A CONTENT ANALYSIS OF HUMAN FACTORS IN SHIPS DESIGN

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SUMMARY

Research shows that more than 80% of accidents at sea were caused by human related factors. Some experts implied that less than adequate design is one significant element that may lead to human errors. There are several ways to discover whether a design has considered human factors, i.e., to refer to the design specification, to consult the designers, to conduct a direct observation through a site visit or through a model, to interview the users, or to look into the system that regulates the design. This paper applied a content analysis methodology to explore how human factors have been covered in the design of marine systems. Various documents such as rules, regulations, design guidelines, standards and other texts have been analysed. The results indicate that there are extensive references that cover human factors in designing ships. They are published with different degrees of enforcement, some are prescriptive and some are obligatory but *still* optional. The topic is developing very rapidly. A more assertive measure is required from the regulators to endorse human factors into implementation.

NOMENCLATURE

ABS	American Bureau of Shipping
ASTM	American Society for Testing and Materials
BS	British Standards
BV	Bureau Veritas
CEPAC	Crew and Embarked Personnel Accommodation Comfort
COMF	Comfort
DNV	Det Norske Veritas
ECR	Engine control room
ER	Engine room
GL	Germanischer Lloyd
HAB	Habitability
HF	Human factors
HFES	Human Factors and Ergonomics Society
HVAC	Heating, ventilation and air conditioning
IEA	International Ergonomics Association
IMO	International Maritime Organization
ISO	International Organization for Standardization
LR	Lloyd's Register
NKK	Nippon Kaiji Kyokai
OHS	Occupational health and safety
RINA	Royal Institution of Naval Architects
SNAME	Society of Naval Architects and Marine Engineers
SOLAS	Safety of Life at Sea
STCW	Seafarers' Training, Certification and Watchkeeping

1. INTRODUCTION

This paper explores how human factors have been covered in marine system design. Extensive studies have been conducted to better understand the role of human factors in maritime accidents by examining available maritime casualty databases [1, 2],claiming that human error continues to be the dominant factor in maritime accidents, contributing to 80-85% of all accidents. Whereof, about 50% initiated by human error, while another 30% associated with human error.

In contrast to the fact mentioned above, designers seem to avoid this so-called human factor. Reason mentions that rather than being the instigator of an accident, operators tend to be the inheritors of system's defects created by poor design, incorrect installation, faulty maintenance and bad management decisions [3]. Squire quoted one ship master stating that it is frustrating for the personnel to sail a vessel which was designed with no crew input and whatsoever [4]. Miller emphasized his message in capital letters [5, 6]:

"YOU CANNOT OVERCOME HUMAN ERRORS INDUCED BY POOR DESIGN OF THE WORKPLACE WITH MORE TRAINING, MORE MANUALS OR WRITTEN PROCEDURES, EXHORTATIONS TO WORK MORE SAFELY, OR THREATS OF PUNITIVE ACTIONS FOR JOB ACCIDENTS."

Graveson mentions similar statement that human factors in shipping draws attention but is rarely addressed and is not taken seriously [7].

A question worth asking is: "Is human factors neglected in ship design?"

There are several ways to find out if a design is good and human-friendly. First, one can do an evaluation through the design itself. For instance, a human factors review in ship design was conducted by means of a 3D computer model [8]. Several onboard surveys were conducted to evaluate engine control rooms and bridge design with regard to human factors [9, 10, 11, 12]. Second, one can do interviews with the designers [13]. Third, one can study the rules and regulations for designing the systems.

Naval architects, marine engineers, and offshore engineers should refer to codes, rules, regulations and guidelines when designing their products. Some of these referrals are compulsory and some are voluntary. To be approved by any classification society, the design obviously must follow the rules and regulations published by the corresponding society, for instance ABS, BV, DNV, GL, LR or NKK. Ross identifies which standards and regulations correspond to which ship design discipline: structure, hull-form, machinery, general arrangements and human-machine interface [15, 16]. The presentation is simple, but beneficial for the designers who intend to apply the specific know-how to their work.

The research presented in this paper applies a content analysis to explore how human factors have been covered in marine system design. The concept of human factors in ship design is explored and relevant literature is reviewed. Applicable codes, rules, regulations and guidelines will be examined. The aim is to investigate which aspects of human factors are mentioned and how they are addressed. The results should be beneficial for those who are involved in the design of marine systems and intend to apply principles related to human factors in their design. The remaining part of the paper will first give an introduction to relevant literature, and then describe the content analysis methodology applied, before results are presented and discussed.

2. LITERATURE REVIEW

A literature review is performed to clarify the concept of human factors in ships design. First, definitions of human factors from its own societies are explored. Then, the process of ships design is discussed. Finally, the application of human factors in ship design is presented.

2.1 HUMAN FACTORS

The International Ergonomics Association (IEA) defines human factors as [18]:

“The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.”

A definition developed by the Human Factors and Ergonomics Society (HFES), stated that “Human Factors is concerned with the application of what we know about people, their abilities, characteristics, and limitations to the design of equipment they use, environments in which they function, and jobs they perform” [19]. Another definition provided by HFES declared that:

“Human factors is that field which is involved in conducting research regarding human psychological, social, physical, and biological characteristics, maintaining the information obtained from that research, and working to apply that information with respect to the design, operation, or use of products or systems for optimizing human performance, health, safety, and/or habitability.”

The International Maritime Organization (IMO) uses the term “human element” for this purpose, and defines [20]: “The human element is a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection. It involves the entire spectrum of human activities performed by ships’ crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively.”

2.2 SHIPS DESIGN

The design process consists of developing requirements, conducting analyses, developing drawings, building electronic models and writing specifications [15]. Ship design is a long and iterative process, divided into stages or phases. The way people divide and name the stages or the phases varies across sources and across time. In the 1980 edition of the Ship Design and Construction textbook, Kiss following Evans (1959) distinguished four phases of ship design process [21]: concept design, preliminary design, contract design and detail design. While, in the latter version of the textbook, Gale, following Lamb (1985, 1986) differentiates two ship design stages [22]: basic design and product engineering. The first stage is then subdivided into four phases: concept design, preliminary design, contract design and functional design. The second stage is subdivided into two phases: transition design and workstation/zone information preparation. Rawson and Tupper propose three major design stages: concept design, feasibility design and full design [23].

Each design stage covers specific issues and considerations. Usually the process will start with the mission statement, like what kind of vessel to be built to carry how much quantity of which particular cargoes in which area of the world. The further the process the more detail the issues cover, for instance the dimensions of the vessel, type of hull that is going to be used, type of machineries that will be installed, layout and arrangement of the vessel, bridge design, ER and ECR design, to plumbing and fixture list, accommodation arrangement, electrical equipment and installation diagram, and HVAC diagram and equipment list. Obviously, most of the topics covered above are typical marine related problems, but not all are under the responsibility of a naval architect or a marine engineer. Furthermore, not all issues are related to human factors, but may still have an effect on people and their safety and effectiveness and efficiency of work.

2.3 HUMAN FACTORS IN SHIPS DESIGN

Humans are involved in the ship life cycle from procurement to disposal. They include the owners, the designers - naval architects, the classification societies, the regulatory authorities, the shipbuilders, the equipment suppliers, the ship managers/operators, the seafarers/unions and the insurers [7]. All of them have a different but significant impact on safety, effectiveness and efficiency. Shipowners play important roles that may have profound consequences on safety. They determine which flag state and which classification society their vessels will carry. The maritime administration, acting as the flag state control, has the job to ensure that regulations are obeyed [24]. Classification societies develop standards and set technical rules. They also have the responsibility to ensure that the design and construction follow the standards. It is a common practice that classification societies carry out the control functions on behalf of the flag state. Much of this knowledge is captured in standards and guides for non-expert use, thus reducing the cost of human centred design.

According to Rawson and Tupper, the human element in design is covered by multi-disciplinary human factors teams. These teams include physiologists, psychologists, engineers and scientists. These human factors teams can advise the naval architect on how to design a system or equipment so that the human can perform more effectively, increase system efficiency, improve human performance and inform the levels of environmental parameters which should not be exceeded [23].

In the ship design and construction textbook published by SNAME, human factors is defined as a comprehensive term that covers all biomedical and psychological considerations applying to the human in the system. Human factors is also stated to cover human engineering and life support, personnel selection, training and training equipment, job performance aids, and performance measures and evaluation as well. Human factors engineering in ship design is defined separately. Human factors engineering includes techniques to define the role of the human in complex systems, simulation and modelling of crew workloads for manning reduction, assessing operator/maintainer workloads, advanced man-machine interfaces, decision aids to reduce human error and accidents and enhance human performance and safety, and ship design methods and data [17]. The role of the naval architects and marine engineers is highlighted to influence the final product of marine design by adequately addressing human factors in the ship design process. The importance of designing for human factors correctly from the bottom up is also emphasized.

Lloyd’s Register (LR) described human factors as something that is concerned with the task people do and the environment they do it in - fitting the job to the person [25]. When applied to the design and operation of a ship and its systems, the term human factors means taking human capabilities, skills, limitations and needs, and the use of people as a component of the system into account. Ergonomics is defined as the study and design of the working environment for the benefit of the workers’ safety, efficiency, effectiveness, health and comfort. Working environments include ship bridges, machinery control rooms, galleys, and the related components, work practices and work procedures. It is mentioned that for any ship to operate safely and effectively, the ship must be designed to support the people who work onboard, without detriment to their health, safety and overall performance.

Examples of ship design elements related to human factors are [14, 15, 25]: ship motions, design arrangement, layout and location of operation, berthing and maintenance spaces, access, gangways, ladders, stairs and work platform, ergonomics and anthropometric considerations, accommodation criteria, maintainability, habitability, survivability and comfort of personnel, indoor climate, lighting, view, sight, visibility, noise, sound, vibration, ventilation, and temperature, human-machine interfaces and interaction, incl. symbols, signs, labels, and job-performance aid, control, display, screen, alarms, workstations, consoles, and manual valve operation.

There are three references to date which particularly cover human factors in ship design: “High Speed Craft Human Factors Engineering Design Guide” [26], “Human Factors in the Maritime Domain” [27] and “Human Factors for Naval Marine Vehicle Design and Operation” [17]. Nine areas of human factors in ship design have been identified [26]: motions, sight, sound, environment, health and safety, man-machine interface, habitability, maintainability, and design review.

LR systematically distinguished several different design qualities in relation to human factors. These include [25]:

- Habitability – the provision of adequate and comfortable accommodation, including furnishings and washing facilities, such as galleys, messrooms and recreational spaces. This provision must take into account seafarer’s variation in size, shape and gender, and various environmental stressors: noise, heat and vibration.
- Maintainability – designing operational maintenance tasks to be rapid, safe and effective, to allow equipment and systems to achieve a specified level of performance. This includes consideration of access, removal routes, tools, expertise, disposal and through-life support.
- Workability – due consideration must be given to the users, tasks, equipment (including any

software), materials and procedures, and the physical and social environments in which a system is used.
- Controllability – designing the layout of ship control centers, machinery control rooms, cargo control rooms etc., considering integration of people with equipment, systems and interfaces, such as communication facilities, controls, displays, alarms, video-display units, and computer stations.
- Manoeuvrability – having the most appropriate manoeuvring capabilities consistent with the intended role, manning and operational pattern of the ship, including the type, number and power of propulsion systems, steering systems and thrusters.
- Survivability – the provision of adequate fire-fighting, damage control and lifesaving facilities (including manpower), and of security arrangements.

In a subsequent publication, LR adds two other qualities to human factors [31]:
- Occupational health and safety (OHS) – consideration of the effect of work, the working environment and living conditions on the health, safety and wellbeing of workers.
- System safety – consideration of the risks from people using (or mis-using) ship systems.

3. METHODOLOGY

To answer the question whether human factors has been considered in marine design by means of published documents such as rules, regulations, standards, and guides, a method of systematic literature survey as for instance content analysis is required.

3.1 CONTENT ANALYSIS

Content analysis is a research technique for making replicable and valid inferences from texts, or other meaningful matter, to the context of their use [28]. Leedy & Omrod and Neuendorf defined content analysis as a careful, detailed, systematic examination and interpretation of a particular body of material in an effort to identify patterns, themes, biases, and meanings [29]. Content analysis can be applied deductively in quantitative research, producing frequencies of pre-selected categories or values associated with particular variables [30]. This method is considered to be relevant to answer the problems that are being addressed in this study. Content analysis will be utilized as a structured and quantified literature study, to see if human factors is covered in the process of designing marine systems and how it is taken into account.

Based on a theoretical construct of human factors in ship design, a coding sheet is developed. It can be seen that the construct is rather complex and multi-dimensional.

Table 1 Coding Sheet

Dimension	Component	Aspect / object
Habitability (HAB)	Accommodation Seafarer's variation Environmental stressors Environmental condition Indoor climate Comfort	Galleys, messroom Recreational spaces Cabins Size Shape Gender Noise, sound Heat, temperature Air velocity, ventilation Air quality, smell Motion Vibration Lighting
Maintainability (MAIN)	Maintenance tasks	Layout, access, removal routes Tools Expertise Disposal Through-life support
Workability (WORK)	Users Tasks Equipment & software Material & procedures Physical & social environment	Accessibility Layout Space
Controllability (CONT)	Control centres	Bridge Engine control room Cargo control facilities
	People-system integration Man-machine interface	Communication facilities Controls and switches Displays, video-display unit Alarms Automation Computer stations
Manoeuvrability (MANV)	Propulsion system Steering system Thrusters	
Survivability (SURV)	Firefighting Damage control Lifesaving facilities	
Occupational Health and Safety (OHS)	Effect to work Working environment Living conditions	
System safety (SS)	Risk consideration	

There is no formal taxonomy of human factors in the maritime domain available to date. The framework provided by LR [31] is regarded as the most logical and comprehensive one, and is therefore employed as the basic skeleton. Eight design qualities are identified and for the coding sheet purpose they are named as dimensions: habitability, maintainability, workability, controllability, manoeuvrability, survivability, occupational health and safety, and system safety. Under each dimension, several components and or aspects are identified. In the process of developing the coding sheet, it is realized that the framework does not really satisfy the mutually exclusive and collectively exhaustive principle; overlapping occurs and there are some inconsistencies in classifying components or aspects. The initial coding sheet is presented in Table 1 which is developed together with the coding process.

3.2 POPULATION AND SAMPLE

There are many documents that can be explored to show how human factors are accounted for in ship design. A good source to start with is existing textbooks and handbooks of ship design, as presented above in section 2.3. Next, periodicals like journal publications, conference papers, reports, bulletins and magazines will be essential sources of information. And finally, but often regarded as most important are codes, standards, rules, regulations, guides and recommended practices, published by the classification societies. Such publications from the class societies can be said to truly represent the reality in the industry, as they are required to class a ship.

This research focus on commercial ship design, thus documents with military, aeronautics and nuclear reactor background is excluded. Documents provided for general purpose design, such as BS 6841:1987 Guide to Measurement and Evaluation of Human Exposure to Whole-body Mechanical Vibration and Repeated Shock and ISO 6385:2004 Ergonomic Principles in the Design of Work Systems, and documents not specifically addressing design issues, such as STCW, SOLAS and Maritime Labour Convention (MLC) 2006 are also excluded from the scope of this research.

The population of the research is defined as those documents, standards, rules, or guides published by classification societies and other relevant international bodies which regulate certain aspects of ship design that can affect human performance, health, and or safety on board. Three classification societies are taken as the samples in the research: ABS, DNV and LR. Three international organizations are also sampled: IMO, and the standards organisations ISO and ASTM.

Two levels of data exploration will be conducted according to the level of the unit analysis. First, a thorough look into the list of publications on each source will be carried out. At this stage, the title of the document will be identified. Next, on each document selected, detail content analysis will be done by applying a pre-defined coding sheet, covering human factors related keywords.

3.2 (a) Classification Societies

ABS, DNV and LR are three major classification societies, representing a considerable part of the ship classification market, and they show a particular interest for human factors considerations in marine design. Each society addresses the human factors issue in its own way. ABS provides quite a few guides addressing human factors issues and offers additional notations like HAB and COMF. DNV offers additional COMF notation. LR offers CEPAC notation and does a lot of efforts in addition to the rules and regulations.

American Bureau of Shipping [32]

ABS publishes 138 rules and guides that are applied in marine industry, covering ships, offshore structures, floating structures, underwater vehicles, equipment, components and materials. As many as seventeen publications can be categorized as targeted documents in this research (see Table 2).

Table 2 ABS rules and guides related to human factors in ship design

Pub#	Title
86	Application of Ergonomics to Marine Systems
94	Bridge Design and Navigational Equipment/Systems
97	Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries
102	Crew Habitability on Ships
103	Passenger Comfort on Ships
116	Review and Approval of Novel Concepts
117	Risk Evaluations for the Classification of Marine-Related Facilities
119	Ergonomic Design of Navigation Bridges
122	Alternative Design and Arrangements for Fire Safety
141	Fire-Fighting Systems
145	Vessel Maneuverability
147	Ship Vibration
151	Vessels Operating in Low Temperature Environments
154	Means of Access to Tanks and Holds for Inspection
163	Crew Habitability on Workboats
170	Rapid Response Damage Assessment
185	Integrated Software Quality Management (ISQM)

Det Norske Veritas [33]

DNV differentiates their rules and standards into: Rules for Classification of Ships, Rules for Classification of High Speed, Light Craft and Naval Surface Craft, Statutory Interpretations, Service Specifications, Offshore Service Specifications, Offshore Standards, Recommended Practices, etc.

Table 3 shows documents published by DNV that are presumed to accommodate human factors in commercial ship design.

Not all documents mentioned in Table 3 are developed based on the human factors viewpoint. For instance, Part 6, Chapter 15 Vibration Class is established considering that vibration may influence function of some essential machineries and equipment as well as cause fatigue damage to some important structures. Chapter 24 SILENT class notation is applied to ensure that those equipment used by the vessel can function properly.

Table 3 DNV rules for classification of ships and craft related to human factors

Rules for Classification of Ships		
Part 3	Hull and Equipment - Main Class	
	Ch 3	Hull Equipment and Safety
Part 4	Machinery and Systems - Main Class	
	Ch 9	Control and Monitoring Systems
	Ch 10	Fire Safety
	Ch 14	Steering Gear
Part 5	Special Service and Type - Additional Class	
	Ch 12	Comfort Class
Part 6	Special Equipment and Systems- Additional Class	
	Ch 2	Redundant Propulsion
	Ch 3	Periodically Unattended Machinery Space
	Ch 4	Additional Fire Protection (F-AMC)
	Ch 6	Centralised Cargo Control for Liquid Cargoes
	Ch 7	Dynamic Positioning Systems
	Ch 8	Nautical Safety
	Ch 9	Loading Computer Systems (LCS) for Stability and Longitudinal Strength
	Ch 15	Vibration Class*)
	Ch 20	Nautical Safety - Offshore Service Vessels
	Ch 24	SILENT Class Notation*)
	Ch 26	Dynamic Positioning System - Enhanced Reliability DYNPOS-ER
*) not developed based on human factors perspective		

Table 4 shows the rest of DNV documents addressing human factors in the design stage.

Table 4 DNV documents related to human factors in design phase

Recommended Practices (DNV-RP)	
A203	Qualification of New Technology
C205	Environmental Conditions and Environmental Loads
D102	Failure Mode and Effect Analysis (FMEA) of Redundant Systems
D201	Integrated Software Dependent Systems

Lloyd's Register [34]

LR differentiates their rules and regulations into two categories: marine and energy. There are 130 documents under the marine category and 25 documents under the energy. Table 5 presents a list of LR documents that are relevant to HF in ship design.

3.2 (b) International Standards and Industry Standards

In addition to those classification societies, three other relevant organizations in the global regulatory and standardization domain are evaluated: IMO, ISO and ASTM.

The International Maritime Organization [35]

IMO is a specialized agency of the United Nations which is responsible for measures to improve the safety and security of international shipping and to prevent marine pollution from ships. IMO is responsible for keeping legislation up to date, ensuring that it is ratified by as many countries as possible, and to ensure that theses conventions and other treaties are properly implemented by the countries that have accepted them. A considerable share of IMO's publications is related to human factors in ship operations. IMO publishes documents in different format: agreements, circulars, codes, conventions, guidelines, manuals, model courses, procedures, recommendations, regulations, rules and resolutions.

Table 5 LR documents related to HF in design

Rules & Regulations for the Classification of Ships		
Part 3	Ship Structures (General)	
	Ch 13	Ship Control System
Part 5	Main and Auxiliary Machinery	
	Ch 18	Integrated Propulsion Systems
	Ch 19	Steering Gear
	Ch 21	Requirements for Condition Monitoring Systems
	Ch 22	Propulsion and Steering Machinery Redundancy
	Ch 23	Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships
Part 6	Control, Electrical, Refrigeration and Fire	
	Ch 1	Control Engineering Systems
	Ch 2	Electrical Engineering
	Ch 4	Fire Protection, Detection and Extinction Requirements
Part 7	Other Ship Types and Systems	
	Ch 4	Dynamic Positioning Systems
	Ch 9	Navigational Arrangements and Integrated Bridge Systems
	Ch 11	Arrangements and Equipment for Environmental Protection
	Ch 12	Integrated Fire Protection (IFP) Systems
	Ch 13	Passenger and Crew Accommodation Comfort
	Ch 15	Requirements for Machinery and Engineering Systems of Unconventional Design
Guidance Note		
	Ship Vibration and Noise Guidance Notes	

Several conventions are significantly important for the human factors' perspective:

- COLREGS – International Regulations for Preventing Collisions at Sea

- Load Lines, 1966 – International Convention on Load Lines
- SOLAS – International Convention for the Safety of Life at Sea
- STCW – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

IMO codes related to human factors are:
- Code on Alerts and Indicators, 2009
- FSS Code – Fire Safety System
- LSA Code – International Life-Saving Appliance Code
- Noise Levels – Code on Noise Levels on Board Ships
- STCW Code – Seafarers' Training, Certification and Watchkeeping

Examples of other IMO publications that are relevant to human factors in ship design include:

Table 6 IMO publications relevant to HF in ship design

Assembly Resolutions (RES)	
A.342(IX)	Recommendation on Performance Standards for Automatic Pilots
A.468(XII)	Code on Noise Levels on Board Ships
A.601(15)	Provision and Display of Manoeuvring Information on Board Ships
A.708(17)	Navigation Bridge Visibility and Functions
A.817(19)	Performance Standards for Electronic Chart Display and Information Systems (ECDIS)
A.861(20)	Performance Standards for Shipborne Voyage Data Recorders (VDRs)
A.947(23)	Human Element Vision, Principles and Goals for the Organization
A.1021 (26)	Code on Alerts and Indicators
Maritime Safety Committee (MSC) Resolutions	
128(75)	Performance Standards for a Bridge Navigational Watch Alarm System (BNWAS)
137(76)	Standards for Ship Manoeuvrability
190(79)	Performance Standards for the Presentation of Navigation-Related Information on Shipborne Navigational Displays
IMO Circulars, MSC Circulars	
587	Life Saving Appliances
601	Fire Protection in Machinery Spaces
616	Evaluation of Free-Fall Lifeboat Launch Performance
645	Guidelines for Vessels with Dynamic Positioning Systems
834	Guidelines for Engine-Room Layout, Design and Arrangement
846	Guidelines on Human Element Considerations for the Design and Management of Emergency Escape Arrangements on Passenger Ships
849	Guidelines for the performance, location, use and care of emergency escape breathing devices (EEBD's)
982	Guidelines on Ergonomic Criteria for Bridge Equipment and Layout
1002	Guidelines on Alternative Design and Arrangements for Fire Safety

Some topics are addressed more than once in IMO publications. For instance, the STCW is published as a convention and also as a code, and noise levels on board is mentioned as a code as well as a resolution. To avoid redundancy, these topics are considered as one.

The International Organization for Standardization [36]

ISO is a non-governmental organization who develops and publishes international standards. Browsing ISO standards can be done in two ways. Through the international classification for standards (ICS) or by the technical committee (TC) responsible to prepare the standard. Standards in shipbuilding and marine structures are covered in ICS number 47, while TC 8 covers standards regarding ship and marine technology. Ergonomics is regulated separately in TC 159.

The scope of this research is covered in ICS 47.020 and 47.040, and TC 8/SC 1, TC 8/SC 6 and TC8/SC 8. Examples of ISO documents that are related to human factors in ships design are presented in Table 7.

Table 7 ISO documents related to HF

ISO	Title of document
2631-1:1997	Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration -- Part 1: General requirements
2923:1996	Acoustics -- Measurement of noise on board vessels
3797:1976	Shipbuilding -- Vertical steel ladders
5488:1979	Shipbuilding -- Accommodation ladders
5489:2008	Ships and marine technology -- Embarkation ladders
6954:2000	Mechanical vibration -- Guidelines for the measurement, reporting and evaluation of vibration with regard to habitability on passenger and merchant ships
17631:2002	Ships and marine technology -- Shipboard plans for fire protection, life-saving appliances and means of escape
17894:2005	Ships and marine technology – Computer applications – General principles for the development and use of programmable electronic systems in marine applications
20283-2:2008	Mechanical vibration -- Measurement of vibration on ships -- Part 2: Measurement of structural vibration
20283-4	Mechanical vibration -- Measurement of vibration on ships -- Part 4: Measurement and evaluation of vibration of the ship propulsion machinery
24409-1:2010	Ships and marine technology -- Design, location and use of shipboard safety signs, safety-related signs, safety notices and safety markings -- Part 1: Design principles
27991:2008	Ships and marine technology -- Marine evacuation systems -- Means of communication
8468:2007	Ships and marine technology -- Ship's bridge layout and associated equipment -- Requirements and guidelines
2412:1982	Shipbuilding -- Colours of indicator lights

Documents under TC 159 exclusively cover ergonomics, such as:

- ISO 6385:2004 Ergonomic principles in the design of work systems
- ISO 26800:2011 Ergonomics -- General approach, principles and concepts
- ISO 9241-1:1997 Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 1: General introduction
- ISO 9241-210:2010 Ergonomics of human-system interaction – Part 210: Human-centered design for interactive systems
- ISO 11064-3:1999 Ergonomic design of control centres -- Part 3: Control room layout
- ISO/TR 16982:2002 Ergonomics of human-system interaction -- Usability methods supporting human-centered design

Since those publications are broadly applied in any domain, they are excluded from this study.

ASTM International [37]

ASTM International develops and delivers international voluntary consensus standards. ASTM formed a committee called F25 to develop standards on Ships and Marine Technology in 1978. Two specific standards are in accordance with the scope of this research:

- F1166 – 07 Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities
- F1337 – 10 Standard Practice for Human Engineering Program Requirements for Ships and Marine Systems, Equipment, and Facilities

4. RESULTS AND ANALYSIS

Two levels of data analyses were conducted with different units of analysis. First, all related publications from six institutions were being processed. The title of the documents was taken as the unit of analysis where the HF dimensions (Table 1) were used as the coding framework. Second, several most significant and most relevant documents were selected and then analysed in detail manner, where components and aspects of human factors were used as the coding framework.

4.1. DOCUMENT ANALYSIS

95 document titles were coded according to human factors dimensions. Detail results are presented in Table A1 in the Appendix while the summary is presented in Table 8.

It should be noted that some documents are very thin; only two pages while some are comprehensive, counting hundreds of pages. Some titles represent one complete document while some others represent chapters from a compiled document. Therefore, those statistics in Table 8 should be interpreted carefully.

Table 8 Summary results of documents covering HF in ship design

Publishing institutions	Number of documents	Human Factors / Ergonomics	Habitability	Maintainability	Workability	Controllability	Maneuverability	Survivability	Occupational Health and Safety	System Safety
ABS	17	2	6	1	7	4	1	3	3	9
DNV	18	0	1	1	6	7	3	3	0	11
LR	16	0	2	1	2	6	3	6	1	7
IMO	27	2	2	1	6	8	3	11	4	14
ISO (TC8)	13	0	7	0	3	2	0	4	0	2
ASTM	2	2	1	1	2	1	0	1	1	2
Total	93	6	17	5	25	28	10	29	9	45

Table 8 shows that all human factors dimensions are covered by the existing documents: codes, rules, regulations, guidelines, etc. Clearly, as safety has long been the main concern in the industry, “System Safety” is the most mentioned by the documents while "Maintainability" is the least covered. This finding confirms the criticism raised by Andersson and Lützhöft [9] regarding how poor the engine control rooms were designed. Similar complaints are also mentioned by the engineers during the exploratory surveys in the study [12][1]. Quite a significant number of documents are available in "Survivability", "Controllability" and "Workability". "Habitability" is sufficiently covered, but not so many documents cover the "OHS" given that the focus of this study is on the ‘design’ part.

4.2. CONTENT ANALYSIS

As mentioned, detailed explorations were conducted by using the components and aspects of each HF dimension. As the coding process took place, more components and aspects were *discovered* and then included to the framework, which then became quite a long list. The coding process was done iteratively as the framework developed. The final result is presented in Table A2 in the Appendix. Some documents that cover a very specific topic such as risk management, software, fire safety, steering gear and life-saving appliances were excluded.

From the results of tabulating the content of the documents it can be seen that "Habitability" (or "Comfort") and "Controllability" are covered the most on the dimensions level. These two dimensions dominate

[1] To be noted, ABS launched a new guide for Ergonomic notations (July 2013).

the content of HF in ship design. Following those are "Workability" and "System safety".

In "Habitability", noise, vibration, indoor climate and lighting or illumination are the most common topics covered by the documents. In "Controllability", alarms, control centres, workstations and control and switches are the most common topics covered. It can be seen that the basic HF issues on board have been addressed by the documents. However, as the basic issues are covered, more specific problems appear. For example, noise was recognized to be a problem on board. As many as 15 documents in this survey are found to regulate the maximum level of noise on board. Apparently, noise is no longer identified as a substantial problem on board. This is consistent with field survey findings [12] which recognize a comfortable level of noises; in general. However, more specific noise problems are recognized. It is the high pitch, impulsive and intermittent types of noise that disturb people on board. Most of those 15 documents do not deal with the specific issues. ISO 2923 is the only document that mentions "impulsive noise" and "tonal sound", but it does not indicate how to deal with them.

Another basic HF issue that has been addressed adequately is "vibration". It is covered by 14 documents according to this survey. Vibration generally should no longer be considered as an intimidating problem. But, some particular types of "vibration" emerge to be problematic [12]: ship motion and slamming. One document discusses ship motion from the HF perspective: ISO 2631-1. This is the only document found that differentiates vibrations into two regimes: high frequencies (>0.5 Hz; for health, comfort and perception) and low frequencies (<0.5 Hz; for motion sickness). ABS 147 and 103 are referring to ISO 2631 as well as BS 6841 to consider Motion Sickness Dose Value (MSDV) on board. Among all documents surveyed in this study, only ABS 86 deals with slamming. Similar pattern occurs also in "alarms" which are sufficiently covered by 14 documents in the survey. The basic issue of alarms has been resolved, but in reality, more specific issues of alarms are discovered, such as overwhelming number of alarms and irrelevant alarms that disturb the operators. *Fortunately,* IMO A.1021(26) points out some of these issues: reducing the variety of alerts and indicators to provide unambiguous information.

4.3. DISCUSSION

Although the human factors issues have been sufficiently addressed by various documents, they are not really mandatory. The rules and regulations published by the class societies are optional or voluntary while the rest are guidelines. The actual implementation of human factors principles primarily relies on the shipowner's commitment. Obviously, shipyards play a significant role. The cargo owner or the clients and the crew may have some contribution to make it happen. But, the classification societies and the regulators could go further. Some basic human factors issues should be made compulsory without exception, such as noise, vibration, motion, and indoor climate. Some of these subjects also need to be introduced to future naval architects and ship designers, such as basic ergonomics, habitability, controllability, workability and human-related criteria in ship design.

It should be noted that the application of HF standard is rather different with the other standards. For instance, a ship that carries COMF class does not guarantee that the people on board will feel comfortable, while a ship that carries Ice Class must be capable to handle ice loads.

Three documents are found to be comprehensive covering the topics of human factors: ABS 86, DNV Nautical Safety and ASTM F1166. These three are the most recommended documents to address human factors in ships design disregarding the colors of the flags, wherever the ships are registered and classed. Some issues were identified in the development stage of the coding sheet but not covered in any document, i.e. seafarer's variations in gender, religious differences and disabilities.

Due to limited resources, the study does not come with any reliability index. However, the validity across time is confirmed. Compared to the findings that were published earlier [38] this study reveals a rapid development of human factor applications in ship design, characterized by the increasing number of documents published. The pattern is relatively consistent. Among all human factors aspects, it was found that noise, vibration, and alarms are covered abundantly, while maintainability still lacks attention, especially related to the engine room. A more intelligent endeavour should be performed to select which aspect of human factors in ship design should be developed in relation with the least considered, but problematic issues on board, such as high pitch intermittent noise, ship motion, slamming, smell, and gender issues, as reported in [12]. A quick comparison with a HF reference [39] shows that human reliability, decision making, and social factors are not yet covered by any of the documents surveyed in this research.

5. CONCLUSIONS

A literature survey on various documents was conducted using a content analysis methodology. The study was carried out to answer if human factors are neglected in ships design. At least 95 documents were identified to be relevant in addressing human factors in ships design, and the numbers keep growing rapidly. Thirty documents were explored in detail. From the study it can be concluded that human factors are not neglected in ship design requirements. A lot of effort has been carried out in the industry to explore human factors and to implement it. Human factors turns to be a broad discipline that covers many dimensions and elements of the ships, but the level of intensity and coverage vary across the dimensions. Safety and survivability are the two dimensions mostly covered, shown by the total number of documents published in the topics. Habitability (comfort) and controllability comprise the broadest spectrum of coverage, shown by the number of aspects found within the dimensions. A more assertive action is recommended to endorse human factors principles to be implemented in ship designs. Further studies by interviewing ship owners, naval architects, marine engineers, and shipyards/shipbuilders are recommended.

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Appendix: Table A.1. Document analysis

No	SOURCE	ID *)	HF	HAB	MAIN	WORK	CONT	MANV	SURV	OHS	SS
1	ABS	86	1	1	1	1	1	0	0	1	1
2	ABS	94	0	0	0	1	1	0	0	0	0
3	ABS	97	0	0	0	0	0	0	0	0	1
4	ABS	102	0	1	0	0	0	0	0	0	0
5	ABS	103	0	1	0	0	0	0	0	0	0
6	ABS	116	0	0	0	0	0	0	0	0	1
7	ABS	117	0	0	0	0	0	0	0	0	1
8	ABS	119	1	0	0	1	1	0	0	0	0
9	ABS	122	0	0	0	0	0	0	1	0	1
10	ABS	141	0	0	0	0	0	0	1	0	0
11	ABS	145	0	0	0	0	0	1	0	0	0
12	ABS	147	0	1	0	1	0	0	0	0	0
13	ABS	151	0	1	0	1	0	0	0	1	1
14	ABS	154	0	0	0	1	0	0	0	1	1
15	ABS	163	0	1	0	0	0	0	0	0	0
16	ABS	170	0	0	0	0	0	0	1	0	1
17	ABS	185	0	0	0	1	1	0	0	0	1
	ABS		**2**	**6**	**1**	**7**	**4**	**1**	**3**	**3**	**9**
18	DNV	Pt 3 Ch 3	0	0	0	0	0	1	0	0	0
19	DNV	Pt 4 Ch 9	0	0	0	1	1	0	0	0	1
20	DNV	Pt 4 Ch 10	0	0	0	0	0	0	1	0	1
21	DNV	Pt 4 Ch 14	0	0	0	0	1	0	0	0	0
22	DNV	Pt 5 Ch 12	0	1	0	0	0	0	0	0	0
23	DNV	Pt 6 Ch 2	0	0	0	0	0	0	0	0	1
24	DNV	Pt 6 Ch 3	0	0	1	0	0	0	0	0	1
25	DNV	Pt 6 Ch 4	0	0	0	0	0	0	1	0	1
26	DNV	Pt 6 Ch 6	0	0	0	0	1	0	0	0	0
27	DNV	Pt 6 Ch 7	0	0	0	0	1	0	0	0	0
28	DNV	Pt 6 Ch 8	0	0	0	1	1	1	0	0	1
29	DNV	Pt 6 Ch 9	0	0	0	0	0	0	0	0	1
30	DNV	Pt 6 Ch 20	0	0	0	1	1	1	1	0	1
31	DNV	Pt 6 Ch 26	0	0	0	1	1	0	0	0	0
32	DNV	A203	0	0	0	1	0	0	0	0	1
33	DNV	C205	0	0	0	0	0	0	0	0	0
34	DNV	D102	0	0	0	0	0	0	0	0	1
35	DNV	D201	0	0	0	1	0	0	0	0	1
	DNV		**0**	**1**	**1**	**6**	**7**	**3**	**3**	**0**	**11**
36	LR	Pt 3 Ch 13	0	0	0	0	0	0	0	0	0
37	LR	Pt 5 Ch 18	0	0	0	0	1	1	0	0	0
38	LR	Pt 5 Ch 19	0	0	0	0	0	0	0	0	0
39	LR	Pt 5 Ch 21	0	0	1	0	0	0	0	0	0
40	LR	Pt 5 Ch 22	0	0	0	0	1	1	1	0	1
41	LR	Pt5 Ch 23	0	0	0	0	0	0	1	0	1
42	LR	Pt 6 Ch 1	0	0	0	0	1	0	1	0	1
43	LR	Pt 6 Ch 2	0	0	0	0	1	1	1	0	1
44	LR	Pt 6 Ch 4	0	0	0	0	0	0	1	0	1
45	LR	Pt 6 Ch 1	0	0	0	0	0	0	0	0	0
46	LR	Pt 7 Ch 4	0	0	0	1	1	0	0	0	0
47	LR	Pt 7 Ch 9	0	0	0	1	1	0	0	0	0
48	LR	Pt 7 Ch 12	0	0	0	0	0	0	1	1	1
49	LR	Pt 7 Ch 13	0	1	0	0	0	0	0	0	0
50	LR	Pt 7Ch 15	0	0	0	0	0	0	0	0	1
51	LR	GN	0	1	0	0	0	0	0	0	0
	LR		**0**	**2**	**1**	**2**	**6**	**3**	**6**	**1**	**7**

No	SOURCE	ID *)	HF	HAB	MAIN	WORK	CONT	MANV	SURV	OHS	SS
52	IMO	COLREGS	0	0	0	0	1	0	0	0	1
53	IMO	LL	0	0	0	0	0	0	0	0	1
54	IMO	SOLAS	0	0	0	0	0	0	0	0	1
55	IMO	STCW	0	0	0	1	0	0	0	0	0
56	IMO	ALI	0	0	0	0	0	0	1	0	1
57	IMO	CAI	0	0	0	0	0	0	1	0	1
58	IMO	FSS	0	0	0	0	0	0	1	0	1
59	IMO	LSA	0	0	0	0	0	0	1	0	1
60	IMO	NOISE	0	1	0	0	0	0	0	0	0
61	IMO	A 342(IX)	0	0	0	0	1	0	0	0	1
62	IMO	A 468(XII)	0	1	0	0	0	0	0	0	0
63	IMO	A 601(15)	0	0	0	0	0	1	0	0	0
64	IMO	A 708(17)	0	0	0	0	1	0	0	0	0
65	IMO	A 817(19)	0	0	0	1	1	1	0	0	0
66	IMO	A 830(19)	0	0	0	0	0	0	0	0	0
67	IMO	A 861(20)	0	0	0	0	0	0	0	0	1
68	IMO	A 947(23)	1	0	0	0	0	0	0	0	0
69	IMO	Res 128(75)	0	0	0	0	0	0	1	1	1
70	IMO	Res 137(76)	0	0	0	0	0	1	0	0	0
71	IMO	Res 190(79)	0	0	0	1	1	0	0	0	0
72	IMO	Circ 587	0	0	0	0	0	0	0	0	0
73	IMO	Circ 601	0	0	0	0	0	0	1	0	1
74	IMO	Circ 616	0	0	0	0	0	0	1	0	1
75	IMO	Circ 645	0	0	0	1	1	0	0	0	0
76	IMO	Circ 834	0	0	1	1	1	0	1	1	1
77	IMO	Circ 846	0	0	0	0	0	0	1	0	0
78	IMO	Circ 849	0	0	0	0	0	0	1	1	0
79	IMO	Circ 982	1	0	0	1	1	0	0	0	0
80	IMO	Circ 1002	0	0	0	0	0	0	1	0	1
	IMO		**2**	**2**	**1**	**6**	**8**	**3**	**11**	**3**	**14**
81	ISO	2631-1:1997	0	1	0	0	0	0	0	0	0
82	ISO	2923:1996	0	1	0	0	0	0	0	0	0
83	ISO	3797:1976	0	0	0	1	0	0	0	0	0
84	ISO	5488:1979	0	1	0	0	0	0	0	0	0
85	ISO	5489:2008	0	1	0	0	0	0	1	0	0
86	ISO	6954:2000	0	1	0	0	0	0	0	0	0
87	ISO	17631:2002	0	0	0	0	0	0	1	0	1
88	ISO	20283-2:2008	0	1	0	0	0	0	0	0	0
89	ISO	20283-4	0	1	0	1	1	0	0	0	0
90	ISO	24409-1:2010	0	0	0	0	0	0	1	0	1
91	ISO	27991:2008	0	0	0	0	0	0	1	0	0
92	ISO	8468:2007	0	0	0	1	0	0	0	0	0
93	ISO	2412:1982	0	0	0	0	1	0	0	0	0
	ISO		**0**	**7**	**0**	**3**	**2**	**0**	**4**	**0**	**2**
94	ASTM	F1166 - 07	1	1	1	1	1	0	1	1	1
95	ASTM	F1337 - 10	1	0	0	1	0	0	0	0	1
	ASTM		**2**	**1**	**1**	**2**	**1**	**0**	**1**	**1**	**2**

*) For detail ID see Section 3.2 in the text

Appendix: Table A.2. Content analysis

	ABS								DNV								LR					IMO			ISO					ASTM	
	86	94	97	102	103	145	147	163	Pt 3 Ch 3	Pt 4 Ch 9	Pt 5 Ch 12	Part 6 Ch 2	Part 6 Ch 3	Pt 6 Ch 7	Pt 6 Ch 8	Pt 6 Ch 20	Pt 3	Pt 5	Pt 6	Pt 7 Ch 9	Pt 7 Ch 13	834	982	137 (76)	2631-1	2923	6954	24409-1	8468	F1166	Sub total
HUMAN FACTORS	1		1												1	1						1								1	6
application of human factors to design	1	1	1			1									1	1															6
previous design, user feedback	1																														1
task analysis	1		1																												2
Habitability, comfort	1			1	1		1	1			1				1	1				1	1				1	1	1			1	14
accommodation	1			1	1			1			1										1					1	1				8
doors				1					1																						2
furniture				1																											1
toilet, sanitary, bathroom				1	1			1																							3
seating	1			1	1																										3
access, layout, arrangement	1			1	1			1																							4
cabins				1	1			1			1										1					1					6
galleys				1	1			1													1										4
messrooms				1	1			1			1										1										5
recreational spaces				1	1			1			1										1					1					6
washing, laundry				1	1			1			1																				4
hospital & medical facilities				1	1			1			1																				4
seafarer's variation	1			1				1																						1	4
size, shape, gender, anthropometric	1	1		1				1								1														1	6
race, religion, disabilities																															0
environment, comfort, (indoor) climate	1			1	1			1			1				1	1				1		1	1		1					1	12
temperature, heat	1	1		1	1			1			1				1	1				1		1	1						1		12
humidity	1			1	1			1			1					1				1											7
thermal gradient	1			1	1			1			1																				5
air velocity, ventilation	1			1	1			1			1					1				1		1	1								9
air quality, smell, odor, effluvia	1			1	1			1																							4
noise, sound, acoustics	1	1		1	1			1			1				1	1				1	1	1	1			1			1	1	15
impulsive noise																										1					1
intermittent noise				1																											1
tonal sound																										1					1
measurement					1			1			1										1					1					5
acoustic/sound insulation				1	1						1										1										4
motion																									1						1
vibration	1			1	1		1	1			1				1	1					1	1	1		1		1		1		14
acceleration	1			1	1		1	1																	1		1				7
frequency	1			1	1		1	1			1																1				7
measurement				1	1		1	1			1										1						1				7
single-impulse shock loads (slamming)	1																														1
radiation, electromagnetic field																				1											1
lighting, illumination	1	1		1	1			1							1	1				1		1	1						1	1	12
red or low-level white illuminance				1				1																							2
specular reflections, glare															1	1				1											3
surfaces		1													1	1				1	1										5
Maintainability	1	1	1							1			1				1					1								1	8
maintenance tasks	1																					1									2
expertise																															0
manuals, diagnostics, schematics	1																													1	2
access, layout, arrangement, routes	1																1					1								1	4
bench space, work platform	1																														1
tools, equipment	1		1																			1								1	4
handling of heavy parts	1																					1									2
spare parts & supplies																						1									1
storage (for spare parts and supplies)																						1									1
Workability	1	1								1			1		1	1						1	1							1	9
users	1		1			1									1	1															5
tasks	1	1				1									1	1															5
equipment & software	1	1	1							1			1		1	1			1	1			1							1	11
materials & material handling	1		1																			1								1	4
procedures, manual			1			1									1	1													1	1	6
physical and social environment	1	1	1												1	1							1		1	1			1	1	10

Continue on the next page

	ABS								DNV								LR					IMO			ISO					ASTM	
	86	94	97	102	103	145	147	163	Pt 3 Ch 3	Pt 4 Ch 9	Pt 5 Ch 12	Part 6 Ch 2	Part 6 Ch 3	Pt 6 Ch 7	Pt 6 Ch 8	Pt 6 Ch 20	Pt 3	Pt 5	Pt 6	Pt 7 Ch 9	Pt 7 Ch 13	834	982	137 (76)	2631-1	2923	6954	24409-1	8468	F1166	Sub total
Workability (cont'd)																															
accessibility, layout, arrangement	1	1							1						1	1				1		1	1							1	9
doors, openings, hatches	1	1							1																						3
stairs, ladders	1	1																													2
seating, chairs	1														1	1				1											4
communication		1	1			1									1	1				1									1	1	8
signage, labeling, symbols	1	1	1																1			1						1		1	7
Controllability	1	1								1			1	1	1	1			1	1		1	1						1	1	13
control centers	1	1				1				1			1	1	1	1	1			1			1						1	1	13
bridge control center		1				1							1	1	1	1				1			1						1	1	10
engine control room, engine room													1						1			1								1	4
cargo control																	1														1
man-machine interface	1	1								1			1	1	1	1				1			1						1	1	11
workstations	1	1								1			1	1	1	1				1		1	1						1	1	12
communication facilities		1				1									1	1			1	1			1						1	1	9
controls and switches	1	1											1	1	1	1		1		1		1	1						1	1	12
view, vision, visibility	1	1													1	1				1			1						1	1	8
displays, video-display units	1	1								1			1		1	1				1			1							1	9
alarms	1	1								1			1	1	1	1		1	1	1		1	1						1	1	14
automation, automatic system	1	1								1			1	1	1	1		1	1	1										1	11
integration	1	1								1				1	1	1			1	1										1	9
monitoring system		1								1				1	1	1		1	1	1											8
remote control										1						1			1												3
potential of human error, slips, lapses	1	1	1			1																								1	5
Maneuverability						1						1	1	1	1	1	1			1				1							9
propulsion system									1			1		1			1	1													5
steering system									1			1		1	1	1	1	1													7
thrusters									1					1			1	1													4
maneuvering capability						1									1	1								1							4
turning ability						1									1									1							3
initial turning ability						1									1									1							3
yaw-checking & coure-keeping abilities						1									1									1							3
stopping ability						1									1									1							3
Survivability	1												1				1	1				1						1		1	7
fire safety measures															1	1			1									1			4
fire detection systems & alarms													1		1				1				1					1			5
firefighting equipment																						1						1			2
damage control									1							1	1	1													4
livesaving facilities																						1						1			2
emergency response / services										1			1	1	1	1	1	1												1	8
failure / hazard detection										1				1		1															3
emergency exit / escape	1								1				1						1			1						1			6
emergency equipment	1																					1									2
security (arrangement)																															0
Occupational health and safety (OHS)	1		1																			1	1		1					1	6
effect of work	1																			1					1						3
working environment	1	1	1						1		1				1	1				1		1	1		1	1				1	13
living conditions	1		1	1					1		1														1	1					7
safety of personnel	1	1	1						1						1	1						1						1	1		9
personal protection equipment (PPE)			1																			1						1			3
System safety	1		1							1		1			1		1	1	1			1						1	1	1	12
vessel's safety			1						1						1	1			1												5
risk considerations	1		1							1		1	1	1	1	1		1	1			1							1		12
hazardous area, situation, or operation	1		1						1			1	1					1													6
hazardous material			1																												1
single failure criterion		1	1							1		1		1																	5
reliability	1		1							1			1	1	1	1															7
worst-case scenario	1		1							1				1	1	1		1	1												8
collision avoidance															1	1															2
risk categorization, prioritization			1																												1
	64	33	27	31	25	15	5	26	13	20	20	7	21	20	50	50	12	14	17	30	12	34	23	6	10	11	6	10	19	38	669