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Formal safety assessment of containerships

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Abstract

Following an introduction to containerships, formal safety assessment and its development in the shipping industry are described. Containership accident statistics are studied and discussed. This is followed by a description of containership characteristics and a proposed formal safety assessment methodology for containerships. Further development in formal safety assessment in the context of containership safety is finally discussed in detail.

Keywords: Containership; Containership safety; Formal safety assessment; Ship safety

1. Introduction

Due to a rapidly expanding world trade, the traditional multi-purpose general-cargo liner became increasingly labour and cost intensive. A system was required to accommodate the needs of physical distribution, a system that would offer convenience, speed, safety and above all low cost. By this system, goods should be able to be moved from manufacturer to final distribution using a common carrying unit, compatible with both sea and land legs of transportation. The result was expected to be that all costly and complicated transhipment operations at seaports would be eliminated. The whole process resulted in the development and introduction of the "freight container", a standard box, filled with commodities, detachable from its carrying vehicle, and as easy to carry by sea as by air, road and rail. The beginning of the container era was marked with the sailing of the "container tanker" "MAXTON" on 26th April 1956 from Newark N.J. to Houston, loaded with 58 containers [1,2].

During the first years of containerisation, transportation was carried out with modified tankers or dry cargo vessels, broadly accepted as the 1st generation of container ships [2,3]. It was not until 1965 that the first orders for purpose built cellular vessels were placed, forming the 2nd generation of container vessels. These were the "Bay Class" ships of 1600 TEUs capacity. In the late 1970s the 3rd generation appeared increasing the sizes up to Panamax and capacities up to 3000 TEUs. Following the increasing demand for tonnage but without being prepared to lose the Panama Canal flexibility the industry moved to the development of the 4th generation of container vessels, keeping the Panamax dimensions and increasing the capacity up to 4200 TEUs represented by the "Econ Class" ships [2,3].

Further development in the shipbuilding industry and the need for the creation of "economies of scale" resulted in the appearance of the 5th generation of container ships, the Post-Panamax in the 1980s [2]. A recent research in the container sector of the shipping industry indicates that the world fully cellular containership fleet increased to more than 3500 vessels with a total carrying capacity exceeding 4.6 million TEUs in 1999 and with an average annual growth rate up to 11.1% as shown in Fig. 1 [4]. It is also noteworthy that the growth rate of post-Panamax containerships is the largest of all the containership sizes, amounting up to 26.3%.

Although there were not many major casualties, in terms of loss of lives, resulting from accidents involving containerships, this particular ship type has more of its fair share of losses due to incidents involving cargo damage, personal injury, collision, ship structural failure and pollution. Major accidents in the last decade include the

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	Under 1000TEU		1000-1999 TEU		2000-2999 TEU	
	VSL	TEU	VSL	TEU	VSL	TEU
1999	1,836	765,922	851	1,177,368	426	1,060,460
(1998)	1,751	714,155	807	1,117,310	381	956,349

	3000-3999 TEU		4000 + TEU		Total	
	VSL	TEU	VSL	TEU	VSL	TEU
1999	205	711,498	188	889,982	3,506	4,605,230
(1998)	189	653,444	152	704,559	3280	4,145,817

Fig. 1. World fully cellular containerships in TEUs.

total loss of the "C/V Pioneer Container" in 1994 due to a collision in the South China Sea, the loss of the "C/V River Gurara" in 1996, the extensive damages suffered by the "C/V Toyama Maersk" in 1997 due to a collision with a Gas Carrier in the Singapore Strait, the loss of the "C/V MSC Carla" in 1998 which broke in two in bad weather conditions, and the extensive damages suffered by the "M/V APL China" in 1999 due to severe bad weather conditions. Statistics indicate that incidents involving containerships account up to about 7% of the total.

In terms of incident categories containerships differ from most other ship types in that shore error accounts for a high percentage of all major incidents. The result is an equally high percentage of cargo damage. Although containerships follow the same pattern as the majority of cargo vessels, as far as the types of damages are concerned, they do differentiate in various aspects. The relative statistics available show that the percentage of incidents is higher in newer containerships, decreasing as they age, while in other cargo ship types, higher incident rates occurs at their middle age. The same statistics show that a high percentage of all incidents caused by human error, was due to shore based personnel error, which is far higher than other cargo ship types. As far as ship size is concerned the smaller ships of this type are better placed with fewer incidents.

Other operational characteristics of containerships, such as the fact that they very rarely travel in ballast condition and the few opportunities for overnight stay at ports, contribute to the overall performance of these vessels and their operators. At this point, it should be stressed out that although a relatively large amount of detailed data exists, organisations such as classification societies, as well as private shipping companies possessing them are reluctant to release them. This is mainly attributable to the high competition in the market. On the other hand, government agencies are either not ready yet to dedicate the necessary resources for data collection, or the time period for which relevant government projects are run is not sufficient to produce reliable data.

Following the investigation on the disaster of the "Herald of Free Enterprise" of 6th March 1987, the House of Lords issued "Lord Carver's Report" [5]. The whole report and its concept was promptly and widely embraced by the UK Maritime and Coastguard Agency (MCA), by introducing in 1993 the "Formal Ship Safety Assessment" as a proposal to the International Maritime Organisation (IMO) [6,7]. Following a period of deliberations, the IMO finally in 1997 broadly accepted Formal Safety Assessment (FAS) for ships as a potentially helpful tool in the rule-making process and issued the relevant circular [8]. What was needed, however, was proof of the theory's feasibility for the various types of ships available. The task of testing the theory and its feasibility in the industry was assigned to the UK MCA, which proceeded to the application of FSA initially to high-speed passenger ships. The product of the application was successful, leading to the submission of a relevant report by the UK MCA to the IMO. The feasibility study of the FSA application to bulk carriers has also been carried out and the final results are expected to be produced in December 2000 [9].

The shipping community, being traditionally conservative in adopting new methods and technologies, in its great majority has yet to openly express its views on FSA. Shipping companies, in general, maintain a waiting policy on the subject, possibly reluctant to expose themselves to premature expenses. Nevertheless, there are exceptions with the most notable ones P&O Nedlloyd and Neptune Oriental Lines (NOL), which have started using scientific methods for risk prediction and management establishing new specialist departments within their organisations for that purpose [10].

The general concept, however, of FSA has entered the wider maritime sector, with classification societies like Lloyds Register of Shipping (LR), DNV and Germanisher Lloyd (GL), proceeding to individual research and providing services. On the other side of the Atlantic Ocean, in the USA, the US Coast Guard (USCG) has applied "Risk Based Decision-Making Guidelines" in order to improve its management system [11] and attempts to pass variations of the FSA in a competitive manner towards its British counterpart. Indicative of the above is the simplistic methodology followed in a test case produced on risk assessment on passenger vessels in co-operation with the US Passenger Vessel Association (PVA) [12].

2. Containership accident statistics

In order to carry out any kind of safety analysis, either qualitative or quantitative, it is essential to obtain reliable failure data. It is admitted that qualitative risk analysis requires less detailed statistical failure data, compared to Quantitative Risk Assessment (QRA) [13]. The existence of a certain amount of relative data is, however, considered to be necessary, in either case, in order to enable us to determine the probability of occurrence and the extent of the consequences of a hazardous event.

The amount of data available will also determine the choice of the risk analysis methods (qualitative or quantitative) that could more suitably be incorporated in the whole process of the FSA. Accident statistics on a generic vessel type can be obtained from the following sources:

1. Field experience (historical data) including:
   1.1. Data collection programmes by government agencies.
   1.2. Data collection programmes by classification societies.
   1.3. Data collection programmes by insurance companies and P&I Clubs.
   1.4. Statistics maintained by private shipping companies.
2. Agreed judgmental estimates of experts.

As far as field experience is concerned, there is a two-folded problem. On one hand, great attention should be paid on the data resources, as the various databases do not always use the same base for data analysis. This is attributable to the fact that different bodies look into safety issues from different prospective, facilitating their own interests. On the other hand, there is the problem of data accuracy. The available information on a certain subject varies with the vessels' working environment. Such factors generally add uncertainties to risk assessment thus reducing the confidence in it and can only be overcome by expert judgement. Equally varying are the risk criteria set around the world, as they depend mostly on local regulators. This gives them a large amount of inflexibility, making it impractical to use them, especially in cases where there is a high level of uncertainty.

Classification societies and P&I Clubs can be a very useful source of failure data mainly because of the large amount of vessels each one represents. Data, however, from these organisations should be critically evaluated before used or combined with others. Classification societies tend to look into safety, mainly from the viewpoint of compliance with the various sets of rules in force. On the other hand, P&I Clubs tend to deal with the matter from the viewpoint of financial losses due to lack of safety and are not immediately interested in the regulatory aspect of loss prevention. A recent research carried out by one of the world's leading P&I Clubs, the UK P&I Club [14] and possibly the most complete one publicly available, shows that for the 10-year period from 1989 to 1999 incidents involving containerships account up to 7% of the total as shown in Fig. 2.

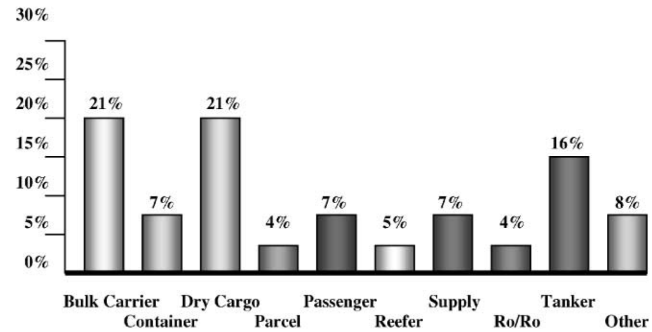

Fig. 2. Distribution of incidents per ship type.

In terms of incident categories, containerships differ from most other ship types in that show error accounts for up to 21% of all major incidents. The result is a fairly high percentage of cargo damage, 54%, as compared with the overall percentage of the Club. All the values of incident categories are shown in Fig. 3 while the total number of incidents is 273 for the period 1989–1999 [14].

In terms of ship size and age, the 10-year study shows that the smaller ships of this type are better placed. 87% of the major incidents have occurred on containerships above 10,000 grt as shown in Fig. 4. Equally interesting is the fact that 44% of incidents involving containerships have occurred on ships of less than 10 years of age as shown in Fig. 5 [14]. The human error factor in incidents involving containerships is shown to be in decline, following two peak periods in 1988 and 1991 as shown in Fig. 6 [14].

Administrations tend to look into marine casualties from the viewpoint of "reportable incidents" within their

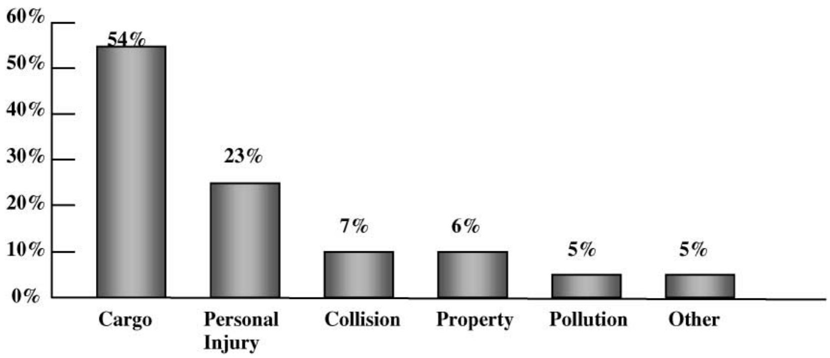

Fig. 3. Incident categories involving containerships.

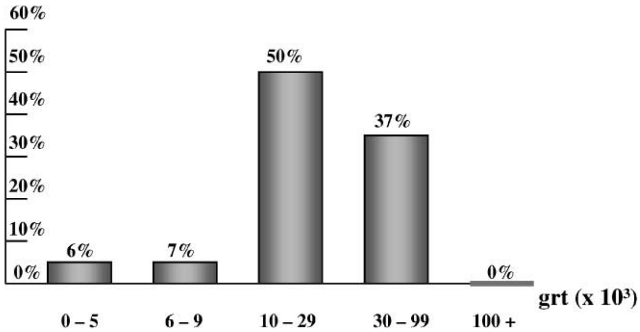

Fig. 4. Distribution of incidents as per ship's size (in grt).

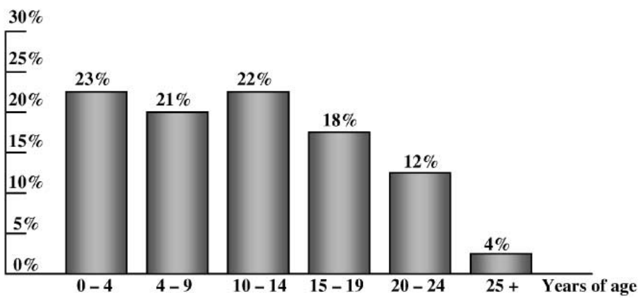

Fig. 5. Distribution of incidents as per ship's age.

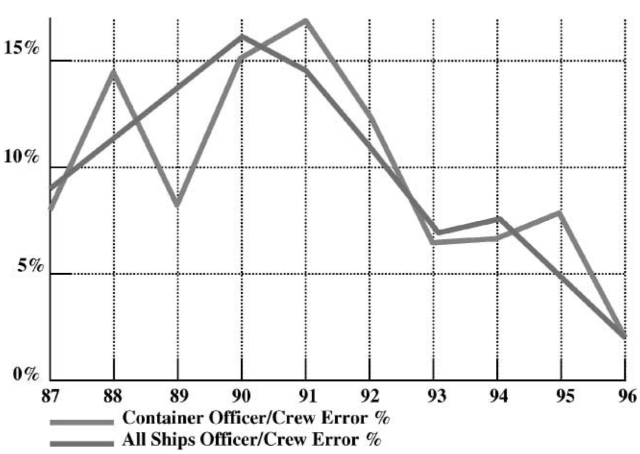

Fig. 6. Containership-officer/crew error-frequency trend.

jurisdiction which results to a differentiation in the relevant numbers, as the sample of vessels considered is smaller than that of P&I Clubs and classification societies. Furthermore, due to their orientation towards ship safety and environmental protection, areas such as cargo damage and third party liability (i.e. fines) are not considered. Nevertheless, results of such data are equally useful for the identification of major problematic areas of the various ship types although in many case there may be a difference between the data from classification societies and government agencies.

3. Formal safety assessment of containerships

Formal Safety Assessment (FSA) is a new approach to marine safety, which combines the techniques developed for risk and cost benefit assessment. The benefits of adopting FSA as a regulatory tool were very accurately pointed out by UK MCA and can be summarised in the following [6]:

- A consistent regulatory regime, which addresses all aspects of safety in an integrated way.
- Cost effectiveness, whereby safety investment is targeted where it will achieve the greatest benefit.
- A proactive approach, enabling hazards that have not yet given rise to accidents to be properly considered.
- Confidence that regulatory requirements are in proportion to the severity of the risks and
- A rational basis for addressing new risks posed by ever changing technology.

The main FSA framework consists of the following five steps [6,8]:

- The identification of the hazards.
- The assessment of the risks associated with those hazards.
- Ways of managing the risks.
- Cost benefit assessment of the options and,
- Decisions on which options to select.

The first three involve the use of risk assessment techniques, while the fourth one is, as stated, cost benefit assessment. The fifth step is nothing else but the logical outcome of the cost benefit assessment.

3.1. The generic containership

The generic model of containership needs to be developed according to IMO's Interim Guidelines [8] taking into consideration the particular systems and characteristics required for the transportation of containerised cargo. The relevant study carried out by the UK MCA on High Speed Passenger Craft [15] as well as the one currently being carried out on Bulk Carrier offer an equally useful guide for the development of our generic model.

The generic containership is not a "typical" vessel but a hypothetical one consisting of all technical, engineering, operational, managerial and environmental (physical, commercial and regulatory) networks that interact during the transportation of containerised cargo. This generic model can be broken down to its component and more detailed levels. Thus the generic container ship can take the form shown in Fig. 7.

Breaking down the model to the four basic levels of the containership operation produces the "generic

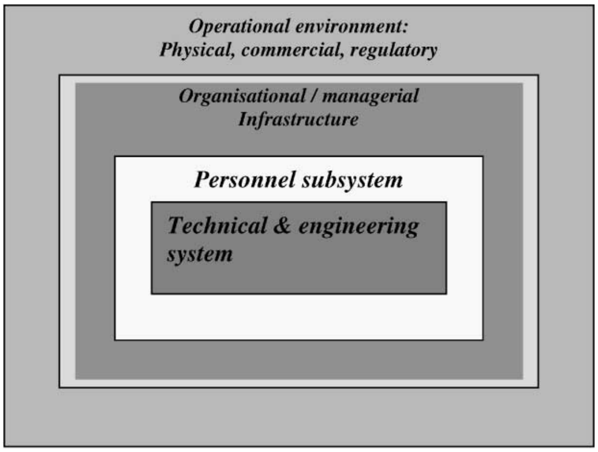

Fig. 7. The component levels of the generic model of containership.

engineering and technical system model" (Fig. 8) [9], the "generic personnel sub-system" (Fig. 9), the "generic operational and managerial infrastructure" (Fig. 10), and the "generic environment of operation" (Fig. 11).

Containerships follow the general pattern that all internationally trading cargo ships do, but they differentiate in various aspects, of which, the primary ones appear to be as follows:

(i) *Structure*: The structure of a containership is typified by holds longitudinally divided in two sections (fore and aft), each being able to accommodate one 40 ft unit or two 20 ft ones in length. Holds are fitted with vertical "L" shaped guides (cell guides) used to guide and secure the units into their storage position. Internally containership holds are box shaped surrounded by ballast, fuel tanks and void spaces.

(ii) *Strength and stability*: Containerships like most cargo vessels are equipped with means to calculate stability, shear-forces (SF) and bending moments (BM). The differentiating feature of containerships is the additional need for the calculation of torsion moments (TM). This need is generated by the uneven distribution of cargoes in cases where the vessel is partly loaded proceeding to various ports before completing its loading.

The existence of deck cargo reduces the stability of the vessel and calls for increased inherent or design stability of the vessel itself. It is not an uncommon phenomenon that a "Metacentric Height" (GM) is 6.5 m for a Panamax size containership in "light ship" condition. The use of high-speed diesel engines increases the fuel consumption rate, which imposes the need for large fuel tanks, usually located at, or close to, the mid-section of the vessels. Thus, as fuel is consumed bending moments and shearing forces are increasing. It is noteworthy that many modern containerships are equipped with real-time stress monitoring equipment allowing for automated correction of excessive values using ballast.

(iii) *Cargo and ballast operations*: This is one of the main differences between containerships and other cargo vessels. Loading and unloading cargo operations are carried out simultaneously and at very high rates. The cargo loaded and discharged is calculated based on the values declared by the shippers for each unit and by weighing the units upon their arrival at the terminal gate. Cargo operations are normally pre-planned by terminal personnel in simulated conditions and are subject to

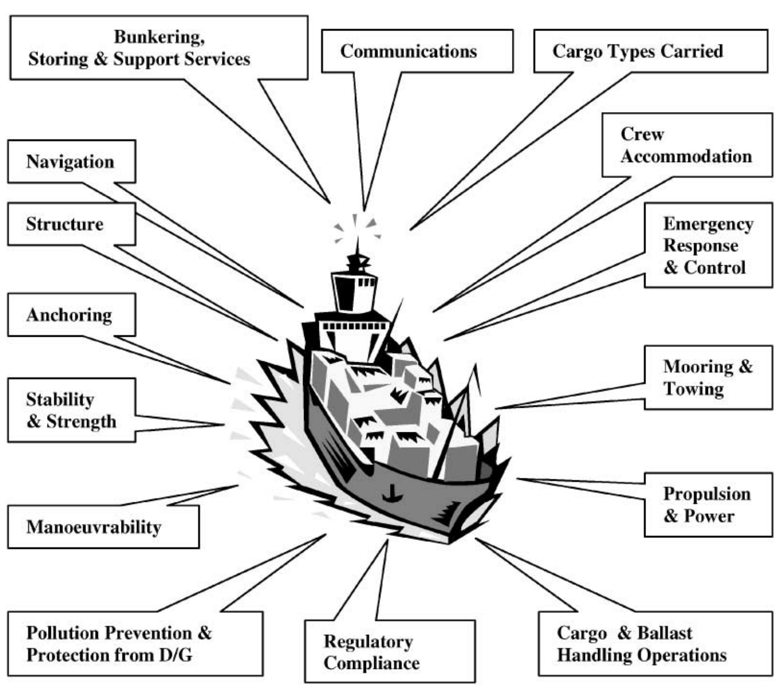

Fig. 8. The generic engineering and technical system.

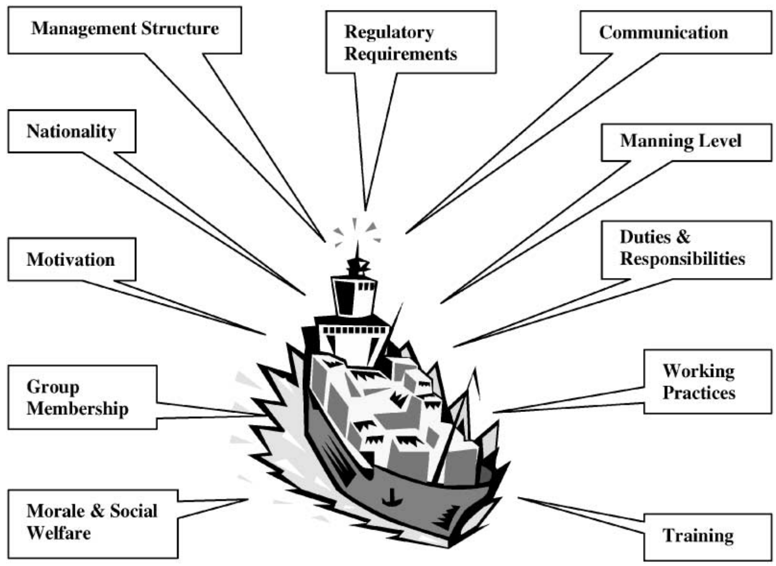

Fig. 9. The generic personnel sub-system.

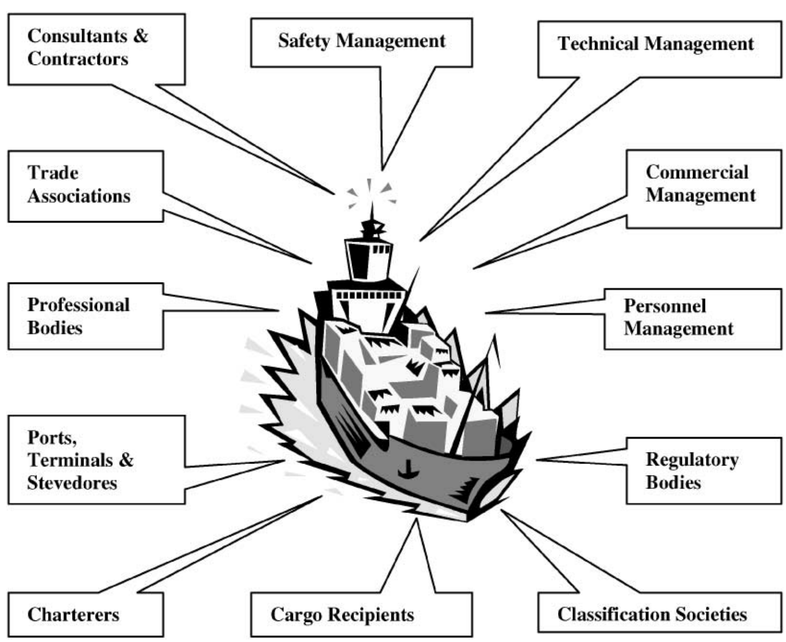

Fig. 10. The generic organisational & managerial infrastructure.

evaluation and acceptance by the ship's personnel. Real-time follow-up of the operation is carried out both onboard and ashore and the final figures of stability, stresses and cargo quantities are then calculated.

(iv) *Manoeuvrability, power and propulsion*: Container-ships are generally fitted with thrusters (bow and/or stern) and in several cases active rudders. This coupled by the advanced hydrostatic features (i.e. block co-efficient) of these vessels, results in a high level of manoeuvrability at all speed levels. High speeds, nevertheless, tend to reduce the time available for reaction by operators, adversely affecting the human reliability in close quarters situations.

(v) *The cargoes carried*: The majority of the cargoes carried are usually of high value, as opposed to bulk carriers and crude oil tankers, which tend to carry raw material of lower values. Containerised cargoes come in small parcels, while bulk cargoes (dry or liquid) come in larger ones. Goods travelling in a sealed container produce a problem of uncertainty as far as the characteristics of the cargo (i.e. quantity, quality security and inherent hazards) are concerned. The information for

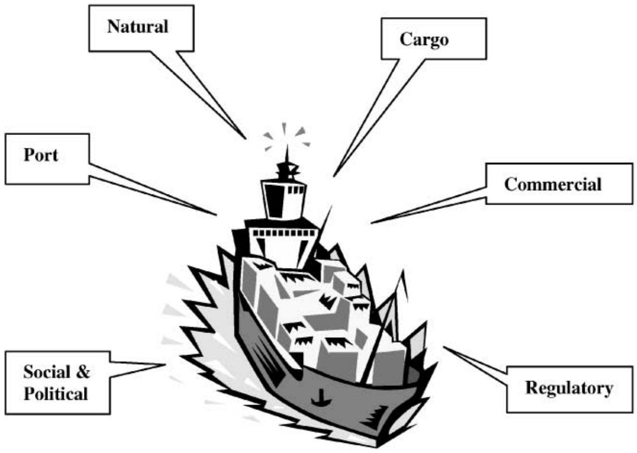

Fig. 11. The generic environment of operation.

such features is received by the documents accompanying the sealed unit and is rarely crosschecked. Only in cases of suspected existence of undeclared dangerous goods does the law provide for ship personnel to demand inspection of the unit's contents.

Again due to the high loading rates and pressure in time, most of the paperwork is received "in good faith" and the burden of avoiding and in the worse case combating hazardous situations falls on the ship personnel. Cases of undeclared hazardous substances as well as poorly maintained containers and tanks, have been identified but rarely reported to the authorities, following a compromising agreement between carriers and cargo owners [10,16].

(vi) *Cargo recipients (consignees)*: Another difference that containerships have is the one connected with the cargo recipients (consignees). Unlike other ship types (i.e. bulk carriers, tankers) the number of cargo consignees is highly increased. Even within the same unit there may be more than one of recipients. This fact, combined with the high value of the cargoes carried and their hazardous nature increases both the exposure of the carriers for possible damage and the difficulty in co-ordination and co-operation, between ship and cargo owners, during contingency situations.

(vii) *Ports and terminals*: Container-handling ports and terminals follow a distinct path, as far as their general layout and organisation are concerned. Container terminals have the ability to concurrently carry out loading and discharging operations, while terminals handling bulk cargoes tend to be specialised loading or discharging ones. In cases where bulk carrier terminals can handle both loading and discharging, the two operations are never carried out simultaneously.

3.2. *Formal safety assessment of containerships*

By considering the characteristics of containerships, a formal safety assessment framework is described in detail in the context of containerships.

3.2.1. *Hazard identification* (*HAZID*)

The aim of this step is to identify the hazards related to a specific problematic area and generate a list of them, according to their likelihood of occurrence and the severity of their consequence towards human life, property and the environment, in order to provide the base or the reference point for the next step. The following assumptions are applied:

- The containership average lifetime: 25 years
- The average number of operational days per year: 330
- Operational hours per day: 24
- Major maintenance frequency: 1 every 2.5 years (30 months).

The most popular expression used for the whole process of hazard identification is called "brainstorming" technique. This technique involves trained and experienced personnel combining their knowledge to identify the hazards through various approaches, such as the following [17]:

- Preliminary Hazard Analysis (PHA).
- Failure Mode and Effects Analysis (FMEA).
- Hazard and Operability (HAZOP) study.

The accident categories identified with regard to the containerships' operation include:

- Contact and/or collision.
- Explosion and fire (including flame and heat).
- External hazards (i.e. heavy weather).
- Flooding.
- Grounding and/or stranding.
- Hazards related to hazardous substances (including leakage, noxious fumes, etc.).
- Loss of hull integrity.
- Machinery failure (including electronic devices, navigation equipment and safety systems).
- Hazards related to loading/discharging operations (including ballast operations).
- Cargo damage.
- Hazards related to human errors.

The containership's compartments include:

- Navigation Bridge.
- Cargo Spaces.
- Engine Room.

		F 1	F2	F3	F4	F5	F6	F7
S1	Minor Injuries	1	2	3	4	5	6	7
S2	Major Injuries	2	3	4	5	6	7	8
S3	1-10 Deaths	3	4	5	6	7	8	9
S4	> 10 Deaths	4	5	6	7	8	9	10

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Fig. 12. Example proposed of risk matrix table.

- Void Spaces.
- Tunnels.
- Upper Deck Areas.
- Crew Accommodation.
- Galley.
- Provisions' Storage Spaces (including Bonded Stores).

The operational phases of a containership include:

- Design—construction—commissioning.
- Entering and leaving port.
- Berthing and unberthing.
- Cargo and ballast operations.
- Coastal navigation.
- Open sea navigation.
- Planned maintenance (day-to-day onboard).
- Major maintenance (dry docking).
- Decommissioning.

Once the hazards are identified with respect to each of above accident categories, compartments and operational phases, it is essential that they are "screened" so that they can be properly evaluated and the trivial ones to be excluded from further investigation. The screening technique evaluates hazards in terms of both frequencies of occurrence "F" and the severity of their consequences "S". Accordingly severity "S" ranges from minor injuries, property and environmental damage up to those with "catastrophic" consequences [8,15].

Using the "Risk Matrix Approach" [6,18,19], the combination of frequency and severity rankings is used for the estimation of the "Risk Ranking Number" (RRN), which is used to categorise risks according to their importance. By pursuing this approach, important risks are identified and forwarded for further analysis while trivial ones can be disregarded. An example of the "Risk Matrix Table" and its associated explanatory notes, as they can be applied to containerships, can be seen in Figs. 12 and 13.

3.2.2. *Risk assessment*

Following the study of the escalation of the basic or initiating events to accidents and their final outcomes, it is necessary for an "influence diagram" to be constructed, in order to study how the regulatory, commercial, technical and political/social environments influence each accident category and eventually quantify these influences with regard to human and hardware failure as well as external events [9,15,19,20]. In general, an "influent diagram" is a combination of fault trees and event trees. Each influence diagram is required to define the "best" and "worse" cases for each factor affecting the particular accident category under review. The whole process must cover each of those systems/compartments and include the escalation of the accident as well as the mitigation aspects such as evaluation of people, marine pollutants' containment, etc. Again the various operational phases of the ship have to be taken into consideration and generic data or expert judgements to be used. A list of ship's systems/compartments and operational phases can be shown in Fig. 14.

Each "frequency-consequence" curve determines the Potential Loss of Life (PLL) for the particular subcategory. By summing the product of frequency and severity across all event tree outcomes, the PLL for the whole accident category can be estimated.

3.2.3. *Ways of managing risks*

The aim at this stage is to propose effective and practical "Risk Control Measures" (RCMs) to high-risk areas identified from the information produced by the risk assessment in the previous step [6,17–19,21]. At this stage the implementation costs and potential benefits of risk control measures are not of concern. In general, there are three main characteristics according to which RCMs are evaluated and which can be summarised as follows [19]:

- Those relating to the fundamental type of risk reduction like the preventative measures forming "safety barriers" not allowing an incident to progress.
- Those relating to the type of action required (i.e. engineering or procedural).
- Those relating to the confidence that can be placed in the measure (single or redundant, active or passive)

Reducing the likelihood of occurrence and/or the severity of the consequences of hazards can achieve risk reduction. There are three main methods used for risk reduction, namely the management, engineering and operational ones [17,19].

Managerial solutions involve activities related to the management of each organisation. The main objective of such activities is the development of a safety culture, while the key factor for their success is effective communication.

Engineering solutions involve the design and/or construction of the ship. Engineering solutions have the inherent advantages that can be clearly identifiable (i.e. introduction of double hull in oil carriers) and address hazards in the early stages of a vessel's life. Nevertheless, large-scale engineering solutions suffer

Likely to occur on a vessel once per frequency	General Interpretation	Generic containership interpretation
F1 10000-100000 years	Extremely remote/improbable	Likely to occur once in a vessel's lifetime
F2 1000-10000 years	Remote to extremely remote	Likely to occur once in 2 years
F3 100-1000 years	Probable	Likely to occur 5 times p.a.
F4 10-100 years	Reasonably probable to remote	Likely to occur 3 times per vessel's life
F5 1-10 years	Reasonably probable	Likely to occur 30 times per vessel's life
F6 Annually	Reasonably probably to frequent	Likely to occur annually
F7	Frequent	Likely to occur monthly

Fig. 13. Example of proposed key to risk matrix table.

Ship's Systems & Compartments	Ship's Operational Phases
Navigation Bridge	Design-Construction-Commissioning
Cargo Spaces	Entering and Leaving Port
Engine Room	Berthing-Unberthing
Void Spaces	Cargo Operations
Crew Accommodation	Coastal Navigation
Passengers' Accommodation (if applicable)	Open Sea Navigation
Galley	Dry-docking
Bonded Stores & Provision Storage Areas	Decommissioning
	Maintenance onboard/in port

Fig. 14. Vessel's compartments and operational phases.

from lack of historical data on design aspects, inability of full-scale experimentation as well as of modification or replacement once vessels are in operation [21].

Operational solutions involve the development and introduction of appropriate procedures for carrying out "risk-critical" tasks, as well as improving the effectiveness of personnel in these tasks. Thus safety procedures, safe working practices, contingency plans and safety exercises (drills) can be included. Such solutions address efficiently human error factors and ensures the existence of uniformity of the adopted safety standards.

The identified measures with the same effect, or applied to the same system, can then be grouped in RCMs and it is up to the experts to estimate the effectiveness of each RCM. The development of casual chains provides a helpful tool for identifying and eventually selecting the appropriate RCMs [19]. The identification of RCMs can, then, be carried out at the nodes of each casual chain. Selected RCMs can then be forwarded to the 4th step, where their cost effectiveness will be evaluated.

3.2.4. *Cost–benefit assessment*

Selected RCMs must also be cost-effective (attractive) so that the benefit gained will be greater than the financial loss incurred as a result of the adoption [8,6,17,19]. Therefore this step is aiming at identifying the benefits from the reduced risks and the associated costs for each RCM. Attention is necessary to be drown to the fact that the evaluation of costs and benefits should initially be carried out for the overall situation and then for the various parties concerned and affected by the problem in concern. The parties affected are commonly referred to as "Stakeholders" [6,19,20].

There are limitations in carrying out cost–benefit analysis. The limitations come from imperfect data and uncertainty. It must also be pointed out that cost–benefit analysis, as suggested for use in FSA is not a precise science, but it is only a way of evaluation. Thus it cannot be used mechanistically, but only as a consulting instrument in decision making.

Each RCO, which has been forwarded from step 3, needs to be evaluated in accordance with the costs for its implementation and maintenance through the vessel's lifetime, as well as the benefits received for the same period. This evaluation is required to be carried out in two levels, primarily for the overall situation and then for each of the parties concerned and/or affected (Stakeholders) by the problem under review [8,9,15,19].

A "base case" is required to be incorporated as a reference for the comparisons that will follow. The base case reflects the existing situation, covering all levels of associated risks arising from a particular activity prior to the implementation of any RCM. The RCM costs, benefits and the "Cost of Unit Risk Reduction"(CURR value) can be estimated by comparing the base case with the one where the RCM is implemented.

The CURR value can be determined by dividing the "Net Present Value"(NPV) of the option's costs and

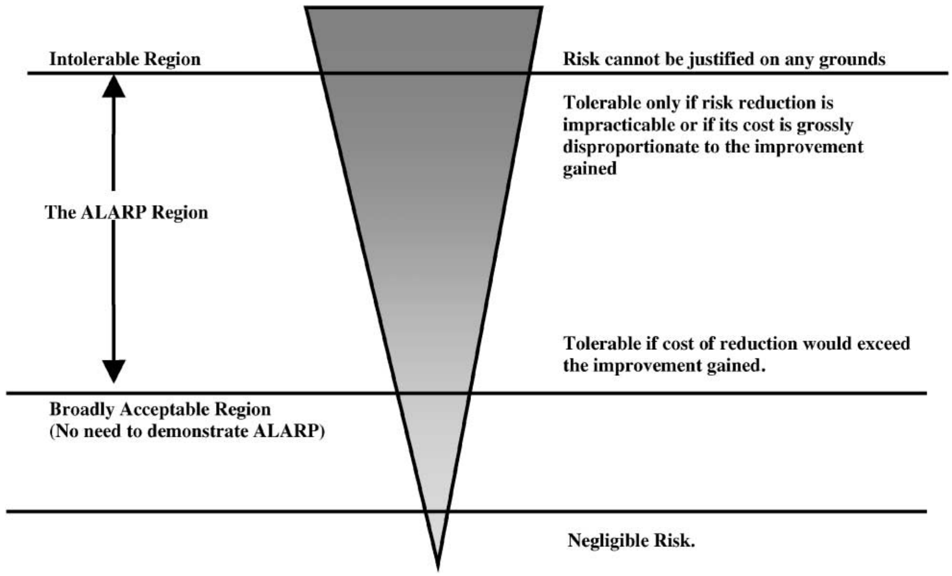

Fig. 15. The ALARP principle.

benefits by the combined reduction in mortality and injury risks [19,20].

Having estimated all costs–benefits and cost unit reduction levels of each RCM, for both the overall situation and for each particular accident category, the next requirement is to list the findings with regard to their significance to the various stakeholders and their relative values.

3.2.5. Decision making

The final step of FSA is "decision making", which aims at giving recommendations and making decisions for safety improvement taking into consideration the findings during the whole process. Thus the pieces of information generated in all four previous steps are used in selecting the risk control option which best combines cost effectiveness and an acceptable risk reduction, according to the set "risk criteria" by the regulators.

It is equally admitted, however, that the application of absolute numerical risk criteria may not always be appropriate, as the whole process of risk assessment involves uncertainties. Furthermore, opinions on acceptable numerical risk criteria may differentiate between individuals and societies with different cultures, experience and mentalities. Thus setting rigid numerical risk criteria may prove the whole decision-making process inflexible [19]. A numerical value could be defined as the upper tolerable/acceptable limit, which should not be exceeded in any circumstances. Below this limit, a more flexible formula could be used in order to ensure the greater risk reduction possible. Such formula may be used to determine whether or not risks are tolerable/acceptable and whether or not they need to be reduced to "As Low As Reasonably Practicable" (ALARP). A graphical representation of the ALARP principle is shown in Fig. 15.

The RCMs that could finally be adopted would be the ones that best balance reduction in PLL with cost-effectiveness for the whole situation as well as for the particular stakeholders.

4. Testing, evaluation and recommendations

4.1. A test case

Following the detailed analysis of the FSA methodology of containerships, a test case study is required in order to demonstrate its feasibility. A full-scale trial application would, however, be too large in volume for this paper. Therefore, the test case is limited to one accident category only, namely "fire". In addition, mainly owing to insufficiency of sufficient historical data assumptions may be employed, based on the expert judgement deriving from the experience in the field.

Step 1: Having identified the accidents, the causes are then grouped in terms of human error, hardware failures, external events, etc. The "fire" accident sub-categories are listed as follows:

- Navigation Bridge.
- Cargo Spaces.
- Engine Room.
- Void Spaces.
- Tunnels.
- Upper Deck Area.

ACCIDENT CATEGORY: FIRE									
Operation / Compartment	Design-const/ion-com/ining	Entering-leaving Port	Berthing-Unberth-Ing	Cargo & Ballast Ops.	Coastal Nav.	Open Sea Nav.	Mainte-nance	Dry-docking	Decommi-sioning
Bridge	F3/S1=3	F3/S1=3	F3/S1=3	F3/S1=3	F3/S1=3	F3/S1=3	F3/S1=3	F3/S1=3	F3/S1=3
Cargo Spaces	F4/S1=4	F4/S2=5	F4/S2=5	F4/S3=6	F4/S3=6	F4/S3=6	F4/S1=4	F4/S1=4	F4/S1=4
E/R	F5/S2=6	F5/S2=6	F5/S1=5	F5/S1=5	F5/S3=7	F5/S3=7	F5/S2=6	F5/S2=6	F5/S2=6
V/S	F4/S1=4	F4/S2=5	F4/S1=4	F4/S1=4	F4/S3=6	F4/S3=6	F4/S1=4	F4/S1=4	F4/S1=4
Tunnels.	F4/S1=4	F4/S2=5	F4/S1=4	F4/S2=5	F4/S3=6	F4/S3=6	F4/S1=4	F4/S1=4	F4/S1=4
Upper Deck	F4/S1=4	F4/S2=5	F4/S2=5	F4/S3=6	F4/S2=5	F4/S2=5	F4/S2=5	F4/S1=4	F4/S1=4
Crew Accom.	F4/S1=4	F4/S2=5	F4/S2=5	F4/S2=5	F4/S3=6	F4/S3=6	F4/S1=4	F4/S1=4	F4/S2=5
Galley	F4/S1=4	F4/S2=5	F4/S2=5	F4/S2=5	F4/S2=5	F4/S2=5	F4/S1=4	F4/S1=4	F4/S1=4
Stores	F1/S1=1	F1/S2=2	F1/S2=2	F1/S2=2	F1/S2=2	F1/S2=2	F1/S1=1	F1/S1=1	F1/S2=2

Fig. 16. Fire rankings, using the "risk matrix approach"—expert judgement.

- Crew Accommodation.
- Galley.
- Provisions' Storage Spaces (including Bonded Stores).

The screening process is carried out using the "Risk Matrix Approach". The final ranking for the accident category of "fire", takes the form as presented in Fig. 16.

Step 2: In this step the PLL and its distribution through the influence diagram will be determined. An illustration of the influence diagram for the accident category of "fire" can be seen in Fig. 17. Below the accident category level the structure is a graphical representation of the accident sub-category, including all the combinations of relevant contributing factors for each accident sub-category. Above the accident category level the structure is an event tree representation of the development of the accident category to its final outcome.

The study can then continue in order for the regulatory, commercial and social/political influencing environments, for each accident category, to be deliberated and eventually quantified with regard to human and hardware failures and external events. The outcomes are shown in Fig. 18.

Step 3: The table constructed for the accident category of "fire" is shown in Fig. 19. From Fig. 19, it can been seen that the areas requiring less consideration are clearly identifiable, and appear to be the "Provision Stores" and "Upper Deck Areas". For each of the remaining areas (sub-categories) casual chains need to be constructed and RCMs to be identified at the nodes of each chain.

RCMs according to their effect to the system under consideration are then grouped. The RCMs will next be evaluated, taking into account their effectiveness within the event trees or influence diagrams, rather than their cost, utilising once more expert judgements. The most effective RCM(s) can afterwards be forwarded to the next step.

Step 4: The most preferable means that for the cost–benefit analysis model construction is the use of nested computer spreadsheets to calculate the costs and benefits for each selected RCM. The quantification of the costs and benefits is to be achieved in terms of Net Present Value (NPV), which can be converted into a CURR value.

The above procedure is essential to be carried out for the overall situation as well as for each particular accident category. The CBA outcomes can then be listed according to their significance to the various stakeholders.

Step 5: In this step final decisions are made, taking into account each individual RCMs CURR value and PLL reduction capabilities, as determined and listed by the safety analysts.

4.2. Evaluation of the FSA requirements and proposals for improvement

FSA can be feasibly applied to containerships, provided that several areas, which cause uncertainties, are further deliberated. These areas influence both the general principles of FSA and the specific requirements for containerships, either directly or indirectly. The most prominent ones are analysed and alternative suggestions are described as follows

4.2.1. The brainstorming technique

Although the knowledge and expertise of the people involved in the brainstorming technique is absolutely respectable, certain safety aspects may be overlooked as it might be considered "natural" from their point of view, while to a person outside the profession it might be something completely new and thus causing concern.

Since by definition the "brainstorming session" ought to be structured to encourage the unfettered thinking and participation of the people involved, the contribution by people with less expertise in the subject would be a positive one, as they might bring up safety issues, which otherwise would have been overlooked.

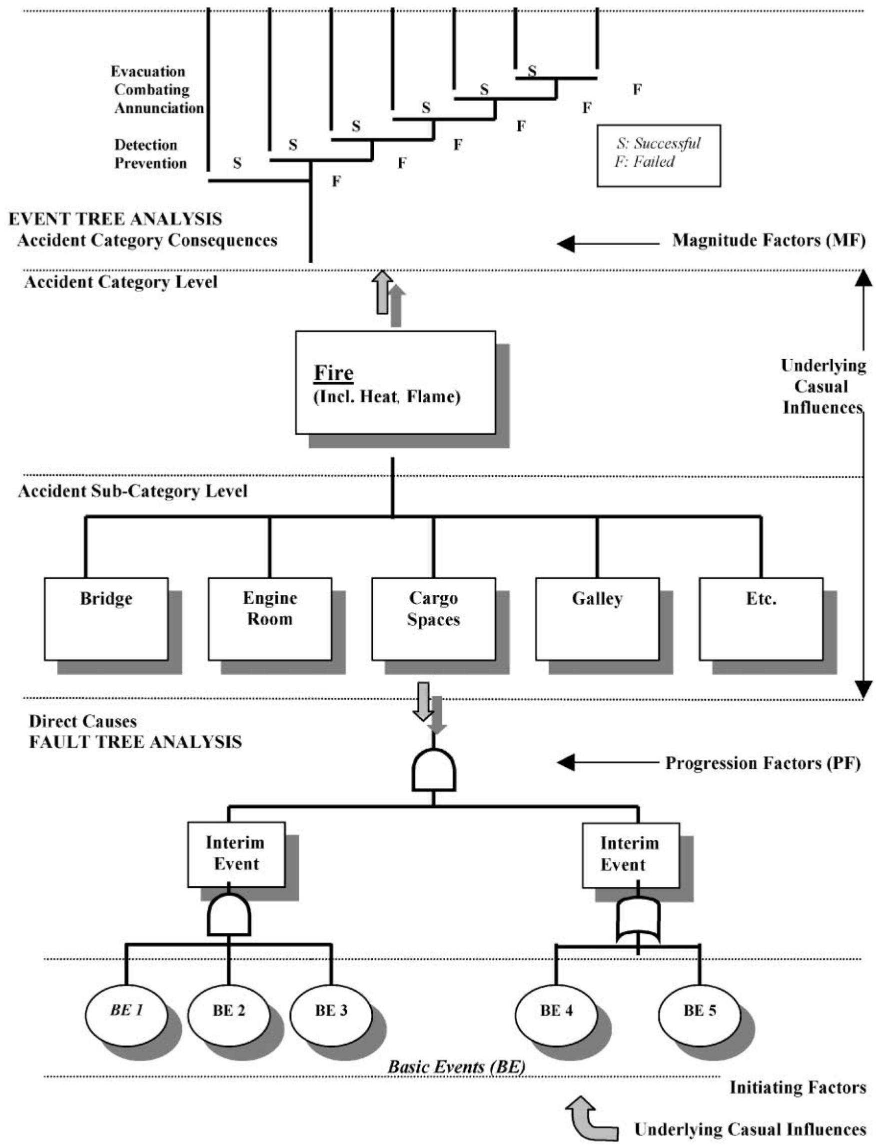

Fig. 17. Risk contribution tree for fire.

4.2.2. Need for interaction with other industries' safety and quality management systems

FSA for ships in general and for containerships in particular, should develop the ability to interact with regulatory bodies responsible for land-based operations. Sharing the relevant data of non-compliance with established safety and quality standards for shore-based industries would eliminate a considerable percentage of the uncertainty created in this direction.

4.2.3. Human element

Another important factor to be taken into consideration is human element. Problems like differences in language, education, training, mentality, etc. have increased over the past years, especially with the introduction of multi-national crews. Such problems largely contribute to marine casualties. On the other hand, crew reductions have increased the workload of operators, which in connection with the reduced opportunities for port stay and recreation (especially with containerships) equally increases the probabilities for errors.

It becomes apparent that FSAs success largely depends on two essential conditions. The first condition is the development of a safety culture at all levels of the industry's infrastructure, from company managers to vessel operators. The second one is the inclusion into the FSA framework itself of further guidance on how human factors would be integrated in a feasible manner.

4.2.4. The availability and reliability of data

Primarily, great attention should be paid on the data resources, as the various databases do not always use the same platform for data analysis. This is attributable to the fact that different organisations look into safety issues

ACCIDENT CATEGORY: FIRE		
Compartment (Sub-Category)	% Incidents expected	Frequency (per vessel/year)
Navigation Bridge	2	1.4E-04
Cargo Spaces	6	4.3E-04
Engine Room	75	5.3E-03
Void Spaces	4	2.8E-04
Tunnels	4	2.8E-04
Upper Deck Areas	0.9	6.4E-05
Crew Accommodation	3	2.1E-04
Galley	5	3.5E-04
Provision Stores	0.1	7.1E-06
TOTAL	100	

Fig. 18. Incident database for fire.

ACCIDENT CATEGORY: FIRE			
Compartment (Sub-category)	Potential Loos of Life (PLL)	Frequency (Per vessel/year)	Severity (max. observed)
Navigation Bridge	2.2E-04	1.4E-04	1
Cargo Space	6.6E-04	4.3E-04	4
Engine Room	7.7E-03	5.3E-03	3
Void Spaces	4.4E-04	2.8E-04	3
Tunnels	4.4E-04	2.8E-04	3
Upper Deck Areas	9.9E-05	6.4E-05	3
Crew Accommodation.	3.3E-04	2.1E-04	3
Galley	5.5E-04	3.5E-04	2
Provision Stores	1.1E-05	7.1E-06	3

Fig. 19. Cumulative table for fire sub-categories.

from a different prospective, which facilitates their own interests. In order to overcome the problems created by the availability and reliability of failure data, international co-operation and co-ordination are required with the intention that a new global database will be established, controlled and updated by an International Regulatory Body (i.e. IMO). Such a database should be easily accessible by both Administrations and Analysts/Researchers providing reliable data with defined parameters upon which the incoming information has been processed.

As far as containerships are concerned, the task of data collection and processing appears to be relatively easier than in other ship types. This is attributable to the fact that containerships and their owning/operating companies form a part of a multi-modal transportation network and therefore are highly computerised. The necessary infrastructure therefore exists. With the adequate adaptations the existing infrastructure can be feasibly utilised for the purpose of FSA and failure data can be easily collected, processed and communicated both internally (i.e. company head offices, branches and ships) and externally (i.e. central international and national databanks, other industrial bodies).

4.2.5. Risk criteria

Large variations also exist in the risk criteria, set around the world, as they depend mainly on local regulators. Up to today, all efforts are being made by administrations individually, without any co-ordination among them. Considering that internationally trading vessels move constantly from one jurisdiction to another, it becomes apparent that this lack of co-ordination is bound to produce further confusion to the industry, which does not seem willing to accept it.

The establishment of universally acceptable risk criteria for ships can be achieved through a compromise between qualitative and quantitative figures. Thus a numerical value could be defined and agreed as the upper tolerable/acceptable limit, which should not be exceeded in any circumstances. Below this limit, a more flexible formula could be used in order to ensure the greater risk reduction possible. Such a formula may be used to determine whether or not risks are tolerable/acceptable and whether or not they need to be reduced to ALARP.

4.2.6. Cost–benefit analysis

The use of cost–benefit analysis as a platform on which a given option is finally selected for implementation is an appealing proposal. In practice, however, it can be quite complicated, especially in cases where human lives are involved. The fact that ships are manned with multinational crews, usually officers from developed countries and crews from developing ones, and obliged to trade in all parts of the world creates a difficulty in selecting the proper human life value for cost–benefit analysis.

Furthermore, the use of different values on different nationalities would have an adverse and undesirable effect on both international relations and working conditions onboard ships.

A feasible solution to this problem would, once more, involve an international agreement on a reliable method of estimating the current value of human life. The international regulatory bodies should not only be responsible for the initial deliberations, but also for the constant follow up of the international economic, political and social trends that influence that value.

5. Conclusion

This paper has attempted a critical evaluation of the FSA framework as it applies to containerships. A test case was used to demonstrate the feasibility of the described approach.

It becomes apparent that there is still plenty of space for improvement on containership safety. Areas on which such improvement can be achieved include, but not limited to, the vessels' strength and stability, fire-fighting and life-saving equipment, human reliability and information availability, reliability and interchange. Such areas are described as follows:

5.1. The containership hull stresses

Mainly due to their configuration and the increased demand for full capacity utilisation, coupled by the subsequent increase in the vessels' sizes, containerships face the problem of increased structural stresses (i.e. bending moments, searing forces and torsion). The establishment of objectives aiming at the advancement of practical design strategies towards containership structures, optimal for both the operator and the operating environment, is considered crucial. Further research and testing towards that direction will greatly contribute to the rule-based treatment of the containership structural strength in the context of FSA.

In addition to the above, stress monitoring both in "harbour" and "open-sea" conditions, would provide a useful tool for the safe operation of large containerships producing information on both the current structural stress levels of the vessel and any possible deviations from the pre-calculated figures. Thus, "Real Time Stress Monitoring Systems", should not be considered "optional", but become compulsory for containership sizes of "Panamax" (3000 TEU) and above.

5.2. The containership fire-fighting and life-saving equipment

The high concentration of dangerous goods with varying properties implies that apart from adequate contingency procedures containerships need to be fitted with the appropriate combating equipment. The available failure data do not show considerable fatalities, serious injuries or damage to the environment in such emergency situations.

The traditional combating methods (i.e. fixed and portable fire fighting arrangements) and material (i.e. sea-water, chemical foam, CO_2 and personal protective equipment) which are used today are not designed to protect from conditions involving corrosive, toxic and biochemical substances or a chain reaction causing extensive fire and/or explosion. Since the introduction of specified combating materials for each particular type of cargo would not prove to be cost-effective, the introduction of advanced escape/evacuation systems and procedures should be considered.

Today the types of escape vehicles (i.e. lifeboats and life rafts) used on containerships follow the general pattern of dry cargo vessels, without taking into consideration the possibility of existence of corrosive, toxic or biochemical environments. Excluding their capacity, the choice of the type of lifeboats or life rafts is left on the shipping company's discretion. The compulsory inclusion, of protectively located and easily accessible lifeboats with "totally enclosed", "free fall", "self-righting" and "air tight" functions, equipped with "external sprinkler system" (as used in Oil and Gas Carriers) for all containerships carrying dangerous goods would provide adequate protection to the evacuees.

5.3. Human element

Considering the relevant statistics and failure data in hand, the human element appears to be the prominent factor for containership failures. The distribution of approximately 1 : 5 (21%) between shore based and ship operating personnel, suggests that the problem in hand is a multi-sided one.

Primarily, there is the need for adequate training of ship personnel, specialising in the containership operation. Containerships should cease to be considered as simple "general dry cargo vessels", as dictated by their particular characteristics. Such characteristics include the increased ship speed, the long list of dangerous cargoes carried (e.g. explosives, biochemical, toxic, corrosive, nuclear, etc.) and the often-marginal structural strength exploitation. The above suggest that personnel serving on containerships should be adequately qualified, with knowledge and skills exceeding the general ones offered by the various Nautical Academies. A similar requirement exists today for personnel serving on Oil and Gas Carriers. Thus, specialist courses and seminars should be introduced providing containership personnel with the adequate theoretical and practical knowledge and the necessary documentation.

Other factors that diversely affect human reliability are the reduced port turnaround and the increased sea-passage time of this ship type. Containerships in very rare occasions have the opportunity for overnight stay in port, reducing the chances for crew recreation and thus increasing personal stress and fatigue. Measures such as in-built swimming pools, gymnasiums and recreation rooms and the introduction by the IMO of limits on the maximum amount of daily working hours per crewmember, where actually implemented, had little effect in reducing crew stress and fatigue. Reductions in the contractual service time of crewmembers rest on each individual shipping company's discretion. It is believed that further consideration should be given to the matter and international agreement be achieved.

Attention should also be paid on the required qualifications for shore-based personnel, as well as on the correct implementation of the relevant legislation regarding the proper inspection and documentation of the cargoes from the point of production to the point of loading. Better policing of the whole network will reduce incidents, which may prove to be disastrous for human lives, the environment and other property. Such incidents include, but not limited to, undeclared dangerous goods packed in inadequate containers, inaccurate or deliberately altered container weights and numbers, forged manifests and poorly if at all maintained reefer containers with inadequate settings.

5.4. *Information availability, reliability and interchange*

Many of the weaknesses existing today in the shipping industry in general and the container sector in particular, would have been remedied if there had been an adequate flow of information amongst the parties concerned. Containerships and their owning/operating companies form a part of a multi-modal transportation system, which bases its successful function on an integrated logistics system and an electronic data interchange network. Thus, each company's existing infrastructure could easily be adapted to carry out the additional task of collection, processing, storing and interchange of safety information including failure rates at all sections.

It could also interact with regulatory bodies outside the shipping industry, responsible for land-based operations, and share the relevant data of non-compliance with established safety and quality standards for shore-based industries. This would eliminate a considerable percentage of errors attributable to factors not related to container shipping.

Until today, ship safety has been subject to sets of prescriptive rules and established good practices. Matters are usually resolved in an intuitive manner by ship personnel. The constantly evolving ship technology and the new hazardous cargoes carried impose new hazards in one form or another and call for equally advanced safety measures with the ability to follow up and adapt to the above evolutions. Possibly, the most illustrative example of fast evolution is the containership sector of the industry. Within only 44 years of life, containerships have moved from 58 to up to 7000 TEU per vessel, from 13 to 27 Knots and from simple dry general cargo to refrigerated, corrosive, toxic, explosive, biochemical, nuclear and other ones.

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