PRELIMINARY HAZARD ANALYSIS FOR AN INNOVATIVE CONTAINER FEEDER CONCEPT

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ABSTRACT

To achieve the goal of sustainability, the maritime industry is currently searching for solutions to decrease emissions and increase efficiency. Towards this end, innovative vessel concepts typically integrate technologies and design solutions, for which, international regulations with detailed design requirements may not yet be in place. In this context, the designer must rely on risk-based design approaches to ensure the design is adequately safe from the early stages of design. Within the EC-funded H2020 project MOSES, an innovative container feeder vessel concept, with highly automated functionalities, has been developed for achieving zero-emissions operation. This paper presents the results of a Preliminary Hazard Analysis (PHA) with the objective to evaluate potential hazardous events and identify possible risk mitigation measures. The identification process resulted in twelve hazardous events, nine of which are considered high-risk, and in requirements for different ship systems that provide the basis for more detailed levels of design.

KEY WORDS

Risk-based design, Preliminary Hazard Analysis, Innovative design, Container feeder vessel, Risk mitigation measures

1. INTRODUCTION

The maritime industry is currently searching for solutions to decrease emissions and increase efficiency for achieving sustainability goals. Towards this end, research efforts are targeted at producing new vessel designs that implement innovations with respect to powering configurations and increased automation. Innovative vessel concepts typically integrate technologies and design solutions, for which, international regulations with detailed design requirements may not yet be in place (see Papanikolaou 2009). Although general guidelines have been published on how these designs may be treated for approval, for example by Classification Societies and Industry bodies, such as the guidelines from Lloyd's Register (2016), the designer must implement tailored risk-based design approaches to ensure the design is adequately safe.

In this context, risk assessment techniques are applied from the early design stages for deriving requirements and focusing the design process on aspects that require more detailed analysis. Indicative examples in the literature include the work by Thieme et al. (2019) who conducted a Preliminary Hazard Analysis (PHA) for an autonomous, small passenger ferry where the list of hazards resulted from expert workshops, their evaluation followed a semi-quantitative approach based on risk matrices, and risk reduction measures were identified for inclusion in the system design. To assess the safety of an autonomous inland waterways ship during the early design phase, Bolbot et al. (2021) have implemented a Hazard Identification (HAZID) process that integrates safety, security and cyber-security issues, and considers the uncertainty of the frequency and consequence severity expert estimations by calculating standard deviations for the corresponding indices.

In the context of the EC-funded H2020 project MOSES (AutoMated Vessels and Supply Chain Optimisation for Sustainable Short Sea Shipping), an innovative container feeder vessel concept has been developed for achieving zero-emissions operation that includes highly automated functionalities with the outlook of autonomous operation in the future. Compared to existing feeders, this vessel includes innovative design choices, which address one of the main expected impacts of the MOSES project. This involves creating sustainable feeder services from large container terminals to small ports with limited or no cargo handling infrastructure. Small ports will therefore be able to actively participate in the EU container supply chain, which in turn will stimulate modal shift from land-based transport modes (i.e. road, rail) to Short Sea Shipping (SSS). The new feeder services will also have the added benefit of decongesting road infrastructure around large container terminals and, as a consequence, reduce the ports' environmental footprint.

The objective of this paper is to present the results of a PHA, which followed the concept design process with the objective to evaluate potential hazardous events that are related to the innovative design choices that have been made and provide a basis for more detailed risk analyses, as well as possible risk mitigation measures to be considered in the detailed design phase. The methodology that has been applied is based on structured brainstorming sessions involving experts. The analysis does not aim for a comprehensive identification and therefore does not include an exhaustive list of hazards. For a more comprehensive list for open-top, diesel powered containerships, the reader is referred to the submitted Formal Safety Assessment for Containerships (IMO 2007).

The rest of this paper is structured as follows: Section 2 outlines the methodology implemented for identifying hazards and risk mitigation measures. Section 3 describes the operational context for the innovative feeder vessel and the main characteristics that differentiate it from existing container feeder designs. Section 4 presents the results of the hazard identification process based on the estimated frequency and consequence severity and identifies the hazardous events with the highest risk. Section 5 discusses the implications with respect to design requirements that may be considered in more detailed design phases with reference to relevant rules and regulations. The paper concludes with a summary of the main results.

2. METHODOLOGY

The methodology for hazard identification is based on the PHA that is typically used in the early stages of system design (Rausand 2011) for "establishing the initial system safety requirements (SSRs) for design from preliminary and limited design information" (Ericson 2005). According to Rausand (2011), PHA is a brainstorming technique where experts participate in the following activities: 1) identification of hazards and hazardous events, 2) determining the frequency of hazardous events, 3) determining the consequences of hazardous events, 4) suggesting risk-reducing measures, and 5) assessing the risk.

According to the IMO's Formal Safety Assessment guidelines (IMO 2015b), a hazard is defined as "a potential to threaten human life, health, property or the environment". Hazards are considered the source of danger and therefore are not events, but a prerequisite property, situation, or state that may lead to a hazardous event and harmful consequences (Rausand 2011). In the context of this analysis, the definition of risk is taken from the IMO FSA as "the combination of the frequency and the severity of the consequence".

The PHA for the innovative feeder has been conducted through brainstorming sessions involving the expert design team. The results of these sessions included the hazards and the corresponding hazardous events, consequences, and potential risk reducing measures (design and operational). The frequency and the severity of the consequences for each hazardous event in the list was rated separately by the experts. For determining the consequences, a worst-case approach has been followed.

The frequency, consequence severity, and risk were assessed with indices that were adapted from the IMO FSA guidelines. The frequency (FI) and severity (SI) indices were defined on a logarithmic scale, where the "distance" of each level is one order of magnitude (see Table 1 and Table 2). The FI and SI indices were separately assessed by each expert and the corresponding average was assigned to each hazardous event. With respect to the FI, Table 1 includes an approximate quantitative frequency only for reasons of completeness and therefore these numbers were not used in the risk assessment.

For the consequence severity, a separate SI has been determined for the following impact areas (see Table 2): 1) safety, related to human health (incl. injuries and fatalities), 2) environment, related to pollutant spills, 3) property, related to minor (local) and major damage to equipment or the ship, up to total loss, and 4) supply chain, related to delays in delivering cargo (i.e. the mission of the innovative feeder) and ultimately disruption of the cargo transport service. Combined with the FI, four different risk indices have been calculated. In addition, the SI includes a level that points to no consequences and therefore no risk related to specific impact areas, similarly to the approach by Thieme et al. (2019). This reflects the fact that a hazardous event can have, for example, an impact on human safety but not on the environment.

Table 1: Definition of the frequency index (FI)

FI	**Frequency**	**Definition**	**F (per year)**
4	Frequent	Likely to occur several times per year	1
3	Reasonably probable	Likely to occur several times in the ship's lifetime	0,1
2	Remote	Likely to occur once in the ship's lifetime	0,01
1	Extremely remote	Unlikely to occur during the ship's lifetime	< 0,01

Table 2: Definition of the consequence severity index (SI)

SI	**Severity**	**Safety**	**Environment**	**Property**	**Supply chain**
0	None	No injuries	No pollution	No damage to equipment, ship	No disruption
1	Minor	Single or minor injuries	Minor (local) pollution	Local damage to equipment, ship	Minor delays
2	Significant	Multiple or severe injuries	Significant pollution	Non-severe damage to ship	Significant delays
3	Severe	Single fatality or multiple severe injuries	Severe pollution, contained locally	Severe damage to ship	Severe delays
4	Catastrophic	Multiple fatalities	Severe pollution, not contained	Total loss	Cargo delivery disrupted

The risk index (RI) was calculated as the sum of the average FI and SI (see Table 3) from the individual expert assessments. In the context of this analysis, the hazardous events have been comparatively ranked in terms of risk without considering specific risk acceptability criteria to differentiate between unacceptable and acceptable risks. However, to identify the hazardous events that could be prioritised for further analysis, high-risk events have been considered as follows:

- Reasonably probable and frequent events with severe consequence in any one of the impact areas (RI = 6, 7).
- Remote, reasonably probable, and frequent events with catastrophic consequence severity in any one of the impact areas (RI = 6, 7, 8).

Table 3: Definition of risk index (RI)

FI	Frequency	Severity (SI)			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
4	Frequent	5	6	7	8
3	Reasonably probable	4	5	6	7
2	Remote	3	4	5	6
1	Extremely remote	2	3	4	5

The results of the PHA were documented in a worksheet that included the following fields, in addition to the FI, SI, and RI indices: system component, hazard, operational phase where the hazardous event may occur, description of the hazardous event (incl. technical failures and operation outside the safe envelope of the system), description of the consequences in a worst-case scenario, maximum RI that is the highest RI in any impact area and is used for identifying the highest risks, and a description of possible risk mitigation measures.

3. MOSES INNOVATIVE FEEDER DESCRIPTION

3.1 CASE STUDIES AND MAIN PARTICULARS

Within the context of the MOSES project, two different case studies (or business cases) have been examined with respect to the operational context of the innovative feeder. One in the Eastern Mediterranean in Greece and one in the Western Mediterranean in Spain. Both involve a hypothetical, new feeder service from a large container terminal (Piraeus in Greece and Valencia in Spain) to smaller ports, which currently serve limited or no container traffic.

The main objective for the Greek case is to decongest the container terminal of Piraeus and integrate small Greek ports into the container supply chain. The total route of 266 nm shown in Figure 1 includes the port of Piraeus and the following six ports, which currently receive general cargo traffic handled by trucks and trailers through Ro-Pax and Ro-Ro lines: Kea, Syros, Tinos, Mykonos, Naxos and Paros. These ports were selected because they gathered 87% of the total Ro-Ro traffic in 2019 (Hellenic Statistical Authority 2019).

The main objective for the Spanish case is to decongest truck transport traffic in the Valencia port area and connect it to the other two satellite ports in Sagunto and Gandia (Figure 2). Sagunto currently serves three container lines, Gandia does not serve any container line, while there is no feeder line connecting these three ports. In addition, hinterland traffic is currently handled through trucks and rail. The round trip for this route has been estimated equal to 85 nm.

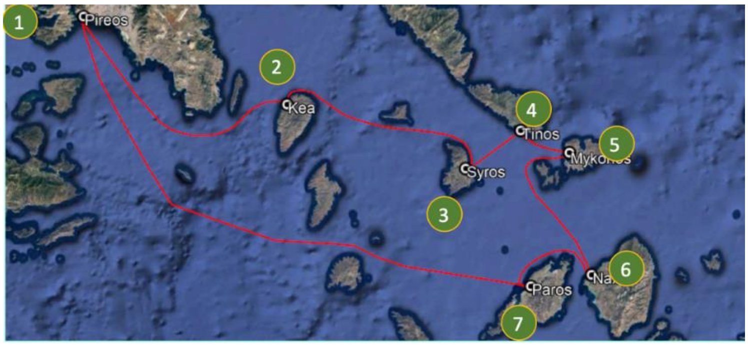


Figure 1: The route of the Greek feeder vessel proposed to link the ports of Piraeus, Kea, Syros, Tinos, Mykonos, Naxos and Paros

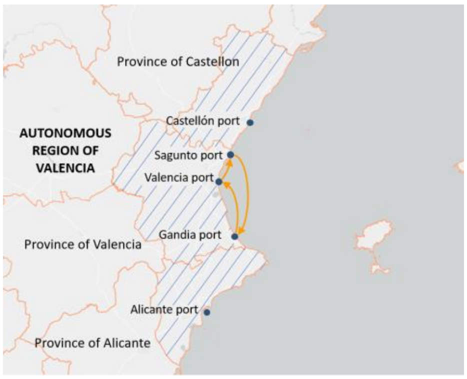


Figure 2: Feeder route proposed to link the ports of Valencia, Sagunto and Gandia

To address the specifics of these case studies, the MOSES Innovative Feeder is designed as a low-capacity container feeder vessel equipped with a highly automated cargo handling system, the MOSES Robotic Container-Handling System, environmentally sustainable propulsion, and envisioned with autonomous functionalities in the future. It will have improved environmental footprint by minimizing emissions during sailing and achieving (near) zero emissions in port. The automated cargo handling system will allow the feeder vessel to be self-sufficient in terms of (un)loading containerized cargo. This aims at solving the problem of missing operational capacity in small ports by (un)loading directly on/from a dedicated area of the quay or on/from container trucks. In addition, it will allow it to be independent from the availability of port services in the large port by not depending on the use of gantry cranes with high operational cost.

The design process has led to the development of three variations that serve the specific needs of the MOSES case studies, two for the Greek case (Greek feeder I is shown in Figure 3) and one for the Spanish case. The main differentiations are related to the capacity, which has been based on estimations for the container demand in each case, and the service speed and range, which have been determined from the operational profile in each case (see Table 4).

(a) (b)

Figure 3: 3D representation of the Greek feeder I concept design: (a) General Arrangement, (b) Accommodation superstructure positioning

Table 4: Main particulars of the innovative feeder concept designs

Category	**Description**	**Symbol**	**Value**			**Units**
			Greek I	**Greek II**	**Spanish**	
Main dimensions	Length over all	Loa	82,00	72,65	135,00	m
	Length between perpendiculars	Lpp	80,00	71,00	132,00	m
	Length on waterline	Lwl	81,50	72,50	134,30	m
	Breadth, moulded	Bm	15,00	13,00	21,00	m
	Draught, summer	T (summer)	5,00	4,50	7,25	m
	Depth, to main deck	D	8,80	7,83	9,5	m
	Block coefficient	Cb	0,683	0,670	0,834	-
	Capacity	-	177	106	670	TEU
	Gross Tonnage	GT	2180	1453	7144	gt
Machinery	Propulsor type	-	2 Azimuth pushing thruster			units
	Required Shaft Power	P (shaft)	798	651	1763	kW
	Propeller type	-	Open, B-Series propeller			-
	Design speed, T (summer)	Ds	10	10	5	kn
	Range	R	266	266	85	nm
Weight	Displacement (sea)	DISM	4207	2914	17197	t
	DWT (Payload)	Containers (13.5 tonnes / container)	2241	1350	9153	t

3.2 DESCRIPTION OF INNOVATIVE DESIGN CHOICES

The following sections briefly describe the innovative design choices that have been made for the MOSES feeder, compared to typical container feeders, which have been used as the ship systems of interest for the hazard identification process.

3.2.1 ENGINE AND PROPULSION MACHINERY CONFIGURATION

In the concept design process the following engine configurations have been examined: hybrid, including a methanol Internal Combustion Engine (ICE) and batteries, and fully battery powered. For the hybrid installation, the methanol tanks have been designed with cofferdams to limit potential leakages. Additional safety barriers that would be required for using methanol as fuel have not been included at this early design phase. The all-electric alternative is considered the most appropriate for the envisioned autonomous operation considering that on board human intervention in case of machinery failure would not be required.

For propulsion and steering, the concepts have been designed with Azimuth thrusters, which although are not the most efficient type for sailing longer distances, have been selected for their enhanced manoeuvrability at low speeds. This will allow the feeder with the automated cargo handling system to perform (un)loading operations without using mooring lines through Dynamic Positioning (DP). The propulsion configuration has been designed to be redundant with the electric grid separated in a port and starboard system. This ensures that a failure in the grid, such as a short circuit, will maintain one propulsion line operational and optimal power management. This arrangement also serves the purpose of supplying power in case of partial grid failures but does not cover the need of additional power for emergency use.

The innovative feeder concepts have also been designed to achieve lower than typical speed, compared to existing container feeder designs, to serve the needs of the vessel's operational profile. At this early stage of the design, the effect of low design speed in cases of extreme weather conditions in the areas of operation has been considered. Specifically, for the Spanish case, which has the lowest service speed (i.e. 5 kn), the propulsor parameters were selected for a condition that enables to sail at 10 knots to be able to provide additional power to the units in case of bad weather conditions when the thruster units will operate at higher loads.

3.2.2 CARGO SPACE

The Greek case I concept has been designed without cargo hold hatches, a design choice that benefits from increased productivity in terms of reduced port turnaround times, increased voyages per year and lower labour and port costs (Bendall and Stent 1995). To limit water ingress and accumulation in the cargo hold during adverse weather conditions, a forecastle with adequate height has been included as per the IMO Interim Guidelines for Open-top Containerships (IMO 1994). It is noted that the Greek case II and Spanish variations have been designed with conventional hatch covers.

3.2.3 ACCOMMODATION SUPERSTRUCTURE LONGITUDINAL POSITION

For the Greek case, the accommodation block, which consists of three decks and the navigational bridge deck (see Figure 3.b), has been positioned at the fore part of the vessel to ensure better visibility during open sea navigation and port operations. Considering the open-top design of the Greek case I, the fore positioning of the superstructures contributes, together with the forecastle, to preventing water ingress inside the ship's cargo holds in case of extreme seas.

For the Spanish case, the accommodation block, which consists of four decks and the navigational bridge deck, has been positioned at midship. The position was determined as per SOLAS Annex A Chapter V Regulation 22, concerning the navigation bridge visibility for ships more than 55 m in length related to the conning position.

4. PRELIMINARY HAZARD ANALYSIS RESULTS

To provide a framework for identifying hazardous events during the brainstorming sessions, the scope of the analysis was determined based on the following: 1) the system component, 2) the types of hazards (or hazard sources), and 3) the operational phase of the innovative feeder. In addition, it should be noted that the hazard identification process was not conducted for each variation of the concept design (i.e. Greek and Spanish cases) separately but considered common hazardous events.

The system components that have been selected are those related to the innovative design choices described in Section 3.2 and include the following: engine and propulsion machinery, fuel/energy storage system, cargo space, and accommodation superstructure. The hazards identified relate to technical failures, human factor issues, properties of the energy source used, and issues related to the limits of the operational envelope and have been categorised as shown in Table 5.

With respect to the operational phases of the innovative feeder, the scope of the PHA included the following overarching categories due to the preliminary nature of the analysis: 1) sailing (open sea, shipping lane, port manoeuvring), and 2) cargo operations during (un)loading at berth.

Table 5: Description of hazard categories identified during the expert brainstorming sessions

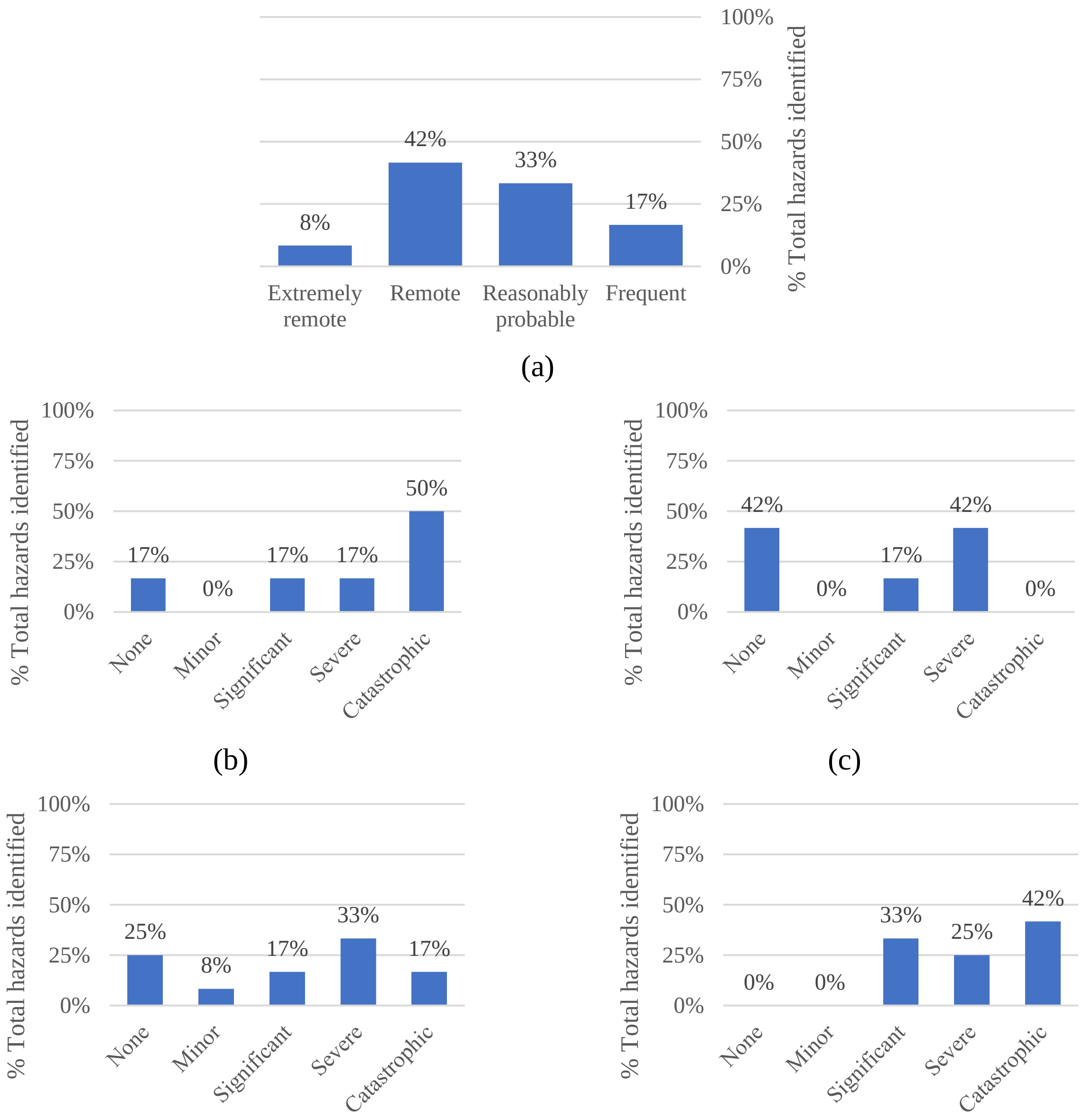
Hazard	**Description related to hazardous events**
System complexity	Operation and maintenance of complex machinery systems (e.g. a hybrid power installation)
Market volatility and variability	Assumptions used in the design process regarding the vessel's mission
Extreme weather	The effects of extreme weather (i.e. wind and waves), including technical failures and the resulting vessel motions
Energy source	The use of methanol as fuel (e.g. toxicity and low flashpoint of methanol) and batteries (e.g. overheating)
Crane operation	The autonomous operation of the on board MOSES Robotic Container-Handling System, as affected by its longitudinal positioning
Evacuation	The effect of the accommodation block's longitudinal position on a safe evacuation process
Situational awareness	The situation awareness required by the crew for maintaining the safety of the vessel throughout its operational phases

The PHA resulted in the identification of twelve hazardous events. Most of the identified events relate to the fuel/energy storage system and the energy source (4 events) during sailing. The events related to engine and propulsion machinery are attributed to system complexity, market volatility and variability, and extreme weather (3 events). The events related to the cargo space are attributed to crane operation and extreme weather during (un)loading at berth (2 events) and water ingress during extreme weather conditions (1 event). The accommodation superstructure relates to hazardous events during evacuation and situation awareness during the sailing phases (2 events).

In terms of expected frequency, 9 hazardous events have been assessed as "Remote" and "Reasonably probable" (42% and 33% in Figure 4 (a) respectively). The following events are expected to occur most frequently during the ship's lifetime:

- **Position of the container crane on board impedes operation of port cranes (event #8)**: The feeder vessel is expected to be (un)loaded using the port cranes once or twice a week.
- **Water accumulates in cargo hold in harsh weather conditions due to open top design (event #12)**: The innovative feeder and particularly the Greek case variations are expected to be exposed to extreme weather several times per year.

Figure 4 (b) – (e) show the distribution of the consequence severity of the identified hazards for each impact area respectively. In terms of safety, all hazards are assessed to have at least significant (i.e. multiple or severe injuries) up to catastrophic (i.e. multiple fatalities), which consist 50% of the identified hazards. In terms of environmental consequences, about 59% of the hazards (7 events) are expected to have significant and severe effects. Similarly, in terms of damage to property, 50% of the hazards (6 events) may have significant, non-severe damage to ship) and severe damage. The consequences on the supply chain for all the identified hazards range from significant (i.e. significant delays in delivering cargo) up to catastrophic (i.e. disruption of cargo delivery). Overall, the most severe consequences are those related to human safety and disruptions to the supply chain.



(a)

(b)

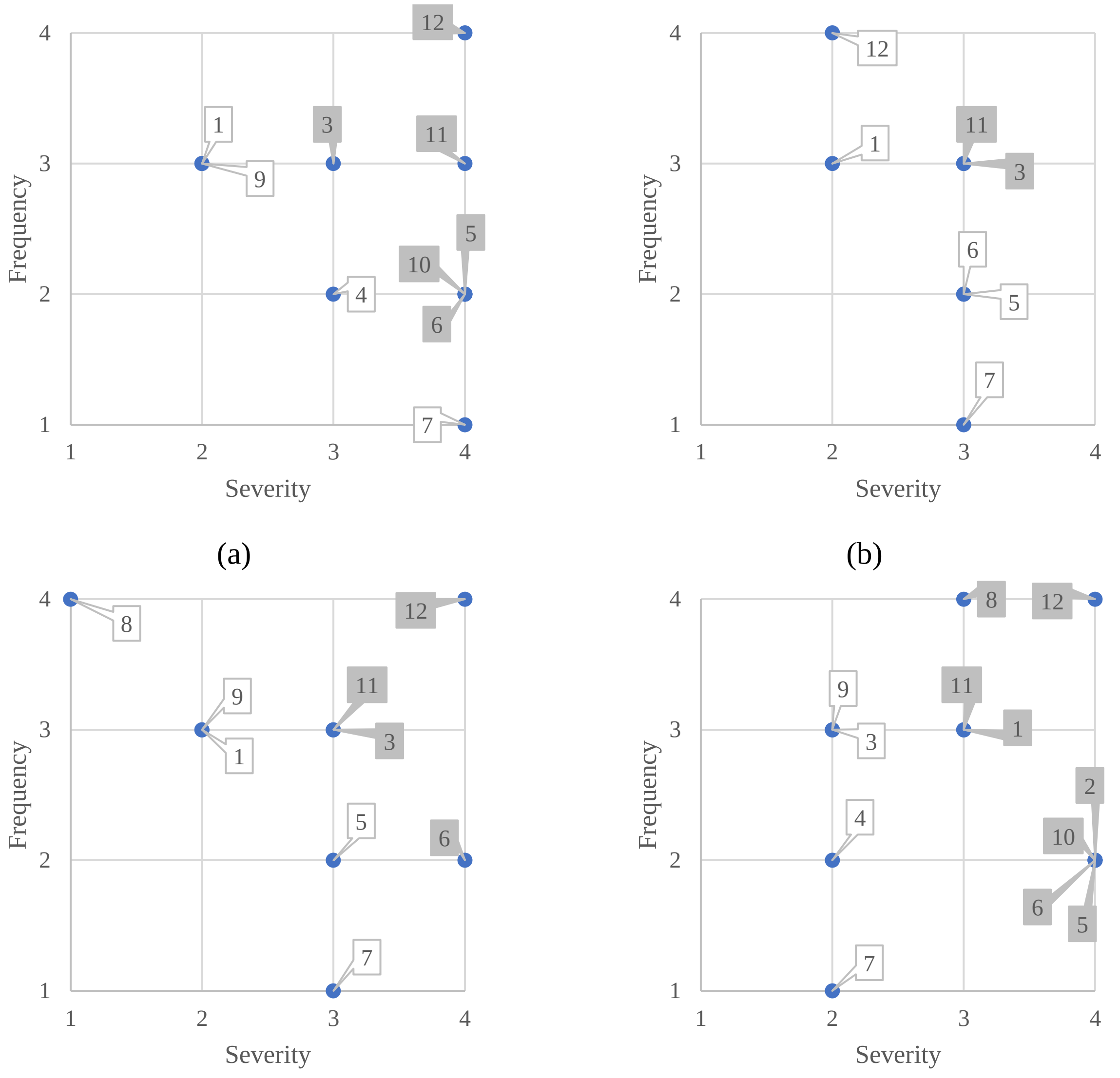
(c)

(d)

(e)

Figure 4: Percentage distribution of total identified hazards according to: (a) frequency, (b) safety consequence severity, (c) environment consequence severity, (d) property consequence severity, and (e) supply chain consequence severity

Although the hazard identification process did not produce an extensive list of hazardous events, identifying high risk events, as described in Section 2, was considered useful for further focusing the identification of risk mitigation measures. The high-risk events for each impact area (9 out of the 12 total) are marked in grey colour in Figure 5, which shows the combination of FI and SI for each hazardous event. Overall, the impact areas with the highest number of high-risk events are safety and supply chain disruptions.



(a) (b)

(c) (d)

Figure 5: Combination of FI and SI for each hazardous event: (a) safety, (b) environment, (c) property, and (d) supply chain. The call-out boxes indicate the event ID; the events with the highest risk are marked in grey colour

Table 6 presents the detailed results of the analysis for the high-risk events, which have been assigned the highest maximum RI value (events #8, #11, and #12). The possibility of the on board container handling system to impede operation of port cranes (event #8) is considered a high-risk event in terms of supply chain disruption. The possibility of a fire in the cargo space or cargo shift/loss due to limited visual monitoring from the bridge (event #11) is considered high-risk mainly in terms of safety. The potential stability degradation and cargo damage due to water ingress in extreme weather is considered high-risk from the following aspects equally: safety, property, and supply chain disruptions.

Table 6: Detailed results for the high-risk events with the highest maximum RI value

(System comp.) Hazard [ID]	**Hazardous event**	**Consequence**	**FI**	**SI**				**Max RI**
				Safety	**Environ.**	**Property**	**Sup. Ch.**	
(Cargo space) *Crane operation* [8]	Position of the container crane on board impedes operation of port cranes	Slower cargo handling when using port cranes	4	0	0	5	7	7
(Accom. Superstructure) *Situation awareness* [11]	Relative longitudinal position of accommodation and crane limits visual monitoring of the cargo space from the bridge	Fire in cargo space or cargo shift/loss is not detected on time due to failure in manual supervision	3	7	6	6	6	7
(Cargo space) *Extreme weather conditions* [12]	Water accumulates in cargo hold in harsh weather conditions due to open top design	Stability degradation and damage to cargo	4	8	6	8	8	8

5. DISCUSSION

In this section, we describe requirements for each ship system and identify existing regulations related to the mitigation of the identified hazardous events. Considering the novelty of the design choices, this analysis has included possible hazardous events that may have significant consequences despite the existence of international regulations and class rules and guidelines aiming at prevention. However, where existing and rules and regulations have been identified, the expected frequency has been estimated as remote to account for safety barriers that would be necessary to be included in more detailed phases of the design process.

Although all identified hazardous events are considered in the discussion, high-risk events should be prioritized in more detailed design phases in terms of resource allocation. It should be noted that the possibility for the innovative feeder to not achieve its market objectives (event #2) due to the specificity of the requirements from the case studies (described in Section 3.1) is the only non-technical risk identified. Mitigation measures for this event could include further exploring the design space by making more accurate estimations of current and future market needs and studying the flexibility of the design regarding potential market variations.

Furthermore, it is noted that the main limitation of the employed methodology is that the FI and SI values are the result of objective assessments by the experts that participated in the brainstorming sessions. The uncertainty relating to the implicit assumptions and knowledge that have supported these assessments has not been quantified, as for example done by Bolbot et al. (2021). Therefore the RI values are used only for an initial ranking that can support more detailed risk analyses in the future.

5.1 ENGINE AND PROPULSION MACHINERY REQUIREMENTS

For addressing the maintenance and operation issues attributed to system complexity of the hybrid configuration (i.e. methanol ICE and batteries) in event #1, the design of the power and propulsion system needs to consider the optimal number of crew on board as a function of the targeted level of automation. With respect to handling load variations in extreme weather conditions, which may lead to failure of the generator system (event #3), the battery system, the power and battery management systems should be designed to cope with transient loading efficiently and safely, providing sufficient power redundancy in different conditions (e.g. extreme weather phenomena, max speed, etc.).

5.2 FUEL/ENERGY STORAGE SYSTEM REQUIREMENTS

For the concept designs, renewable hydrogen with Low Temperature Polymer Electrolyte Membrane (LTPEM) fuel cells has also been considered as one of the alternatives, but not covered in this assessment due to the increased complexity and novelty of this configuration.

As methanol is considered a promising option towards the decarbonisation of the maritime industry (see Harmsen et al. 2020), the IMO has published the Interim Guidelines for the Safety of Ships using Methyl/Ethyl alcohol as fuel (IMO 2020), which includes technical requirements and guidelines for conducting risk assessment. For example, the methanol piping system should be specified with a double wall, and the fuel handling system with the ability to be isolated to avoid the crew coming into contact with toxic methanol fumes and/or spills (event #4). Relevant Class notations and guidelines have also been published, for example, the ABS guidelines for methanol as fuel (ABS 2022) and the DNV Low Flashpoint Liquid fuelled engines (LFL) Class notation (DNV 2019), which includes requirements from the vessel's fuel bunkering connection up to and including the consumers. The design should also consider the optimal manning level for effective operation and maintenance, which could contribute to avoiding methanol leakage near hot surfaces in Engine Room (event #5).

For both hybrid and all electric cases, the battery room needs to be designed to be fire-proof according to classification standards. The design specification should also be complemented by detailed risk assessment for the system arrangement and the interactions among the different systems and spaces. These requirements will contribute to avoiding the possibility of a failure in the fuel storage and handling system leading to a fire that can spread to other spaces, such as the battery room and the cargo space (events #6 and #7). The importance of cargo hold fires in containerships are also illustrated in the evaluation in the relevant FSA for containerships (IMO 2007). In addition, previous battery related maritime incidents show that relatively small issues can cause a large and difficult to extinguish fire (Corvus Energy 2020).

It is clear that classification societies, system integrators and suppliers are taking measures to make new systems safer than existing systems through fire proofing, monitoring, and extinguishing systems. However, given the case of the fully battery-electric feeder, the required battery system is beyond any capacity installed to date. The energy storage requirements for the MOSES feeder range from 23 – 37 MWh, which is at least four times higher compared to the 6.7 MWh of batteries installed on the autonomous battery electric container vessel Yara Birkeland (NRP 2021). This makes it more likely that somewhere throughout the ship’s lifetime a hazardous situation occurs, which may not be covered by the classification requirements.

5.3 ACCOMMODATION SUPERSTRUCTURE REQUIREMENTS

The potential limited ability to effectively monitor the cargo space and provide early detection of initiating events (e.g. fires –event #11) could be addressed by increasing visibility from the bridge to 360 degrees and installing sensors for detection to limit the dependence on visual monitoring.

Apart from the requirements set by Class on the relative position of the superstructure position with machinery, fuel handling and battery system positions, requirements regarding safety systems, such as safety corridors, will need to be adopted in the final design, as prescribed in Class rules (e.g. DNV LFL class notation) and the IMO IGF Code (IMO 2016). Furthermore, to evaluate the crew’s access to Life Saving Appliances (LSAs) during an evacuation, considering the longitudinal position of the accommodation block that may lead to delays (event #10), Class rules need to be considered and detailed risk analysis should be conducted. Evacuation analysis should also comply with the IMO regulations, SOLAS Reg. III/31.1.4 (see IMO 2015a).

5.4 CARGO SPACE REQUIREMENTS

The position of the crane on the main deck should be optimised to ensure that the operation of the port cranes is not impeded when (un)loading the innovative feeder (event #8). This process should be complemented with detailed risk assessment to identify more hazardous scenarios and required safety systems (e.g. emergency stop), in accordance with relevant Class rules. In addition, to ensure safe cargo operations without mooring when using DP mode (event #9), additional scenarios should be identified, the capacity of the batteries, the engines, and the thrusters should be evaluated for this state, and a safety system should be designed for safely aborting the operation if necessary. Furthermore, the requirements of additional class notation Crane (DNV 2017), such as safety equipment for locking the crane in a parked position during sailing and for supporting the crane structure, can be considered in the detailed design phase.

With respect to the possibility of water accumulating in the cargo hold in extreme weather due to the open top design (event #12), which is also identified as a high-risk event in the FSA for containerships (IMO 2007), the requirements of Hatchcoverless additional class notation (DNV 2017) can be considered in the detailed design. Furthermore, an analysis based on model tests, as well as assessment of intact and damage stability following the procedure and the requirements described in the IMO Interim Guidelines for Open-top Containerships (IMO 1994) shall be carried out. Additional considerations should be made in accordance with the following rules: IACS UI SC109 Rev.1, Open top container holds – Water supplies; IACS UI SC110 Rev.1, Open top container holds – Ventilation; IACS UI SC111 Rev.1, Open top container holds – Bilge pumping (IACS 2022).

6. CONCLUSIONS

The purpose of the analysis was to identify hazardous events and corresponding risk mitigation measures for subsequent, more detailed design phases of the innovative feeder, which has been conceptually designed within the MOSES project. The motivation for the hazard identification process was based on the innovative design choices, compared to typical container feeders, that include: 1) the alternative powering options of a hybrid (methanol ICE and batteries) and all electric power installation, combined with Azimuth thrusters for propulsion and a lower than typical design speed, 2) the open top hull design of the Greek case I concept variation, and 3) the positioning of the accommodation block at the fore (Greek cases) and midships (Spanish case).

The identification process resulted in a non-exhaustive list that included twelve hazardous events, which involved technical failures, human factor issues, properties of the energy source used, and issues related to the limits of the operational envelope, during all operational phases. The identified events relate to the following system components and hazards, in order of decreasing number of identified events: the fuel/energy storage system and properties of the energy sources (i.e. methanol as fuel and batteries), the complexities for operation and maintenance of the engine and propulsion machinery configuration, market volatility and extreme weather, the cargo space with respect to the operation of the on board container-handling system and extreme weather, and the accommodation superstructure position related to evacuation and situation awareness for cargo monitoring.

Considering the combination of frequency and consequence severity (i.e. risk), six (6) events have been identified as high-risk for human safety, while eight (8) events are high-risk with respect to impact on the supply chain. Considering the maximum RI values, nine (9) hazardous events have been identified as high-risk, which means that they would be prioritized in more detailed design phases with respect to implementing the identified risk mitigation measures. Furthermore, the three high-risk events with the highest maximum RI values are related to the cargo space (on board crane impeding port crane operation, water accumulation in cargo hold in extreme weather) and accommodation superstructure (limited effectiveness of visual monitoring of the cargo space from the bridge).

The analysis resulted in requirements for the ship systems of interest, which are intended to provide the basis for more detailed design stages where specifications may be derived. The existing international regulations and class rules that have been identified mainly relate to the following aspects: using methanol as fuel and batteries as an energy source; estimating the effectiveness of evacuation given the position of the accommodation superstructures; stowage of the Robotic Container-Handling System during sailing; water accumulation in the cargo hold in extreme weather due to the open top design. In addition to implementing existing regulatory requirements in the detailed design stage, the results of this analysis aim to support focusing the design effort on more detailed risk assessments regarding the following issues: optimal manning as a function of the targeted automation level, situation awareness from the bridge, (un)loading without using mooring lines through DP, and handling load variations in extreme weather conditions.

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