridge team leadership of the master will make the team members adopt their tasks and their teammates, and will make the ship operations safer. Therefore, when the ship operators are assigning a captain, they should consider to avoid early promotion, and assign the person who will take over the management of the entire ship based on their sea experience and passenger ship experience.

Table 2. Frequency of HOFs under Organizational Influence level

Table 3. Frequency of HOFs under Unsafe Supervision level

Table 4. Frequency of HOFs under Pre-conditions for Unsafe Acts level

Table 5. Frequency of HOFs under Unsafe Acts level

Table 6. Frequency of factors under Operational Conditions level

Figure 12. Percentage distribution of HFACS-PV sub-categories in grounding accidents

6. The Advantages of HFACS-PV Structure

- The results of this study showed that the HFACS-PV structure can be used not only for the analysis of collision accidents but also for the analysis of other categories of ship accidents. The 51 grounding accidents examined in the study, the 3 different case studies and similar studies conducted in the literature verify this [5, 63].
- The most important feature that distinguishes the HFACS-PV structure from other HFACS structures in the literature is that it examines the Operational Conditions separately and at the last level. In addition, the categories under the levels of Unsafe Acts and Preconditions for Unsafe Acts have been modified to make them compatible with maritime applications. Each ship accident includes at least one operational condition [40]. Operational conditions play a complementary role in causing unsafe action to result in an accident. There is an interaction (conditional relationship) rather than a cause and effect relationship between operational conditions and unsafe actions. Accidents occur as a result of this interaction.
- With the HFACS-PV structure, researchers can accurately detect general HOFs and operational conditions without losing the details of accidents.

7. Conclusion

Providing maritime safety is a requirement for sustainable, safe, cost efficient and environmentally friendly global trade. The role of HOFs in providing maritime safety is one of the frequently studied topics in the literature [31, 64, 65, 66, 67, 68, 69]. Ship accidents occur as a chain of subsequent events. Latent factors give rise to active failures and if active failures are combined with appropriate environmental (operational) conditions, the accident becomes inevitable. Although accidents appear as instant events, the underlying factors require a long period of time to occur. Therefore, understanding and being aware of the occurrence of accidents is the best step to ensure sustainable maritime safety. HFACS is one of the best hybrid (epidemiological and systemic) accident analysis approaches that make it possible to evaluate the impact of the human factor in the causal chains in ship accidents. The results of this study show that the HFACS-PV structure created for passenger vessel accidents is compatible with contact, grounding and sinking accidents as well as collisions [40].

The HFACS-PV structure allows for clearer and coherent identification of human and organizational factors in marine accidents. It is evident that this systematic approach, when combined with appropriate quantitative analysis models such as Bayesian Networks and Analytic Hierarchy Process, has the potential to produce useful results when used to analyse accidents in maritime transport.

Acknowledgements

This research has received funding from the International Association of Maritime Universities (IAMU) “Research Project Grant FY 2020-Young Academic Staff “as a project, and the article is produced from the PhD thesis entitled “Maritime Risk Evaluation and Safety Optimization in Narrow Straits: A Case Study in Istanbul Strait and English Channel” which has been executed in a PhD Program at Maritime Transportation and Management Engineering of Karadeniz Technical University, Graduate Institute of Natural and Applied Sciences.

References

[1] Hollnagel E, Woods DD, Leveson N. Resilience engineering: Concepts and precepts. United Kingdom: Ashgate Publishing, Ltd.; 2006.

[2] Rondinelli D, Berry M. Multimodal transportation, logistics, and the environment: managing interactions in a global economy. European Management Journal 2000;18:398-410. https://doi.org/10.1016/S0263-2373(00)00029-3
[3] Heij C, Bijwaard GE, Knapp S. Ship inspection strategies: Effects on maritime safety and environmental protection. Transportation research part D: transport and environment. 2011;16:42-8. https://doi.org/10.1016/j.trd.2010.07.006
[4] Aydogdu YV, Yurtoren C, Kum S, Park J-S. Questionnaire survey on the risk perception in the Istanbul Strait. Journal of Navigation and Port Research. 2010;34:517-23. https://doi.org/10.5394/KINPR.2010.34.7.517
[5] Uğurlu Ö, Yıldız S, Loughney S, Wang J, Kuntchulia S, Sharabidze I. Analysing of Collision, Grounding and Sinking Accident Occurring in the Black Sea Utilizing GIS, HFACS and Bayesian Networks. Risk Analysis. 2020:1-14. https://doi.org/10.1111/risa.13568[6] Etman E, Halawa A. Safety Culture, the Cure for Human Error: a Critique. IAMU Journal. 2007:115-26.
[7] EMSA. Annual Overview of Marine Casualties and Incidents 2018. In: Agency EMS, editor. Annual Overview of Marine Casualties and Incidents. Lisbon/Portugal: European Maritime Safety Agency; 2018. p. 1-175. http://www.emsa.europa.eu/news-a-press-centre/external-news/item/3406-annual-overview-of-marine-casualties-and-incidents-2018.html
[8] Hetherington C, Flin R, Mearns K. Safety in shipping: The human element. Journal of safety research. 2006;37:401-11. https://doi.org/10.1016/j.jsr.2006.04.007
[9] Huang HZ, Tong X, Zuo MJ. Posbist fault tree analysis of coherent systems. Reliability Engineering & System Safety. 2004;84:141-8. https://doi.org/10.1016/j.ress.2003.11.002
[10] Pietrzykowski Z, Wielgosz M, Breitsprecher M. Navigators' Behavior Analysis Using Data Mining. Journal of Marine Science and Engineering. 2020;8:50. https://doi.org/10.3390/jmse8010050
[11] Katsakiori P, Sakellaropoulos G, Manatakis E. Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. Safety Science. 2009;47:1007-15. https://doi.org/10.1016/j.ssci.2008.11.002
[12] Bakdi A, Glad IK, Vanem E, Engelhardtsen Ø. AIS-Based Multiple Vessel Collision and Grounding Risk Identification based on Adaptive Safety Domain. Journal of Marine Science and Engineering. 2020;8:5. https://doi.org/10.3390/jmse8010005
[13] Uğurlu Ö, Kum S, Aydoğdu YV. Analysis of occupational accidents encountered by deck cadets in maritime transportation. Maritime Policy & Management. 2016:1-19. https://doi.org/10.1080/03088839.2016.1245449
[14] Kum S, Sahin B. A root cause analysis for Arctic Marine accidents from 1993 to 2011. Safety Science. 2015;74:206-20. https://doi.org/10.1016/j.ssci.2014.12.010
[15] Qureshi ZH. A review of accident modelling approaches for complex socio-technical systems. Proceedings of the twelfth Australian workshop on Safety critical systems and software and safety-related programmable systems-Volume 86, 30-31 August, 2007, Adelaide, Australia, pp. 47-59.
[16] Awal Z, Hasegawa K. Accident analysis by logic programming technique. Safety and Reliability of Complex Engineered Systems (ESREL), 7-10 September 2015, Zurich, Switzerland, pp. 13-21.
[17] Leveson N. A new accident model for engineering safer systems. Safety Science. 2004;42:237-70. https://doi.org/10.1016/S0925-7535(03)00047-X

[18] Johansson B, Lindgren M. A quick and dirty evaluation of resilience enhancing properties in safety critical systems. Proceedings of the third symposium on resilience engineering, 28-30 October 2008, Juan-les-Pins, France, pp. 133-141.
[19] Afenyo M, Khan F, Veitch B, Yang M. Arctic shipping accident scenario analysis using Bayesian Network approach. Ocean Engineering. 2017;133:224-30. https://doi.org/10.1016/j.oceaneng.2017.02.002
[20] Underwood P, Waterson P. Systemic accident analysis: Examining the gap between research and practice. Accident Analysis & Prevention. 2013;55:154-64. https://doi.org/10.1016/j.aap.2013.02.041
[21] Uğurlu F, Yıldız S, Boran M, Uğurlu Ö, Wang J. Analysis of fishing vessel accidents with Bayesian network and Chi-square methods. Ocean Engineering. 2020;198:106956. https://doi.org/10.1016/j.oceaneng.2020.106956
[22] Chauvin C, Lardjane S, Morel G, Clostermann JP, Langard B. Human and organisational factors in maritime accidents: analysis of collisions at sea using the HFACS. Accident Analysis and Prevention. 2013;59:26-37. https://doi.org/10.1016/j.aap.2013.05.006
[23] Chen ST, Wall A, Davies P, Yang ZL, Wang J, Chou YH. A Human and Organisational Factors (HOFs) analysis method for marine casualties using HFACS-Maritime Accidents (HFACS-MA). Safety Science. 2013;60:105-14. https://doi.org/10.1016/j.ssci.2013.06.009
[24] Macrae C. Human factors at sea: common patterns of error in groundings and collisions. Maritime Policy & Management. 2009;36:21-38. https://doi.org/10.1080/03088830802652262
[25] Li WC, Harris D. Pilot error and its relationship with higher organizational levels: HFACS analysis of 523 accidents. Aviation, space, and environmental medicine. 2006;77:1056-61.
[26] Rashid HSJ, Place CS, Braithwaite GR. Helicopter maintenance error analysis: Beyond the third order of the HFACS-ME. International Journal of Industrial Ergonomics. 2010;40:636-47. https://doi.org/10.1016/j.ergon.2010.04.005
[27] Tvaryanas AP, Thompson WT, Constable SH. Human factors in remotely piloted aircraft operations: HFACS analysis of 221 mishaps over 10 years. Aviation, space, and environmental medicine. 2006;77:724-32.
[28] Olsen NS. Coding ATC incident data using HFACS: Inter-coder consensus. Safety Science. 2011;49:1365-70. https://doi.org/10.1016/j.ssci.2011.05.007
[29] Shappell S, Wiegmann D. HFACS Analysis of Military and Civilian Aviation Accidents: A North American Comparison. Proceedings of the Annual Meeting of the International Society of Air Safety Investigators (ISASI) Forum. November 2004, Gold Coast, Australia, pp.1-8.
[30] Wiegmann DA, Shappell SA. Human factors analysis of postaccident data: Applying theoretical taxonomies of human error. The International Journal of Aviation Psychology. 1997;7:67-81. https://doi.org/10.1207/s15327108ijap0701_4
[31] Akhtar MJ, Utne IB. Human fatigue's effect on the risk of maritime groundings – A Bayesian Network modeling approach. Safety Science. 2014;62:427-40. https://doi.org/10.1016/j.ssci.2013.10.002
[32] Shappel SA, Wiegmann DA. The Human Factors Analysis and Classification System-HFACS. US Federal Aviation Administration; 2000. Illinois, United States, pp. 1-19.
[33] Theophilus SC, Esenowo VN, Arewa AO, Ifelebuegu AO, Nnadi EO, Mbanaso FU. Human factors analysis and classification system for the oil and gas industry (HFACS-OGI). Reliability Engineering & System Safety. 2017;167:168-76. https://doi.org/10.1016/j.ress.2017.05.036

[34] Zhang M, Zhang D, Goerlandt F, Yan X, Kujala P. Use of HFACS and fault tree model for collision risk factors analysis of icebreaker assistance in ice-covered waters. Safety Science. 2019;111:128-43. https://doi.org/10.1016/j.ssci.2018.07.002

[35] Schröder-Hinrichs JU, Baldauf M, Ghirxi KT. Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. Accident Analysis and Prevention. 2011;43:1187-96. https://doi.org/10.1016/j.aap.2010.12.033

[36] Patterson JM, Shappell SA. Operator error and system deficiencies: analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS. Accident Analysis and prevention. 2010;42:1379-85. https://doi.org/10.1016/j.aap.2010.02.018

[37] Zhan Q, Zheng W, Zhao B. A hybrid human and organizational analysis method for railway accidents based on HFACS-Railway Accidents (HFACS-RAs). Safety Science. 2017;91:232-50. https://doi.org/10.1016/j.ssci.2016.08.017

[38] Li WC, Head T, Wu FE, Chen SY, Yu CS. The investigation of decision errors in aviation mishaps by applying the human factors analysis and classification system (HFACS). Human Performance, Situation Awareness and Automation: Current Research and Trends, Vol 1. 2004:283-9.

[39] Chen ST, Chou YH. Examining Human Factors for Marine Casualties using HFACS - Maritime Accidents (HFACS-MA). 12th International Conference on Its Telecommunications (ITST-2012). 2012:385-90. https://doi.org/10.1109/ITST.2012.6425205

[40] Uğurlu Ö, Yıldız S, Loughney S, Wang J. Modified human factor analysis and classification system for passenger vessel accidents (HFACS-PV). Ocean Engineering. 2018;161:47-61. https://doi.org/10.1016/j.oceaneng.2018.04.086

[41] IMO. Amendments to the Code for the Investigation of Marine Casualties and Incidents (Resolution A.849(20)). In: Organization IM, editor. A884(21). United Kingdom: International Maritime Organization; 1999. pp. 1-42.

[42] Ergai A, Cohen T, Sharp J, Wiegmann D, Gramopadhye A, Shappell S. Assessment of the Human Factors Analysis and Classification System (HFACS): Intra-rater and inter-rater reliability. Safety Science. 2016;82:393-8. https://doi.org/10.1016/j.ssci.2015.09.028

[43] Celik M, Cebi S. Analytical HFACS for investigating human errors in shipping accidents. Accident Analysis and Prevention. 2009;41:66-75. https://www.sciencedirect.com/science/article/pii/S0001457508001838

[44] Xi YT, Fang QG, Chen WJ, Hu SP. Case-based HFACS for Collecting, Classifying and Analyzing Human Errors in Marine Accidents. International Conference on Industrial Engineering and Engineering Management. 2009:2148-53. https://doi.org/10.1109/IEEM.2009.5373128

[45] Xi Y, Chen W, Fang Q, Hu S. HFACS model based data mining of human factors-a marine study. Industrial Engineering and Engineering Management (IEEM), 2010 IEEE International Conference on: IEEE; 2010. p. 1499-504. https://ieeexplore.ieee.org/document/5674153/

[46] Wiegmann D, Boquet A, Detwiler C, Holcomb K, Shappell S. Human Error and General Aviation Accidents : A Comprehensive, Fine-grained Analysis Using HFACS. Federal Aviation Administration, 2005, Washington, United States pp. 1-24.

[47] MAIB. P&OSL Aquitaine accident report. In: Branch MAI, editor. United Kingdom: Marine Accident Investigation Branch, 2001. United Kingdom, pp. 1-49.

[48] MTITC. M/V Tolstoy accident final report. In: Directorate for Aircraft MaRAI, editor. Bulgaria: Republic of Bulgaria Ministry of Transport, 2009. Bulgaria, pp. 1-23.

[49] STA. MARIA M Accident Report. In: Unit MI, editor. Swedish Transport Agency, Sweden, 2010, pp. 1-15.
[50] Han DF, Ding S. Review of human factors in maritime system. In: Xu XP, editor. Applied Mechanics and Materials. Switzerland: Trans Tech Publications; 2013. pp. 679-82. https://doi.org/10.4028/www.scientific.net/AMM.397-400.679
[51] Mazaheri A, Montewka J, Kujala P. Towards an evidence-based probabilistic risk model for ship-grounding accidents. Safety Science. 2016;86:195-210. https://doi.org/10.1016/j.ssci.2016.03.002
[52] Graziano A, Teixeira A, Soares CG. Classification of human errors in grounding and collision accidents using the TRACEr taxonomy. Safety Science. 2016;86:245-57. https://doi.org/10.1016/j.ssci.2016.02.026
[53] Tzannatos E. Human element and accidents in Greek shipping. Journal of Navigation. 2010;63:1-9. https://doi:10.1017/S0373463309990312
[54] Rothblum AM. Human error and marine safety. National Safety Council Congress and Expo, 2000, Orlando, United States, pp. 7-18.
[55] Uğurlu Ö, Köse E, Yıldırım U, Yüksekyıldız E. Marine accident analysis for collision and grounding in oil tanker using FTA method. Maritime Policy & Management. 2015;42:163-85. https://doi.org/10.1080/03088839.2013.856524
[56] Yoo Y, Kim T-G. An Improved Ship Collision Risk Evaluation Method for Korea Maritime Safety Audit Considering Traffic Flow Characteristics. Journal of Marine Science and Engineering. 2019;7:448. https://doi.org/10.3390/jmse7120448
[57] Aydogdu YV, Yurtoren C, Park J-S, Park Y-S. A study on local traffic management to improve marine traffic safety in the Istanbul Strait. The Journal of Navigation. 2012;65:99-112. https://doi.org/10.1017/S0373463311000555
[58] Akyuz E. A marine accident analysing model to evaluate potential operational causes in cargo ships. Safety Science. 2017;92:17-25. https://doi.org/10.1016/j.ssci.2016.09.010
[59] Arslan V, Kurt RE, Turan O, De Wolff L. Safety Culture Assessment and Implementation Framework to Enhance Maritime Safety. Transportation Research Procedia. 2016;14:3895-904. https://doi.org/10.1016/j.trpro.2016.05.477
[60] Sætrevik B, Hystad SW. Situation awareness as a determinant for unsafe actions and subjective risk assessment on offshore attendant vessels. Safety Science. 2017;93:214-21. https://doi.org/10.1016/j.ssci.2016.12.012
[61] Uğurlu Ö. Analysis of fire and explosion accidents occurring in tankers transporting hazardous cargoes. Int J Ind Ergonom. 2016:1-20. https://doi.org/10.1016/j.ergon.2016.06.006
[62] Ugurlu O, Yıldırım U, Yuksekyıldız E. Marine Accident Analysis with GIS. Journal of Shipping and Ocean Engineering. 2013;3:21-9.
[63] Sarıalioğlu S, Uğurlu Ö, Aydın M, Vardar B, Wang J. A hybrid model for human-factor analysis of engine-room fires on ships: HFACS-PV&FFTA. Ocean Engineering. 2020;217:1-19. https://doi.org/10.1016/j.oceaneng.2020.107992
[64] Antão P, Almeida T, Jacinto C, Guedes Soares C. Causes of occupational accidents in the fishing sector in Portugal. Safety Science. 2008;46:885-99. https://doi.org/10.1016/j.ssci.2007.11.007
[65] Li KX, Yin J, Bang HS, Yang Z, Wang J. Bayesian network with quantitative input for maritime risk analysis. Transportmetrica A: Transport Science. 2014;10:89-118. https://doi.org/10.1080/18128602.2012.675527

[66] Loughney S, Wang J. Bayesian network modelling of an offshore electrical generation system for applications within an asset integrity case for normally unattended offshore installations. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment. 2017;232:402-20. https://doi.org/10.1177/1475090217704787
[67] Trucco P, Cagno E, Ruggeri F, Grande O. A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. Reliability Engineering & System Safety. 2008;93:845-56. https://doi.org/10.1016/j.ress.2007.03.035
[68] Wang J, Pillay A, Kwon Y, Wall A, Loughran C. An analysis of fishing vessel accidents. Accident Analysis & Prevention. 2005;37:1019-24. https://doi.org/10.1016/j.aap.2005.05.005
[69] Zhang J, Teixeira Â P, Soares C G, Yan X. Quantitative assessment of collision risk influence factors in the Tianjin port. Safety science. 2018; 110, 363-71. https://doi.org/10.1016/j.ssci.2018.05.002

Table 1. List of maritime accident investigation organizations scrutinized in the study

Name of the Organization	Abbreviation	Country
Accident Investigation Board Norway	AIBN	Norway
Australian Transport Safety Bureau	ATSB	Australia
Bahamas Maritime Authority	BMA	Bahamas
Bureau of Maritime Casualty Investigation	BSU	Germany
Bureau d'enquêtessur les événements de mer	BEAMER	France
Danish Maritime Accident Investigation Board	DMAIB	Denmark
Dutch Safety Board	DSB	Netherlands
European Maritime Safety Agency	EMSA	Portugal
Global Integrated Shipping Information System	GISIS	IMO
Japan Transport Safety Board	JTSB	Japan
Marine Accident Investigation Branch	MAIB	United Kingdom
Marine Casualty Investigation Board	MCIB	Ireland
Maritime Safety Administration of People's Republic of China	MSA	China
National Transportation Safety Committee	NTSC	Indonesia
Safety Investigation Authority	SIA	Finland
Swedish Transport Agency	STA	Sweden
United States National Transportation Safety Board	NTSB	USA

Table 2. Frequency of HOFs under the Organizational Influence level

			f	%
Resource Management	Human Resources	**Lack of Training and Familiarization**		
		Vessel		
		Lack of training and familiarization with navigation devices (ECDIS, RADAR, GPS, Autopilot, *etc*.)	14	3.66
		Lack of BRM training	7	1.83
		Lack of training and familiarization with the ship's manoeuvring characteristics	4	1.05
		Lack of training and familiarization with the ship's propeller type	2	0.52
		Engine crew unfamiliar with the ship's engine and equipment	1	0.26
		Navigation Area		
		Pilot unfamiliar with the navigation area	1	0.26
		Bridge team unfamiliar with the navigation area	5	1.31
		Master unfamiliar with the navigation area	2	0.52
		Crew Assignment		
		Minimum safe manning strategy	4	1.05
		Inappropriate crew assignment (unqualified crew)	1	0.26
	Equipment & Facility Resources	**Lack of Equipment**		
		Bridge navigation equipment	5	1.31
		VTS equipment	1	0.26
		Fixed navigation aids at port	3	0.79
		Inappropriate Equipment and Facilities		
		Inappropriate echo sounder (primitive)	1	0.26
		Ergonomic Design Flaws		
		Inappropriate bridge design (voice insulation, visual restrictions, *etc*.)	6	1.57
		Arrangement of navigation equipment on bridge	1	0.26
Organizationa	Organizationa	**Communication and Coordination**	-	-
		Chain of Command	-	-

		Distribution of Authority	-	-
	Policies	**Promotion**	-	-
		Drug and Alcohol	-	-
	Organizational Culture	Appropriate environment for efficient use of bridge navigation equipment	1	0.26
Organizational Process	Operation Management	Inappropriate voyage management- VTS	2	0.52
		Inappropriate manoeuvre management- Port	2	0.52
	Legal Shortcomings	**Procedure Based**		
		Manoeuvring in heavy weather conditions	1	0.26
		Lack of emergency procedures	1	0.26
		Lack of risk assessment procedures	1	0.26
		Manoeuvring instructions	1	0.26
		Legislation Based		
		Navigation plan preparation	1	0.26
		Flag state's manning standards	1	0.26
	Oversight	**Risk Assessment**		
		Ignoring risk assessment	4	1.05
		No pre-arrival checks	1	0.26
		Lack of check of navigation equipment before manoeuvre	1	0.26
		Safety Assessment		
		Failure to review the navigation safety bulletin	2	0.52
		Failure to check weather reports	1	0.26
		Total	78	20.4

Table 3. Frequency of HOFs under the Unsafe Supervision level

		f	%
Insufficient Supervision	Bridge alarm panel	1	0.26
	Engine alarm panel	1	0.26
	Main engine routine overhaul	1	0.26
	Lack of internal audits	3	0.79
Planned Inappropriate Operations	Inappropriate navigation plan	13	3.40
	Watchkeeping without enough lookout	3	0.79
	Lack of tugboat to be used in manoeuvre	1	0.26
	Planning manoeuvre without tug	3	0.79
	Cargo shifting	1	0.26
	Navigating without pilot in icy waters	1	0.26
Failure to Correct a Known Problem	Existence of uncharted shallow water	5	1.31
	Modified buoyage system has not mapped	1	0.26
	Failure to mark port depths	1	0.26
	Total	35	9.2

Table 4. Frequency of HOFs under Pre-conditions for the Unsafe Acts level

			f	%
Substandard Team Members	Substandard Conditions of Team Members	**Adverse Mental Conditions**		
		Lack of situational awareness (bridge team)	13	3.4
		Lack of situational awareness (master)	4	1.05
		Lack of situational awareness (engine team)	1	0.26
		Lack of attention	3	0.79
		Over self-confidence (bridge team)	2	0.52
		Over self-confidence (master)	5	1.31
		Over confidence in bridge navigation equipment	4	1.05
		Adverse Physical Conditions		
		Physical fatigue of the officer	2	0.52
		Physical and Mental Limitations		
		Excessive workload of watch officer	2	0.52
		Master’s excessive workload due to pilot exemption certificate	2	0.52
		Lookout in night watch	20	5.24
		Excessive workload of master	1	0.26
		Master’s occupation with phone	1	0.26
	Substandard Practices of Team Members	**Readiness for Operation**		
		Inappropriate Management Activities		
		Master’s lack of authority	2	0.52
		Failure in emergency management	5	1.31
		Master's lack of management	1	0.26
		Lack of briefing before navigation	1	0.26
		Lack of Communication		
		Lack of communication (Ship-VTS)	1	0.26
		Lack of communication (Bridge-Engine)	2	0.52
		Lack of communication (Master-Pilot)	4	1.05
		Lack of Coordination		
		Pilot-tug boat cannot agree on the intended manoeuvre	3	0.79
		Lack of coordination between master-watch officer	8	2.09
		Lack of bridge team coordination	3	0.79
		Master-pilot cannot agree on the intended manoeuvre	3	0.79
Technology and Interface Malfunctions	Gyro compass failure		1	0.26
	GPS failure		2	0.52
		Total	96	25.1

Table 5. Frequency of HOFs under the Unsafe Acts level

			f	%
Errors	Skill Based	Master's inability to use engine control panel effectively	2	0.52
		Master's failure to detect the ship's heading by radar	1	0.26
		Failure of the watch officer to track the route	2	0.52
		Failure of bridge team to use ECDIS	2	0.52
		Failure of the watch officer to use the variable range marker	1	0.26
		Failure of the watch officer to use navigation devices	4	1.05
		Master's failure to use the ship's propellers in synchronized mode	2	0.52
		Watch officer's failure to use rudder modes (follow up, non-follow up *etc.*)	1	0.26
		Failure of bridge team to use autopilot in port mode	2	0.52
		Master's failure to use navigation equipment	6	1.57
		Incorrect tide calculation of bridge team	1	0.26
		Inability of the bridge team to apply parallel index on radar	2	0.52
	Decision Based	Watch officer's manoeuvring error	1	0.26
		Bridge team member's manoeuvring error	3	0.79
		Master makes turn by using autopilot in the narrow waterway	2	0.52
		Master's faulty manoeuvre to avoid collision	1	0.26
		Improper route selection	4	1.05
		Deviation from planned route	4	1.05
		Master's disregard of pilot advices	1	0.26
	Perceptual	Interpretation error of bridge team	2	0.52
		Master's interpretation error	9	2.36
		Master's failure in detection of the existing danger (COLREG Rule 8)	5	1.31
Violations	Regulation	Watch handover (STCW)	1	0.26
		Improper lookout (COLREG Rule 5)	1	0.26
		Unsafe speed (COLREG Rule 6)	6	1.57
		Improper manoeuvre in restricted visibility (COLREG Rule 19)	1	0.26
	Procedure	Safety of navigation	4	1.05
		Vessel position check	4	1.05
		Inappropriate chart usage	2	0.52
		Inability to use echo sounder in restricted waters	3	0.79
	Abuse of Authority	Deleting VDR records (destroying evidence)	6	1.57
		Deviation from the safe route for demonstration purposes	3	0.79
		Total	89	23.3

Table 6. Frequency of factors under the Operational Conditions level

			f	%
External Conditions	Weather Conditions	**Impairing Visibility**		
		Fog	1	0.26
		Preventing Vessel’s Motion		
		Heavy seas	1	0.26
		Ice condition	4	1.05
		Tide	5	1.31
		Current	7	1.83
		Strong wind	8	2.09
	Locational Restrictions	Port	26	6.81
		Narrow water	19	4.97
		Coastal water	6	1.57
		Heavy traffic	2	0.52
		Open sea	-	-
Internal Conditions	Non-conformities and failures of preventing the ship's motion	Engine failure	2	0.52
		Rudder failure	2	0.52
		Generator power loss (Blackout)	1	0.26
	Vessel Structural Defects		-	-
		Total	84	22.0

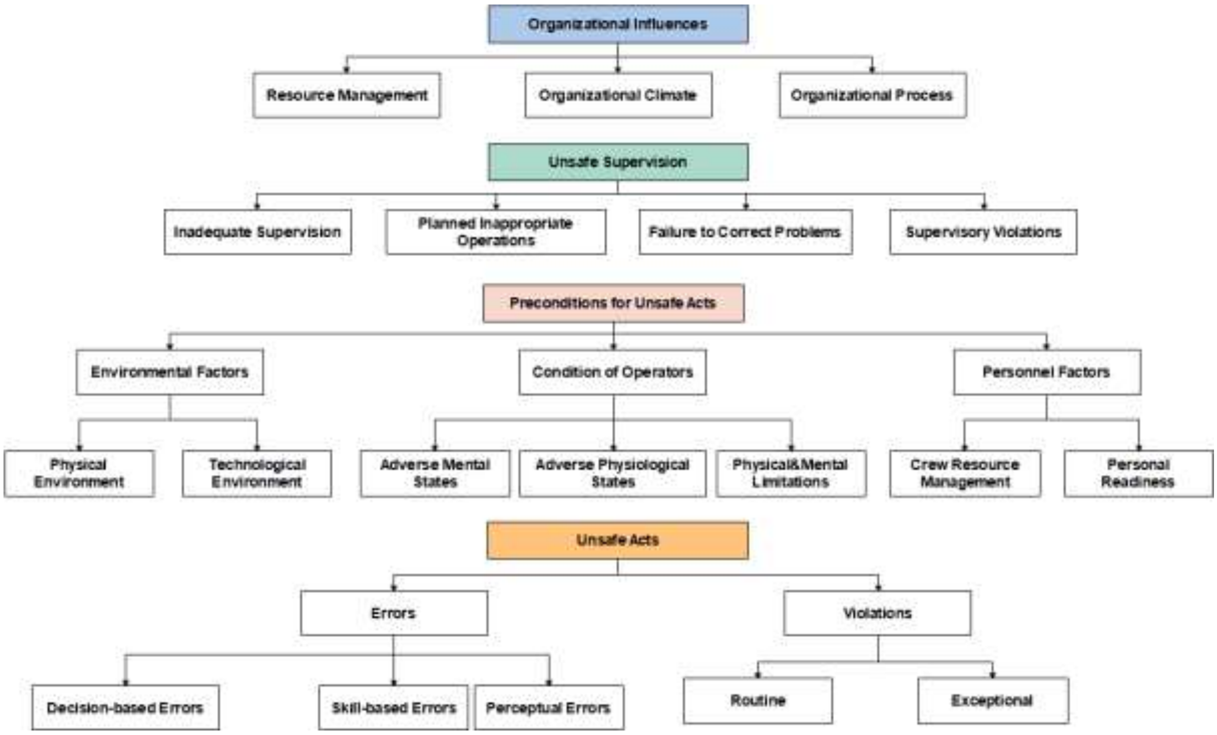

Figure 1. Traditional HFACS structure

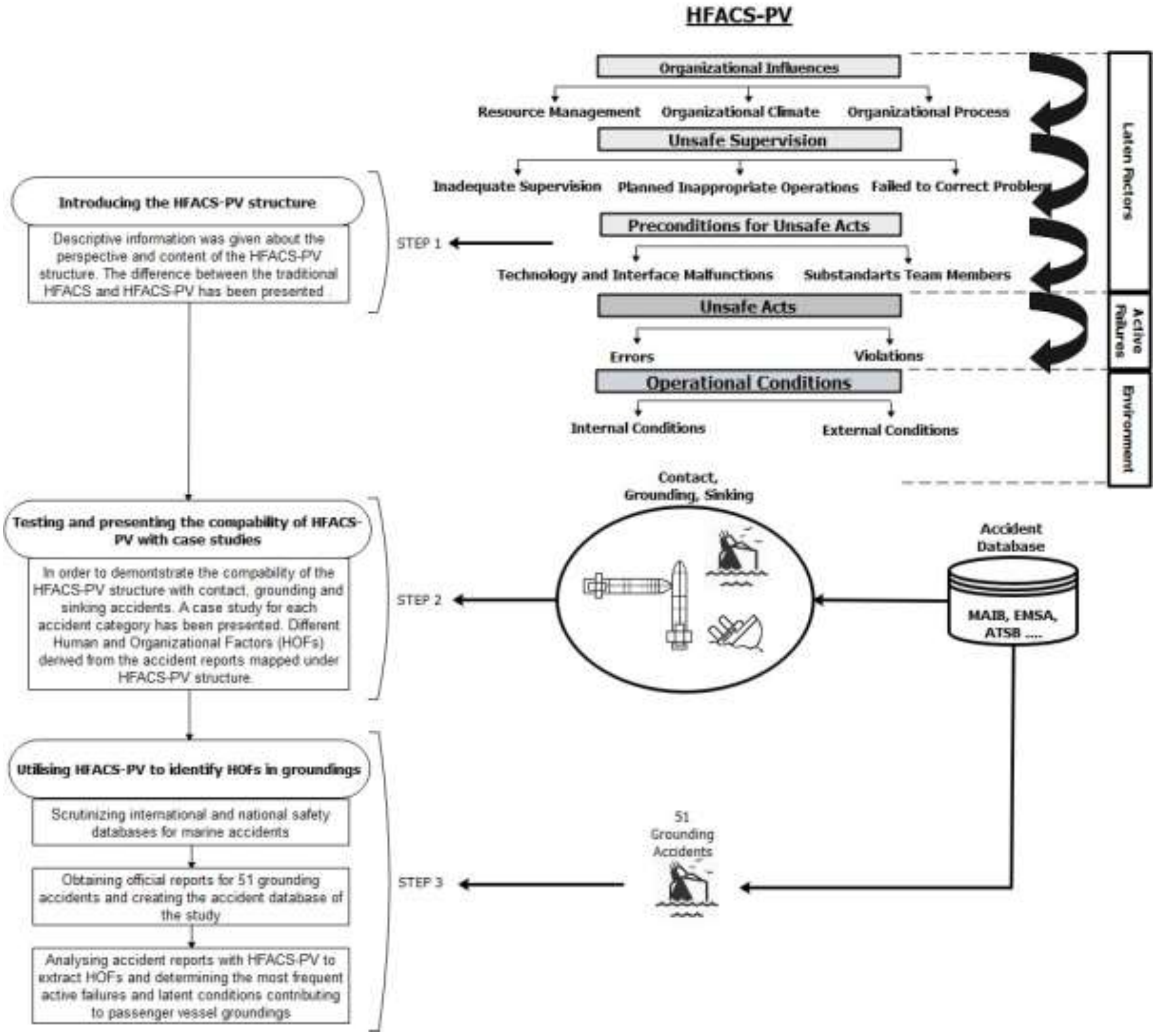

Figure 2. Flow chart of the study

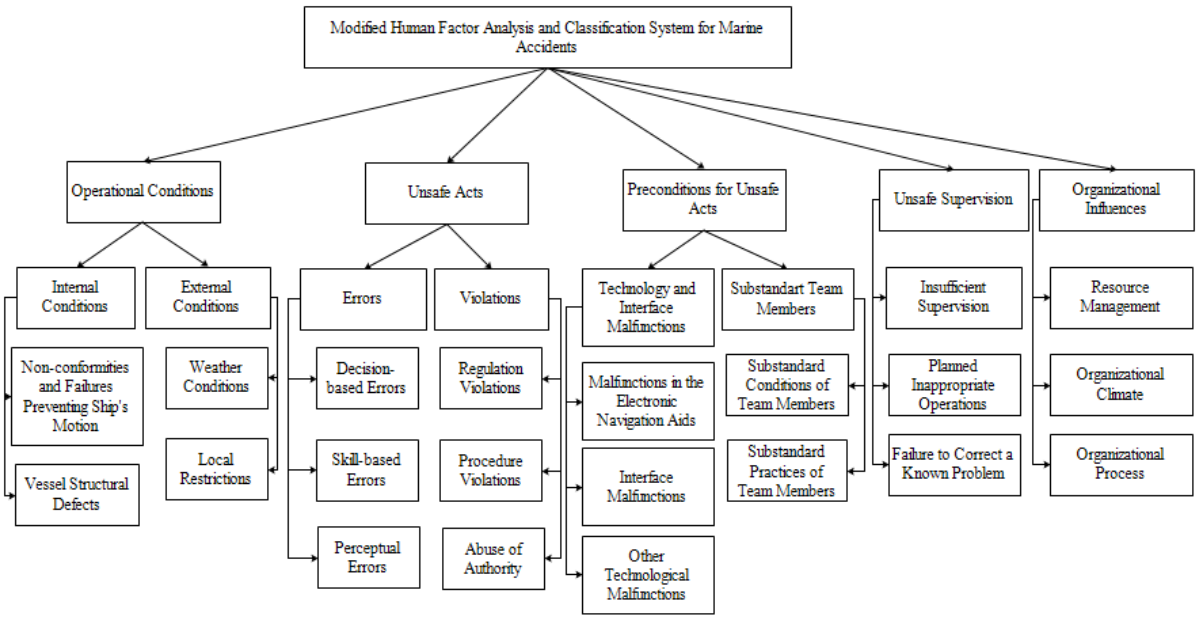

Figure 3. Modified HFACS-PV structure [40]

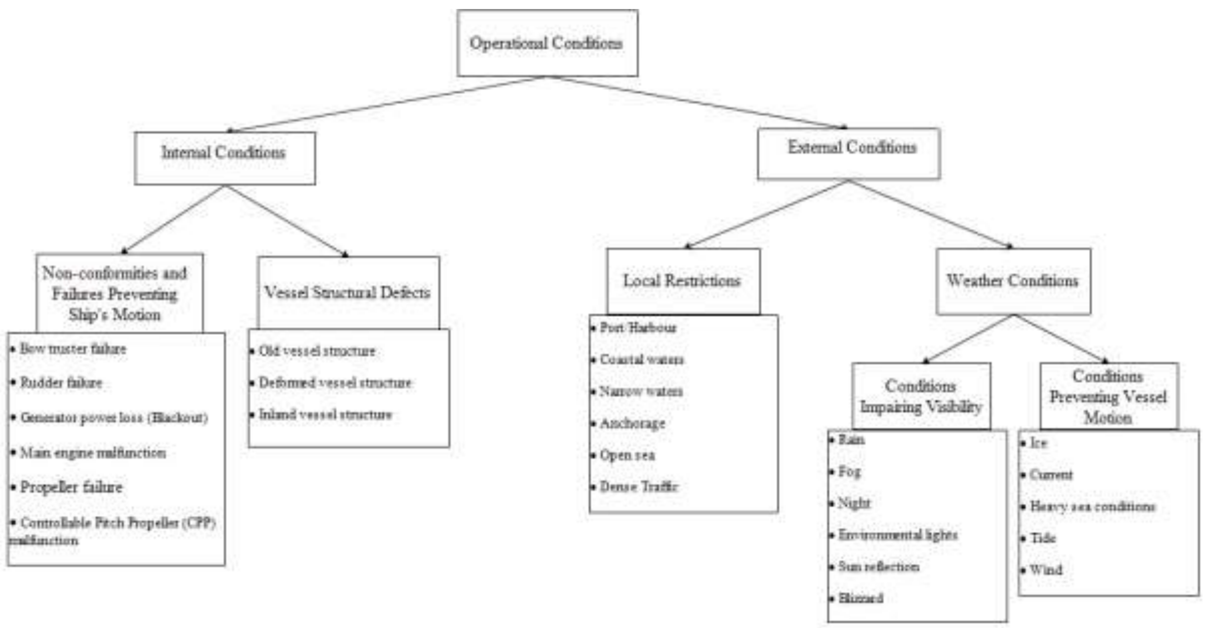

Figure 4. Operational conditions

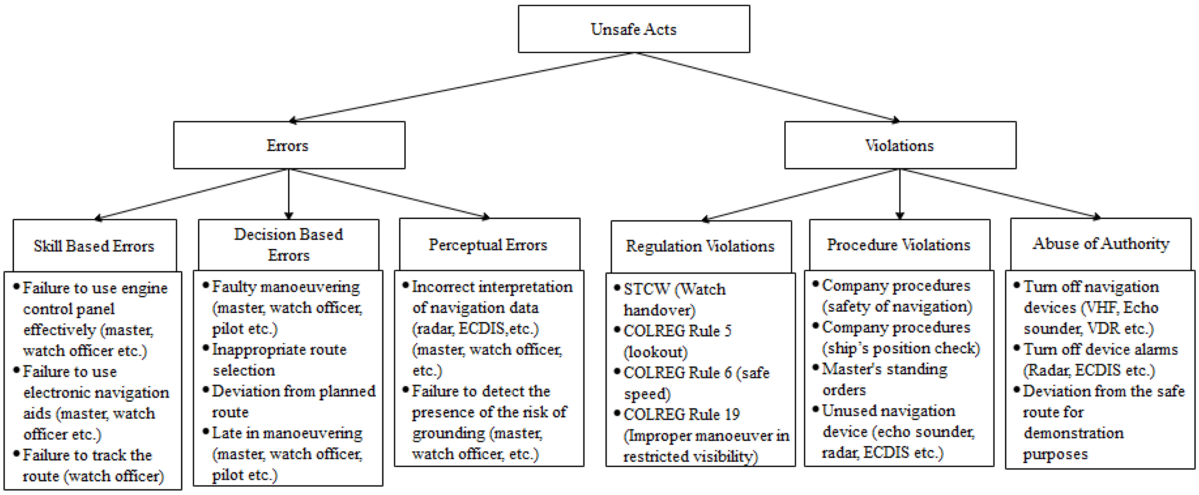

Figure 5. Unsafe acts

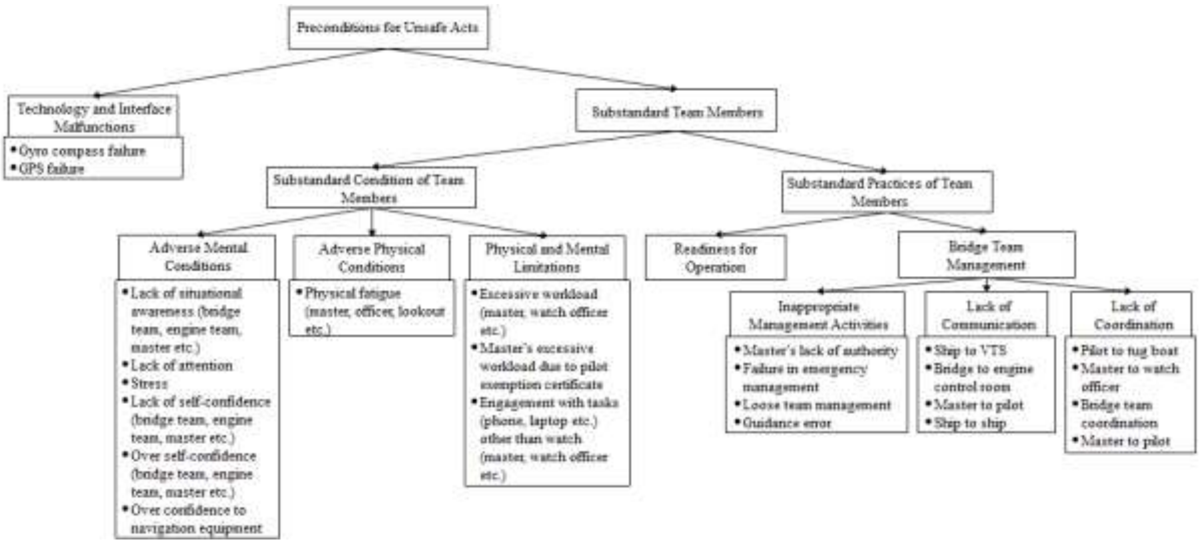

Figure 6. Pre-conditions for unsafe act

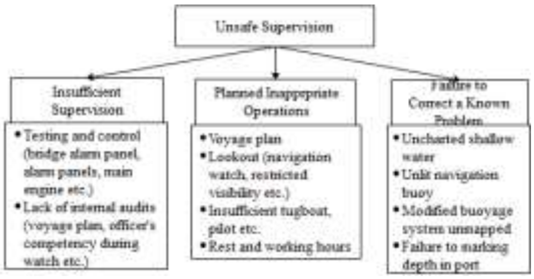

Figure 7. Unsafe supervision

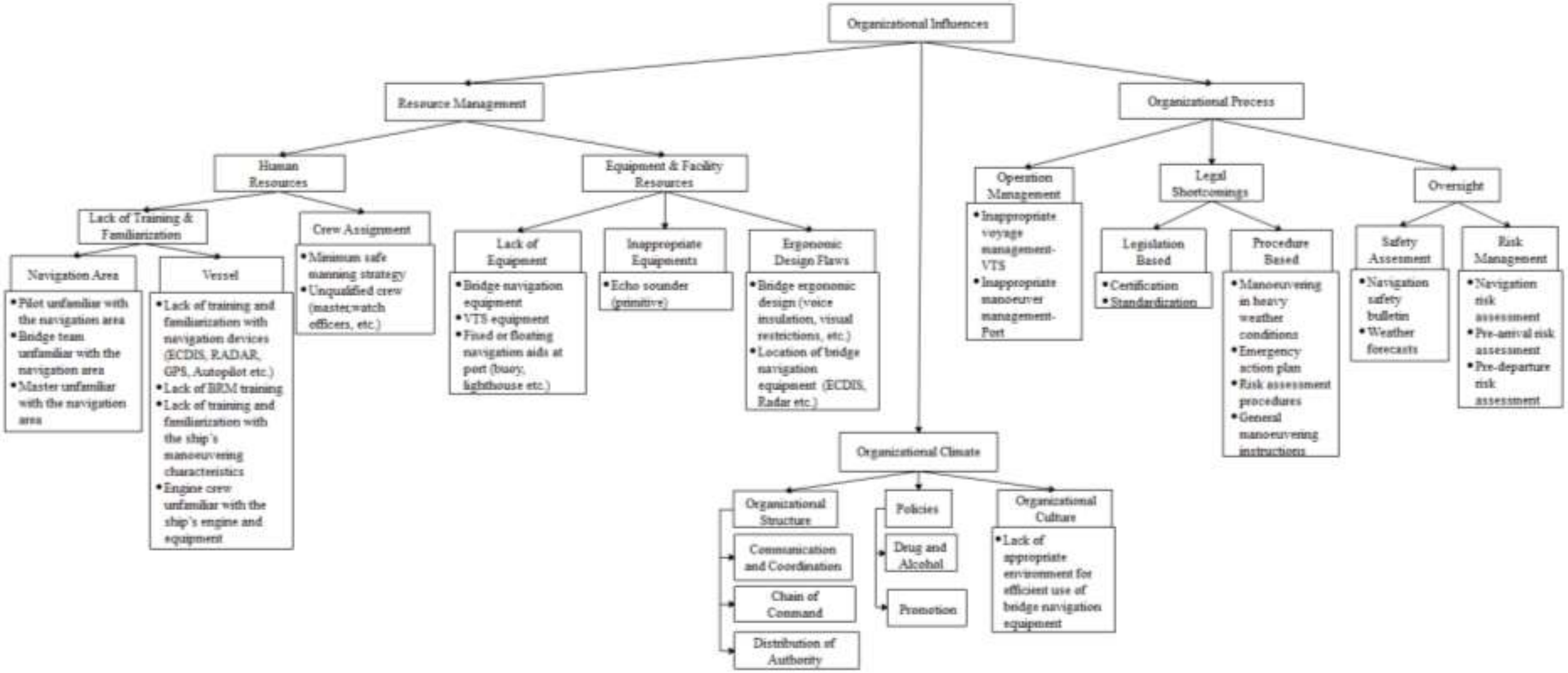

Figure 8. Organizational influences

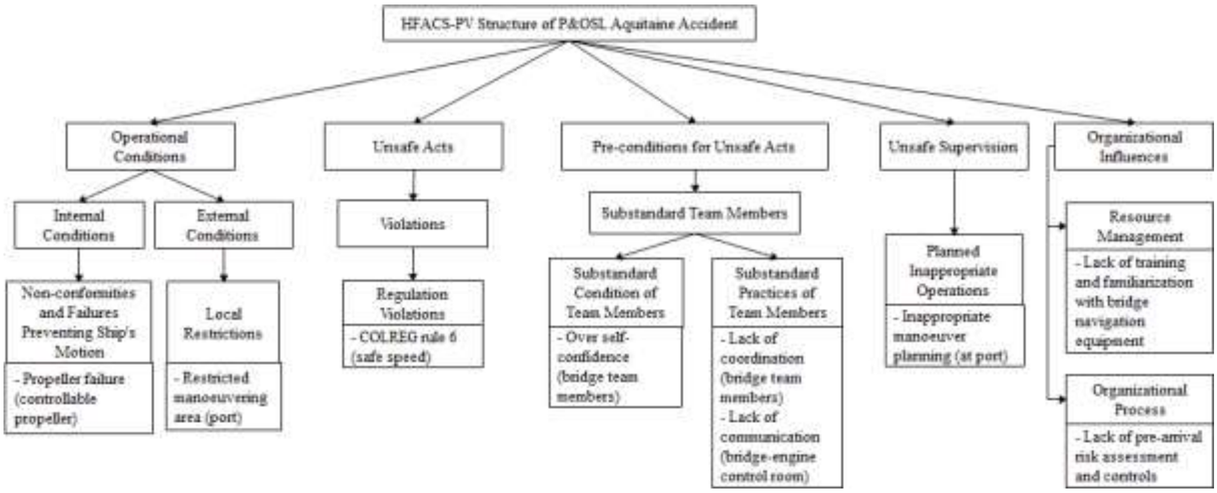

Figure 9. HFACS-PV structure of the P&OSL Aquitaine accident

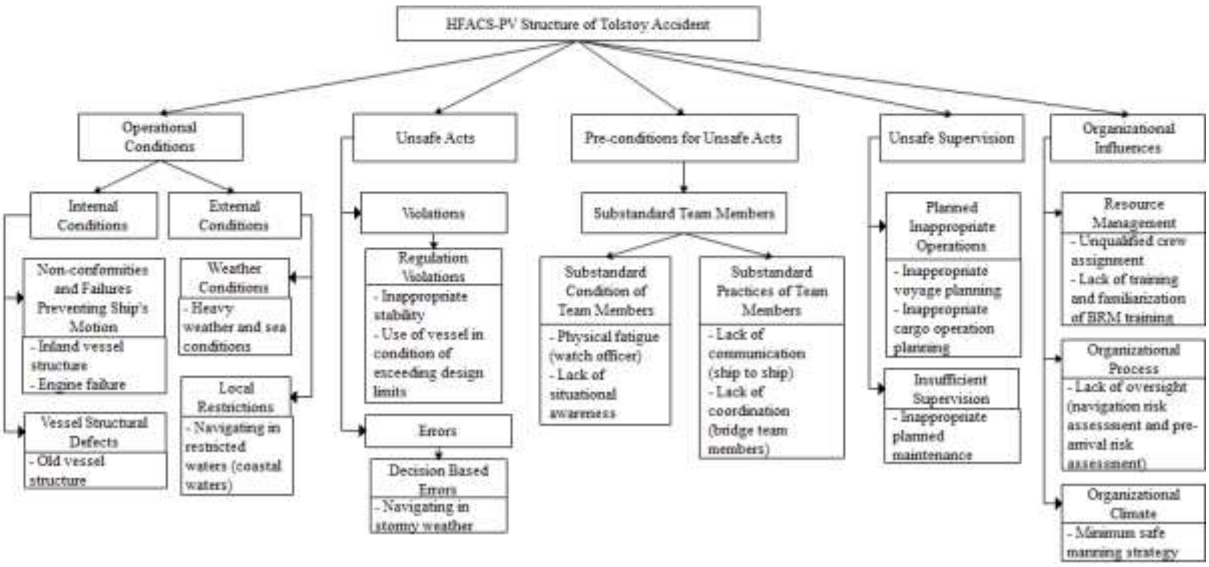

Figure 10. HFACS-PV structure of the Tolstoy accident

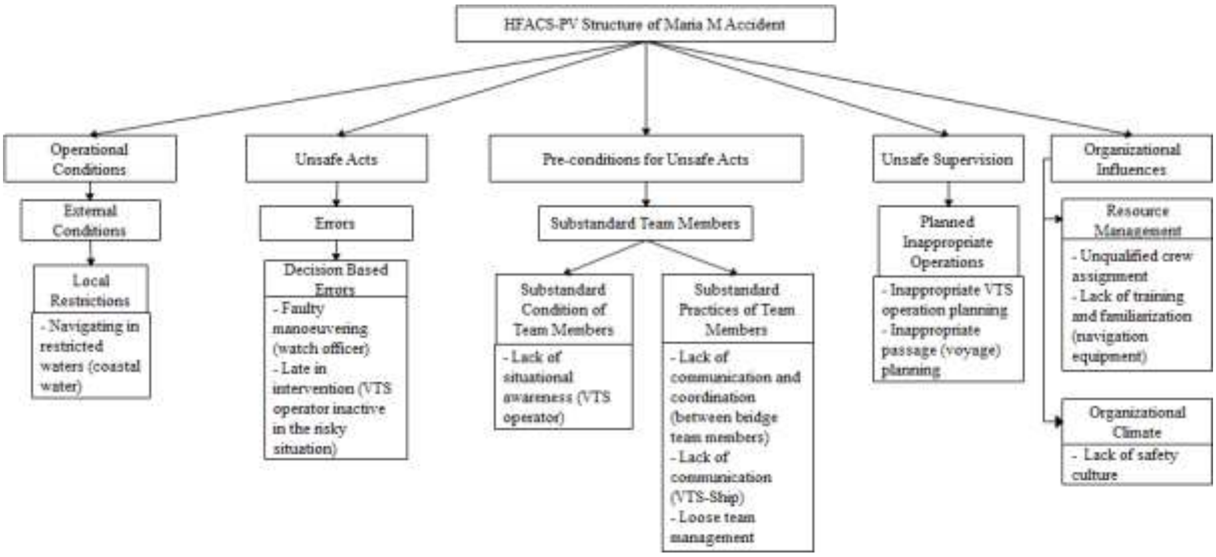

Figure 11. HFACS-PV structure of the Maria M accident

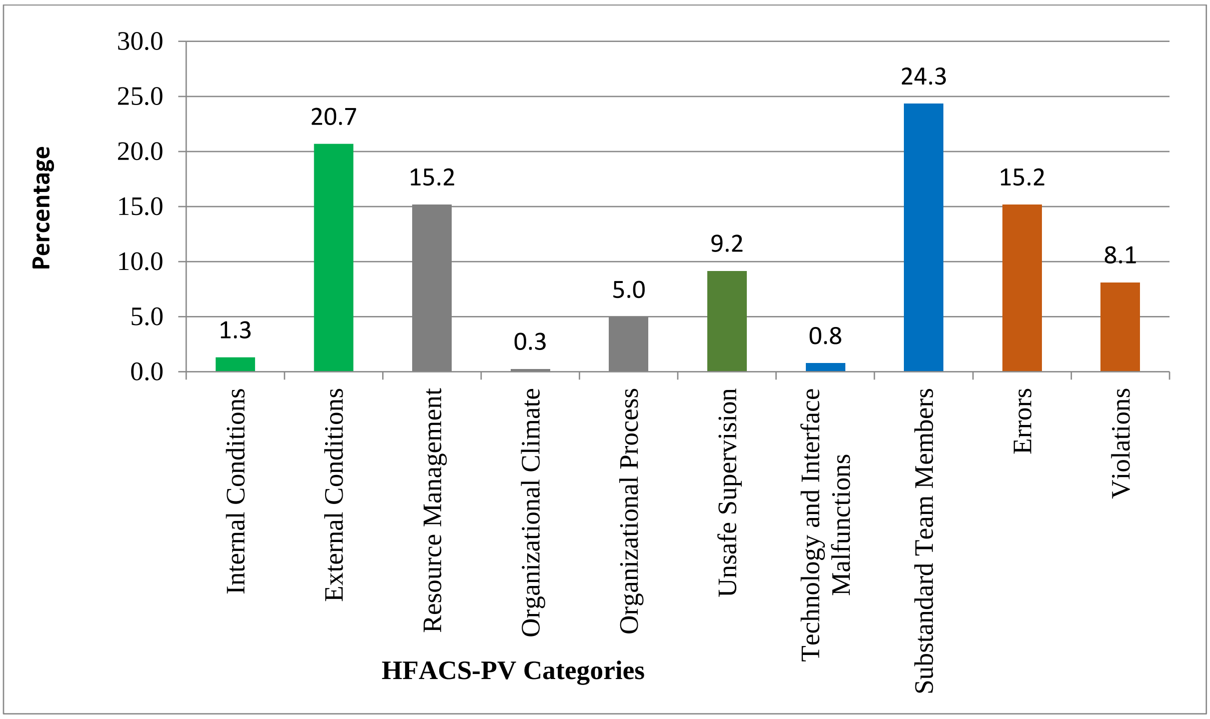

Figure 12. Percentage distribution of HFACS-PV subcategories for grounding accidents