A Risk Model for the Operation of Container Vessels

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Abstract

Commercial shipping of containerized goods involves certain risks for human safety and environment. In order to actively manage these risks, they must be identified, analyzed, modeled, and quantified. This requires a systematical analysis of design and operation of container vessels. Within the EU-funded research project SAFEDOR, a Formal Safety Assessment has been applied to establish the current safety level of generic container ships and to identify potential cost-effective risk control options. This paper describes a structured approach to develop the underlying high-level risk model. It is structured as risk contribution tree consisting of a series of fault trees and event trees for the major accident categories. Statistical analysis of casualty data is used to estimate the probability of occurrence. Finally, the summation over all individual risk contributions yields the current risk profile for the operation of container vessels is presented as FN-curve.

Keywords

Risk; risk model; Formal Safety Assessment, accident category, container vessel

1. Introduction

Since the early days of maritime shipping, vessels have been lost due to various, often unknown reasons. Crew and passengers lost their lives, valuable cargo was lost. It is therefore common sense, that shipping involves risks to human safety and property. In recent years, the risk to the environment became an additional concern. Obviously, people, organizations, companies and countries have to decide whether it is worth taking a specific risk, in other words, they balance the risk against expected benefits. Formerly, this balancing was done mostly intuitive, but rational, scientific approaches to risk have been developed exactly based on the idea of balancing.

For this, the domain of interest – here the maritime shipping – needs to be analyzed with respect to the following questions:

- What can go wrong?
- How likely is it that it will go wrong?
- What are the consequences?

Answers can be given qualitatively, semi-quantitatively, and quantitatively. The latter case leads to a quantification of risk, which is defined as combination of probability of occurrence and size of consequences. Risk model are a very useful tool that are employed to answer these questions.

SAFEDOR is a large Integrated Project under the 6th Framework Programme of the EU aiming at “Design, Operation and Regulation for Safety”. It was launched in February 2005. The project focuses on risk-based ship design, approval of ships designed using a risk-based process, as well as the development of new tools and the application of those tools to innovative ship designs as showcases demonstrating usability and effectiveness of the risk-based approach.

Among of the key activities were 4 Formal Safety Assessment (FSA) studies carried out on cruise ships, gas tankers and container ships and on RoPax ferries. For each of them, the aim was to

- To make the current risk level explicit for all major accident scenarios,
- To document the total risk level in appropriate form,
- To develop a generic risk models for later use, e.g. within other subprojects,
- To identify cost-effective risk-control options.

The studies were done on high-level, i.e., only the main modes of operation and major systems were considered. Furthermore, historic data was used to determine frequency of occurrence for the accident categories and event trees were established to compute the consequences. The event trees were developed as generic as possible for later reuse in other subprojects and better harmonization across ship types.

The completed studies were reviewed, updated and recently submitted to IMO MSC 83 (2007a, 2007b)

2 Formal Safety Assessment

2.1 General

Formal Safety Assessment is a proactive approach introduced by the IMO to develop and establish new regulations on a more rational basis. It is intended to be used as a tool in the rulemaking process as “one way of ensuring that action is taken before a disaster occurs”. The FSA preferably addresses a specific category of ships or navigational area but may also be applied to specific maritime safety issue to identify cost effective risk reduction options. The FSA process consists of five main steps plus a preparatory step (Fig. 1).

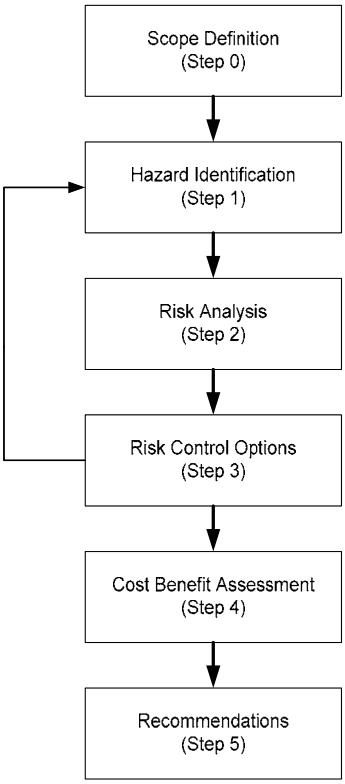

Figure 1: Formal Safety Assessment process (IMO 2002)

The initial step 0 was to carefully define and agree with the partners on the scope of the study. Within step 1 a series of hazard identification sessions were conducted. The second step covers the risk analysis – starting with building a risk model and focusing on determination of probabilities and consequences for all branches of the risk model. Step 3 aims at the identification of risk control options that are pre-screened and evaluated within step 4. Finally, step 5 is to summarise the results for decision-making.

Within the context of this paper, both scope definition and hazard identification are important prerequisites to clarify the scope of the risk model to be developed.

2.2 Scope Definition

The scope of the FSA – and hence the risk models – was limited to modern, fully cellular container ships, defined as sea-going vessel specifically designed, constructed and equipped with the appropriate facilities to carry cargo containers. These facilities are, e.g. cell-guides under deck and necessary fittings and equipment on deck. The containers are stowed in cargo spaces, i.e. in cargo holds below or above deck. A fully cellular ship means that this ship carries only containers. In normal operation, container vessels typical carry a certain share of dangerous cargo – typically stowed in designated and protected areas. Also many container vessels are equipped with a fixed amount of plugs for reefer containers. However, no further requirements apply model, e.g. regarding installed equipment in order to deal with a generic model.

Feeder and liner operations are investigated focusing on loading and unloading, approach in restricted waters and transit on open sea. Other lifecycle phases, e.g. construction, bunkering, docking, repair and dismantling are not considered. Neither specific trades nor environments are addressed.

For the analysis of the domain of interest preceding the model development, for illustration purposes during the hazard identification, but also calculation of consequences two reference vessels were chosen. They are representative for two different vessel sizes, a handysize feeder (Fig. 2) and a Post-Panamax vessel with a capacity of 1700 TEU and 4400 TEU, respectively. Both vessels have a crew of 20. The length between perpendiculars is 173 m and 271 m, respectively.

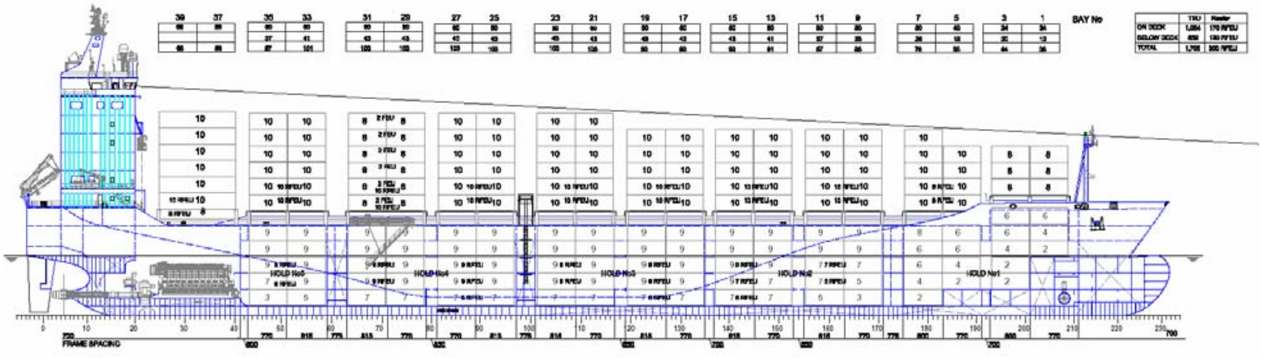

Figure 2: Handysize - Feeder (Lpp = 173 m, 1700 TEU, 20 crew)

A breakdown of the world container fleet as of January 2007 is shown in Tab. 1. According to this breakdown, 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.

Table 1: World container fleet by category (Jan. 2007)

Category	Number		Capacity (TEU)	
	Total	%	Total	%
Post-Panamax	831	8.9	1638754	25.7
Panamax	297	14.7	1779287	27.9
Sub-Panamax	646	15.5	1224795	19.2
Handysize	1036	28.5	1282917	20.1
Feedermax	690	18.4	414188	6.5
Feeder	375	14.0	37359	0.6
Total	3875	100.0	6377300	100.0

Additionally, it seems worth noting that the world container fleet is rather young compared with other ship types. 71% of the fleet, 78% of the total deadweight tonnage, and 81% of the total capacity were built less than 16 years ago.

2.3 Hazard Identification

Three hazard identification sessions were organised addressing the operational phases loading and unloading at berth, operations in port, restricted and coastal waters, and open sea voyage. Each session started with an introduction, followed by a structured brainstorming – moderated by a trained facilitator – and the grouping and ranking of identified hazards. Causes and consequences for each hazard were identified and documented using an FMEA-type approach. The identified hazards were combined into scenarios and ranked afterwards. The ranking was performed using an index scheme for the frequency and severity as described in (IMO 2002). Furthermore, intermediate frequency indices were introduced and an additional severity index was supplied reflecting to realistic values for loss or damage of ship damage, cargo, 3rd party assets and environmental impacts correlating to human safety.

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. As a result, Lashing, Large Ship Motions and Structural failure were identified as top ranked hazards for human safety, see Table 2 below.

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.

In the same way, Collision, Large Ship Motions, Grounding, Contact, Fire and Explosion as well as Structural Failure were identified as top-ranked hazards with respect to potential damage to the environment.

Experts from the project partners and selected external companies were invited based on a knowledge profile defined along the modes of operation. Thereby it was possible to ensure a good coverage of required expertise in the areas design, operation and regulation.

Table 2: 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	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

3. Risk Modeling

Based on the scope defined above and the outcome of the hazard identification, an overall structure of the risk model was devised. After selecting the relevant accident categories a detailed event tree model was developed for each of them. After the model structure was fixed the models were then populated with data for both probabilities and consequences. These data result from statistical analyses as well as from expert judgement, simple approximation formulas, databases etc.

Although the main focus of the risk model is human safety and damage to the environment, only small extensions to the model were necessary to enable the calculation of monetary losses due to damage or loss of ship and loss of cargo. Risk to third party onshore as well as occupational accidents were out of scope of the study.

For container vessels, damage to the environment include is typically caused by two main factors, spillage of fuel oil and release of dangerous cargo.

3.1 Statistical Analysis of Casualties

When developing risk models to be used in quantitative studies, there are different options to determine the probability of initiating hazardous events. It is possible to use, e.g., Bayesian networks, failure trees or accident statistics. Here, in the context of a high-level risk model, without investigating causes of hazardous events in detail, the use of accident statistics seemed to provide sufficient information.

The main source of information for accident statistics was the LMIU database (LMIU, 2004), 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.

Casualty records were analyzed for unitized container carriers (LMIU code: UCC), excluding mixed-mode container carriers. Pre-screening of the data revealed, that homogeneous data were available only for the reporting period 1993 – 2004. Within this period, 1680 casualties were reported. From those, 98 are out of scope as they relate to other operational phases (in dry dock, at sea trial), or to piracy. This leaves 1582 known and relevant incidents involving container carriers. The available data indicates that incidents occur for all vessels sizes similarly.

Within LMIU all records are classified by their initial cause using the following categories:

- Collision
- Contact
- Fire / Explosion
- Wrecked / Stranded
- Piracy
- Hull damage
- Foundered
- War loss / Hostilities
- Piracy
- Miscellaneous
- Labour dispute

From these categories, “War loss”, “Labour dispute” and “Piracy” are out of scope. A breakdown of accidents by category is shown in Table 3 below.

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

Accident category	Total number	Thereof Serious	Thereof Heavy weather
Collision	493	78	34
Contact	112	15	12
Grounding	210	64	17
Fire/Explosion	109	44	1
Machinery damage	395	108	5
Hull damage	39	6	13
Foundered	2	2	1
Miscellaneous	222	10	67
Total	1582	327	150

Accidents are marked as “serious” when they result in rendering the vessel unseaworthy, breakdowns requiring tug assistance; sinking, long grounding events, or anything involving major disruption to a vessels schedule or requiring lengthy repairs. “Heavy weather” indicates an accident where weather was a factor in the casualty.

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.

Accident frequencies are calculated by relating accident numbers to the fleet at risk, i.e. all unitized container carriers in service during the reference period. This results in 30,682 ship years.

3.2 Selection of Accident Scenarios

Based on the results from both, statistical analysis and HAZID five accident categories were chosen to represent the total risk for container vessels.

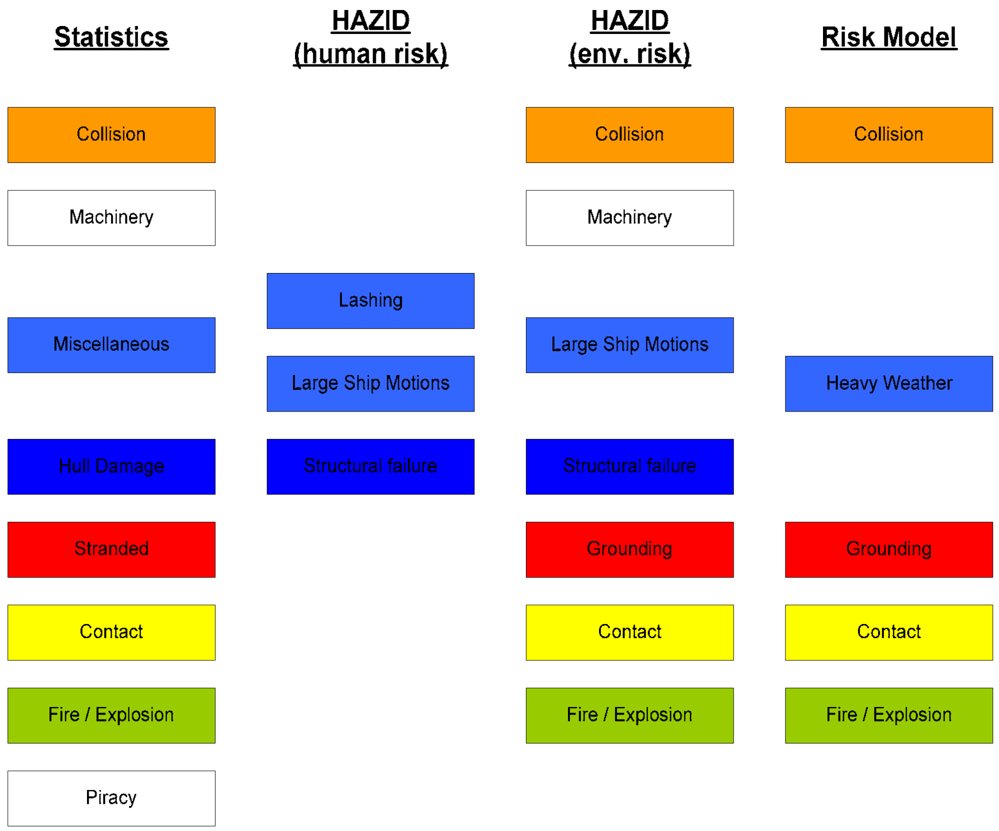

Figure 3: Accident scenarios covered by the risk model

Generally, Figure 3 shows a good agreement for most categories and some deviations that are explained below. The most familiar accident categories "collision", "grounding", "contact" and "fire / explosion" were all addressed in the HAZID sessions. Other categories like "piracy", "war loss", "unlawful act", and "labour dispute" were excluded from the scope beforehand.

The accident category "heavy weather" was introduced to cover large ship motions and associated cargo losses due to lashing failures, typically occurring in heavy weather. This accident category also covers water ingress through structural openings, in particular for open top vessels as well as structural failure. Often structural damages and container losses are reported as "miscellaneous", but there seems to be a general underreporting in the statistics.

As explained above, machinery failures and damages are not modelled as separate accident category, because they are considered as causes for collisions, groundings, and fires which in turn are well covered. This type of failure could be modelled by failure trees, although those were dismissed from the high-level model developed here.

3.3 Risk Model Structure

Risk is defined as a measure of the likelihood that an undesirable event will occur together with a measure of the resulting consequence within a specified time i.e. the combination of the frequency and the severity of the consequence (IMO 1998). Hence risk analysis requires developing a risk model structure, determination of event frequencies, determination of consequences and risk summation of all contributions related to risk to human life and to the environment.

Basically, the risk model was setup as a risk contribution tree consisting of a number of event trees, each of them associated to an accident category. For all branches of the events trees frequencies were determined and potential outcomes were quantified. Statistical data from the LMIU database were used to estimate the frequencies for initiating events. To determine consequences, simplified tools, databases and expert judgement were used.

3.4 Probability of Initiating Events

Historic casualty data for the period 1993 – 2004 were used to determine the probability of the initiating events, see Table 5. The fleet at risk in this period was 30.682 ship years as explained above.

In total, there are 1582 relevant casualties with 80 dead and 28 missing crew members. "Collision" is the most frequent event with 493 casualties. The accident category with the largest loss of human life was "fire / explosion" with 42 recorded fatalities. The accident categories collision, contact, grounding (called "wrecked / stranded") and fire/explosion, represent 58% of the casualties and 59% of the recorded fatalities within scope. The categories "foundering" and "miscellaneous" represent 41% of the casualties within the scope. These are combined into a new accident scenario covering heavy weather incidents.

The accident category with the largest recorded loss of containers was "Miscellaneous / water ingress", the second largest group of losses (738 containers) is associated with initial cause "hull damage", which is not shown in the table above. However, it is believed that the number of reported containers lost is affected by underreporting.

Table 4: Frequencies and consequences for container vessel accidents 1993 – 2004 (IMO 2007a, LMIU 2004)

Initial cause	No. of casualties	Frequency h(E)	Consequences: No. of fatalities	No. of missing	Tot No. of fatalities dead + missing	Pollution events	Container loss events
Collision	493	1.61×10^{-2}	5	13	18	16	23
Contact	112	3.65×10^{-3}	0	0	0	4	3
Foundered	2	6.52×10^{-5}	30	0	30	0	0
Fire/Explosion	109	3.55×10^{-3}	42	0	42	1	2
Hull damage	39	1.27×10^{-3}	0	0	0	2	738
Wrecked/Stranded	210	6.84×10^{-3}	0	15	15	8	0
Miscellaneous	222	7.24×10^{-3}	3	0	3	17	1239
Machinery dam.	395	1.29×10^{-2}	0	0	0	0	0
Total	1582	5.16×10^{-2}	80	28	108	48	2005

3.5 Event Trees

For all accident categories selected above, risk models were created as conceptual models first. After that, the actual event trees were implemented by spreadsheets. Setting up conceptual models first proved to be useful for identification and communication of the main elements of the event sequence.

Since not all event trees can be presented in detail here, the conceptual model for grounding is presented as an example (Figure 4).

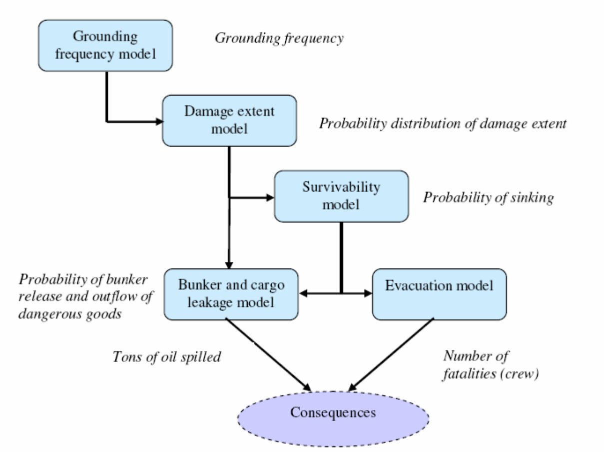

Figure 4: Conceptual risk model for grounding

Starting with a frequency of the event – taken from historic data – the probability distribution of the damage extent is predicted with a damage extent model. The consequences of damages to the hull are possibly bunker and cargo outflow and water ingress. Both consequences are addressed and for survivability, the probability of coming loose is also accounted for.

After translation of the conceptual models into an event tree (modelled in MS-Excel), probabilities have been assigned to each node. For example, the damage extent model predicts the damage extent and location based on the HARDER results and MARPOL regulation. The probability of coming loose and beaching deliberately was assumed to be ship-type independent (Skjong, Vanem 2004). It was assumed that 50% of critically damaged vessels which were coming loose and not beached again would sink fast, i.e., in less than 20 minutes.

Consequences for human life were assumed to be severe, i.e. all crew lost, if the vessel sinks fast. Consequences to the environment are assumed mainly due to release of dangerous goods or leakage of bunker. Three distinct scenarios were considered:

1. Complete loss of the ship resulting in complete spill of fuel and complete loss of dangerous cargo,
2. Critical damage (penetrating the double bottom) but the ship staying aground resulting in partial spill of fuel and partial loss of dangerous cargo, and
3. Critical damage (penetrating the double bottom) and the ship beached deliberately resulting in partial spill of fuel tanks, but no release of dangerous goods.

Basically, for each path through the event tree corresponding to a chain of events the outcome is described verbally and quantified in terms of potential lives lost, damage to the environment and loss of property.

Likewise, event trees were developed for all other categories.

Regarding fire and explosion, the model focuses on cargo room fire since they are specific to container vessels. Since fires in engine room and accommodation area contribute significantly to the overall number of fires onboard, corresponding branches were added to the event tree, but only on a very general level.

3.6 Risk Summation

After all event trees are modeled and quantified, the total risk can be calculated from the risk contribution tree by summing up all individual contributions for risk to human life and risk to the environment.

The societal risk is expressed as potential loss of life (PLL) for crew members per ship year, see Table 5.

Table 5: Risk for human safety (PLL per ship year)

Accident scenario	PLL (Crew) (per ship year)	PLL share
Collision	6.11×10^{-3}	67.9%
Contact	1.25×10^{-4}	1.4%
Grounding	1.24×10^{-3}	13.7%
Fire / Explosion	1.50×10^{-3}	16.7%
Heavy weather	3.10×10^{-5}	0.3%
Total	9.00×10^{-3}	100.0%

Clearly, collision, fire and grounding represent the highest risk contributions. Together, they account for 98% of the total risk. Compared to the statistically derived frequencies in Table 4, the figures derived from the event trees are significantly higher, in particular for the collisions. This can be explained by the fact that the risk model also covers accidents that did not occur in the past.

From the total PLL the individual risk for crew members is calculated, assuming that all crew members are equally exposed to the risk. Using a typical crew size of 20 and a 50-50 rotation scheme, the individual risk for a crew member is calculated to 2.25×10^{-4} per year. The high-level FSA for LNG carriers (IMO 2007b) gives similar results for the generic scenarios. Also, the result agrees reasonably well to the historic individual risk level for crew members. The societal risk to crew is typically presented in form of a cumulative FN diagram showing the frequency of N or more fatalities versus the number of fatalities, see Figure 5.

FN-diagrams can be used to apply acceptance criteria. For instance, the diagram can be divided into the three areas by introducing a band "as low as reasonably practical" (ALARP). These areas are denoted by

- *intolerable* (upper right)
- *ALARP* (between the dashed boundaries), and
- *tolerable* (lower left).

A suggested procedure how to set ALARP bounds was proposed in (IMO, 2000). While any measures must be taken for a risk within the intolerable domain, no measures are required for entries within the tolerable domain. In between, measure to reduce the risk should be applied, when cost-effective.

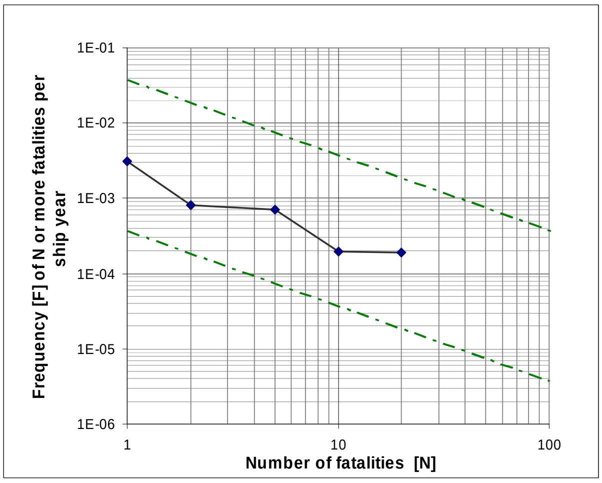

Figure 5: Societal risk of crew member onboard container vessels (and associated ALARP region)

As a result of this study the current risk profile for container vessels was found to be within the ALARP area. This agrees reasonably well with a risk profile purely based on historic data presented in (IMO, 2000). The new risk profile contains a predictive element and hence yields a slightly higher societal risk than recorded in statistics due to the fact that it already covers some events that have not happened yet.

The fact that the current risk level for container vessels is in the ALARP region, justifies continuous activities to introduce of cost-effective risk control options.

In addition to risk to human life, this high level risk assessment also addressed risks for the environment due to the release of dangerous cargo and spillage of bunker oil. For calculation of environmental consequences, the same event trees were used after extending them in such a way that for all final events, the expected quantity of dangerous cargo released from damaged containers and bunker oil spilled from damaged fuel tanks are estimated. The assigned quantities reflect either partial or total damage of the containers and fuel tanks. The final environmental consequences of the released dangerous goods and fuel oil spills for each accident scenario are summarised in the table below. The risk figures indicate that the collision and grounding scenarios represent the highest contribution to the total risk for the environment.

Table 6: Environmental risk (tons per ship year)

Accident scenario	Dangerous goods	Bunker spill
Collision	5.38×10^{-1}	1.05×10^{0}
Contact	3.17×10^{-2}	4.58×10^{-2}
Grounding	2.69×10^{-1}	4.52×10^{-1}
Fire/explosion	1.04×10^{-1}	5.65×10^{-2}
Heavy weather	6.45×10^{-2}	2.31×10^{-3}
Total	1.01	1.61

Since discussion how to quantify environmental impacts resulting from the release of harmful substances (in tons/ship year) has only started a couple of years ago there is no universal measure agreed yet. In particular, no risk acceptance criteria related to the environment is accepted by IMO today and criteria differentiating between dangerous goods and bunker are not expected to be published soon.

4. Risk Model Usage

4.1 Assessment of Risk Control Options

As part of the FSA, risk control options were identified, assessed and prioritised. Although not in the focus of this paper, it is presented shortly because it illustrates the use of the risk model is two different ways: for calculating the risk reduction as well as calculating benefits resulting from reduced loss of property (cargo, ship).

According to the risk analysis, the highest potential for risk reduction is related to collision, grounding and fire/explosion which are associated with 68%, 14%, and 16% of the total risk, respectively. Furthermore, the overall risk associated to the operation of container vessels was found to be in the ALARP area, thereby giving justification to search for cost effective risk control measures.

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 33 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 prescreened by the project team by taking into account the number of accident scenarios affected, perceived risk reduction, and perceived scale of economic benefits. 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

Some 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.

4.2 Other Uses

The potential use of the risk model presented is manifold. Interest is anticipated by regulators like IMO, flag states and classification societies, but also by ship owners, maritime insurance companies and ship yards.

IMO and flag states are focused on human safety for crew and passengers as well as protected of the environment. Continuously aiming at lower risk in both areas, acceptability criteria for societal and individual risk have been proposed as explained above. First of all, the total risk calculated from the model could be used as reference value for rule making. At the same time, using the risk model could be within the Formal Safety process established by IMO for quantifying the effect of any new safety measure under investigation.

On the other hand, ship owners can use the risk model for risk assessment related to the operation of a specific vessel. It supports a cost-benefit analysis related to the introduction of a risk control option, i.e. new features or measures aiming at enhanced safety. At least for optional measures the decision is up to the owner based on a trade-off between investment and safety increase achieved.

Finally, a risk-based approach provides a more flexible approach for ship yards developing innovations that are outside current regulation, but can be show to be as safe as or safer than current design (proof of equivalence).

5. Conclusions

This paper presents a high-level risk model that has been developed as part of a Formal Safety Assessment (FSA) for container vessels within the EU-funded research project SAFEDOR. The model takes the form of a risk contribution tree consisting of a set of event trees covering all relevant accident categories.

The resulting model was used to establish the current risk profile of generic container ships in terms of individual and societal risk for crew members – presented as FN-curve – as well as to calculate and document the risk to the environment.

Various inputs including results from hazard identification and statistical analysis of casualty data have been used for quantification and to estimate the probability initiating events.

Finally, the model was employed to assess potential risk control options for their cost-effectiveness by calculating the risk reduction as well as benefits resulting from reduced loss of property.

The FSA including the risk model was submitted to IMO MSC 83 hoping that it will effectively support the development of the safety-level approach to goal-based standards in IMO.

Acknowledgements

The work reported in this paper has been carried out under the SAFEDOR project, IP-516278, with partial funding from the European Commission. The opinions expressed are those of the authors and should not be construed to represent the views of the SAFEDOR partnership.

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