THE SHIP SAFETY FROM SEAFARERS PERSPECTIVE: APPLICATION OF FUZZY AHP FOR DECISION SUPPORT

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Abstract. *In recent years, many studies explored the ship safety enhancement through the application of monitoring systems. Despite their indisputable benefit, the growing number of independent safety and control systems is also increasing the amount of information that masters and officers have to deal with. In order to reduce human error occurrence, decision-making techniques allow developing effective onboard Decision Support Systems (DSSs), capable to assess and measure objectively the overall ship safety during navigation as well as during an emergency. In the present work, the fuzzy analytical hierarchical process is applied to define the weights of importance of a large number of criteria and sub-criteria composing a risk-based framework. The framework is devoted to onboard application as a part of DSS in order to quantify the ship safety level during navigation and emergencies. The structure of the framework has been discussed with a small pool of masters from major shipping companies, while the weights of importance have been evaluated on the base of a large group of masters and officers. The analysis, carried out for different ship types, provides a portrait of the seafarers' safety perception, being a solid base for further development of onboard DSSs.*

Key words: *Fuzzy AHP; risk-based framework; onboard safety; decision support*

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1 INTRODUCTION

The human factor is the primary factor in order to assure ship safety during navigation and harbour operations. In fact, during the period 2011-2018, 65.8 % of maritime casualties have been attributed to human errors (EMSA, 2019). Therefore, in order to prevent accidents as well as to soften their consequences, acting on the human factor could have the strongest impact on navigation safety. To this end, seafarers' training can be improved and even more safe procedures can be defined, but also the situational awareness and onboard decision support can play a relevant role. Often, in real operations, situational awareness is far from optimal. Seafarers have to deal with partial or unreliable information, especially on old ships complying with outdated regulations having less stringent requirements concerning onboard detection systems, control systems, etc. Recently, exploiting the onboard monitoring systems, more data can be available on bridge. However, the safety state of the ship is dependant on a very large set of heterogeneous information having different relevance, hence the adoption of several different monitoring and alarm systems could be critical and might lead anyway to human error. In such situations, it is likely to neglect some crucial information during the synthesis process, which is, in any case, subjective and based on the master's experience. This issue has been already reported by masters and officers from the latest large passenger ships. To overcome this problem, a viable solution is the onboard application of decision-making techniques, defining rational and objective synthesis procedures to assess ship safety. The information from all crucial systems should be collected in a single Decision Support System (DSS) capable to perform a reliable analysis, providing the outcomes by means of user-friendly interfaces (**Perera *et al.*, 2012**, **Nordström *et al.*, 2016**). A viable solution could be the application of Fuzzy Analytic Hierarchy Process (FAHP) to assess the safety state of the ship through a modular synthesis process (**Trincas *et al.*, 2017**). The FAHP technique is widely applied in the maritime industry field to support Multiple Criteria Decision Making (MCDM) processes related to economic, technical, safety and design issues. However, its application to a global onboard Risk-Based Framework (RBF) has been only hypothesised in a previous explorative study (**Braidotti *et al.*, 2018a**), based on the opinion of a small set of experts mainly from Academic institutions. Here, to enhance previous results, a revised FAHP methodology has been applied to assess the mutual importance of the criteria and sub-criteria included in an onboard RBF. The framework covers the widest range of safety issues and it is applicable to any ship type. Aiming to an onboard application, a functional and effective structure of the framework cannot be achieved only involving scholars. Therefore, officers and crew members have been inquired to update the RBF's structure, in an initial phase, and then to assess the weights of importance of its criteria and sub-criteria. In this way, multiple subjective experiences are exploited to assess a synthesis process, going beyond the limits related to the assessment based on scholars' opinion only. Finally, the analysis has been carried out highlighting the specific safety issues affecting different ship types.

2 METHODOLOGY

In the present section, the adopted FAHP technique is presented. Namely, the assessment of weights of importance on the base of experts opinion is briefly described. Finally, the group of expert seafarers inquired in the present study is discussed in terms of its composition.

2.1 Adopted Methods. In AHP (**Saaty, 1980**), the problem is decomposed in a hierarchic set of sub-problems subject to the experts' judgement by means of pairwise comparison. For each couple of criteria, sub-criteria or attributes their relative importance is assigned using a linguistic scale. Among MCDC techniques, it provides the methodology to convert those simple comparisons into weights of importance. However, since the experts' opinions are by definition imprecise and vague, the fuzzy set theory has been applied developing FAHP (**van Laarhoven and Pedrycz, 1983**). It is common practice (**Ishizaka and Nguyen, 2013**, **Grošelj and Zadnik Stirn, 2018**) to convert each expert's preference into a triangular fuzzy number $\mathbf{t} = (t^l, t^m, t^u)$ by means of a linguistic scale (**Table 1**). Each expert compares all the couples of criteria via linguistic preferences. Then, all the results are converted into the pairwise comparison matrix containing associated fuzzy numbers:

$$\mathbf{D}^k = \begin{bmatrix} \mathbf{d}_{11}^k & \cdots & \mathbf{d}_{1n}^k \\ \vdots & \ddots & \vdots \\ \mathbf{d}_{n1}^k & \cdots & \mathbf{d}_{nn}^k \end{bmatrix} \tag{1}$$

where $\mathbf{d}^k_{ij}$ is the k-th expert's preference related to the i-th criterion over the j-th criterion.

If more than 7 ± 2 alternatives are considered, the consistency of each pairwise comparison matrix shall be checked and, if necessary, enhanced (**Saaty, 1977**). In the present work, an algorithm based on linear programming (**Zhang *et al.*, 2014**) has been adopted to reduce inconsistency of all pairwise matrixes having a consistency index *NI* greater than 0.1.

When a number $K > 1$ of experts are taken into account, the group fuzzy preferences have to be evaluated. Several methods have been proposed to deal with multiple expert judgements. Among the others, the geometric mean has been applied, since it is one of the higher quality synthesis techniques according to **Grošelj and Zadnik Stirn** (**2018**).

Table 1. Adopted linguistic scale.

	Preference	1st criteria fuzzy number	2nd criteria fuzzy number
1st criteria	Extreme	(9,9,9)	(1/9,1/9,1/9)
	Strong	(6,7,8)	(1/8,1/7,1/6)
	Fair	(4,5,6)	(1/6,1/5,1/4)
	Moderate	(2,3,4)	(1/4,1/3,1/2)
vs	Equal	(1,1,1)	(1,1,1)
2nd criteria	Moderate	(1/4,1/3,1/2)	(2,3,4)
	Fair	(1/6,1/5,1/4)	(4,5,6)
	Strong	(1/8,1/7,1/6)	(6,7,8)
	Extreme	(1/9,1/9,1/9)	(9,9,9)

$$\mathbf{d}_{ij} = \left(\prod_{k=1}^{K} \mathbf{d}_{ij}^{k}\right)^{1/K} \tag{2}$$

Based on averaged preferences, the fuzzy pairwise comparison matrix is updated obtaining the average pairwise comparison matrix **D**. Then, the fuzzy weight $\mathbf{w}_i$ of each criterion is calculated as the normalized geometric mean of all the items from the corresponding row of the average matrix (**Buckley, 1985**):

$$\mathbf{w}_{ij} = \left(\prod_{j=1}^{n} \mathbf{d}_{ij}\right)^{1/n} \otimes \left[\sum_{i=1}^{n}\left(\prod_{j=1}^{n} \mathbf{d}_{ij}\right)^{1/n}\right]^{-1} \tag{3}$$

Since such weights are still triangular fuzzy numbers, they are defuzzified obtaining a mean weight for each criterion evaluated with the centre of area method as:

$$\bar{w}_i = \frac{w_i^l + w_i^m + w_i^u}{3} \tag{4}$$

Eventually, the mean weights are normalized to obtain the final weight for each criterion:

$$w_i = \bar{w}_i \left(\sum_{i=1}^{n} \bar{w}_i \right)^{-1} \tag{5}$$

2.2 Experts inquired in the Study. The present study is based on the opinions of expert seafarers, that have been required to perform pairwise comparisons by means of the linguistic scale preferences. Besides, they commented on the structure of the framework and checked if the adopted nomenclature is suitable for an onboard DSS. Most of them are captains and deck officers engaged in periodic training courses at the University of Rijeka, Faculty of Maritime Studies. In detail, 45 experts (26 from Croatia, 16 from Italy, 2 from Montenegro, and 1 from Slovenia) has been inquired between August and November 2018. Most of them (43) are male and have a long service period (**Figure 1**). The experts provide services on many different vessels' type (**Figure 2**): mainly on container ships, cruise ships and chemical tankers, but also from bulk carriers, oil tankers and a few LNG carriers, RoRo and navy ships.

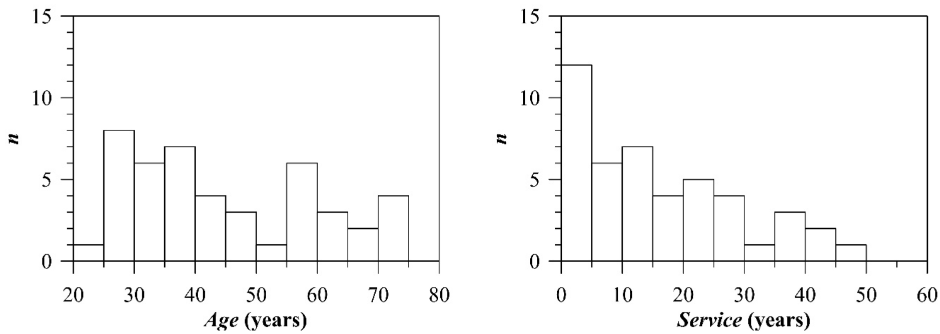

Figure 1. Age and service time of experts.

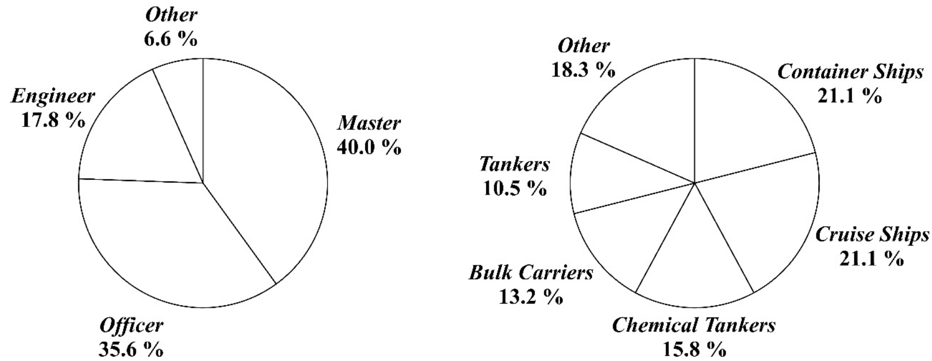

Figure 2. Role in the crew and ship type of subjects.

Considering how difficult is collecting information from onboard personnel, the application of FAHP is particularly suitable since it provided effective results even with very limited sets of experts. Hence, the number of experts inquired in the present work was judged sufficient to carry out the analysis by type of ship and by the role in the crew. Considering all the opinions globally, the set of experts is very large compared to other FAHP applications in the maritime domain present in literature (**Celik *et al.*, 2009**, **Ding *et al.*, 2014**).

3 TEST CASE: THE ONBOARD RBF

The main goal of the RBF is to synthesise all the aspects related to the ship safety with a global risk index r_G, quantifying its safety status by means of an objective process based on multiple experiences from the maritime community. The safety level can be evaluated for a generic ship condition (loading and weather condition, eventual damage, etc.). Following AHP pattern, the MCDM problem is decomposed by means of a hierarchical network (**Figure 3**) with three levels, each one contributing to the r_G through an aggregation process described in (**Trincas *et al.*, 2017**). According to a small group of masters from major shipping companies, the criteria included in the RBF are related to both the rules requirements and the current ship status assessed by means of monitoring systems. In the following, the criteria and their sub-criteria are briefly introduced.

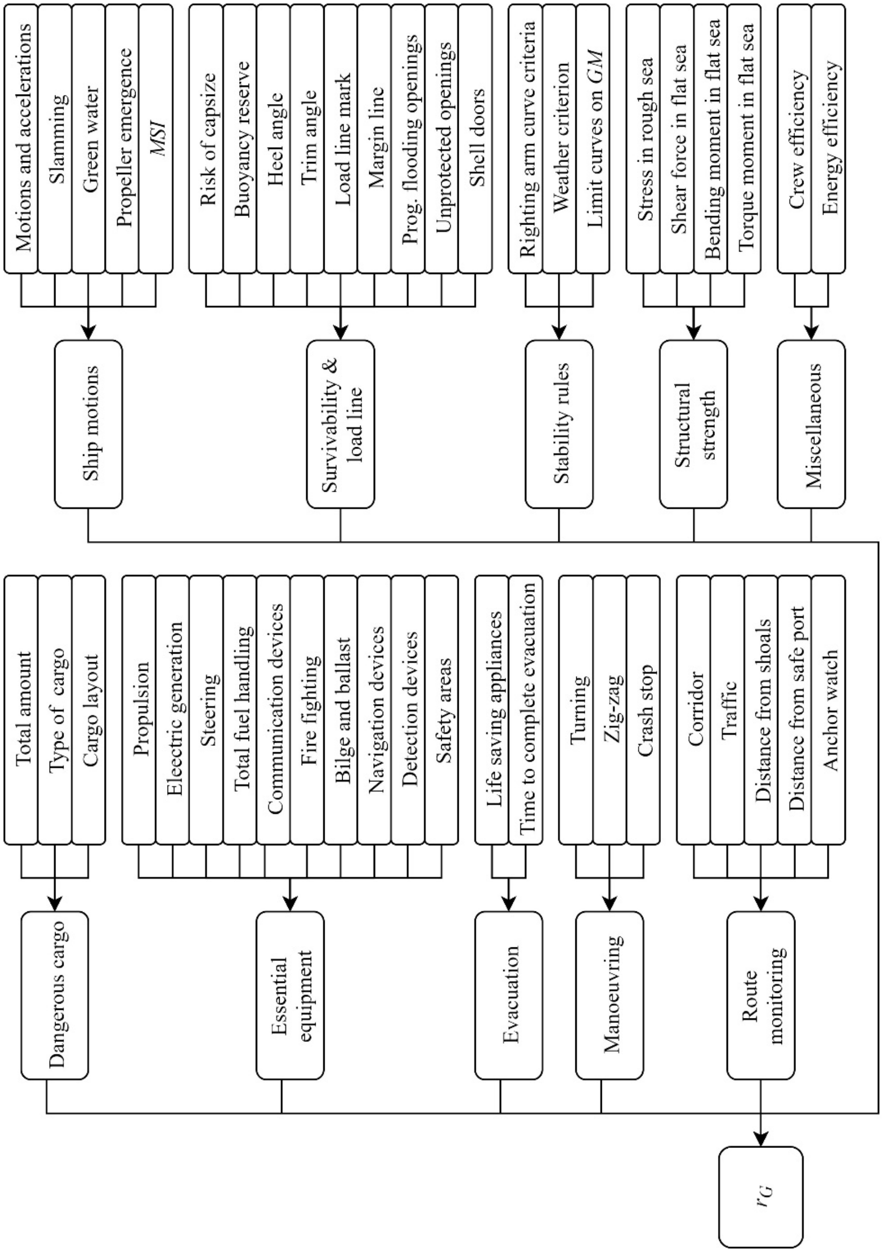

Figure 3. Composition of criteria and sub-criteria.

3.1 Dangerous Cargo. The dangerous cargo criterion is related to the type of cargo defined in *IMDG Code* and its distribution onboard. The total amount of cargo sub-criterion is related to the weight of dangerous cargo versus the allowed amount that can be transported by the ship. The dangerous cargo is classified into classes due to its level of danger providing an intrinsic measure of the risk related to the type of cargo. The cargo layout sub-criterion measures the risk connected to the distance of dangerous cargo from critical spots (essential equipment, heat sources, accommodations, etc.), intervention stations and detection devices, giving a safety measure related to the actual or simulated cargo stowage.

3.2 Essential Equipment. The essential equipment criterion is related to the effective operation of the essential systems as defined by SRtP regulations (*MSC.1/Circ.1214*), considering the effect of shut-down for maintenance, heel/trim angles, fire and/or flooding water. It is worth to notice that the onboard assessment of the operation of essential equipment in case of emergency is recommended by *MSC.1/Circ.1400*.

3.3 Evacuation. The evacuation criterion is related to the effect of a casualty on escape routes and the effect of the ship's list on evacuation time as required by *MSC.1/Circ.1400*. In detail, the number of operative lifesaving appliances is considered, taking into account the effect of fire and/or flooding. The time required to complete the evacuation procedure should be determined, taking into account the effect of the heel, trim, fire, and/or flooding. It can be compared with the time to reach an unsafe condition during progressive flooding (**Braidotti and Mauro, 2019**).

3.4 Manoeuvring. Currently, no rule prescribes to evaluate during navigation the ship's manoeuvring capabilities in the actual loading condition. Anyway, they can affect ship safety, especially in restricted waters and port operations. Hence, manoeuvring has been included in the framework taking into account all the most important manoeuvres defined IMO standards (*MSC 76/23/add.1*).

3.5 Route Monitoring. The route monitoring criterion is related to the main navigational issues to prevent the occurrence of accidents (collisions or grounding). The corridor sub-criterion monitors the deviation from the planned route. The related risk increases as much as the ship approaches the limits of a predefined corridor. Traffic and Distance from shoals sub-criteria are related to the probability of a collision or grounding respectively. This probability could be defined as a function of ship speed, route and distance from other vessels and main obstacles monitored by navigation sensors or provided by sensors and electronic chart display and information system. The distance from safe port criterion takes into account the risk associated with large distances from search and rescue facilities or from a sheltered anchorage. Finally, the anchor watch is related to distance from anchoring point, in order to early detect a mooring failure and it is not considered during navigation.

3.6 Ship Motions. Nowadays, no rule prescribes to take under control seakeeping during navigation and neither during ship design. Nevertheless, it should be taken into account, especially for passenger ships, having a strong impact on passenger comfort, and for navy ships/offshore vessels (**Mauro and Nabergoj, 2015**), fixing ship's operation limits. Eventually, dynamic phenomena might result also in stress on ship structure (**Mauro and Monacolli, 2018**), reduction of propulsion efficiency or lead to embark seawater. All these considerations led to include seakeeping in the RBF within the ship motions criterion. The Motions and Accelerations sub-criterion deals with the average period of motions, which is compared with the natural periods in order to avoid resonance phenomena. Slamming, green water, and propeller emergence are well-known undesirable phenomena connected to seakeeping (**Prpić-Oršić *et al.*, 2014**), whose occurrence probability shall be considered in the RBF. Finally, the motion sickness index (MSI) measures the passengers' comfort.

3.7 Survivability & Load Line. This criterion is related to all the aspects connected to ship floating position (such as freeboard requirements, submersion of the margin line, unprotected openings, load line mark, etc.). Moreover, it deals with the most important ship survivability issues: buoyancy reserve and risk of capsizing due to actual weather condition. The buoyancy reserve sub-criterion is a function of the difference between the actual displacement and the displacement at unprotected openings or bulkhead deck submersion in intact or damaged condition, respectively. During navigation, a continuous assessment of the risk of capsizing should be also adopted, based on actual loading and weather condition. For this purpose, the extreme values of roll motion (**Mauro and Nabergoj, 2017**), which might lead to capsizing, should be inferred from a record period representative of current weather condition.

3.8 Stability Rules. Stability rules criterion deals with compliance with stability requirements for the intact and damaged condition. In the RBF, a fuzzy satisfaction measurement is adopted, introducing a safe reference condition in addition to the rule threshold. The safe condition could be defined for each attribute as the value providing the larger margin among the values from design loading conditions.

3.9 Structural Strength. The structural strength criterion deals with the compliance with longitudinal strength rules in still water and the assessment of the risk of structural failure in waves. The class rules based on statistical formulation, define the limit curves for shear force, bending moment and, for special types of ships, torque moment. This approach, although included in the framework, is not capable to consider the current weather condition. An approach should be preferred based on extreme values (**Mauro *et al.*, 2019a**, **b**) inferred from direct stress measurement through an onboard monitoring system.

3.10 Miscellaneous. The miscellaneous criterion is related to the crew efficiency and reduction of emissions. Measuring the crew efficiency onboard is not an easy task. A viable solution could be considering efficiency as a function of Ship Risk Profile (SRP), as defined in the *Paris memorandum of understanding* document. In a given ship condition, a optimal floating position can be defined in order to reduce fuel consumption and, thus, the emissions (**Braidotti *et al.*, 2018b**). The normalized distance between actual and optimal fuel consumption can be assumed as an "environmental risk" to be included in the RBF.

4 RESULTS AND DISCUSSION

In the present study the weight of importance of all the criteria and sub-criteria has been studied. A global analysis of rough data coming from experts' preferences has been performed taking into account all the ship types in order to provide an overall perspective. Moreover, they have been analysed also by ship type, considering only groups composed of three or more experts, highlighting significant differences in weights of importance. The results are reported in Tables 2-12 and, in order to ease the interpretation, their increasing relevance is highlighted with a colour scale ranging from green (less important) to red (most important). In the tables, the judgements according to scholars' opinion (**Braidotti *et al.*, 2018a**) are also reported in a dedicated column ("Old"). As expected, the old outcome often is completely different compared with the seafarers' opinion. In the following, the results are discussed criterion by criterion.

Concerning dangerous cargo (**Table 2**), the cargo layout sub-criterion is widely the most important according to seafarers, whereas the total amount is less important. This trend was obtained mainly from judgements of oil tankers' crewmembers, whilst people from chemical tankers is slightly in countertrend. Personnel from container ships, cruise ships and bulk carriers do not assign significant differences to these sub-criteria.

The results for essential equipment are shown in **Table 3**. Since all these machinery, systems and devices are considered crucial by international rules, it is interesting to study what is really essential from an onboard perspective. Although the judgements differ substantially due to ship type, some common trends can be identified: the fuel handling system is not considered a threat for ship safety, as well as bilge and ballast system, navigation and communication devices. On the other hand, the fire fighting systems are considered of the utmost importance for almost all ship types.

Table 2. Weights of importance of dangerous cargo sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Total amount	0.325	0.312	0.383	0.331	0.263	0.279	0.264
Type of cargo	0.346	0.323	0.330	0.338	0.328	0.341	0.093
Cargo layout	0.328	0.365	0.286	0.331	0.409	0.380	0.643

Table 3. Weights of importance of essential equipment sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Propulsion	0.104	0.106	0.072	0.099	0.094	0.100	0.131
Electric generation	0.099	0.106	0.061	0.099	0.094	0.102	0.260
Steering	0.102	0.102	0.112	0.099	0.094	0.110	0.166
Total fuel handling	0.097	0.087	0.052	0.099	0.072	0.072	0.100
Communication devices	0.099	0.095	0.080	0.096	0.121	0.086	0.042
Fire fighting	0.101	0.116	0.133	0.104	0.147	0.140	0.121
Bilge and ballast	0.094	0.090	0.112	0.097	0.072	0.091	0.062
Navigation devices	0.104	0.096	0.112	0.101	0.121	0.092	0.035
Detection devices	0.104	0.099	0.133	0.102	0.093	0.112	0.047
Safety areas	0.096	0.103	0.133	0.104	0.093	0.095	0.036

Table 4. Weights of importance of evacuation sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Life saving appliances	0.514	0.500	0.544	0.500	0.566	0.532	0.616
Time to comp. evac.	0.486	0.500	0.456	0.500	0.434	0.468	0.384

Table 5. Weights of importance of manoeuvring sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Turning	0.341	0.333	0.412	0.327	0.387	0.339	0.237
Zig-Zag	0.314	0.319	0.242	0.320	0.227	0.254	0.332
Crash Stop	0.344	0.348	0.346	0.353	0.387	0.407	0.431

Table 6. Weights of importance of ship motions sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Motions and acc.	0.211	0.203	0.159	0.199	0.133	0.217	0.310
Slamming	0.205	0.194	0.183	0.199	0.210	0.213	0.314
Green water	0.206	0.208	0.211	0.204	0.274	0.205	0.044
Propeller emergence	0.210	0.208	0.301	0.204	0.274	0.256	0.265
Motion Sickness Index	0.167	0.186	0.146	0.195	0.108	0.110	0.068

This is not surprising especially on ships carrying flammable products in bulk, e.g. Oil/Chemical tankers. Moreover, the relevance of detection devices enforces this conclusion, being comparable with the one assigned to propulsion, electric generation and steering. It can be concluded that seafarers are more concerned by means for emergency response and the functionality of the main machinery rather than auxiliary systems. It is worth to notice that the ranking from scholars' opinions is completely different, especially concerning the auxiliaries (considered essential) and emergency response devices (less important).

Table 4 shows the weights of importance of evacuation criterion. Comparable importance has been assigned to availability of lifesaving appliances and to the time required to complete evacuation procedure since both are crucial during ship abandonment. In this case, the seafarers' opinion is considered more reasonable than the one from academic experts.

The analysis of manoeuvring sub-criterion (**Table 5**) highlights a good agreement between people from different ship types. The main manoeuvres defined by IMO, ordered by decreasing importance are crash stop, turning, zig-zag. It could be concluded that from an onboard perspective, crash stop and turning are the most effective to define actual manoeuvring capability, but it could be more representative of the manoeuvres crews are more familiar with. In fact, especially to avoid collisions, the yaw-checking ability, assessed via the zig-zag test, is essential and requires higher importance as was done by scholars.

Ship motions criterion provided surprising results too (**Table 6**). Globally, propeller emergence was always considered a primary concern. Motions and accelerations are also relevant for all ship types other than chemical/oil tankers. On the contrary, slamming is not as important for seafarers, especially for those from cruise ships. Furthermore, green water sub-criterion is inexplicably considered very important for cruise ships, having a much reduced exposed deck, while it is not a primary concern on container ships, where it could cause a cargo loss. The other ship types show more reasonable results for this sub-criterion.

As expected, among survivability and load line sub-criteria (**Table 7**), the ones having the strongest influence on ship safety are the risk of capsizing and the buoyancy reserve, even though the gap with the other sub-criteria is lower than the old one. However, it was unexpected that the risk of capsizing is not considered as one of the most important safety issues on cruise ships. In fact, these vessels are characterized by critical stability: the large wind areas, combined to short free-board, likely drives to serious progressive flooding issues and a probable capsize after major damages. Nevertheless, cruise ships' crews are aware of subdivision issues, assigning high importance to shell doors, unprotected and progressive flooding openings.

Table 7. Weights of importance of survivability & load line sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Buoyancy reserve	0.113	0.110	0.139	0.115	0.120	0.135	0.217
Heeling angle	0.110	0.110	0.089	0.115	0.120	0.108	0.147
Load line marks	0.108	0.110	0.139	0.110	0.092	0.091	0.034
Margin Line	0.111	0.106	0.084	0.108	0.092	0.083	0.037
Prog. flooding openings	0.111	0.119	0.117	0.115	0.120	0.132	0.088
Risk of capsize	0.113	0.110	0.117	0.110	0.120	0.135	0.222
Shell doors	0.111	0.124	0.117	0.108	0.120	0.109	0.047
Trim angle	0.105	0.097	0.099	0.105	0.120	0.083	0.103
Unprotected openings	0.118	0.114	0.099	0.113	0.093	0.124	0.105

Table 8. Weights of importance of stability rules sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Righting arm c. criteria	0.343	0.324	0.333	0.336	0.287	0.343	0.389
Weather criterion	0.315	0.352	0.333	0.328	0.427	0.339	0.258
Limit curves on KG/GM	0.343	0.324	0.333	0.336	0.287	0.318	0.353

Table 9. Weights of importance of structural strength sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Stress in rough sea	0.273	0.268	0.296	0.263	0.266	0.358	0.601
Shear force in flat see	0.247	0.247	0.248	0.246	0.265	0.230	0.172
Bending m. in flat see	0.240	0.247	0.248	0.240	0.265	0.208	0.094
Torque m. in flat see	0.240	0.238	0.208	0.251	0.204	0.204	0.133

The stability rules results (**Table 8**) shows that related sub-criteria are considered almost equally important for all ship types. Only personnel from tankers identified a clear preference for weather criterion.

Concerning structural strength (**Table 9**), for all the types of vessel, more importance has been given to stress in rough sea sub-criterion, based on the assessment of structural stress in the current weather and loading condition, in agreement with scholars' preferences. The still-water rule requirements on the shear force, bending and torque moments are considered less important and their rank differs due to ship type, highlighting the most critical structural issues. In fact, for ships with large deck openings (bulk carriers and container ships), more importance has been assigned to torque moment, confirming that seafarers are aware of risks connected to the structural layout of their ship.

In **Table 10** the results for miscellaneous criterion are provided. The crew efficiency has been considered more important compared to energy efficiency for all ship types other than chemical tankers. The gap is relevant especially for tankers and for other ships like RoRo and navy ships, highlighting the importance of crew training on these ship types.

The route monitoring sub-criterion (**Table 11**) was not present in the previous study since was added in a second time as suggested by onboard personnel. As expected, the risk of collision or grounding, i.e. traffic and distance from shoals sub-criteria, concerns seafarers from any kind of ship other than chemical tankers and bulk carriers. For the latter ship types, traffic is not considered as relevant. The distance from a safe port has been considered the less important by most of the crewmembers frequently engaged in long voyages.

Table 10. Weights of importance of miscellaneous sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Crew efficiency	0.521	0.521	0.456	0.506	0.566	0.602	0.892
Energy efficiency	0.479	0.479	0.544	0.494	0.434	0.398	0.108

Table 11. Weights of importance of route monitoring sub-criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Corridor	0.192	0.195	0.178	0.199	0.197	0.171	-
Traffic	0.210	0.210	0.178	0.200	0.197	0.239	-
Distance from shoals	0.216	0.196	0.253	0.204	0.257	0.251	-
Distance from safe port	0.182	0.187	0.178	0.196	0.151	0.152	-
Anchor watch	0.200	0.212	0.213	0.201	0.197	0.187	-

Table 12. Weights of importance of all the criteria.

	Container Ships	Cruise Ships	Chemical Tankers	Bulk Carriers	Tankers	Global	Old
Dangerous Cargo	0.106	0.080	0.087	0.102	0.094	0.094	0.087
Essential Equipment	0.098	0.100	0.123	0.102	0.123	0.118	0.118
Evacuation	0.100	0.116	0.123	0.107	0.094	0.126	0.088
Manoeuvring	0.109	0.104	0.086	0.096	0.094	0.096	0.130
Route Monitoring	0.097	0.096	0.086	0.100	0.094	0.086	-
Ship Motions	0.098	0.095	0.072	0.095	0.094	0.078	0.120
Surv. & Load Line	0.100	0.099	0.123	0.100	0.094	0.105	0.117
Stability Rules	0.103	0.104	0.123	0.098	0.094	0.101	0.059
Structural Strenght	0.100	0.099	0.123	0.102	0.094	0.108	0.094
Miscellaneous	0.087	0.107	0.052	0.098	0.123	0.088	0.187

Eventually, **Table 12** provides the weight of importance of all the criteria, highlighting once again a strong dependence on ship type. An overall analysis divides the criteria into three categories. Evacuation and essential equipment were considered the most important, followed by survivability and load line, structural strength, stability rules, manoeuvring, crew and energy efficiency, and dangerous cargo. The least criteria by importance are route monitoring and ship motions. Hence, crewmembers mainly focus on resilience and safety of essential systems while giving particular attention to real-time monitoring. This trend is also confirmed by the importance given to survivability and structural strength criteria, which are both based on monitoring systems outcomes. This conclusion is in line with the previous results, despite scholars gave more attention to hydrodynamic issues compared to seafarers. In fact, seafarers do not consider essential any mean preventing motions magnification or aiding navigation.

5 CONCLUSIONS

The present work provides an overview of ship safety in the operative condition, according to seafarers' perception. The results are useful not only for the development of an onboard RBF but also to raise some issues concerning rules revision and identify some lacks in masters training. In general, the outcomes show the importance given by masters and officers to the exploitation of monitoring systems. They are considered more effective in assessing ship safety compared with prescriptive rules requirements. This trend, although less evident, confirms the conclusion coming from scholars' opinion.

Moreover, seafarers appear confident on their own navigational capability assigning low importance on criteria and sub-criteria related to route monitoring, navigation and communications devices. These leanings are in sharp contrast with casualties statistics and with scholars and shipowners perspective too. In fact, several shipping companies are recently increasing fleet monitoring in order to gradually reduce the masters' responsibilities in favour of ship operation centres and automation. On the other hand, it can be concluded that ship safety assessment is strongly influenced by ship type. In fact, the results for the analysed ship types are not usually in good agreement. Nevertheless, FAHP provides a viable methodology to assess these preferences, even with a small set of experts. Therefore, for ships categories here not included, a dedicated study is recommended.

The multiple subjective seafarers' experiences, led to define a hierarchical structure to decompose the safety-assessment problem and quantify the relative importance of a very large set of criteria and sub-criteria. Its application as the core of a new DDS could exploit data from monitoring systems to enhance situational awareness and reduce the occurrence of human error in marine operations. Moreover, this framework, due to its modular nature, can be further extended with other criteria/sub-criteria in order to fit vessels special requirement.

Finally, several judgements collected in the present study were somehow unexpected and not completely justiciable, highlighting some seafarers' lacks of knowledge regarding hydrodynamics. For these topics, further training is advisable for onboard personnel and an assessment of preferences based on naval architects preferences should be preferred.

Acknowledgements

This work has been fully supported by the Croatian Science Foundation under the project IP-2018-01-3739. The authors would like to thank the captains from Grimaldi Lines, CMA CGM and MSC Cruises for their important support.

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