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Agenda item 21

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FORMAL SAFETY ASSESSMENT

FSA – container vessels

Submitted by Denmark

SUMMARY	
Executive summary:	This document reports on the Formal Safety Assessment study on container vessels carried out within the research project SAFEDOR[1].
Action to be taken:	Paragraph 10
Related documents:	MSC 83/INF.8; MSC 72/16; MSC/Circ.1023 – MEPC/Circ.392 and MSC 83/INF.2

Introduction

1 The Maritime Safety Committee, at its seventy-fourth session (2001), and the Marine Environment Protection Committee, at its forty-seventh session (2002), approved Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process, as set out in MSC/Circ.1023 – MEPC/Circ.392 (consolidated with amendments in document MSC 83/INF.2).

2 Member Governments and non-governmental organizations were invited to apply FSA in accordance with the Guidelines and to submit the results thereof to the Organization in accordance with the Standard Format for Reporting shown in appendix 8 of the Guidelines.

3 As part of the research project SAFEDOR, a high-level FSA study on container vessels has been performed. The main results of that study are provided in the annex of this submission and supplementary information is submitted as document MSC 83/INF.8.

Summary of results from the study

4 The FSA study on container vessels demonstrated that:

.1 the risk profile for the operation of container vessels lies within the ALARP[2] region;

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1 SAFEDOR: EU-funded research project titled: Design, Operation and Regulation for Safety.

2 ALARP: As Low As Reasonably Practicable.

.2 the risk level is dominated by collision, grounding and fire scenarios resulting in loss of lives and causing environmental damages by accidental release of fuel and cargo; and

.3 some identified risk control options were found to be cost effective according to the cost effectiveness criteria in document MSC 72/16.

5 The following risk control options were found to be cost effective:

.1 AIS integrated with radar for improved navigational safety;

.2 track control system for improved navigational safety; and

.3 high bilge level alarm in open cargo holds of open-top container vessels.

Proposal

6 Based on the FSA results reported in the annex and document MSC 83/INF.8, the following risk control options may be proposed to be made mandatory IMO requirements for container vessels:

.1 AIS integrated with radar for improved navigational safety; and

.2 track control system for improved navigational safety.

7 In addition, the following risk control option required by MSC/Circ.608/Rev.1 (Interim guidelines for open-top container ships) was proven to be cost effective:

.1 bilge alarm in open cargo holds of open-top container vessels.

8 A summary of the full FSA report is attached in the annex.

Further information on SAFEDOR

9 Further information about the EU funded research project SAFEDOR can be found at www.safedor.org.

Action requested of the Committee

10 The Committee is invited to consider the information provided and take action as appropriate.

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ANNEX

FORMAL SAFETY ASSESSMENT OF CONTAINER VESSELS

1 SUMMARY

A Formal Safety Assessment (FSA) was performed to estimate the risk level and to identify and evaluate possible risk control options (RCOs) for container vessels.

The FSA study concluded that both the individual and the societal risk associated with the operation of container vessels are within the proposed ALARP area. This means that risk reduction measures should be implemented as long as they are cost-effective according to a predefined criterion.

It was further concluded that generic accident categories collision, grounding and fire are responsible for 68%, 14% and 17% of the total risk, respectively.

The basis for the recommendations given in this study is the following:

- An RCO is considered cost-effective if the GCAF (Gross Cost of Averting a Fatality) is less than US$3 million. This is the value used in all decisions made following the FSA studies submitted under agenda item 5, Bulk carrier safety, at MSC 76, December 2002, and suggested in document MSC 72/16.

The study demonstrates that the following RCOs provide considerable risk reduction in a cost-effective manner:

- AIS (Automatic Identification System) integrated with radar
- Track control system
- High bilge level alarm in open cargo holds of open-top container vessels.

It is recommended to introduce the first two RCOs related to navigation as IMO requirements as they are cost-effective and offer significant potential to reduce loss of lives. Some of them are typically implemented on current container vessels, but they are not mandated by IMO in general.

In addition, the risk control option of introducing high bilge level alarms that is required by MSC/Circ.608 for open-top container ships /5/ was proven to be cost effective.

The cost benefit assessment is based on the introduction of one RCO at a time; an interaction analysis is required to determine the effect when several RCOs are introduced simultaneously.

2 DEFINITION OF THE PROBLEM

Container vessels are workhorses in global supply chains and this involvement is expected to increase in the coming years. They are used to carry large quantities of goods – some of high value – over long distances, e.g. between Asia, Europe and North America. Generally, within the maritime industry and the public, container vessels have a reputation of being well designed, constructed, maintained, manned and operated with a high focus on safety. In addition to this, accident statistics suggest a safety record above the average of the merchant fleet today.

However, no firm and conclusive statement is available about the current risk level of the world container fleet. Hence, in accordance with MSC/Circ.1023, a Formal Safety Assessment was performed for a generic container vessel with the aim of determining this risk level. This included the identification of major risk types and the quantification of a baseline risk level for container vessels, as well as the identification and evaluation of risk control options related to their design and operation. It is assumed that the established baseline risk level implicitly reflects the current safety level of rules and regulations related to container vessels, despite the fact that specific vessels may have an even lower risk level due to commercial considerations. While many regulations pertain to all ship types, the International Convention for Safe Containers (CSC), the International Maritime Dangerous Goods (IMDG) Code, and the Interim Guidelines for Open-top Container Ships apply to container vessels specifically. Both the IMDG code and the CSC code are mandatory under the SOLAS Convention.

The scope of this study is limited to human safety of crew members in terms of potential loss of lives. Security risks as well as third party risks to people onshore or onboard other vessels are out of scope.

Environmental risks related to the spillage of bunker fuel oil as well as the release of dangerous goods are taken into account.

Risks to property, i.e. to ship and cargo, are only considered as far as necessary for the cost-benefit analysis. Risk to third party property like other vessels, shore-side buildings, installations, cranes in port, bridges, and waterways are out of scope. Loss of business due to interruption of service or loss of reputation for the operating company is out of scope here, too.

The study covers the operational phase of a container vessels' life cycle, focusing on 1) open sea transit, 2) operation in port, restricted and coastal waters, and 3) loading and unloading operations in the harbour. Risks associated to construction, docking, repair, inspection, maintenance, decommissioning or scrapping are considered out of scope.

The design of container ships has changed significantly since the first ships were built in the 1960s. The latest significant changes to rules and regulations were introduced in the early 1990s. Therefore, this study is limited to modern, fully cellular container vessels built since 1990, which nevertheless represent the vast majority of the world container fleet today. General purpose ships capable of carrying containers as well as other combined carriers are excluded due to their relatively small number.

A number of factors and developments could have an impact on the future safety level for container vessel. These include significant growth rates in world trade and vessel new building numbers, new vessel designs with significantly larger capacity and new propulsion concepts, increased traffic density in particular areas, routes and harbour approaches, and a shortage of qualified and well trained crew personnel. However, none of these are addressed in the current study.

3 BACKGROUND INFORMATION

Container shipping[1]

The first container ships built in the 1950s were converted tankers. Subsequently, dedicated designs for container vessels have been developed. Today, there is more than 40 years' experience in designing, building and operating container vessels.

The number of ships has been continuously growing over the last 15 years. As of January 2007, the world container fleet consisted of 3,875 ships of 100 GT and above, comprising some 10% of the total merchant fleet /1/. The total capacity and total tonnage of this fleet are approximately 9,400,000 TEU and 127,000,000 tonnes deadweight, respectively. In 2006, 325 container ships with an overall capacity of 1,245,304 TEU were delivered. During the year 2005, the fully cellular container fleet grew by 13.5 per cent (based on TEU). Compared with 1996, the fully cellular container fleet has more than doubled its TEU capacity, whereby the disproportionate increase of the TEU capacity indicates the trend towards larger container ships. Another 1,180 vessels are in the order books of the ship yards.

The world container fleet is relatively young. On average a container vessel is 11.6 years old. 71% of the fleet, 78% of the total deadweight tonnage, and 81% of the total capacity were built less than 16 years ago.

Container ships can be grouped by their size, capacity and main dimensions. Typical categories are presented in Table 1, which displays total values and shares for number, capacity and tonnage.

Table 1: Breakdown of container vessel fleet (/1/, January 2007)

	Total			Share			Average
Category	**Number**	**Capacity (TEU)**	**Tonnage**	**Number**	**Capacity (TEU)**	**Tonnage**	**Capacity (TEU)**
Post-Panamax	831	4,684,326	59,961,119	21.4%	49.8%	47.0%	5,637
Panamax	297	1,015,287	13,717,507	7.7%	10.8%	10.7%	3,418
Sub-Panamax	646	1,626,273	23,201,565	16.7%	17.3%	18.2%	2,517
Handysize	1,036	1,463,333	21,540,685	26.7%	15.5%	16.9%	1,412
Feedermax	690	506,398	7,218,570	17.8%	5.4%	5.7%	734
Feeder	375	115,579	2,052,578	9.7%	1.2%	1.6%	308
Total	*3,875*	*9,411,196*	*127,692,024*	*100.0%*	*100.0%*	*100.0%*	*2,429*

While the average capacity is 2,400 TEU, an increasing number of ships with more than 8,000 TEU capacity are on order, some as large as 12,500 TEU.

[1] This section has been updated to present the latest figures as background information. However, this does not change any of the results. Basically, the trend towards younger ships and the clustering by numbers and capacity continue.

For container vessels, there are two main operational patterns. Line operation typically involves ships with large transportation capacities. They sail on a fixed route with a limited number of ports according to a schedule with fixed arrival and departures times. These schedules enable long term planning for the transport of large quantities. Their operating profile includes fewer stays in port and more open sea voyage. Loading and unloading requires significant time. Major line trades are Europe – North America and Europe – East Asia. Feeder operation typically involves much smaller ships on short distances, e.g. along coastlines. They are characterized by frequent port calls. Their routes, cargo and departure times are dominated by short term demands. Additionally, they are required for areas with limitations in draught or breadth.

According to the figures above, two segments are equally important. While large line vessels (Panamax, Post-Panamax) provide nearly 60% of the total transport capacity, small feeder vessels (Feeder, FeederMax, HandySize) comprise nearly 55% of the total number of ships.

Generic vessels

A container ship is defined as a sea-going vessel specifically designed, constructed and equipped with the appropriate facilities to carry cargo containers. Containers are stowed in cargo spaces, i.e. in cargo holds below or above deck. The share of deck containers can more be than 50% and there are typically up to 10 tiers per cargo hold of a large vessel. Fully cellular containerships carry only containers. They have cell-guides under deck and necessary fittings and equipment on deck for loading, unloading, and securing. Ships with onboard cranes are commonly referred to as “geared ships”. Many container ships have the capability to carry a certain percentage of refrigerated (or reefer) containers that are placed in dedicated positions with electric connection, so-called reefer-plugs. These places can be on deck or in a hold, but no reefers will be stowed at the outer rows.

Most container vessels comply with SOLAS regulations regarding construction and equipment requirements for carriage of dangerous goods, for at least some of the holds and open deck spaces. However, the type and amount of dangerous goods carried can vary considerably for individual ships and routes.

In order to represent the two major segments properly – as indicated in Table 1 – two generic designs were selected; see Table 2 for their characteristics. In addition to the nominal transport capacity, there is a more typical capacity according to a homogeneous load of 14 t/TEU.

Table 2: Generic vessel characteristics

	Vessel 1	**Vessel 2**
Operating Profile	Feeder	Liner
Capacity (TEU)	1,706	4,444
- in hold	652	2,051
- on deck	1,054	2,393
- at 14 t homog. load	1,250	3,100
Length (m)	173	271
Deadweight (t)	21,750	58,255
Speed (kn)	20.2	25.5
Crew	20	20

Containerized cargo

Containers are metal boxes in standardized format able to carry almost any kind of goods. They are built from a steel frame with bottom girders together with corrugated top and side panels made from steel or aluminum and a wooden floor designed for homogeneous loads up to 2.5 tonnes per square metre. The most common type is a general-purpose container, but there are many specialized types, e.g. reefer and ducted reefer container (needs a connection to an onboard cooling unit) and containers with controlled atmosphere. Other types include open-top, hard-top, platform, flat racks, tank container, isolating, cooling, bulk container, special purpose, e.g. for dangerous goods.

There are two standard sizes for containers, 20 and 40 feet, referred to as *Twenty-Foot Equivalent Unit* (TEU) and *Forty-Foot Equivalent Unit* (FEU), respectively. Other sizes are possible, but much less common. 20 foot containers are 20 ft long, 8 ft wide and 8 ft high (6.06 x 2.24 x 2.24 m), have a volume of 33 m^3, a net weight of 2 – 2.5 t and a payload of 20 – 28 t. 40 foot containers have double length and volume. They have a net weight of 3.5 – 4 t and a payload of 28 – 33 t.

Containerized transport is characterized by a large variety of cargo, a certain percentage of which is dangerous goods. The hazards associated with each class of dangerous goods also vary and are related to the inherent characteristics of the dangerous goods themselves. They include properties such as corrosiveness, explosiveness, toxicity, radioactivity, and flammability.

Dangerous goods may not only initiate or contribute to a fire and explosion incident, but may also impact the consequences of fire, explosion, grounding, and collision incident. The accidental release of hazardous substances due to container damage, fire, leaks, etc. can result in injuries or fatalities among crew members and potentially third parties, environmental impacts, and damage to the vessel. The extent of consequences depends on the type and quantity of goods released. Some goods such as toxic gases will have a more serious implication for crew health and safety, as well impacts to third party if the vessel is in port near populated areas.

The information about amount and type of dangerous goods typically carried on container ships is limited and varies widely between vessels and routes. Furthermore, observations suggest that there is a discrepancy between dangerous cargo declared in the Dangerous Cargo Manifest (DCM) and the real amount onboard. In fact, undeclared dangerous goods have been identified as the cause of a number of serious incidents.

For the purpose of this study, it was assumed that 6% of the cargo were dangerous goods – both declared and undeclared. No specific assumptions were made about the breakdown of specific types of dangerous goods according to IMDG classes or other classifications.

Accident statistics

The main source of information for accident statistics was the LMIU database /2/, a comprehensive database containing more than 40,000 casualty reports for the seagoing merchant fleet > 100 GT. On average, some 2,500 incidents, serious and non-serious, are recorded every year. These casualty records can be associated to IMO number and other important vessel characteristics. Data from secondary sources were added where appropriate.

According to the scope of this study, casualty records were analysed for unitized container carriers, excluding mixed-mode container carriers. Furthermore, pre-screening of the data revealed, that homogeneous data were available only for the reporting period 1993 – 2004.

Within this period, 1,680 casualty reports were found. 98 of these were out of scope of this FSA application. While some are related to other operational phases (in dry dock, at sea trial), most are recorded piracy acts. This leaves 1,582 known and relevant incidents involving container carriers. Information about these has been utilized in the FSA study. The available material indicates that incidents occur for all vessels sizes similarly. A breakdown of accidents according to categories is shown in Table 3 below. The category "serious" includes accidents rendering a vessel unseaworthy, breakdowns requiring tug assistance; sinking, long grounding events, or anything involving major disruption to a vessels schedule or requiring lengthy repairs. The category "heavy weather" indicates those accidents where weather was a factor in the casualty.
Accident frequencies were calculated by relating total accident numbers to all ships at risk in that period – 30,682 ship years.

Table 3: Reported accidents of fully cellular container ships, 1993 – 2004

Accident category	Total number	Thereof Serious	Thereof Heavy weather	Accident Frequency (per ship year)
Collision	493	78	34	1.61×10^{-2}
Contact	112	15	12	3.65×10^{-3}
Grounding	210	64	17	6.84×10^{-3}
Fire/Explosion	109	44	1	3.55×10^{-3}
Machinery damage	395	108	5	1.29×10^{-2}
Hull damage	39	6	13	1.27×10^{-3}
Foundered	2	2	1	6.52×10^{-5}
Miscellaneous	222	10	67	7.24×10^{-3}
Total	*1,582*	*327*	*150*	*5.16* $\times 10^{-2}$

Note that this classification is by accident category, e.g. accidents leading to grounding or collision are recorded under the respective category, despite the fact that machinery damage was possibly a contributing factor. Hence, machinery damage is only reported when it does not lead to another accident category. Within the category "Miscellaneous" most entries are related to container losses and pollution, often coupled with bad weather conditions. Furthermore, only a few accidents within categories "Hull damage" and "Miscellaneous" are reported as serious.

Within the reporting period under consideration, 19 of the casualties involved fatalities and missing crew members. For the analysis, the total number of fatalities includes crew members who were reported missing. The fatality rate is based on the same fleet size as above, i.e. 30,682 ship years.

Table 4: Fatalities, missing crew members, pollution and container losses, 1993 – 2004					
Accident category	**Number of fatalities**	**Number of missing**	**Pollution events**	**Containers lost**	**Fatalities and missing per ship year**
Collision	5	13	16	23	5.87×10^{-4}
Contact	0	0	4	3	0.00
Grounding	0	15	8	0	4.89×10^{-4}
Fire/explosion	42	0	1	2	1.37×10^{-3}
Machinery damage	0	0	0	0	0.00
Hull damage	0	0	2	738	0.00
Foundered	30	0	0	0	9.78×10^{-4}
Miscellaneous	3	0	17	1,239	9.78×10^{-5}
Total	*80*	*28*	*48*	*2,005*	*3.52×10^{-3}*

The largest single contribution to risk of human life is from fire accidents according to historic information. Furthermore, the database contains information about reported pollution and containers lost or damaged. As these items are typically not safety related, significant underreporting is assumed. Most pollution events are associated with the accident categories "collision", "grounding", and "miscellaneous", while most container losses are associated with accident categories "miscellaneous", "hull damage", and "collision".

Based on the relative frequency of fatalities and missing per ship year, a typical crew size of 20 and a 50-50 rotation scheme, the historic individual risk level for a container vessel crew member evaluates to 8.8×10^{-5} per year.

4 METHOD OF WORK

The FSA methodology outlined in the FSA Guidelines has been used in this study. The FSA application has been carried out as a joint effort between Germanischer Lloyd (Germany), Aker Yards (Germany), SSPA (Sweden), and Peter Döhle Schiffahrts-KG (Germany) and the project team has comprised risk analysts, naval architects and other experts from the partners above. Technical experts have been extensively consulted throughout the work with the FSA. The work was conducted within the SAFEDOR project, partially funded by the EU /6/.

The FSA commenced with HAZID meetings in June 2005, and the final report was completed in July 2006. Three HAZID sessions were organized in June 2005. Subsequently, harmonized risk and severity estimates were established by using the Delphi method over e-mail. Additionally, a number of co-ordination meetings were held between the partners. Technical workshops involving additional experts were arranged to identify and prioritize risk control options. After an internal review by the SAFEDOR Steering Committee, an additional workshop with technical experts was held in May 2007, developing a consolidated risk model for the accident category "Heavy weather" covering large ship motions as well as water ingress into cargo holds.

The HAZID (FSA step 1) was conducted as a series of three moderated expert meetings including brainstorming sessions, each of them associated with one phase of operation. The following phases were considered most relevant for a high-level analysis:

- Loading and unloading at a terminal
- Operation in port, restricted and coastal waters
- Open sea transit.

A Failure Mode and Effect Analysis (FMEA) technique was used to record the findings. The outcome of the HAZID was a risk register containing the hazards and their subjective risk rankings from which a list of the highest ranked hazards could be extracted.

The risk analysis (FSA step 2) comprised an investigation of accident statistics for container vessels as well as risk modelling utilizing event tree methodology for the most important accident scenarios. Based on the survey of accident statistics and the outcome of the HAZID, relevant accident scenarios were selected for further risk analysis.

The risk analysis contained two parts, a frequency assessment and a consequence assessment. For the frequency assessment, estimating the initiating frequency of generic incidents, accident statistics were utilized for the selected accident scenarios. The estimates arrived at in this way were compared to similar studies for other ship types, leading to the conclusion that they are reasonable and adequate.

The consequence assessment was performed using event tree methodology. First, conceptual risk models were developed for each accident category and event trees were constructed accordingly. The event trees were subsequently populated using different techniques for each branch probability according to what was deemed the best approach in each case. The approaches employed included accident statistics, damage statistics, fleet statistics, simplified calculations and modelling and expert opinion elicitation.

The frequency and consequence assessments provided the risk associated with the different generic accident scenarios and these risks were summarized to estimate individual and societal risks to human life and the environment pertaining to the operation of container vessels.

Risk control options (FSA step 3) were identified and prioritized during workshops involving additional experts. Existing measures and risk control options identified by similar FSA studies for other ship types were reviewed for applicability. Subsequently, the identified risk control options were screened by the project team taking into account the number of scenarios affected as well as the potential for risk reduction, resulting in a list of risk control options for further evaluation and cost benefit assessment.

A cost benefit assessment (FSA step 4) was performed for risk control options identified in step 3. The cost effectiveness was estimated in terms of the Gross Cost of Averting a Fatality (GCAF) and the Net Cost of Averting a Fatality (NCAF) for each risk control option. For this, expected costs, economic benefits and risk reduction in terms of averted fatalities were estimated. Within this study, economic benefits are limited to reduced loss of property (ship and cargo) and reduced damage to the environment due to accidents. Other benefits resulting such as reduced downtime or lower accident repair costs were not accounted for. For estimation of economic benefit and risk reduction, the event trees developed during the risk analysis were used.

All costs and benefits were depreciated to a Net Present Value (NPV) assuming an interest rate of 5%, an expected lifetime of 20 years, and a crew of 20 persons. Cost estimates were based on information from suppliers, service providers, training centres, yards, technical experts and previous studies.

Recommendations for decision-making (FSA step 5) were developed based on the outcome of the cost benefit assessment for risk control options in step 4. In accordance with previous FSA studies, GCAF < US$3 million was used as main decision criterion. The potential for absolute risk reduction was also taken into account.

Risk acceptance criteria

In order to assess the risk as estimated by the risk analysis, appropriate risk acceptance criteria are needed. Such criteria regarding individual and societal risk were proposed in document MSC 72/16, based on figures published by the United Kingdom Health and Safety Executive. Table 5 presents these acceptance levels for the individual risk of crew members that were used in this study too.

Table 5: Individual risk levels for exposed crew members

Risk level	Annual risk
Maximum tolerable risk for crew members	10^{-3}
Negligible risk	10^{-6}

Risks below the tolerable risk, but above the negligible risk, should be made as low as reasonably practical (ALARP) by adopting cost effective risk reduction measures.

Document MSC 72/16 also presents an approach for determining societal risk acceptance criteria for crew on particular vessel types based on the respective economic value of shipping. This approach is applied here using average daily charter rates. As a result, the economic value of a typical container vessel is approximately US$8.5 million per year. On that basis, the risk acceptance criteria illustrated in Figure 1 are derived.

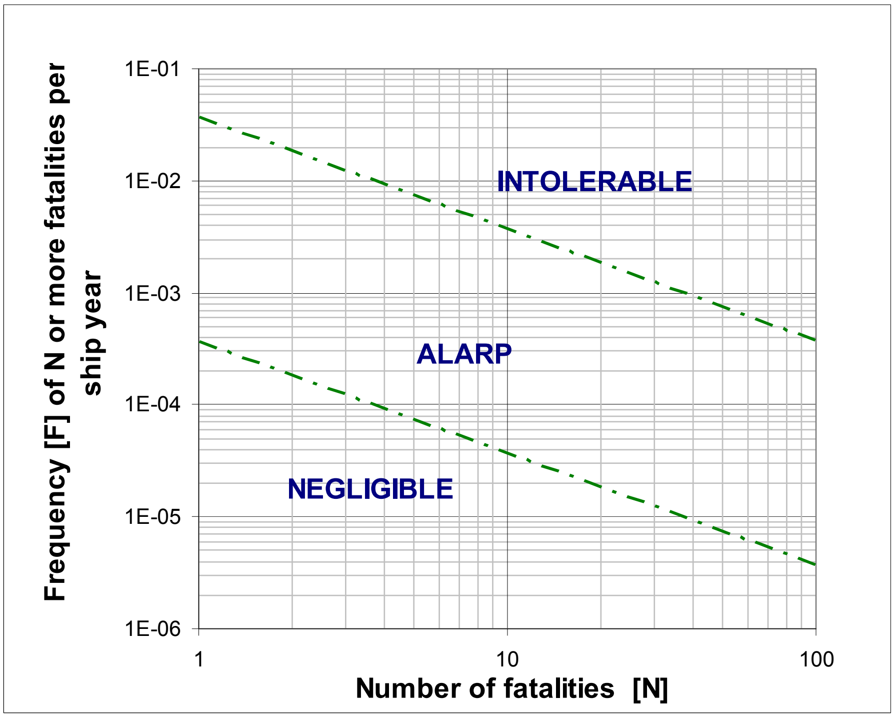

Figure 1: Acceptance criteria for societal risk of crew onboard container vessels

5 DESCRIPTION OF THE RESULTS ACHIEVED IN EACH STEP

STEP 1 – Hazard identification

The HAZID was conducted as a series of three moderated expert sessions, each of them addressing a particular operational phase – loading and unloading at berth, operations in port, restricted and coastal waters, and open sea voyage. Sixteen experts from six companies with backgrounds in design, operation, and regulation of container ships as well as in risk analysis participated.

For each hazard, potential causes and consequences were identified and recorded using a Failure Mode, Effects and Criticality Analysis technique. The identified hazards were combined into scenarios. Afterwards, the frequencies and consequences were estimated by the participants and a consolidated result was compiled using a Delphi method to streamline the individual assessments. Frequency and severity index tables from MSC/Circ.1023 were used in a slightly extended format, allowing better granularity and reflecting more realistic values for loss of ship or cargo as well as damage to the environment.

In total, 91 hazards in 22 scenarios were identified, recorded and ranked. Some scenarios were covered more than once. Each hazard is associated with a risk index based on qualitative judgement by the HAZID participants. The top ranked hazards for human safety are presented in Table 6. In the same way, hazards were estimated with respect to potential damage to the environment.

Table 6: HAZID results: top-ranked hazards for human safety

Id	Hazard	Scenario	Phase	Risk index
I-4.3	Bad working conditions during lashing (icy, wet floor)	Lashing[1]	Loading/unloading	7.4
III-1.9	Wrong decision in course, speed, timing, etc.	Large ship motions	Open sea	7.2
I-7.1	Communication problems	Human error	Loading/unloading	7.0
III-5.1	Stability problems caused by ballast water exchange	Structural failure	Open sea	7.0
III-5.1	Overpressure in tanks caused by ballast water exchange	Structural failure	Open sea	7.0
III-1.6	Extreme pitch motions	Large ship motions	Open sea	7.0
II-2.3	Contact after navigational failure	Contact	Restricted waters	6.6
II-3	Grounding after navigational failure	Grounding	Restricted waters	6.6
II-6.2	Plate buckling after damage by tug	Structural failure	Restricted waters	6.5
III-7.1	Contact with floating object	Contact	Open sea	6.5

[1] It should be noted that hazards identified for the lashing process do not necessarily involve the crew members, but often terminal workers instead. It is therefore considered as an occupational hazard which is out of scope for this study. However, the ranking suggests that those occupational hazards should be addressed separately.

STEP 2 – Risk analysis

The main inputs to the risk modelling and analysis are the results of the HAZID as well as an in-depth analysis of historic casualty data. A statistical analysis of reported casualties was carried out to establish the historic risk level for container vessels and to reveal critical scenarios that occurred in the past. Based on both sources, the following generic accident categories were selected to represent the total risk for container vessels:

1. Collision
2. Contact
3. Grounding
4. Fire/explosion
5. Heavy weather.

The findings from HAZID and the statistical analysis do not match completely. On one hand, there is a good correlation for the well known accident categories “Collision”, “Grounding”, “Contact”, and “Fire/explosion”, but on the other hand, incidents due to large ship motions and cargo losses due to lashing failures are prominent hazards but underreported in the statistics.

Despite the fact that a significant number of casualties are attributed to “Machinery damage”, a separate model was not considered necessary, since those cases leading to collision, grounding, and fire are already covered by the respective scenarios and for the remaining cases the impact to human safety was considered negligible.

Finally, the accident category “Heavy weather” addresses consequences of heavy seas and tropical rain, including large ship motions as well as water ingress into the cargo hold. Well-known consequences are hull damages, loss of deck equipment, and loss of or damage to deck containers. Water ingress into cargo room includes situations where one or more cargo holds are flooded due to green water, heavy rain or fire fighting measures, excluding hull damage. This is mostly relevant for hatchless container vessels.

All accident scenarios listed above are generic, i.e. apply to all ship types; however some of them are specific to container vessels with respect to the consequences.

Following the selection of accident categories, the frequency of each initiating event was estimated. It was concluded that accident statistics provide a sufficiently accurate estimate of initiating frequencies to be used in this study, refer to table 7. For the category “Heavy weather”, the respective initiating frequencies take into account all casualties that occurred in heavy weather, except those considered separately as other scenarios, i.e. collision, contact, grounding, and fire/explosion.

Table 7: Estimated frequency of initiating events	
Accident scenario	**Accidents frequency (per ship year)**
Collision	1.61×10^{-2}
Contact	3.65×10^{-3}
Grounding	6.84×10^{-3}
Fire / Explosion	3.55×10^{-3}
Heavy weather	2.64×10^{-3}

The next step in the risk analysis was to assess the expected consequences for each of the identified scenarios. This was done using event tree modelling techniques. In an initial step, a conceptual risk model was developed for each accident category.

To assign probabilities for the events and quantify the event trees accordingly, different approaches and techniques were used. For each sub-model and each branch of the event trees, the method that was found to be most practical and the information sources that were assumed most relevant were utilized. For details about those sources and models used as well as the resulting event trees, please refer to /9/. Based on the risk modelling, the individual contributions from each accident scenario to the total potential loss of life (PLL) for container vessels were determined. The contributions as well as the total risk are presented in Table 8.

Table 8: Potential loss of life due to container shipping	
Accident scenario	**PLL (Crew) (per ship year)**
Collision	6.11×10^{-3}
Contact	1.25×10^{-4}
Grounding	1.24×10^{-3}
Fire / Explosion	1.50×10^{-3}
Heavy weather	3.10×10^{-5}
Total PLL	$\mathbf{9.00 \times 10^{-3}}$

From the total PLL the individual risk for container vessel crew members was calculated, assuming that all crew members are equally exposed to the risk. Given a typical crew size of 20 and a 50-50 rotation scheme, the individual risk for a container vessel crew member is estimated to be 2.25×10^{-4} per year. According to the risk acceptance criteria presented above, this value is within the ALARP region. A cross check to the high-level FSA for LNG carriers /3/ gives similar results for the generic scenarios "collision", "grounding", "contact", and "fire/explosion". Also, the result agrees reasonably well to the historic individual risk level for crew members derived above.

The societal risk to crew is typically presented in form of a cumulative FN diagram. This diagram and risk acceptance criteria are shown in Figure 2. It can be seen that the societal risk associated with container shipping also falls within the ALARP area.

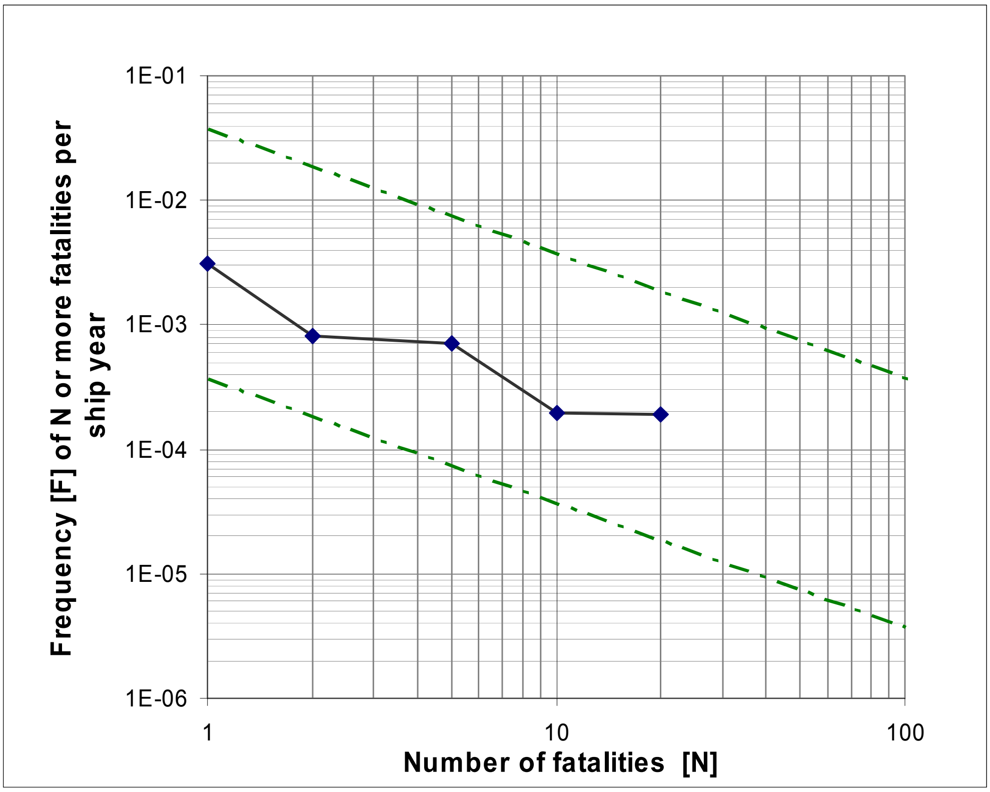

Figure 2: Societal risk of crew member onboard container vessels

As the final part of the risk analysis, a critical review of assumptions and sources of uncertainties was carried out. While some assumptions would bias the results in a conservative way, others tend to be somewhat optimistic. However, it was concluded that the overall effect of all assumptions and uncertainties was more likely to be conservative than optimistic. Hence, the results from the risk analysis should be regarded as conservative estimates of the actual risk.

STEP 3 – Identification of risk control options

The main risk drivers according to the risk analysis were presented to experts at workshops at which through brainstorming a number of risk control options were found. Additionally, existing measures (both optional and mandatory) from current regulations, guidelines and similar FSA studies for other ship types were reviewed regarding their applicability to container vessels. As a result, a total of thirty-three risk control options were identified and documented. Only those risk control measures related to the heavy weather scenario are mitigating, while all other identified measures are preventive. Subsequently the identified options were pre-screened by the project team by taking into account the number of accident scenarios affected, perceived risk reduction, and perceived scale of economic benefits. A prioritized list of seven risk control options was thereby established.

The outcome of this process was the following list of risk control options for further investigation and detailed cost benefit assessment:

RCO to reduce the risk related to collision and contact:

- Bow camera system

RCO to reduce the risk related to grounding:

- ECDIS
- Track control

RCOs to reduce the risk related collision:

- AIS integrated with radar

RCOs to reduce the risk related collision, contact, and grounding:

- Improved navigator training
- Improved bridge design
- Additional officer on the bridge
- Implementation of guidelines for Bridge Resource Management (BRM)

RCO to reduce fire and explosion risks:

- Reduced amount of undeclared dangerous goods

RCOs to reduce the risk related to heavy weather:

- Increased efficiency of bilge system
- Bilge alarms in cargo holds.

A number of these risk control options are preventive measures adopted from the FSA "Large Passenger Ships Navigation". Similar effects on the initiating frequency of collisions and groundings are expected independent of the ship type, but they will be less cost-effective for container vessels compared to passenger vessels due to the lower risk reduction potential.

A more detailed description for each of these risk control options can be found in /9/.

STEP 4 – Cost Benefit Assessment

The objective of the cost benefit assessment is to evaluate the cost effectiveness of implementing risk control options. The aim of performing such an analysis is to establish a list of recommendations on cost effective risk control options that will reduce the risk of accidents on container vessels. The GCAF and NCAF values are presented in table 9.

Table 9: GCAF and NCAF values associated with each risk control option.			
RCO No.	**Risk control option**	**GCAF** [10^6 US$]	**NCAF** [10^6 US$]
3 a)	Increased efficiency of bilge system (conventional design)	143.72	96.69
3 b)	Increased efficiency of bilge system (open-top design)	28.67	< 0
4 a)	High bilge level alarm in cargo holds (conventional design)	8.64	< 0
4 b)	High bilge level alarm in cargo holds (open-top design)	1.72	< 0
4 c)	Second bilge alarm in cargo holds (conventional design)	76.83	25.71
4 d)	Second bilge alarm in cargo holds (open-top design)	15.32	< 0
5	Improved navigator training	11.66	5.72
10 a)	Bow camera system (standard)	109.35	85.34
10 b)	Bow camera system (including night vision)	407.12	383.23
11	Reduced amount of undeclared dangerous goods	203.02	189.02
15	Improved bridge design	5.27	< 0
22	AIS integrated with radar	0.22	< 0
25 a)	Additional officer on the bridge (always)	197.25	191.45
25 b)	Additional officer on the bridge (on demand)	85.47	79.67
30	ECDIS	12.27	6.62
31	Track control system	1.14	< 0
32	Implementation of BRM guidelines	9.87	4.07

Cost estimates have been based on information from suppliers, service providers, training centres, yards, technical experts and previous studies where appropriate.

The economic benefit and risk reduction ascribed to each risk control options were calculated using the event trees developed during the risk analysis and on considerations on which accident scenarios would be affected. As a basis for the cost benefit calculations, the following important assumptions were made for an average container vessel:

- Expected lifetime: 20 years
- Depreciation rate: 5%
- Newbuilding price: US$51,750,000
- Value of 20 ft container US$20,000
- Payload capacity at 14t homog. load: 2,175 TEU

Payload capacity and newbuilding price are calculated as average of both reference vessels.

Potential effects regarding expected downtime, accidental repair costs, loss of business etc. were not included; hence the NCAF results are conservative estimates. Benefits would increase even further if the consequential costs of environmental damages were taken into account.

All numbers are based on introduction of one risk control option at a time. The introduction of several risk control options simultaneously has not been investigated. However, it is safe to assume, that the cost-effectiveness will be less than the sum of individual NCAF/GCAF values. The results from the cost effectiveness assessments demonstrate that:

- For RCOs 22 and 31 – "AIS integrated with radar" and "Track control", related to improved navigational safety, the calculated GCAF values are below the limit of US$3 million. Hence, these RCOs could be recommended.

- RCO 4 b) – "High bilge level alarm in cargo holds (open-top design)" has a GCAF value below the limit of US$3 million. Hence, this RCO could be recommended.

- All other risk control options have GCAF values that clearly exceed the GCAF criterion of US$3 million. Hence these RCOs are not cost effective according to the assessment carried out.

- Some RCOs with GCAF value exceeding the specified limit, have negative NCAF values, which indicates that they would be economically beneficial even if their contribution to human safety is not cost effective.

It should be noted that RCOs 22, 30, and 31 – related to navigational safety – are already implemented on many modern container vessels, however they are currently not mandatory by rules or regulations, e.g. SOLAS.

STEP 5 – Recommendations

As basis for the recommendations it is taken into account that:

- A RCO is considered cost-effective if the GCAF (Gross Cost of Averting a Fatality) is less than US$3 million. This is the value used in all decisions made following the FSA studies submitted under agenda item 5, Bulk carrier safety, at MSC 76, December 2002, and suggested in document MSC 72/16.

- Collision, grounding and contact due to failure of navigational equipment in coastal waters are among the highest ranked hazards from the HAZID. Other high ranking hazards are related to large ship motions in heavy weather causing injuries and/or loss of cargo.

- The risk level, both for individual risk for crew members and the societal risk, was found to be in the ALARP region. A number of risk control options were identified allowing further cost-effective reduction of the risk within "as low as reasonably practical" range. These RCOs should be made a mandatory requirement for all container vessels.

- According to the risk analysis, collision and grounding were found to be responsible for 68% and 14% of the total risk, respectively. Fire and explosion correspond to 17% of the overall human risk.

- The average size and capacity of container vessels is increasing. Furthermore they operate at relatively high speeds – between 20 and 25 knots. As a result, high energies are released by collision and grounding impacts, making the consequence mitigation difficult. In addition to human safety, impacts to the environment from the release of large quantities of fuel oil and dangerous cargo may be severe. Thus, preventing such accidents from occurring seems intuitively to be the best strategy for reducing the risk. This can be achieved by measures related to safer navigation.

This FSA study demonstrates that the following RCOs, all related to improved navigational safety by collision and grounding avoidance, provide considerable risk reduction in a cost-effective manner and are thus recommended as mandatory IMO requirements for container vessels:

- RCO 22: AIS integrated with radar
- RCO 31: Track control system.

Additionally,

- RCO 4 b): High bilge level alarm in cargo holds (open-top design)

proved to be a cost-effective risk control option for open-top container vessels. It has to be noted that this RCO is already required by guideline MSC/Circ.608.

The following RCOs were not found to be cost-effective and are, therefore, not recommended as mandatory requirements:

- RCO 3: Increased efficiency of bilge system
- RCO 4 a): High bilge level alarm in cargo holds (conventional design)
- RCO 4c) + d): Second bilge alarm in all cargo holds (conventional and open-top design)
- RCO 5: Improved navigator training
- RCO 10: Bow camera system
- RCO 11: Reduced amount of undeclared dangerous goods
- RCO 15: Improved bridge design
- RCO 25: Additional officer on the bridge
- RCO 30: ECDIS
- RCO 32: Implementation of BRM guidelines.

As a final note, it is acknowledged that some of the risk control options that were assessed to be not cost effective in general may turn out to be effective in specific cases, i.e. for particular ships or particular trades, and the results from this FSA should not be construed to mean that it will not be sensible to reconsider them on a case by case basis. Some options may become relevant for innovative designs or a new generation of container vessels.

For example, this high-level FSA study concludes that there is no need to regulate increased simulator training in general by IMO. However, increased use of simulator training or navigator training can be important and even necessary for specific ports or trades, e.g. within areas of high traffic density. In those cases, this risk control option may prove to be cost effective, but it is the responsibility of the owner, operator, port states or terminal owners to require specific measures for certain to ship types or particular trades. Even today, many operators train their crews above minimum SOLAS requirements on purely commercial considerations, and they are encouraged to continue that way.

6 FINAL RECOMMENDATIONS FOR DECISION MAKING

Based on the outcome of this FSA study, it is recommended to introduce the following risk control options related to navigational equipment on board container vessels as mandatory requirements:

- AIS (Automatic Identification System) integrated with radar.
- Track control system.

These options are cost-effective according to GCAF criterion. Some of them are typically implemented on current container vessels, but they are not mandated by IMO in general.

Furthermore, the risk control option of introducing high bilge level alarms in cargo holds, already mandated by interim guidelines /5/, proved to be a cost-effective risk control option for open-top container vessels.

REFERENCES

/1/ Lloyd Register Fairplay, world fleet database, January 2007
/2/ Lloyd Maritime Information Unit: Casualty database, December 2004
/3/ FSA on LNG carriers, MSC 83/21/1, IMO, 2007
/4/ FSA – Decision parameters including risk acceptance criteria, MSC 72/16, IMO, 2000
/5/ Interim Guidelines for open-top containerships, MSC/Circ.608/Rev.1, IMO, 1994
/6/ Design, Operation and Regulation for Safety, EU Integrated Project 516278
/7/ Guidelines for the Formal Safety Assessment, MSC/Circ.1023, IMO, 2002
/8/ UNCTAD Review Maritime Transport, 2005
/9/ FSA on Container Vessels, Details of the Formal Safety Assessment, MSC 83/INF.8, IMO, 2007

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