Title: Application of a SOAM-based systemic method to conduct a comprehensive analysis of a maritime accident.

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Abstract: The current trends in maritime accidents worldwide are often linked to environmental, economic, and human consequences, such as oil spills, insurance costs, or human injuries or fatalities. Despite the continuous improvement in safety measures, maritime accidents are still occurring, and this remains a major concern in our society. The main aim of this paper is to contribute to the current safety measures by identifying the significant human and organisational accident contributors, and therefore, reducing the current accident trends. With this aim, this paper proposes to apply a systemic method known as the Systemic Occurrence Analysis Methodology (SOAM) for the first time in the maritime domain. SOAM, which is a 'Swiss-cheese" based organisational technique for analysing incidents and accidents, was developed by EUROCONTROL for the aviation domain. SOAM methodology is fully applied to three maritime accident collisions to identify the major accident contributors, absent or failed barriers, human involvement, and contextual conditions.

Keywords: Human Factors; maritime accidents; maritime safety; accident analysis; SOAM

1. Introduction

Advances in technology do not necessarily ensure that significant improvements in engineering safer systems are reached (Leveson 2011). Accidents continue to happen in many leading sectors, including the maritime domain, with detrimental and even fatal consequences. Statistical analyses on industrial causalities indicate that Human Factors are the major causes of at least 66% of the accidents, and more than 90% of the incidents in various strategic industries such as aerospace or nuclear (Azadeh and Zarrin 2016). Within the scope of the maritime industry, different authors have also stated that more than 80% of maritime accidents are due to human factors. For instance, according to Rothblum (2000), between 75% and 96% of marine casualties are caused, at least partially, by some form of human error. In addition, Graziano, Teixeira et al. (2016) assert that HFs are implicated in around 80% of marine casualties. Furthermore, it has also been suggested that human and/or organisational errors contribute to more than 80% of shipping accidents (Turan, Kurt et al. 2016, Navas de Maya and Kurt 2018, de Maya, Babaleye et al. 2019). In addition, despite technological improvements, maritime records more fatalities than aviation (Turan, Kurt et al. 2016). Therefore, exploring methods of accident analysis which incorporate human factors might help address the influence of human factors and, consequently, reduce fatalities. In the maritime sector, most of the accident analysis reports seek to provide the sequence of facts to report the accidents, but a detailed analysis will provide an insightful explanation around the factors that lead and/or contributed to the accident. Therefore it is crucial to select and apply an appropriate method for accident analysis. In particular, learning from past accidents usually helps understand the system deficiencies and probabilities of deviation from ideal functioning, if there are sufficient data. Therefore, past accidents analysis is useful for preventing future disasters. There are various methods for accidents analysis, and these are usually categorised based on the way they approach the accident. The main categories are epidemiological, sequential, and systemic (Underwood and Waterson 2013). Systemic methods see the system as a whole rather than sequential, ensuring in this way that it is possible to capture socio-technical systems accidents (de Carvalho, 2011; Underwood and Waterson, 2012).

According to a review of more than 400 papers investigating the usage of systemic methods, the three most cited methods were STAMP, FRAM and AcciMap (Underwood and Waterson, 2012). Moreover, these methods have evolved in recent years due to the differences in accidents causation and due to the culture which evolves alongside the safety knowledge; for example, the analysis of the maritime accident is shifting from naval architecture to human error (Luo and Shin 2016), and future direction will include multidisciplinary approaches, with the human element and the protection of the environment to be of greater importance (Luo and Shin 2016). Therefore, the objective of this study is to utilise the aviation-based SOAM methodology for accident analyses for the first time in the maritime domain via the analysis of various collision accidents.

While the context and objective of this study have been introduced above, the rest of this paper is structured as follows: Section 2 provides an initial review of the available systemic methods for accident analysis and their application in previous studies in various critical domains. Section 3 provides the methodology section, which describes the Systemic Occurrence Analysis Methodology (SOAM. The application of the SOAM methodology into various maritime accidents is included in Section 4. Finally, Section 5 and Section 6 provide the results and discussion and the conclusions, respectively.

2. Systemic Methods for Accident Analysis

Systemic methods are commonly characterised by strong links between the various components of the system and their mutual influence (Wienen, Bukhsh et al. 2017). Nevertheless, this is the main common feature amongst systemic methods since they are mostly known by their ontologies, as the Systems-Theoretic Accident Model and Processes (STAMP), the Functional Resonance Analysis Method (FRAM), and AcciMap (Rasmussen, 1997) utilise different paradigms for analysing safety occurrences, according to how they each believe the reality 'works' and can be represented. Therefore, there is little correspondence between the main entities in these methods. STAMP utilises a system-theoretical control cycle model, containing the process under specific parameters such as control, sensors, or actuators. On the other hand, FRAM only knows functions with several parameters that influence the output of the functions (Wienen, Bukhsh et al. 2017), and AcciMap provides a relationship between factors causing an accident and details on how these factors lead to the accident, by using a graphical representation (Murray, Waterson et al., 2017).

STAMP is a systemic accident analysis model developed in the Massachusetts Institute of Technology (MIT) for the aviation and space industries (Leveson 2011), as a combination of two models, Rasmussen and Svedung's model (Rasmussen and Svedung, 2000) and Forrester's model (Ameziane 2016). STAMP focuses on inadequate control or enforcement of safety-related constraints on the system design, development, and operation (Leveson 2011), and it is designed around three major areas, namely constraints, hierarchical level of control, and process models. In addition, each area allows classifying certain controlling errors that could lead to an accident (Hollnagel, Woods et al. 2007).

The STAMP method is based not only on events and human actions individually but also on system process dynamics (Alvarenga, e Melo et al. 2014). STAMP views systems as interrelated components in a state of dynamic equilibrium. Within this method, accidents are the result of errors from interaction among people, organisational structures, engineering activities, and systems components. Hence, an accident occurs when an adaptive feedback function fails to maintain safety and performance over time (Hollnagel, Woods et al. 2007).

STAMP has been already widely applied in the analysis of numerous safety occurrences. For instance, in the aviation domain, STAMP was applied to represent an aircraft rapid decompression event (Allison, Revell et al. 2017); in small drone operations (Chatzimichailidou, Karanikas et al. 2017); and in the safety analysis regarding unmanned protective vehicles (Bagschik, Stolte et al. 2017). In addition, STAMP has also been applied extensively to various domains of the maritime sector, for example, to design maritime safety management systems (Aps, Fetissov et al. 2015, Aps, Fetissov et al. 2016, Banda and Goerlandt 2018, Banda, Goerlandt et al. 2019), to increase port security (Williams 2015), and to analyse maritime accidents (Kim, Nazir et al. 2016, Goncalves Filho, Jun et al. 2019).

Furthermore, the STAMP method involves creating a model of the organisational safety structure. This model can be applied to investigate safety occurrences, aiming to establish the role played by any components regarding the safety control structure. Thus, STAMP can also be utilised to learn how to prevent a future accident from happening, to perform hazard analysis and reduce risks, or to create and support a risk management program in which risk can be controlled and monitored (Hollnagel, Woods et al. 2007). STAMP is demonstrated to be an adequate method for analysing an accident in any technical system. However, it is not the most suitable method to analyse Human Factors (HFs), as capturing the interactions of socio-technical systems is complex and not a straightforward process. Therefore, the required software might not be able to accurately predict the behaviour of the system (Ameziane 2016).

On the other hand, the FRAM method was originally proposed as a risk assessment and accident analysis method (Hollnagel, 2012), aiming to identify and model the required functions to carry out a specific activity (Hollnagel and Fujita, 2013). FRAM principles are based on a non-linear accident model, wherein accidents occur as the result of unexpected combinations of normal performance variability. According to this interpretation, accidents can be prevented by monitoring and dampening variability among system functions, and safety may be achieved through the constant ability to anticipate future events (de Carvalho 2011). FRAM consists of four major principles (de Carvalho 2011, Hollnagel 2012, Ameziane 2016, Smith, Veitch et al. 2017), namely a) Principle of equivalence of successes and failures, b) Principle of approximate adjustments, c) Principle of emergence, and d) Principle of functional resonance.

FRAM has been successfully applied in various domains. For example, in the aviation domain, it was utilised to analyse accidents (Woltjer 2008, Herrera and Woltjer 2010, de Carvalho 2011) for aircraft control (Rutkowska and Krzyżanowski 2018), and for aviation safety (Tian and Caponecchia 2020). In addition, FRAM has also been applied extensively in maritime for accident analysis (Salihoglu and Beşikçi, Praetorius, Lundh et al. 2011, Lee and Chung 2018) and maritime safety (Lee, Yoon et al. 2019).

Finally, AcciMap was first created and used by Rasmussen (Rasmussen, 1997) for analysing accidents, and it has been demonstrated to be generally applicable to various sectors (Salmon et al., 2010). The AcciMap diagram permits system hierarchy and components with input-output interactions. However, the use of Accimaps requires training which makes it difficult to be accessed. Moreover, it is subjective (Murray, Waterson et al., 2017). The subjectivity of the method depends on its core methodology, which is the diagram, without taxonomies of failures, which makes the analysis dependent entirely upon the analyst (Salmon et al., 2012).

In line with the STAMP, FRAM, and AcciMap methodologies, SOAM is also able to provide a systemic approach for accident analysis. The SOAM is an accident analysis methodology developed initially by EUROCONTROL for the aviation domain, constructed upon Reasons' model of organisational accidents (Reason 1990, Licu, Cioran et al. 2007). SOAM contributes to accident analysis from a human involvement perspective, unravelling the main human and organisational contributors into an accident, summarising, and reporting this information using a structured framework and standard terminology.

In addition, SOAM provides a systemic view of causality and examines non-linear and indirect relationships between existing systems and barriers (Licu, Cioran et al. 2007).

Therefore, the current study aims to utilise the SOAM methodology for the first time in the maritime domain and apply SOAM to analyse various maritime accidents to unravel its main contributing factors.

3. Methodology

The methodology adopted in this paper follows and utilises the Systemic Occurrence Analysis Methodology (SOAM). The SOAM methodology consists of six steps or stages, as displayed in Table 1. In addition, a detailed description of each step and the techniques and methods utilised in each step is provided below. Furthermore, for each stage of the SOAM process, a check question is applied to ensure that the item being considered fits the definition of the category it is being considered for. Table 2 provides the check question for each stage of the SOAM process.

Table 1. Causal analysis based on SOAM (adapted from (Licu, Cioran et al. 2007))

No.	Step	Description
1	Revision of gathered data	Gather and review factual information from an accident
2	Identification of barriers	Identify the absent or failed barriers that contributed to the accident
3	Identification of the Human involvement	Identify the contributing human action or non-actions that preceded the accident
4	Identification of contextual conditions	Describe the circumstances that existed at the time of the accident
5	Identification of Organisational Factors	Identify circumstances on the organisation that influenced the accident
6	Preparation of the SOAM Chart	Provide a summary chart

Table 2. Questions for each stage of the SOAM process (adapted from (Licu, Cioran et al. 2007))

No	Stage	Question
1	Absent/failed barrier	Does the item describe a work procedure, aspect of human awareness, physical obstacle, warning or control system, or protection measure designed to prevent an occurrence or lessen its consequences?
2	Human involvement	Does the item describe an action or non-action taking place immediately prior to and contributing to the occurrence?
3	Contextual condition	Does the item describe an aspect of the workplace, local organisational climate, or a person's attitudes, personality, performance limitations, physiological or emotional state that helps explain their actions?
4	Organisational factor	Does the item describe an aspect of the organisation's culture, systems, processes, or decision-making that existed before the occurrence and which resulted in the contextual conditions or allowed those conditions to continue?

3.1. Step 1: Revision of gathered data

While there is no definitive or prescribed method for the gathering of data (Licu, Cioran et al. 2007), it is highly recommended to employ a descriptive framework that allows the initial sorting of accidental facts. SHEL has been applied in previous studies in the literature (Licu, Cioran et al. 2007). Nevertheless, in the SOAM methodology, data should be gathered across five areas (Licu, Cioran et al. 2007) and SHEL covers only four major areas since the organisational element is not addressed in the original SHEL model.

As part of the SAFEMODE project, a number of HF taxonomies were considered, highlighting their main advantages and limitations. As a result of this activity, the NASA Human Factors Analysis and Classification System (NASAHFACS) taxonomy was selected as being of most practical use for maritime accidents (SAFEMODE 2020). Thus, the NASAHFACS provides a usable basis for such a descriptive framework and it already addresses elements at the organisational level, which makes it more suitable than the SHEL model to gather data across the required five areas. The main categories of the NASAHFACS model are depicted in Figure 1. In addition, the complete list of factors can be accessed in the NASA Office of Safety and Mission Assurance Human Factors Handbook (Dillinger and Kiriokos 2019).

NASAHFACS is a version of HFACS devoted to NASA space missions. HFACS was developed by Wiegmann and Shappell for analysis of aviation accidents (Wiegmann and Shappell 2017). HFACS is based on the so-called 'Swiss Cheese' model for accident causation by Reason (Reason 1990, Hawkins 2017). It describes four types of failed or absent defences (i.e., holes) in layers of a barrier model (i.e., cheese slices):

- **Unsafe acts:** They are closely tied to the mishap and described as active failures or actions committed by an individual that results in a human event.
- **Preconditions for unsafe acts:** They are environmental factors or conditions of individuals that affect performance, contributing to an error.
- **Unsafe supervision:** They are methods or decisions of the supervisory chain that directly affect practices or individual actions, resulting in human error or an unsafe situation.
- **Organisational influences:** They are methods, decisions or policies of an organisation that affect both supervisory and individual task and mission accomplishment.

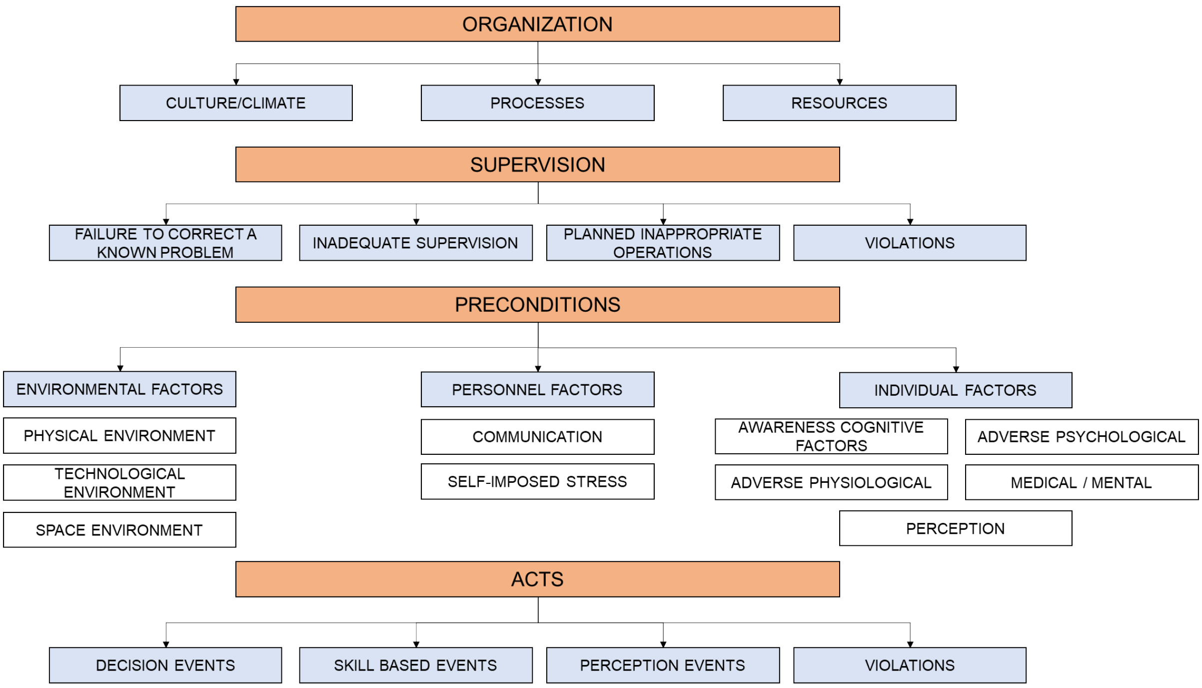

Figure 1. A higher-level view of the NASAHFACS model

Following the coding of an event in the above layers, a bar chart can be obtained from the reporting system that highlights the frequency of the various contributing factors.

The NASAHFACS method is then applied to collect the underlying conditions or accident contributors for the accident being analysed. In addition, the remaining stages of the SOAM analysis involve sorting each piece of factual information collected from the analysis into an appropriate classification. To classify the factual information into the right category, it is mandatory to answer two questions for each identified fact as follows (Licu, Cioran et al. 2007):

- Does the fact represent a condition or event that contributed to the eventual occurrence?

- Under which category or categories can the fact be classified?

The first question allows to filter key facts from the factual information that did not contribute to the occurrence (if any), and therefore, to exclude them from further SOAM analysis. In addition, the second question allows the user to classify the remaining facts into the correspondent category (i.e. absent/failed barrier, human involvement, contextual condition, or organisational factor) as displayed in Table 2.

3.2. Step 2: Identification of barriers

Barriers are in place to protect complex socio-technical systems against both technical and human failures. Absent or failed barriers are the last-minute measures which failed or were missing, and therefore did not (a) prevent an action from being carried out or an event from taking place; or (b) prevent or lessen the impact of the consequences (Licu, Cioran et al. 2007). To facilitate the identification of absent or failed barriers, the barrier types and their descriptions are provided in Table 3 (Hollnagel, 2004).

Table 3. Barrier types and their description (adapted from (Hollnagel, 2004))

Barrier	Description
Awareness	Barriers helping to understand the system state, risks and hazards, and to know the rules, guidelines, procedures and controls that apply to the task
Restriction	Barriers limiting movement or actions, or establishing pre-conditions for action, through physical, functional or administrative means
Detection	Human or engineered barriers that warn about the system status, including the presence of non-normal conditions or imminent dangers
Control and interim recovery	Barriers helping the recovery from a non-normal condition and restoring the system to a safe state, with minimal harm or loss
Protection and containment	Barriers defending people against injury and minimising environmental damage by controlling the accidental release of harmful energy or substances
Escape and rescue	Barriers enabling potential victims to escape from out-of-control hazards, treating injuries, restoring the environment

3.3. Step 3: Identification of the Human involvement

The next step is to identify the contributing human actions (or lack of them) that led to the accident by applying an Information Processing Model (IPM). The IPM suggested in the SOAM methodology is the Rasmussen's Decision Ladder Technique (DLT) (Rasmussen 1982), which has been widely reviewed, adapted and applied in the literature (Burns and Vicente 2001; Licu, Cioran et al. 2007; Jenkins, Stanton et al. 2010; McIlroy and Stanton 2015; Jenkins, Boyd et al. 2016).

Rasmussen's DLT utilised in the SOAM methodology assumes that information is processed by following a six-step sequence as displayed in Figure 2. However, it is not mandatory to follow every step, as shortcuts may be taken to bypass some of the steps, depending on the level of information required (Rasmussen 1982).

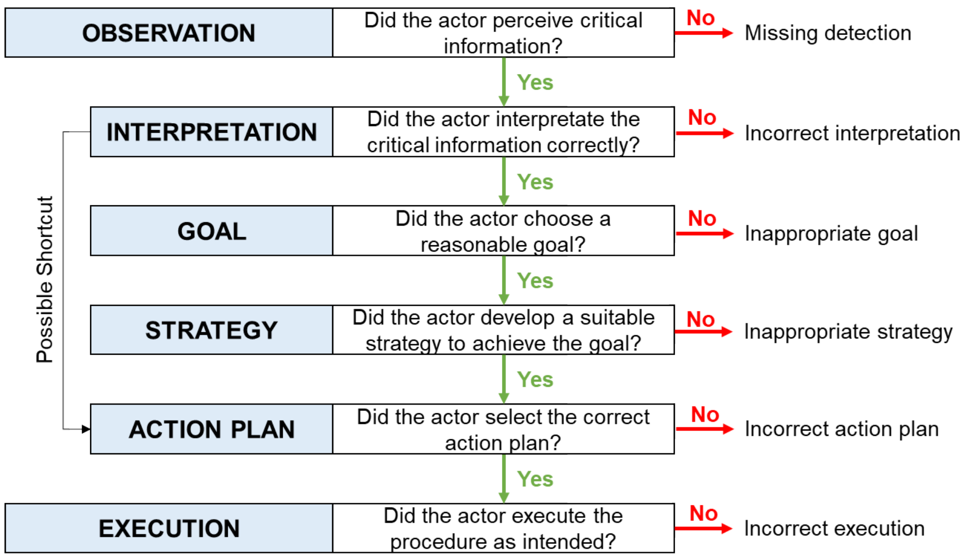

Figure 2. Decision Ladder technique (adapted from (Rasmussen 1982))

3.4. Step 4: Identification of contextual conditions

Contextual conditions describe the circumstances that exist at the time of the accident that can directly influence human performance in the workplace. During the analysis process, the SOAM methodology allows the user to identify five categories of contextual conditions by asking, "What were the conditions in place at the time of the accident that help explain why a person acted as they did?"; two relating to the local workplace, and three to people, as follows:

- **Local workplace:** Workplace conditions
- **Local workplace:** Organisational climate
- **People:** Attitudes and personality
- **People:** Human performance limitations
- **People:** Physiological and emotional factors

3.5. Step 5: Identification of Organisational Factors

Finally, the Organisational Factors describe circumstances that existed at the organisational level prior to the accident. For example, methods, decisions or policies of the organisation that affected supervisory or individual tasks. NASAHFACS identifies three categories of organisational factors (Dillinger and Kiriokos 2019). The full list of factors within each category is provided in Table 4.

Table 4. NASAHFACS Organizational Factors

Culture/Climate	Processes	Resources
OC001 Culture	OP001 Organization Structure	OR001 Personnel
OC002 Climate / Morale	OP002 Ops tempo	OR002 Funding
OC003 Contractor Relations	OP003 Organizational risk assessment	OR003 Material / Parts
	OP004 Program Oversight or Management	OR004 Equipment
	OP005 Publications / Procedures / Written guidance	OR005 Design
	OP006 Organisational training	OR006 Operational Information
		OR007 Facilities / Buildings
		OR008 Facilities / Grounds

3.6. Step 6: Preparation of the SOAM Chart

The preparation of a graphic chart is the final step of the SOAM methodology. The SOAM chart aims not only to depict the individual contributing factors based on the layers of the methodology (e.g., barriers or human involvement) but also to inform about the links that exist and represent the association between the various layers.

4. SOAM analysis applied to three maritime collision accidents

For the purpose of demonstrating the SOAM methodology application in the maritime domain, three different collision accidents were selected from the Marine Accident Investigation Branch (MAIB) as follows:

- The collision between the Hampoel and Atlantic Mermaid vessels (i.e, Accident no. 1).
- The collision between the Wintertide and MSC Sabrina (i.e, Accident no. 2).
- The collision between Scot Isles and Wadi Halfa (i.e, Accident no. 3).

With the aim of avoiding duplications during a complete analysis, including the presentation of the proximate events, the revision of gathered data and the SOAM analysis was performed for each of the three accidents mentioned above. The next sub-sections only includes the details of the first accident, the collision between the Hampoel and Atlantic Mermaid vessels. Furthermore, results obtained from the complete analysis of the three accidents are summarised and discussed in the discussion section.

4.1. The proximate events in the collision between the Hampoel and Atlantic Mermaid vessels

Information about the collision accident between the Hampoel and Atlantic Mermaid vessels was obtained from the original investigation report conducted by the Marine Accident Investigation Branch (MAIB) (MAIB 2002), and available literature (Tang, Acejo et al. 2013). MAIB conducts an official investigation not only for marine accidents involving UK flagged vessels worldwide, but also for all vessels operating in UK territorial waters. In addition, accident reports prepared by MAIB are publicly available. The following facts can be established as far as the official investigation reports states:

On the 7th of June 2001, the Panamanian registered refrigerated cargo vessel Atlantic Mermaid (9829 Gross ton) collided with the Cypriot-registered general cargo vessel Hampoel (2568 Gross ton), off the Varne section of the south-west bound lane of the Dover Strait traffic separation scheme. The Varne, a stretch inside the Dover Strait, known for its 9 miles long sandbank and shallow water, is a concern for shipping. Vessels using the south-west lane of the TSS tend to pass to the north of the Varne as this is the most direct route to follow and does not involve an additional waypoint and course alteration as would be required if passing to the south of the Varne. This results in "bunching" in the TSS to the north of the Varne. In addition, the problem of traffic bunching in the south-west lane of the Dover TSS is also well known.

Atlantic Mermaid departed Sheerness at 1900 on 6 June 2001, in ballast, bound for San Antonio in Argentina. Her draughts were 3.30 m forward and 6.20 m aft. She was ballasting the forepeak on departure, and this continued until the time of the incident. The bridge of Atlantic Mermaid was manned by the master, third officer and a deck rating, who was sent at periodic intervals to sound the forepeak. On the other hand, Hampoel carried a crew of seven and had a draught of 4.8 m. Both radars were in operation, with relative trails being used to determine the risk of collision. The chief officer normally fixed the ship's position every 2 hours at sea, but every hour when close to the coast.

Atlantic Mermaid was the faster of the two vessels and was approaching Hampoel from astern. About 17 minutes before the collision, when the distance between the vessels was about 2.4 miles, the officer on watch on Hampoel noticed the approaching vessel astern of his own vessel. At 0149 UTC, he made a brief VHF call to the other vessel, which went unanswered. At 0153 UTC on 7 June 2001, the collision between both vessels occurred, Hampoel suffered damage to her starboard quarter while Atlantic Mermaid sustained damage to her bow.

In addition, within an accident analysis, the creation of a timeline can be critically useful to provide a deep insight into the causes and the development of the accident. Furthermore, it can also be utilised to compare with similar accidents, for example, collision accidents, to identify common patterns and to define Key Performance Indicators (KPIs), where efforts can be focused on reducing the probabilities of an accident and, therefore, to enhance overall safety. Therefore, a timeline for the collision between the Hampoel and the Atlantic Mermaid is provided in Figure 3, where it is possible to observe the main actions taken by each vessel since their departure until the collision accident.

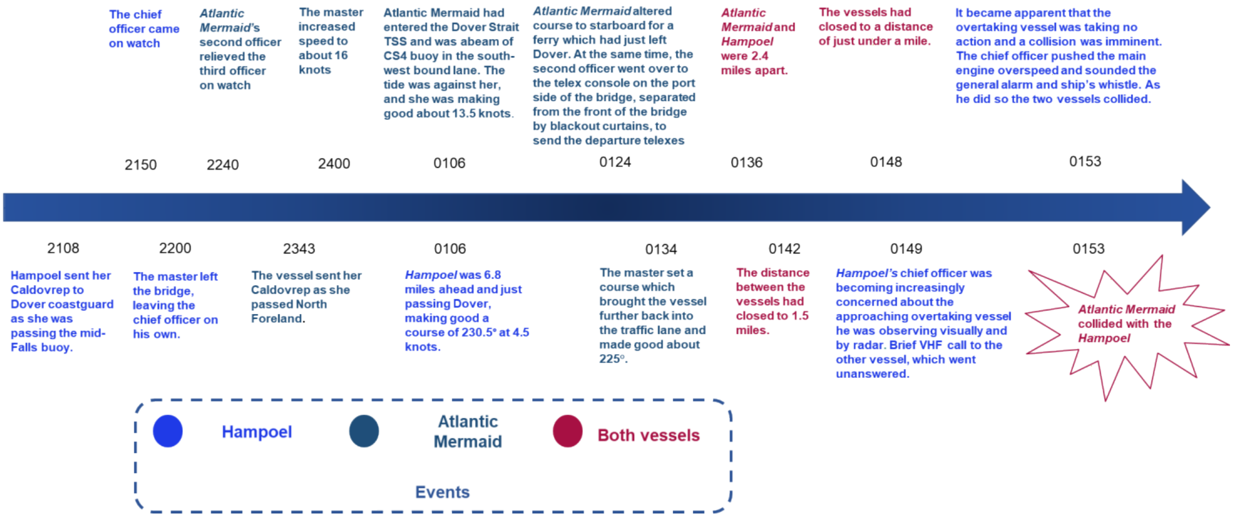

Figure 3. Timeline for the collision between the Hampoel and the Atlantic Mermaid vessels

4.2. Revision of gathered data, including organisational factors, in the collision between the Hampoel and Atlantic Mermaid vessels

The application of the SOAM methodology is a progressive sorting activity that can be conducted individually or as a group exercise between team members. For this study, five members from different areas of expertise participated. Thus, experts involved mostly had a combination of a Naval Architecture degree, expertise with ship design and operations, in-depth knowledge of regulatory elements, safety, and expertise in Human Factors. More details on the expertise area of each participant are displayed in Table 5. First, each person individually analysed the accidents. Second, a group session was organised, where every participant shared their own findings, and discussions took place to come up with agreed outcomes. In addition, the same accident was later discussed in a separate group workshop involving a Master Mariner, a Chief Officer, and a Deck officer, who agreed not only with the factors selected as contributing factors for this accident but also with the reasoning behind the selection.

Table 5. Group composition and expertise area

No.	Expertise area
1	Human Factors, Accident Analysis, Resilience Engineering
2	Human Factors, Process Safety, Risk Assessment, Ship Operations, Process Safety
3	Human Factors, Ergonomics, Ship Design
4	Human Factors, Ship Recycling

No.	Expertise area
5	Human Factors, Regulatory Framework, Maritime Safety

The NASAHFACS method was then applied during the group session to collect the factual information for the collision accident, which allowed the group to identify the main layers and the factors that failed in each accident. Results from this exercise for the collision between the Hampoel and Atlantic Mermaid vessels are displayed in Table 6.

Table 6. Gathered data. Results from applying NASAHFACS method

Layer	Sub-layer	Coding	Factor/Item
ACTS	DECISION EVENTS	AD004 No action executed	Hampoel's Chief Officer failed to take avoiding action.
ACTS	DECISION EVENTS	AD004 No action executed	Hampoel failed to use searchlights or signal light astern
ACTS	DECISION EVENTS	AD004 No action executed	The master of the Atlantic Mermaid had the conduct of the navigation, with the second officer and a helmsman/lookout making up the rest of the bridge team. However, none of the three persons saw Hampoel before the collision.
PRECONDITIONS	COMMUNICATION	PC005 Failure to communicate critical information	Contrary to the advice given in the regulations and Marine Guidance Notice (MGN 67), the Hampoel's Chief officer made a brief VHF call to the approaching vessel, which was not answered by Atlantic Mermaid.
PRECONDITIONS	ADVERSE PHYSIOLOGICAL	PP202 Fatigue (Physiological/Mental)	The master of the Atlantic Mermaid was suffering from a headache and it was over 8 hours since his last rest.
PRECONDITIONS	AWARENESS COGNITIVE FACTORS	PA001 Channelised attention	The Atlantic Mermaid was in the middle of the Dover Strait, in the most heavily concentrated traffic. This was not an ideal time or place for the bridge team to be reduced
PRECONDITIONS	TECHNOLOGICAL ENVIRONMENT	PT006 Workspace Incompatible with Operation	In the Atlantic Mermaid, there was a blind area ahead of the bow of around 50 to 70 metres.
PRECONDITIONS	TECHNOLOGICAL ENVIRONMENT	PT004 Controls and Switches are Inadequate.	The master of the Atlantic Mermaid was not familiar with the radar control settings and associated problems on this vessel. The vessels' controls and switches had known problems. The vessel had a known radar issue, that has persisted for over 12 months.
PRECONDITIONS	TECHNOLOGICAL ENVIRONMENT	PT005 Automated System Creates an Unsafe Situation	Hampoel was maintaining the course line by use of the cross-track-error on the GPS which increased the risk of a close quarter situation.
PRECONDITIONS	PHYSICAL ENVIRONMENT	PE001 Vision affected by the environment	The visual lookout at the Atlantic Mermaid was affected by the weather conditions
SUPERVISION	PLANNED INAPPROPRIATE OPERATIONS	SP002 Crew/Team/Flight Makeup/Composition	The master of the Atlantic Mermaid was burdened with entering the chart room to put the vessel's position on the chart, and ensuring she was on the course line, in addition to keeping a lookout, since the second officer was performing non-navigational duties.
SUPERVISION	PLANNED INAPPROPRIATE OPERATIONS	SP004 Limited Recent Experience	The master was new to the company and the Atlantic Mermaid.
ORGANISATION	RESOURCES	OR004 Equipment	No 2 radar (port) at the Atlantic Mermaid had an intermittent fault for at least 12 months before the collision.
ORGANISATION	RESOURCES	OR001 Personnel	The Atlantic Mermaid's master was the only person keeping a lookout.
ORGANISATION	RESOURCES	OR001 Personnel	Hampoel's Chief officer was the sole watchkeeper.

4.3. SOAM Analysis for the collision between the Hampoel and Atlantic Mermaid vessels

As stated in the previous section, the remaining stages of the SOAM analysis involve sorting each piece of factual information identified in Table 6 into the right category or categories (i.e., absent/failed barrier, human involvement, contextual condition, or organisational factor) since the same factor can be presented in more than one category. Therefore, for each factor or item identified from the accident analysis, a check question (see Table 2) was applied to ensure if a factor being considered fits within the definition of each category.

Results from the SOAM analysis included the analysis of absent or failed barriers (Hollnagel, 2004), the analysis of human involvement, and the analysis of contextual conditions, which are displayed in Table 7, Table 8, and Table 9, respectively.

Table 7. Analysis of absent or failed barriers for the collision between the Hampoel and Atlantic Mermaid vessels

Factor/Item	**Barrier**	**Absent or failed barriers**
Hampoel's Chief Officer failed to take avoiding action.	Detection	As per COLREG, Rule 17, Hampoel was respectively permitted and required to take avoiding action.
Hampoel failed to use searchlights or signal light astern	Detection	Searchlights or signal light astern were not used by the Hampoel, preventing detection from the Atlantic Mermaid vessel.
The master of the Atlantic Mermaid was not familiar with the radar control settings and associated problems on this vessel.	Detection	The possibility that the radar clutter controls in the Atlantic Mermaid had been turned up to an extent where a small vessel at close range could not be detected.
No 2 radar (port) at the Atlantic Mermaid had had an intermittent fault for at least the 12 months before the collision	Detection	The overall condition of the Atlantic Mermaid's radars might have been below that required to enable a satisfactory radar watch to be maintained

Table 8. Analysis of human involvement for the collision between the Hampoel and Atlantic Mermaid vessels

Factor/Item	**DLT Failure**	**Human Involvement**
Hampoel's Chief Officer failed to take avoiding action	Incorrect interpretation	Hampoel's Chief Officer failed to take avoiding action. As per COLREG, Rule 17, Hampoel was required to take avoiding action
The master of the Atlantic Mermaid had the conduct of the navigation, with the second officer and a helmsman/lookout making up the rest of the bridge team. However, none of the three persons saw Hampoel before the collision.	Missing detection	Manning levels were inadequate. None of the three persons on the bridge saw Hampoel, either visually or by radar, before the collision. Therefore, contrary to the COLREG and Manning on the Bridge, crewmembers were not doing their lookout duties. This leads to a lack of situational awareness and missing the detection.
The Hampoel's Chief officer made a brief VHF call to the approaching vessel which was not answered.	Inappropriate strategy	The Hampoel's Chief officer made a brief VHF call on channel 16 directed to the approaching vessel which was not answered. Using VHF was contrary to the advice given in Marine Guidance Notice' MGN 167 (M+G)', (Maritime and Coastguard Agency, 2017).
Hampoel was maintaining the course line by use of the cross-track-error on the GPS which increased the risk of a close quarter's situation.	Inappropriate strategy	Hampoel was maintaining the course line precisely by use of the cross-track-error on the GPS which increased the risk of a close-quarters situation with overtaking vessels using the same course line.

Table 9. Analysis of contextual conditions for the collision between the Hampoel and Atlantic Mermaid vessels

Factor/Item	Circumstances	Contextual conditions
The master of the Atlantic Mermaid was suffering from a headache and it was over 8 hours since his last rest.	Physiological and emotional factors	The master of the Atlantic Mermaid was suffering from a headache and, although he had slept the previous night and, in the afternoon, it was over 8 hours since his last rest.
The Atlantic Mermaid was in the middle of the Dover Strait, in the most heavily concentrated traffic. It was also night time. This was not an ideal time or place for the bridge team to be reduced	Attitudes and personality	The master at the Atlantic Mermaid might have become less vigilant because the vessel had passed through the busiest and narrowest part of the Dover Strait, and because the traffic around him was travelling in the same direction.
In the Atlantic Mermaid, there was a blind area ahead of the bow of around 50 to 70 metres.	Workplace conditions	The visual lookout at the Atlantic Mermaid may have been hampered by a blind area
The visual lookout at the Atlantic Mermaid was affected by the weather conditions	Workplace conditions	The visual look out at the Atlantic Mermaid may have been hampered by the weather conditions
The master of the Atlantic Mermaid was burdened with entering the chart room to put the vessel's position on the chart, and ensuring she was on the course line, in addition to keeping a lookout, since the second officer was performing non-navigational duties.	Human performance limitations	The second officer, and occasionally the lookout at the Atlantic Mermaid were involved in non-watchkeeping duties which reduced the number of persons keeping a lookout and hence the situational awareness.
The master was new to the company and the Atlantic Mermaid.	Human performance limitations	The master was new to the company and the Atlantic Mermaid and had been in command of her for just a few hours.
No 2 radar (port) at the Atlantic Mermaid had had an intermittent fault for at least 12 months before the collision.	Workplace conditions	No 2 radar's fault occurred apparently only on ranges below 12 miles and on the short pulse. Stabilisation became lost, and, with the heading marker remaining in the correct position, all targets rotated clockwise around the screen. According to the Atlantic Mermaid's radar operating manual: "excessive clockwise rotation may eliminate small targets on the screen".
Hampoel's Chief officer was the sole watchkeeper.	Human performance limitations	Hampoel's Chief officer was the sole watchkeeper.

4.4. The SOAM Chart for the collision between the Hampoel and Atlantic Mermaid vessels

Finally, the SOAM Chart for the collision between the Hampoel and Atlantic Mermaid vessels, which includes the individual contributions and their interrelationships is depicted in Figure 4.

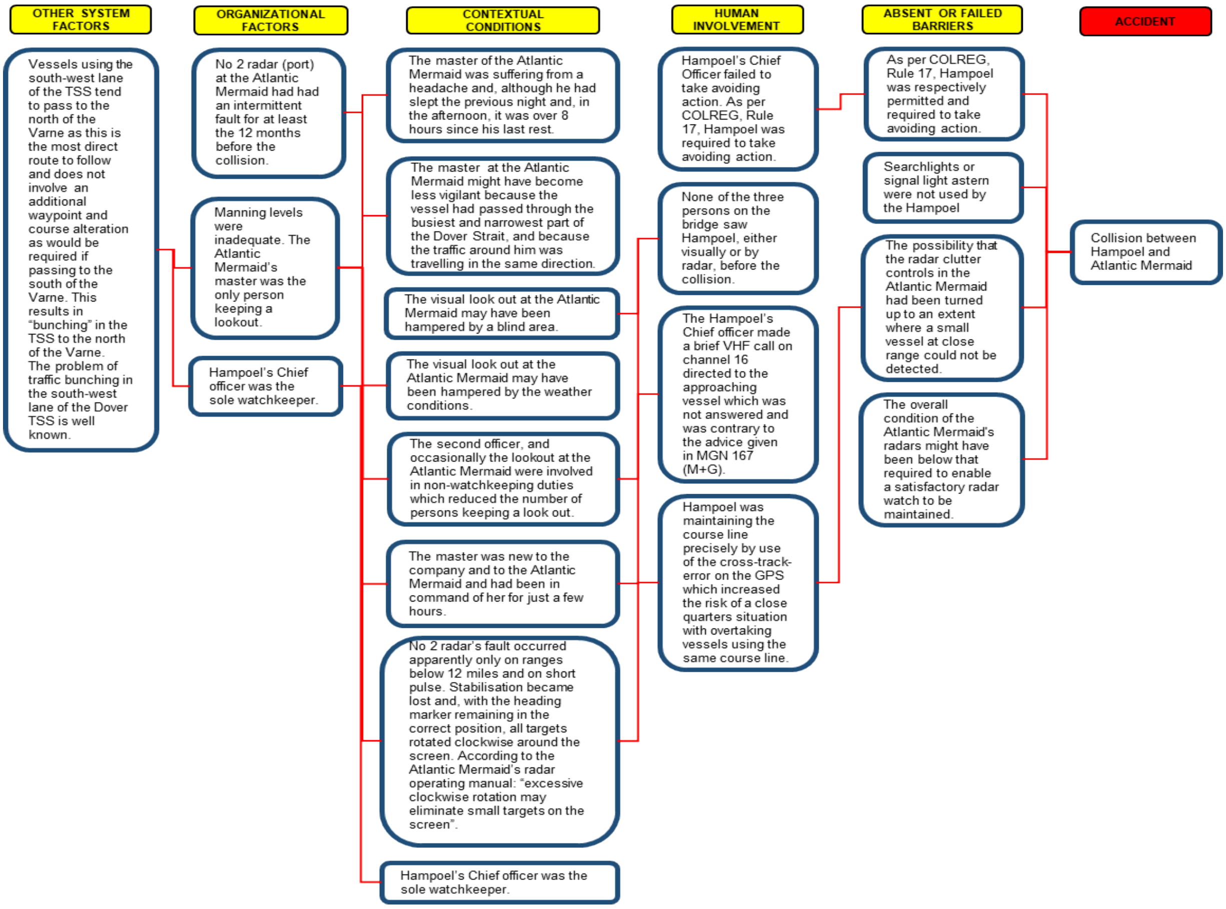

Figure 4. SOAM Chart for the collision between Hampoel and Atlantic Mermaid

5. Results and Discussion

As it was stated before, most of the maritime investigation reports lack a systematic analysis that can provide an insightful explanation of the factors that lead and/or contributed to the accident. Therefore, in the context of this paper, SOAM methodology was selected to explore if a methodology used in aviation can be fully adapted and applied for accident analysis in the maritime sector. SOAM is an effective tool to categorise, visualise and present accident contributors in a practical way, which will enhance learning from maritime accidents, as it is able to capture more accident contributing factors than the current accident reports. In addition, in terms of analysis, SOAM provides more concise information than a factual report, where simple answers to traditional questions such as "What happened, where and when?" are collected. To provide a deeper understanding of the event, SOAM collects data about the conditions that existed at the time of the occurrence, which influenced the actions of the individuals involved. These factors, in turn, must be explained by asking what part the organisation played a role in creating these conditions, or allowing them to exist, thereby increasing the likelihood of a safety occurrence. In addition, SOAM together with the NASAHFACS model supports the fundamental purpose of safety analysis, as it aims to identify and understand the factors that contributed to an accident and to prevent them from reoccurrence.

Moreover, by adopting a systemic approach, SOAM is aligned with the principles of "Just Culture" (Licu, Cioran et al. 2007), which switch the focus from individual errors to latent organisational factors that allowed less than ideal conditions to exist, under which a safety occurrence could be triggered. Therefore, compared to current accident reports, SOAM can provide a richer contributory database that clearly highlights the deficiencies with regards to the human and organisational aspects even in the presence of technical issues. Moreover, SOAM can help accident investigators to gather human and organisational related evidence with regards to maritime accidents to highlight the issue within the regulatory framework as well.

The SOAM methodology consisted of six steps, and the first step is related to data gathering. Although there is not a prescribed method for the gathering of analysis data, the original SOAM methodology applied the SHEL model (Licu, Cioran et al. 2007). Nevertheless, this study opted for using the NASAHFACS model for two particular reasons. First, NASAHFACS is based on the traditional aviation HFACS, but adapted to space operations. Therefore, NASAHFACS is more versatile to be applied in the maritime context than HFACS since it has been already adapted to work in a different domain than the one it was originally designed for (i.e. aviation), and therefore, the NASAHFACS taxonomy is not only targeted to specific terms from the aviation domain. Second, in the SOAM methodology, data should be gathered across five areas (Licu, Cioran et al. 2007) and SHEL covers only four major areas since the organisational element is not addressed in the original SHEL model, as explained in the methodology section.

By applying the NASAHFACS to the selected collision accidents, it was found that most of the factors were related to the preconditions layer (30.28%) followed by the acts layer (25.68%), and the supervision layer (22.94%). The layer with the less amount of related factors was organisation (21.10%). In addition, factors related to the technological environment were also found in the preconditions layer, such as automation or design of the workspace factors that affect the actions of an individual. The importance of design and automation has been discussed extensively in the literature (Hanzu-Pazara, Barsan et al. 2008, Psarros, Skjong et al. 2010). As an example, it was stated that reducing the probability of collision and grounding events can be facilitated with improved bridge design management, also addressing human interaction with navigation systems (Psarros, Skjong et al. 2010). Therefore, given the increasing prevalence of automated systems onboard ships, it is important that the human element is considered throughout bridge design, implementation and operational use. In addition, decision events and lack of resources from the organisation were also found to be contributing significantly to the accidents, which is in line with findings from past studies in the literature (Chauvin, Lardjane et al. 2013, Chen, Wall et al. 2013, Coraddu, Oneto et al. 2020, Navas de Maya and Kurt 2020). Moreover, a more detailed distribution of the factors identified in each accident can be observed in Figure 5.

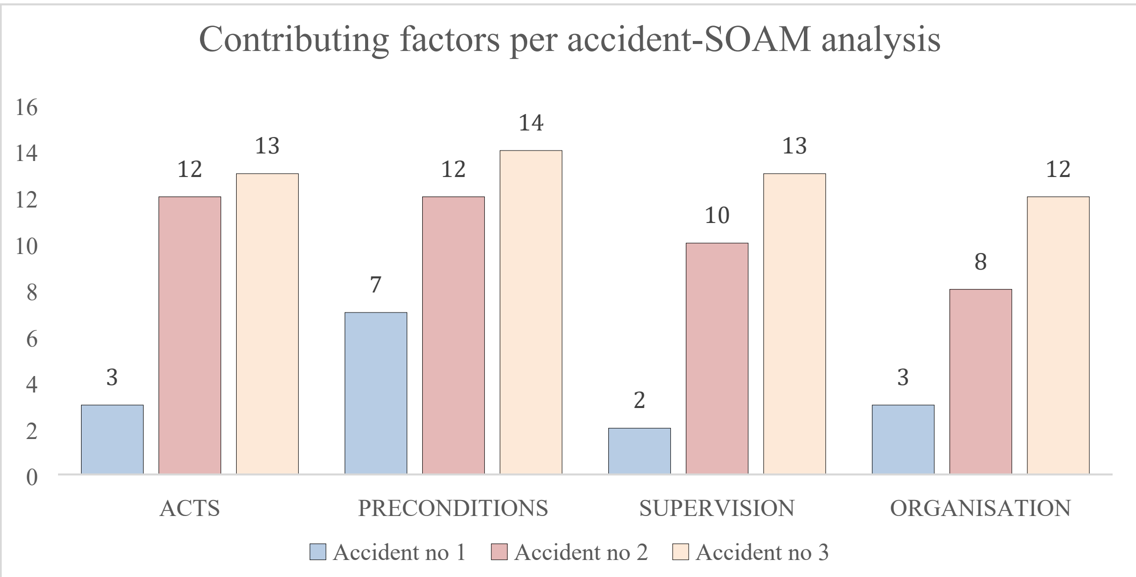

Figure 5. Accident contributing factors per accident analysed

In addition, to validate the findings obtained by applying the SOAM methodology, the results of the SOAM analysis were compared with the causes and the contributory causes, which are included within the conclusion section from the original accident reports. Figure 6 shows the initial distribution of contributing factors amongst each layer from both data sources. It is important to mention that not only the SOAM analysis captured all the major factors included in the original accident reports successfully, but it also identified additional contributing factors as shown in Figure 6. Thus, although the original accident reports were able to capture accident contributing factors amongst the four layers, it is possible to notice the rate between both data sources. For instance, while the original accidents reports only captured six organisational issues, the SOAM analysis together with the NASAHFACS model increased the issues identified by performing a more detailed analysis. Especially, SOAM was able to capture organisational and supervisory issues that are not well-captured on the original accident reports.

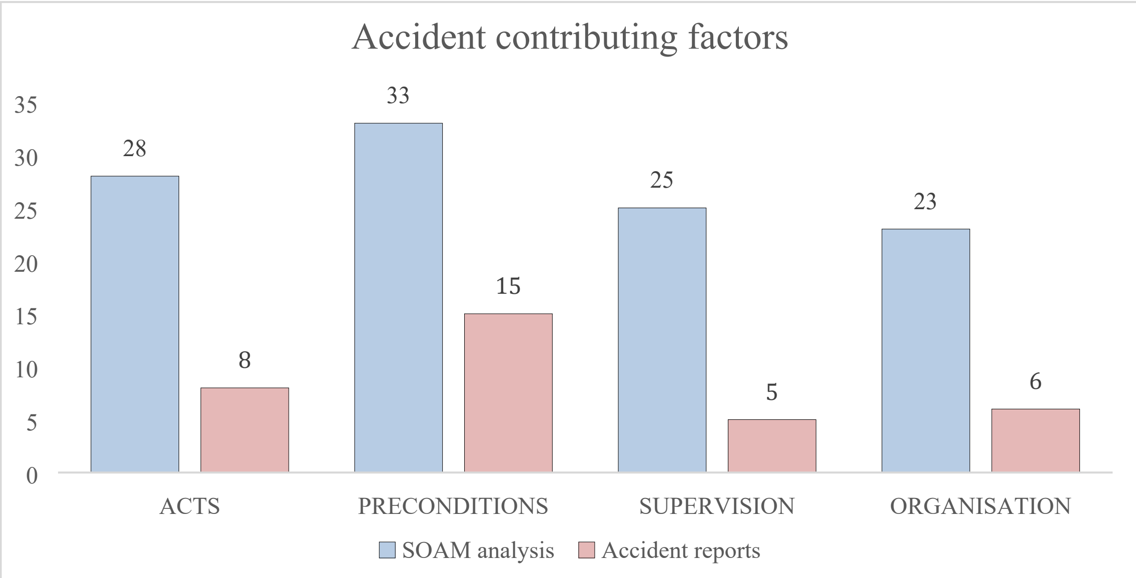

Figure 6. Accident contributing factors per layer. Comparison between the findings from the original accident reports and the results from SOAM analysis

A more detailed comparison between the SOAM analysis and the original accident reports, together with the coding for each contributing factor and the reasoning behind each accident contributing factor selected, is displayed in Table 10.

Table 10. Main causes of the accident. Comparison between the findings from the original accident report and the results from SOAM analysis

Vessel	Main causes of the accident. Original accident reports	SOAM Analysis findings	Coding
Hampoel	Hampoel failed to take avoiding action.	Chief Officer failed to take avoiding action.	AD004 No action executed.
Hampoel	Failing to use a searchlight or signal light astern.	Failed to use searchlights or signal light astern.	AD004 No action executed.
Atlantic Mermaid	N/A	Master had the conduct of the navigation, with the second officer and a helmsman/lookout making up the rest of the bridge team. However, nobody saw Hampoel before the collision.	AD004 No action executed.
Hampoel	N/A	Contrary to the advice given in the regulations and Marine Guidance Notice (MGN 67), the Chief officer made a brief VHF call to the approaching vessel which was not answered.	PC005 Failure to communicate critical information.

Vessel	Main causes of the accident. Original accident reports	SOAM Analysis findings	Coding
Atlantic Mermaid	The master was probably feeling tired which, along with his headache, might have impaired his ability to maintain a proper watch.	Master was suffering from a headache and it was over 8 hours since his last rest.	PP202 Fatigue (Physiological/Mental).
Atlantic Mermaid	The master might have become less vigilant because the vessel had passed through the busiest and narrowest part of the Dover Strait, and also because the traffic around him was travelling in the same direction.	The vessel was in the middle of the Dover Strait, in the most heavily concentrated traffic. This was not an ideal time or place for the bridge team to be reduced.	PA001 Channelised attention.
Atlantic Mermaid	The blind area ahead of the bow. The deck cranes obscuring vessels fine on the port bow from where the master probably spent a large proportion of his time.	There was a blind area ahead of the bow of around 50 to 70 metres.	PT006 Workspace Incompatible with Operation.
Atlantic Mermaid	The possibility that the radar clutter controls had been turned up to an extent where a small vessel at close range could not be detected. The overall condition of the radars might have been below that required to enable a satisfactory radar watch to be maintained.	Master was not familiar with the radar control settings and associated problems on this vessel. The vessels' controls and switches had known problems. The vessel had a known radar issue, that has persisted for over 12 months.	PT004 Controls and Switches are Inadequate.
Hampoel	The vessel was maintaining the course line precisely by use of the cross-track-error on the GPS which increased the risk of a close quarters situation with overtaking vessels using the same course line. Failing to appreciate that there was available sea room to port, probably because of his reliance on the GPS for passage monitoring rather than a reference to the working chart.	The vessel was maintaining the course line by use of the cross-track-error on the GPS, which increased the risk of a close quarter situation.	PT005 Automated System Creates an Unsafe Situation.
Atlantic Mermaid	The visual lookout is being hampered by the weather conditions.	The visual lookout was affected by the weather conditions.	PE001 Vision affected by the environment.
Atlantic Mermaid	The second officer was involved in non-watchkeeping duties which reduced the number of persons keeping a lookout.	Master was burdened with entering the chart room to put the vessel's position on the chart, and ensuring she was on the course line, in addition to keeping a lookout, since the second officer was performing non-navigational duties.	SP002 Crew/Team/Flight Makeup/Composition.
Atlantic Mermaid	N/A	Master was new to the company and to the Atlantic Mermaid.	SP004 Limited Recent Experience.
Atlantic Mermaid	N/A	No 2 radar (port) at the Atlantic Mermaid had an intermittent fault for at least 12 months before the collision.	OR004 Equipment.

Vessel	Main causes of the accident. Original accident reports	SOAM Analysis findings	Coding
Atlantic Mermaid	N/A	Master was the only person keeping a lookout.	OR001 Personnel.
Hampoel	The chief officer was being the sole watchkeeper.	The chief officer was the sole watchkeeper.	OR001 Personnel.
Wintertide	N/A	Restricted visibility.	AP001 error due to misperception.
Wintertide	The alteration to 230" was made to follow the planned track and without due consideration for MSC Sabrina overtaking on the starboard quarter.	With an overtaking vessel 1 mile on the starboard quarter in the visibility of between 2 and 5 cables, the alteration to 230" was imprudent.	PE001 Vision affected by the environment.
Wintertide	N/A	The use of chart BA 1408, a small scale chart, may also have influenced the chief officer's spatial awareness, by visually condensing the width of the traffic lanes and influencing his perception of the safe water available.	AD003 Incorrect action executed PP104 Complacency.
Wintertide	N/A	OOWs reliance on GPS.	SP004 Limited Recent Experience.
MSC Sabrina	N/A	Master's night orders gave no specific distance at which to pass other vessels.	AD004 No action executed. PC004 Miscommunication. SF002 – Operations Management. OP005 Publications / Procedures / Written guidance.
Wintertide	The resulting information led the OOW to incorrectly assume MSC Sabrina would pass under the stern.	Chief officer incorrectly assumed that the vessel would pass under the stern to the port quarter.	AD003 Incorrect action executed. SP004 Limited Recent Experience.
Wintertide	The plotting of MSC Sabrina by radar on a six-mile range scale was inaccurate.	The plots were conducted with the radar on the six-mile range scale, so even the smallest movement away from the target echo, while initiating either plot, would have resulted in significant errors.	PP305 Limited experience.
Wintertide	N/A	The radar display in use was not an ARPA. The accuracy of the information displayed relies on a reasonable time interval between manually injected plots, a reliance on the vessel being plotted maintaining a steady course and speed, and the accuracy of the plot by the operator.	OR005 Design.
Wintertide	N/A	It is not known how closely the second officer routinely monitored his radar display.	AP001 error due to misperception.
Wintertide	N/A	It is possible that the crew was distracted by the collision with Concordia.	PA004 Distraction.
Wintertide / MSC Sabrina	N/A	Neither vessel reduced speed on entering the fog, even though visibility was reduced to less than 2 cables.	AD003 Incorrect action executed. PP104 Complacency. SP007 Risk Assessment.
Wintertide / MSC Sabrina	N/A	The requirement to proceed at a safe speed in restricted visibility is endorsed in the company orders of both vessels.	OP005 Publications / Procedures / Written guidance.

Vessel	Main causes of the accident. Original accident reports	SOAM Analysis findings	Coding
Wintertide	N/A	Neither the second officer nor the chief officer called the master.	AD004 No action executed. PC005 Failure to communicate critical information. SP007 Risk Assessment.
Wintertide	Neither master was made aware of the reduced visibility as required by company orders.	The OOW was directed in the company orders, and the master's night orders to inform the master when entering restricted visibility.	OP005 Publications / Procedures / Written guidance.
MSC Sabrina	Neither master was made aware of the reduced visibility as required by company orders.	Second officer did not call the master when visibility was reduced.	AD004 No action executed.
MSC Sabrina	N/A	Since the master was new to the ship, he might not have read and understood the company orders.	PP305 Limited experience. SP004 Limited Recent Experience.
MSC Sabrina	N/A	When to call the master was stated in the company orders.	OP005 Publications / Procedures / Written guidance.
MSC Sabrina	Had MSC Sabrina been making sound signals, they might have been heard, and might have prompted avoiding action to be taken sooner.	The general alarm should have been sounded.	AP001 error due to misperception.
MSC Sabrina	N/A	The vessel attempted to call the vessel via VHF radio but did not get a response.	PC005 Failure to communicate critical information.
MSC Sabrina	A speed of 17.5 knots was not a safe speed in the prevailing visibility. It was too fast to enable sufficient avoiding action to be taken.	Second officer should have reduced speed and remained in a position to render assistance if required.	SV003 Directed Violation.
MSC Sabrina	N/A	Not able to detect the other vessel.	AP001 error due to misperception.
MSC Sabrina	A proper radar lookout was not maintained; the OOW was distracted by the collision with Concordia and did not detect that Wintertide had altered course and was on a steady bearing. An aural lookout was not maintained.	With only two people on the bridge, it is difficult to maintain a comprehensive visual, radar, and aural lookout.	PA001 Channelised attention. SP002 Crew/Team/Flight Makeup/Composition.
Wintertide /MSC Sabrina	Neither bridge was manned as required by company orders.	Company orders state that on entering restricted visibility, a helmsman and lookout should be posted.	OP005 Publications / Procedures / Written guidance.
Wintertide	Lookout was not instructed to keep a lookout astern.	Not able to detect the other vessel.	AP001 error due to misperception.
Wintertide	N/A	With only two people on the bridge it is difficult to maintain a comprehensive visual, radar, and aural lookout.	PA001 Channelised attention. SP002 Crew/Team/Flight Makeup/Composition.

Vessel	Main causes of the accident. Original accident reports	SOAM Analysis findings	Coding
Scot Isles	N/A	Despite the specific requirements contained in the manager's SMS, it was the master's custom not to post a lookout during his bridge watches.	AV001 Violation-Work Around. PA003 Negative Habit (using old procedures for a new system). SP002 Crew/Team/Flight Makeup/Composition. OP005 Publications / Procedures / Written guidance.
Scot Isles	N/A	The master did not leave night orders.	AD004 No action executed. OC002 Climate / Morale.
Scot Isles	N/A	Master assumed that because the bridge watchkeeping officers all held certificates of competency, they were aware of the procedures.	PP103 Confidence level. SI001 Leadership/ Supervision/ Oversight Inadequate.
Scot Isles/Wadi Halfa	The masters of both vessels were complacent, a factor that had not been identified by the respective ship managers and which did not engender best practice in either bridge team.	Master had become complacent.	PP104 Complacency.
Scot Isles	N/A	Master left the second officer as the sole watchkeeping officer.	SP002 Crew/Team/Flight Makeup/Composition.
Scot Isles	N/A	Lookout was unaware that the chief officer had not registered his report.	AP001 error due to misperception. PC004 Miscommunication.
Scot Isles	N/A	Effective Bridge Resource Management was lacking in this case.	SP002 Crew/Team/Flight Makeup/Composition.
Scot Isles	Chief officer demonstrated a complacent attitude to his bridge watchkeeping responsibilities and could have made better use of available resources.	Chief officer was sitting in front of a radar fitted with ARPA, but this facility was not used to acquire and plot any of the radar targets. Chief officer had become complacent.	AV001 Violation-Work Around. PP104 Complacency.
Scot Isles	Chief officer's apparent lethargic approach to his watchkeeping responsibilities was due to a lack of stimuli.	Chief officer failed to maintain a proper lookout by sight or use of the navigational equipment available to him.	PP306 lack of proficiency. SI003 Local Training Issues/Programs.
Scot Isles/Wadi Halfa	N/A	Rule 5 of the COLREGS was not followed.	OP005 Publications / Procedures / Written guidance.
Wadi Halfa	N/A	The vessel's passage through the Sandettie deep water route to the NW of the Sandettie bank was contrary to the advice given on the chart.	AD003 Incorrect action executed.
Wadi Halfa	N/A	Deep water route is for the use of vessels with a draught of 16m or more. Vessel’s draught was less than 6m.	PP404 Misperception of Changing Environment. SP007 Risk Assessment.
Wadi Halfa	N/A	The Admiralty Sailing Directions for the Dover Strait (NP 28), which states that the deep water route is for the use of vessels with a draught of 16m or more.	OP005 Publications / Procedures / Written guidance.

Vessel	Main causes of the accident. Original accident reports	SOAM Analysis findings	Coding
Wadi Halfa	N/A	Master did not leave night orders.	AD004 No action executed. SI001 Leadership/ Supervision/ Oversight Inadequate. OC002 Climate / Morale.
Wadi Halfa	N/A	Master left no night orders on this occasion, he did so the night before and the night following the accident.	PC008 Rank/Position Intimidation.
Wadi Halfa	N/A	Master did not engender best practices in his bridge watchkeeping personnel.	AV001 Violation-Work Around. P002 Crew/Team/Flight Makeup/Composition.
Wadi Halfa	N/A	The owner's required procedures and the recommendations promulgated internationally with respect to bridge watchkeeping were not followed.	OP005 Publications / Procedures / Written guidance.
Wadi Halfa	N/A	Chief officer was then the sole lookout.	AV001 Violation-Work Around. PA003 Negative Habit (using old procedures for a new system). SP002 Crew/Team/Flight Makeup/Composition.
Scot Isles/Wadi Halfa	Navigational equipment was not used effectively and provided an inadequate substitute for maintaining a proper lookout by sight.	Although bridge equipment was available to assist both chief officers in keeping a proper lookout in the absence of a dedicated lookout, this was not used effectively.	AD003 Incorrect action executed. PP306 lack of proficiency.
Scot Isles/Wadi Halfa	N/A	The need to maintain a proper lookout should determine the basic composition of the navigational watch. A dedicated lookout should be an integral part of the bridge team.	SP002 Crew/Team/Flight Makeup/Composition.
Scot Isles/Wadi Halfa	N/A	MGN 315 (M) and the Bridge Procedures Guide were not followed.	OP005 Publications / Procedures / Written guidance.
Scot Isles/Wadi Halfa	Safety management system non-conformities on each vessel with respect to the formation of effective bridge teams and the use of lookouts had not been misidentified during internal company audits.	The company had failed in the formation of effective bridge teams.	OC001 Culture.
Scot Isles	N/A	The crew did not sound the alarm or carry out a full muster.	AD004 No action executed. PC004 Miscommunication. SP007 Risk Assessment
Scot Isles	N/A	The vessel was not detected prior to the collision.	AP001 error due to misperception.
Scot Isles	N/A	Chief officer periods of rest were interrupted by the operational requirements of the vessel's arrival and departure from Rocheste.	PP202 Fatigue (Physiological/Mental). SP002 Crew/Team/Flight Makeup/Composition.

For instance, by looking at the first accident analysed, the main cause of the collision as per the accident report was Atlantic Mermaid failing to observe the presence of Hampoel which also failed to take avoiding action (MAIB 2002). This factor was also recorded in SOAM under human involvement as an incorrect interpretation of the current regulations, since as per COLREG, Rule 17, Hampoel was required to take avoiding action. Moreover, from the Atlantic Mermaid perspective, the accident report (MAIB 2002) found as contributing causes mainly technological environment factors (i.e. the blind area ahead of the bow and the deck cranes); inadequate resources (i.e. the faulty radar and the number of persons keeping a lookout); weather conditions; and adverse physiological conditions (i.e. the master was probably feeling tired which, along with the headache from which he was suffering, might have impaired his ability to maintain a proper watch). All the above-mentioned factors were also successfully captured via the SOAM analysis, In addition, SOAM was also able to capture additional details such as the fact that No 2 radar (port) had an intermittent fault for at least the 12 months before the collision. Although this factor was mentioned in the accident report, it was not highlighted as a contributory cause of the accident. On the other hand, from the Hampoel perspective, the accident report (MAIB 2002) found as contributing causes inadequate resources (i.e. a sole watchkeeper), technological environment factors (i.e. over-rely on GPS system), and inadequate decisions (i.e. failing to use a searchlight or signal light astern). The SOAM analysis also captured the previous factors together with further insight, such as the fact that the chief officer made a brief VHF call to the Atlantic Mermaid vessel, which was not answered or the fact that that the chief officer should have followed COLREG regulations and use light and sound signals. These facts were also mentioned in the accident report, however, it was not defined as a contributory cause of the accident. Therefore, as per the SOAM analysis, many organisational aspects were captured as contributing factors in this accident, which led to the confirmation that SOAM can provide a richer contributory database that highlights the deficiencies related to organisational aspects.

Finally, regarding the advantages of the SOAM methodology, first, it is a suitable method for capturing and organising the key human elements of interest in accident analysis. In addition, SOAM does not require a high level of expertise. While competent investigators will always be required for complex analyses, SOAM is suitable for use with all levels of occurrence by investigators with limited training and experience (Licu, Cioran et al. 2007).

6. Conclusions

This paper has investigated the feasibility of applying the SOAM methodology, which was originally developed for the aviation domain, together with the NASAHFACS to identify the main accident contributors into three maritime accidents. In addition, SOAM allows for a better visualisation of the accident evolution, which can be very beneficial for structuring the accident, and allows to understand the accident process better. This information can be extremely valuable for maritime stakeholders, especially ship owners and shipping companies since they can allocate more efforts to addressing the major accident contributors identified. Moreover, it can unveil contributory factors that are not identified as contributing factors in an accident analysis report, thus it might help marine safety experts and professionals to draft better safety policies by including barriers or optimise processes.

With this aim in mind, three accident analysis reports were first obtained to provide an initial understanding of the accidents. Secondly, a more detailed analysis was carried out by a group of experts in ship operation, human factor, ship design, accident analysis, and maritime safety areas that consisted of applying the SOAM methodology into the aforementioned accidents. This allowed for the identification of the main accident contributing factors. In addition, the analysis conducted revealed that the collision accidents analysed were the result of a combination of organisational factors, absent or failed barriers, human involvement, and contextual conditions. SOAM together with the NASAHFACS are trying to capture the human and organisational issues that are not necessarily captured by the current accident reports. For instance, in the case of the first accident analysed, the Atlantic Mermaid communication technology failed and this was revealed crucial by the SOAM analysis. Thus, SOAM is trying to capture those elements in a systematic manner, and if this is applied to additional accident reports, it will provide a rich database of evidence highlighting the deficiencies with regards to the human and organisational aspects.

Furthermore, although the proposed application of the SOAM methodology to identify maritime accident contributors is novel, it is worth highlighting some limitations. First, it was only demonstrated on three maritime accidents, hence, it will be necessary to apply SOAM to additional accidents in order to discover and highlight the main advantages of this methodology. Second, as SOAM is a relatively new method when compared to the traditional systemic methods for accident analysis, a limited amount of guidance, previous studies, and applications are available. Considering this limitation, for the analysis of these collision accidents, experts were selected with a relevant background in ship operations, knowledge of regulatory elements, or expertise in Human Factors. In addition, results of these analyses were also discussed in a workshop involving a Master Mariner, a Chief Officer, and a Deck officer, who agreed not only with the factors selected as contributing to this accident but also with the reasoning behind the selection.

Regarding future applications, the SOAM methodology can be further applied in the maritime sector, including a larger database of accidents. This will allow us to identify trends on the most critical contributing factors and to encourage a more official adoption of the SOAM methodology for maritime accident analyses. Moreover, it can also be applied to identify the main accident contributors in other critical domains such as nuclear, railway, or chemical. Finally, after applying the SOAM methodology, recommendations can be formulated upon the results. The formulation of recommendations for corrective action in an accident analysis process is a final critical element, since the quality and practicality of the formulated recommendations will determine their acceptability (Licu, Cioran et al. 2007). In addition, it is important to mention that the purpose of this work was to show and demonstrate that SOAM can be used as a tool to support for maritime accident investigation as well as analysis. In order to demonstrate if its application will produce more insightful results than other methods, further studies need to be conducted as a comparison study is beyond the scope of this paper.

Finally, the level the detail in maritime analyses change from accident to accident, but in general, a detailed report is available describing the sequence of events and main findings. However, the key problem is that the details about human contributors are not systematically analysed and reported in a way that makes future extraction of trends and comparisons possible. As a result, in maritime, each accident is treated as a unique case, and recommendations will stay mainly at the "act level". In this situation, the outcome of analyses may lead to punishing those involved in accidents but may fail to provide deeper "structural" recommendations, including organisational issues, to prevent reoccurrence. Therefore, a more systematic approach for analysing and recoding human contributions and factors affecting human performance is needed so that learning from accidents can be improved.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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