INTERNATIONAL MARITIME ORGANIZATION

IMO

E

MARITIME SAFETY COMMITTEE
85th session
Agenda item 17

MSC 85/17/2
21 July 2008
Original: ENGLISH

FORMAL SAFETY ASSESSMENT

FSA – RoPax ships

Submitted by Denmark

SUMMARY

Executive summary:	This document reports on the FSA study on RoPax ships carried out within the research project SAFEDOR
Strategic direction:	12.1
High-level action:	12.1.1
Planned output:	12.1.1.1
Action to be taken:	Paragraph 9
Related documents:	MSC 85/INF.3, 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 the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process, as set out in MSC/Circ.1023 – MEPC/Circ.392.

2 The Maritime Safety Committee, at its eighty-first session, and the Marine Environment Protection Committee, at its fifty-fifth session, agreed on draft amendments to MSC/Circ.1023 - MEPC/Circ.392, and the Secretariat prepared a consolidated version of the FSA Guidelines (MSC 83/INF.2).

3 The Maritime Safety Committee, at its eighty-third session, agreed to convene an FSA Experts Group with the purpose of reviewing the FSA studies submitted to the Organization. The FSA Experts Group is expected to meet during MSC 86 under the provisions of the Guidance on the use of human element analysing process (HEAP) and formal safety assessment (FSA) in the IMO rule-making process (MSC/Circ.1022 – MEPC/Circ.391).

4 As part of the research project SAFEDOR, a high-level FSA study on crude oil tankers has been performed. The main results of the FSA study are provided in the annex and a more comprehensive report is submitted as document MSC 85/INF.3.

Summary of results from the study

5 The FSA study on RoPax ships demonstrated that:

.1 the safety level of RoPax ships lie within the ALARP region;

.2 the risk level is dominated by collision and grounding-related flooding; and

.3 some identified risk control options were found to be cost-effective according to the cost-effectiveness criteria in MSC 83/INF.2.

6 The following risk control options were found to be cost-effective, in order of importance:

.1 improved damage stability and survivability after flooding, in particular to avoid rapid capsize;

.2 all measures aimed at improving navigational safety not requiring additional manning levels. Risk-based maintenance of navigational systems;

.3 improved fire prevention and protection; and

.4 improved evacuation arrangements.

Proposal

7 Based on the FSA study reported in document MSC 85/INF.3, the following recommendations may be proposed to be made mandatory IMO requirements for the RoPax fleet:

.1 measures to improve the damage stability for RoPax vessels to levels consistent with current cost-effectiveness criteria and commensurate with the specialized operation of these ships. For the range of ships analysed, it was found that CAF values associated with the introduction of measures to improve survivability in flooded condition would be well below the current cost-effectiveness criterion (US$ 3 million), even for pessimistic assumptions of marginal costs; and

.2 all measures aimed at improving navigation safety, not requiring additional manning levels; they are all well below the US$ 3 million cost-effectiveness criterion.

8 An abridged version of the full FSA report is attached at annex.

Action requested of the Committee

9 The Committee is invited to consider the information provided, and to refer the FSA study to the FSA Experts Group for review, as appropriate.

***

ANNEX

FORMAL SAFETY ASSESSMENT OF ROPAX SHIPS

1 SUMMARY

A Formal Safety Assessment (FSA) is performed to estimate the risk level and to identify and evaluate possible risk control options (RCOs) for RoPax ships.

The FSA study concluded that both the individual and the societal risk associated with RoPax ships are within the ALARP area. This means that risks should be made ALARP by implementing cost effective risk control options. On the basis of the developed risk model, it was further concluded that generic accident categories collision, grounding, flooding from other causes and fire/explosion are responsible for 11%, 12%, 50% and 27% 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 MSC 72/16, also described in the consolidated text of the FSA Guidelines (MSC 83/INF.2).

- An RCO is also considered cost effective if the NCAF (Net Cost of Averting a Fatality) is less than US$ 3 million.

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

- All measures to improve the damage stability for RoPax vessels to levels consistent with current cost-effectiveness criteria and commensurate with the specialized operation of these ships. For the range of ships analyzed, it was found that CAF values associated with the introduction of measures to improve survivability in flooded condition would be well below the current cost-effectiveness criterion (US$ 3M), even for pessimistic assumptions of marginal costs.

- All measures aimed at improving navigation safety not requiring additional manning levels; they are all well below the US$ 3M cost-effectiveness criterion.

2 DEFINITION OF THE PROBLEM

The roll-on/roll-off (RoRo) ship is defined in Chapter II-1 of the International Convention for the Safety of Life at Sea (SOLAS), 1974 as being "a passenger ship with RoRo cargo spaces or special category spaces...". Also in SOLAS, a passenger ship is defined as one which provides accommodation for at least 12 passengers. RoPax is an acronym used to describe ships that combine roll-on/roll-off features for the carriage of private cars and commercial vehicles with the provision of accommodation spaces for the carriage of large number of passengers, usually on short voyages. In this respect, the term “RoPax” is synonymous to “passenger RoRo vessel”.

Due to the combination of these features, it is considered one of the most successful ship types commercially. Its flexibility, ability to integrate with other transport systems and speed of operation has made it extremely popular on many shipping routes throughout the world. RoPax prime areas of operation include Europe, Japan, the Great Lakes and Asia Pacific.

In an attempt to quantify a baseline risk level for the world fleet of RoPax ships, and also to identify and evaluate alternative risk control options for improved safety, the Formal Safety Assessment methodology has been applied on the world fleet of RoPax ships of 1,000 GRT and above.

The scope of this study is limited to investigate credible accident scenarios of a certain scale that may occur during RoPax operations and estimate the risk of loss of life among passengers and crew onboard RoPax ships. Environmental issues are left out of the scope of the study, due to the fact that RoPax operation does not represent any extraordinary hazard to the environment. Occupational hazards that would affect individual members of the crew and passengers' personal accidents, such as slips or falls, have not been included in the study. Finally, no analysis has been carried out for accident scenarios that may occur during construction, sea trials, dry docking, repairs and scrapping, as well as for security hazards.

3 BACKGROUND INFORMATION

Risk acceptance criteria

The following outlines the acceptance criteria used in this study for individual risk (passengers and crew members) and for societal risk.

Individual risk is usually expressed as the frequency of an individual fatality per year. MSC72/16 proposes criteria for individual risk for shipping operations at the same level as those used by the UK Health and Safety Executive. These criteria are reproduced below for passengers and crew members.

Boundary between negligible risk and the ALARP area	10^{-6} per year
Maximum tolerable risk for passengers (risks below this limit should be made ALARP)	10^{-4} per year
Maximum tolerable risk for crew members (risks below this limit should be made ALARP)	10^{-3} per year

Societal risk acceptance criteria for RoPax ships are established in the SAFEDOR public deliverable D4.5.2 (Risk Acceptance Criteria), in accordance with to the approach presented in document MSC 72/16, i.e. based on the economic importance of RoPax shipping. These criteria are presented in Figure 1.

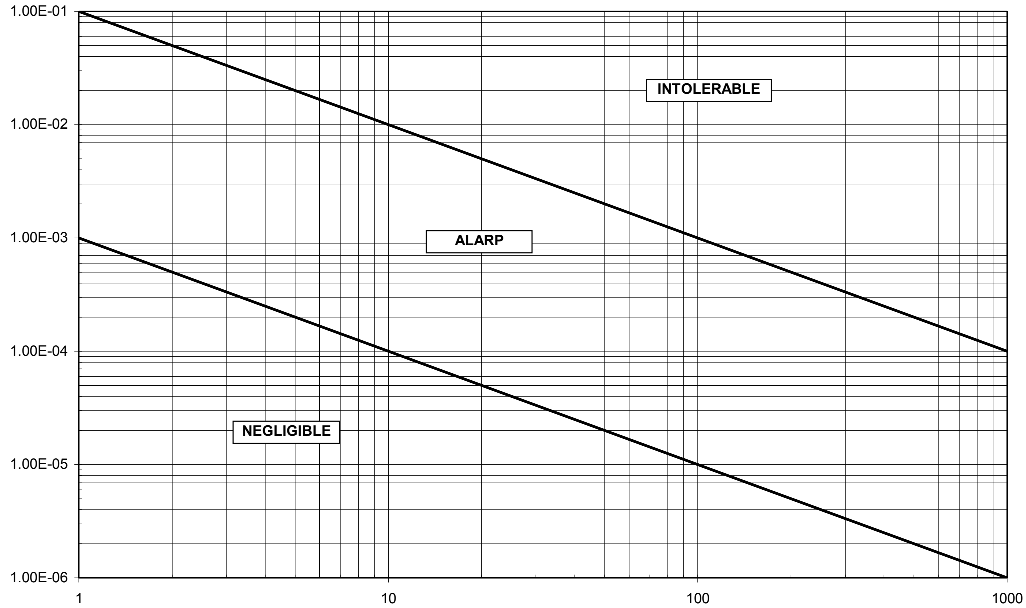

Figure 1: Societal risk acceptance criteria for RoPax ships

Safety regulations

The International Maritime Organisation has developed and adopted a series of regulations with special focus on RoPax characteristics. The principal consequences on a RoPax following an accident may be graceful sinking or capsize and/or fire which can result in great loss of life among the passengers and crew onboard. Some of IMO's regulations are particularly relevant to RoPax operations and are briefly outlined in the following under the headings: subdivision and damage stability; fire safety; and implementation of the International Safety Management (ISM) Code.

Subdivision and Damage Stability (SOLAS Chapter II-1). Currently the global standard for damage stability of RoPax ships is the vessel to be able to sustain any two-compartment damage and also fulfilling a set of deterministic requirements known as SOLAS 90. This represents a significant improvement with the standards applicable at the beginning of 1990s and is in general considered a sufficient and satisfactory standard. In North West Europe, an increased standard is applied for existing ships, known as the "Stockholm Agreement" or SOLAS 90+50, which requires either fulfilment of the deterministic standards of SOLAS 90 with an additional height of water on deck (maximum of 50 cm), or the demonstration by means of model experiments that the vessel can survive in the damaged condition the sea state at the area of operation.

The IMO's Sub-Committee on Subdivision, Load Lines and Fishing Vessel Safety (SLF) has developed a new set of probabilistic rules for all ship types for global application from 2009 onwards. These rules follow the approach developed at Resolution A.265 (IMO issued this resolution at 1974, as an alternative to the deterministic SOLAS damage stability requirements) and are mainly based on extensive research work carried out at the late 1990s / early 2000s as part of the activities of the EC-funded research project HARDER.

Fire Safety (SOLAS Chapter II-2). To accommodate novel designs and issues relating to the human element, the IMO Sub-Committee on Fire Protection (FP) undertook an eight-year effort that led to the adoption of an entirely new structure for SOLAS Chapter II-2 which may better accommodate the way Port and Flag States and ship designers deal with fire safety issues in the future.

The new structure focuses on the "fire scenario process" rather than on ship type, as the current SOLAS Chapter II-2 is structured. Thus, the regulations start with prevention, detection, and suppression and progress to cover all aspects of the process through to escape. In addition, to make the revised SOLAS Chapter II-2 more user-friendly, specific system related technical requirements were moved to a new International Fire Safety Systems (FSS) Code and each regulation will now have a purpose statement and functional requirements to assist Port and Flag States in resolving matters which may not be fully addressed in the prescription requirements.

The revised SOLAS Chapter II-2 also has a new Part E that deals exclusively with human element matters such as training, drills and maintenance issues and a new Part F that sets out a methodology for approving alternative (or novel) designs and arrangements. In regard to the latter, the regulations contained in Part F will be supported by a new set of guidelines. The new guidelines, once adopted, are intended to provide technical justification for alternative design and arrangements to SOLAS Chapter II-2. The guidelines will outline the methodology for the engineering analysis required by the new SOLAS Regulation II-2/17, dealing with alternative design and arrangements, where approval of an alternative design deviating from the prescriptive requirements of SOLAS Chapter II-2 is sought.

The revised SOLAS Chapter II-2 and the associated FSS Code entered into force on 1 July 2002 and will apply to all ships built on or after 1 July 2002, although some of the amendments apply to existing ships as well as new ones.

ISM Code (SOLAS Chapter IX). The ISM Code was adopted by the 1993 IMO Assembly as Resolution A.741(18). The ISM Code is mandatory for all SOLAS ships, regardless of their year of construction.

The Code requires a Safety Management System (SMS) to be established by the shipowner or manager to ensure compliance with all mandatory regulations and that codes, guidelines and standards recommended by IMO and others are taken into account. Companies are required to prepare plans and instructions for key shipboard operations and to make preparations for dealing with any emergencies which might arise. The importance of maintenance is stressed and companies are required to ensure that regular inspections are held and corrective measures taken where necessary. The procedures required by the Code should be documented and compiled in a Safety Management Manual, a copy of which should be kept onboard. Regular checks and audits should be held by the company to ensure that the SMS is being complied with and the system itself should be reviewed periodically to evaluate its efficiency. The ISM Code is being applied on RoPax ships since July 1998.

Accident Statistics

A thorough casualty statistics analysis has been carried out, based on historical data for the period 1994-2004, obtained by the Lloyds Maritime Information Unit (LMIU) and on fleet statistics for the same period, obtained by Lloyds Register Fairplay (LMFP).

The LMIU casualty database includes 1,147 incidents for RoPax ships world-wide for the period 1994-2004. 54 incidents have happened during repairs or conventions, labour and other disputes, on vessels that were already laid-up or to be broken up (9 incidents for RoPax of 1,000 to 4,000 GRT range and 45 incidents for RoPax of 4,000 GRT and above). These incidents have not been taken into account in the analysis. Also, there were a further 3 incidents which are attributed as acts of terrorism (notably one explosion involving considerable number of fatalities), which have also not been taken into account in the analysis.

42 of the incidents included in the database have occurred on RoPax ships of 100 to 1,000 GRT. These are excluded from the analysis due to the fact that these smaller ships are usually engaged on short crossings and passages and are often of an open-type configuration and hence are not representative for a generic risk analysis study on RoPax ships (typically of a closed-type configuration and part of her trip exposed to weather).

Casualty records held by LMIU classify incidents as serious and non-serious. An incident is considered as serious if it has involved a single or multiple fatalities, damage to the vessel that has interrupted her service or if the vessel has been lost.

Table 1 contains an analysis of the LMIU RoPax casualty data for the period 1994-2004, for RoPax of 1,000 GRT and above.

Table 2 contains a list of the 14 fatal incidents occurred world-wide during the period 1994-2004.

In addition to the fatal incidents presented in the table above, a very serious accident occurred on 3 February 2006, when the RoPax Al Salam Boccaccio 98 caught fire resulting in 1,000 fatalities among the 1,300 people onboard. Figure 2 illustrates the F-N for RoPax based on world-wide operation for the period 1994-2006 (i.e. including the Al Salam Boccaccio 98 incident). The figure also includes, for comparison purposes, the F-N line representing experience with fatal incidents in North West Europe during the period 1978-2004.

Comparison on the F-N curve of the potential loss of life of the period 1994-2004 world-wide with North West European experience for the period 1978-1996, demonstrates a considerable risk reduction; however, it also demonstrates that risk is still high at the ALARP region

Table 1: Number of Incidents and Frequencies

	# Incidents		% Total	% Serious	Frequency (per ship year)	
	Total	Serious			Total	Serious
Collision	194	20	18.4%	11.0%	1.25E-02	1.29E-03
Contact	193	21	18.3%	11.6%	1.25E-02	1.36E-03
Fire/Explosion	128	50	12.2%	27.6%	8.28E-03	3.23E-03
Wrecked/Stranded	148	47	14.1%	26.0%	9.57E-03	3.04E-03
Hull Damage	35	7	3.3%	3.9%	2.26E-03	4.53E-04
Foundered	2	2	0.2%	1.1%	1.29E-04	1.29E-04
Machinery damage/failure	289	31	27.5%	17.1%	1.87E-02	2.00E-03
Miscellaneous	63	3	6.0%	1.7%	4.07E-03	1.94E-04
TOTAL	**1,052**	**181**	**100.0%**	**100.0%**	**6.80E-02**	**1.17E-02**

Table 2: RoPax Fatal Incidents, World-Wide, Period 1994-2004					
Incident Date	**Vessel**	**Year Built**	**Event**	**Incident Location[1]**	**Fatalities**
18.05.1994	Al-Qamar Al-Saudi Al-Misri	1970	Fire/Explosion	RED	21
28.06.1994	Tag Al Salam	1969	Fire/Explosion	BAL	1
28.09.1994	Estonia	1980	Flooding	BAL	852
18.09.1998	Princess of the Orient	1974	Flooding	SCH	94
01.11.1999	Spirit of Tasmania II	1988	Fire/Explosion	EME	14
25.11.1999	Dashun	1983	Fire/Explosion	SCH	282
23.12.1999	Asia South Korea	1972	Fire/Explosion	SCH	56
16.07.2000	Ciudad de Ceuta	1975	Collision	WME	6
17.08.2000	Gurgen 2	1966	Fire/Explosion	EME	1
26.09.2000	Express Samina	1966	Grounding	EME	94
22.06.2002	Al Salam Petrarca 90	1971	Fire/Explosion	RED	1
11.08.2002	Tacloban Princess	1970	Fire/Explosion	SCH	2
22.10.2002	Mercuri 2	1984	Flooding	EME	49
01.07.2003	Paglia Orba	1994	Collision	WME	1

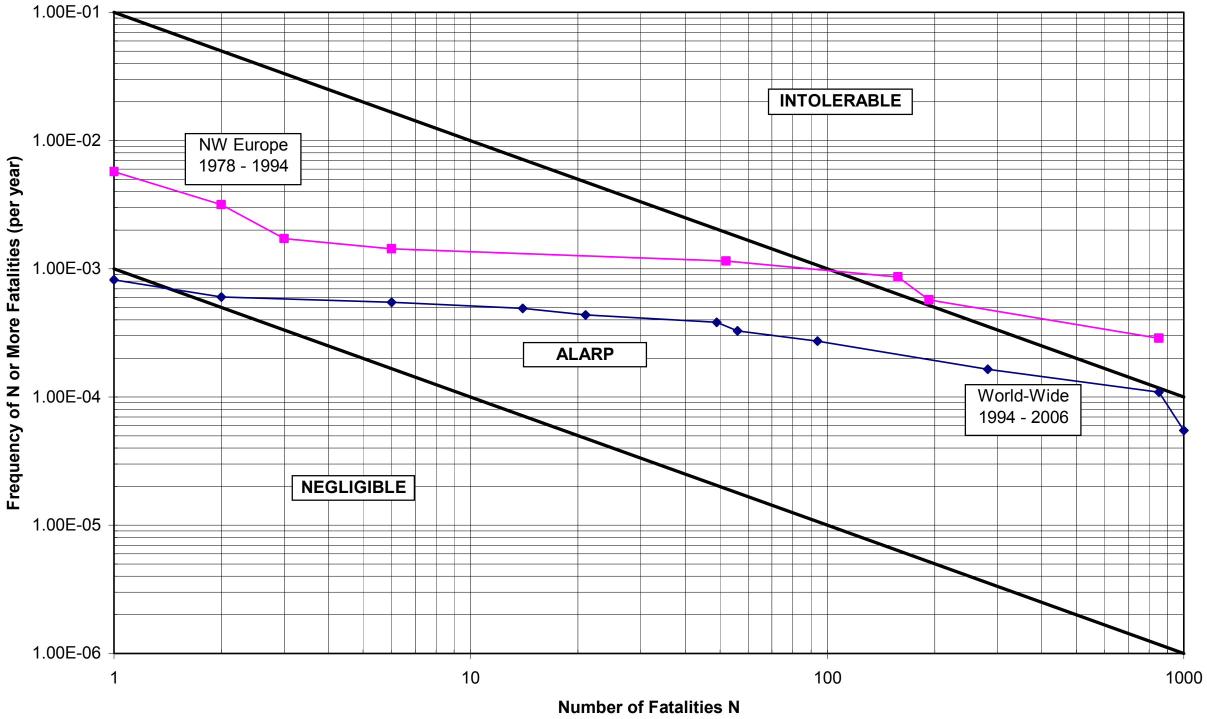

Figure 2: RoPax F-N Curve (Historical Risk)

[1] Location of Casualty: BAL – Baltic; EME – East Mediterranean and Black Sea; RED – Red Sea; SCH – South China, Indochina, Indonesia and Philippines; WME – West Mediterranean.

4 METHOD OF WORK

The five-step 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 Color Line Marine (Norway), Flensburger Shipyard (Germany), LMG Marin (Norway) and The Ship Stability Research Centre, Universities of Glasgow and Strathclyde (UK). Det Norske Veritas (DNV) has acted as reviewer of the work being carried out. The project team has comprised risk analysts, naval architects and other experts from the above partners.

The FSA commenced with a HAZID meeting in June 2005 with the final report on cost-effectiveness and recommendations produced on August 2007.

The HAZID (step 1 of the FSA) was conducted as a two-day technical meeting including brainstorming sessions. In addition to staff from the organizations referred to above, staff from the UK's Maritime and Coastguard Agency and Safety at Sea Ltd. also participated in the HAZID session. The outcome of the HAZID was a risk register containing the hazards and their subjective risk ratings from which a list of the highest ranked hazards could be extracted.

The risk analysis (step 2 of the FSA) comprised a thorough investigation of accident statistics for RoPax ships as well as risk modelling utilizing event trees for the most important accident scenarios, also taking into account the results of the HAZID work. A previous comprehensive study on the safety assessment of passenger RoRo vessels sailing in North West European waters, covering the period 1978-1994 and carried out by DNV Technica, was used as the basis in constructing the high-level risk model of the current study. All scenarios are presented in the form of event trees, quantification of which is done on the basis of world-wide accident experience, relevant past research studies and judgement.

Risk control options (step 3 of the FSA) were identified and prioritized. Navigational safety measures (for the prevention of collisions and grounding) and measures to mitigate the consequences following large scale flooding and fire incidents were extensively reviewed in the process.

Cost benefit assessments (step 4 of the FSA) were performed on selected risk control options based on the outcome of step 3. All costs and benefits were depreciated to a Net Present Value (NPV) using a depreciation rate of 5% and assuming an expected lifetime of 30 years for RoPax ships. The calculations were carried out for a RoPax ship of 1,000 passengers with 100 crew (considered as the average-capacity RoPax ship). Cost estimates were mainly based on estimates provided by Color Line Marine for the navigational safety risk control options examined. For the assessment of the effectiveness of the mitigating (large scale flooding and fire risk control options) a cost model was developed for the purpose. The economic benefit and risk reduction ascribed to each risk control options were based on the event trees developed during the risk analysis and on considerations on which accident scenarios would be affected.

Recommendations for decision-making (step 5 of the FSA) were suggested based on the cost benefit assessment of risk control options carried out in step 4 and on the evaluation criteria GCAF < US$ 3 million and NCAF < US$ 3 million. Considerations on the potential for risk reduction for each evaluated risk control option were also taken into account in suggesting recommendations.

5 DESCRIPTION OF THE RESULTS ACHIEVED IN EACH STEP

STEP 1 – Hazard Identification

The HAZID was conducted as a two-day workshop with participants from various sectors within the RoPax industry, i.e. ship owner/operator, shipyard, ship design office/maritime engineering consultancy, classification society, flag state and research centre/university.

The results from the HAZID were recorded in a risk register, which contains a total of 58 hazards within 9 different operational categories. The top ranked hazards according to the outcome of the HAZID is presented in Table 2. Each hazard is associated with a risk index based on qualitative judgement by the HAZID participants.

Table 2: Top-ranked hazards

No	Hazard	FI	SI	RI
8-2	Failure of evacuation equipment during an emergency	4.78	3.33	**8.11**
4-1 & 3-5	Fire in accommodation while in open sea or navigating in coastal waters	3.89	4.00	**7.89**
8-3	Human error and/or lack of training during an evacuation	4.56	3.22	**7.78**
4-2 & 3-2	Collision with other ships while in open sea or navigating in coastal waters	3.22	3.78	**7.00**
6-1	Fire on vehicle deck while unloading due to accumulation of fuel spills during journey	3.33	3.22	**6.56**
4-1 & 3-4	Fire in machinery spaces while in open sea or navigating in coastal waters	3.44	3.11	**6.56**
8-7	Evacuation arrangements and plans not as effective as designed for	3.44	3.11	**6.56**
8-5	No or reduced visibility and high toxicity due to smoke during evacuation	3.00	3.33	**6.33**
8-4	Evacuating following a fire or explosion	3.11	3.00	**6.11**
3-1	Grounding while navigating in coastal waters	3.22	2.89	**6.11**

The top-ranked major hazards identified through the HAZID are: *failure of evacuation equipment during an emergency*; *fire in accommodation, vehicle deck and machinery spaces*; *collisions with other ships while in open sea or navigating in coastal waters*; and *grounding while navigating in coastal waters*. This ranking, in general, confirms the hazards expected to be significant.

The high-level risk model for RoPax ships, to be outlined in the following section, comprises 5 event trees (*collision*; *grounding*; *impact*; *flooding from other causes*; and *fire/explosion*), covering this way all the expected significant hazards, as these have also been highlighted through the HAZID. The top-ranked hazard (*failure of evacuation equipment during an emergency*) is taken into account in the event tree modelling through the explicit consideration of different potential outcomes which may (or may not) require evacuation of the ship.

STEP 2 – Risk analysis

Based on the results from the HAZID session and the analysis of available accident statistics, five generic top events were selected for further analysis, as follows:

- Collision
- Grounding
- Impact
- Flooding from other causes
- Fire/Explosion

Accident experience for the period 1994-2004 provides an accurate basis for the estimation of frequencies of these five generic top events. The results are presented in Table 1.

The next step in the risk analysis was to assess the expected consequences for each of the identified events. This was done using event trees, i.e. by constructing and quantifying a sufficient number of scenarios of potential outcomes. These event trees are presented in Figures 3 to 7.

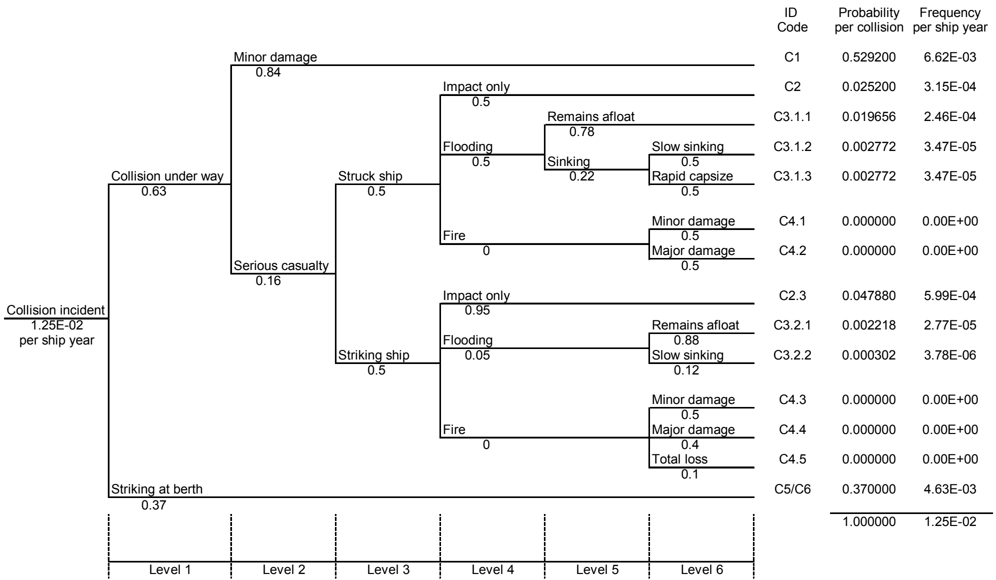

Figure 3: Generic Collision Event Tree

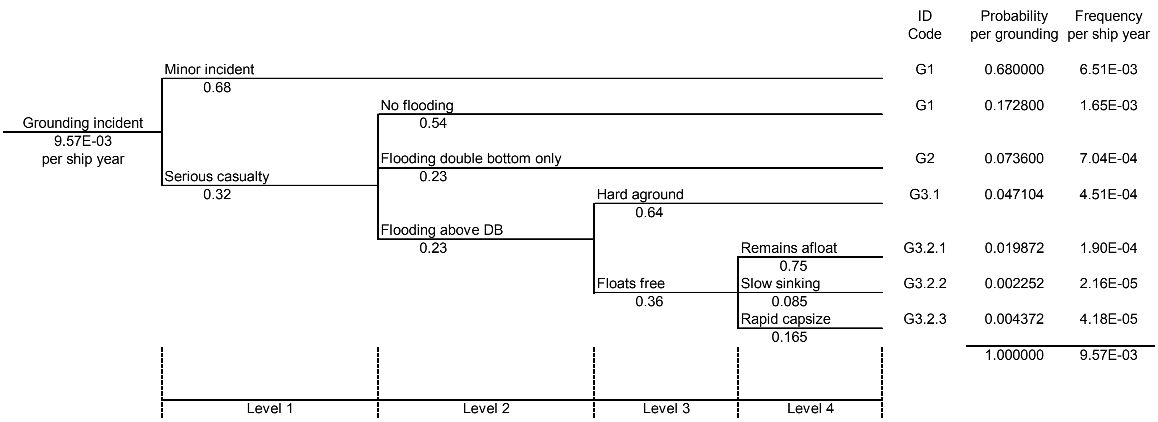

Figure 4: Generic Grounding Event Tree

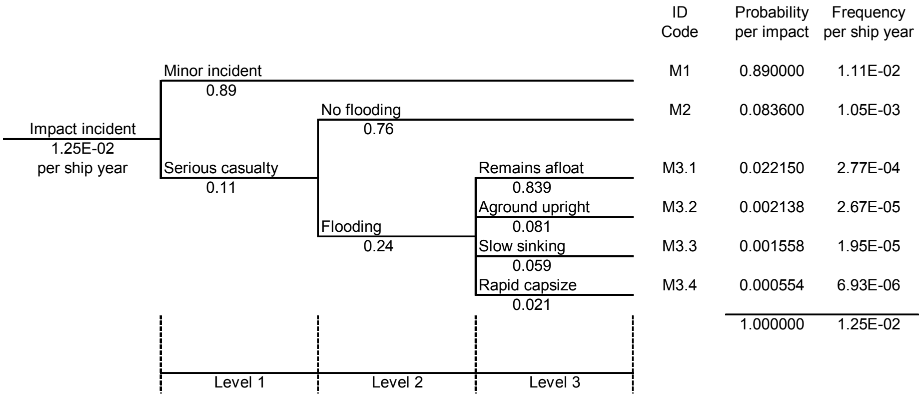

Figure 5: Generic Impact Event Tree

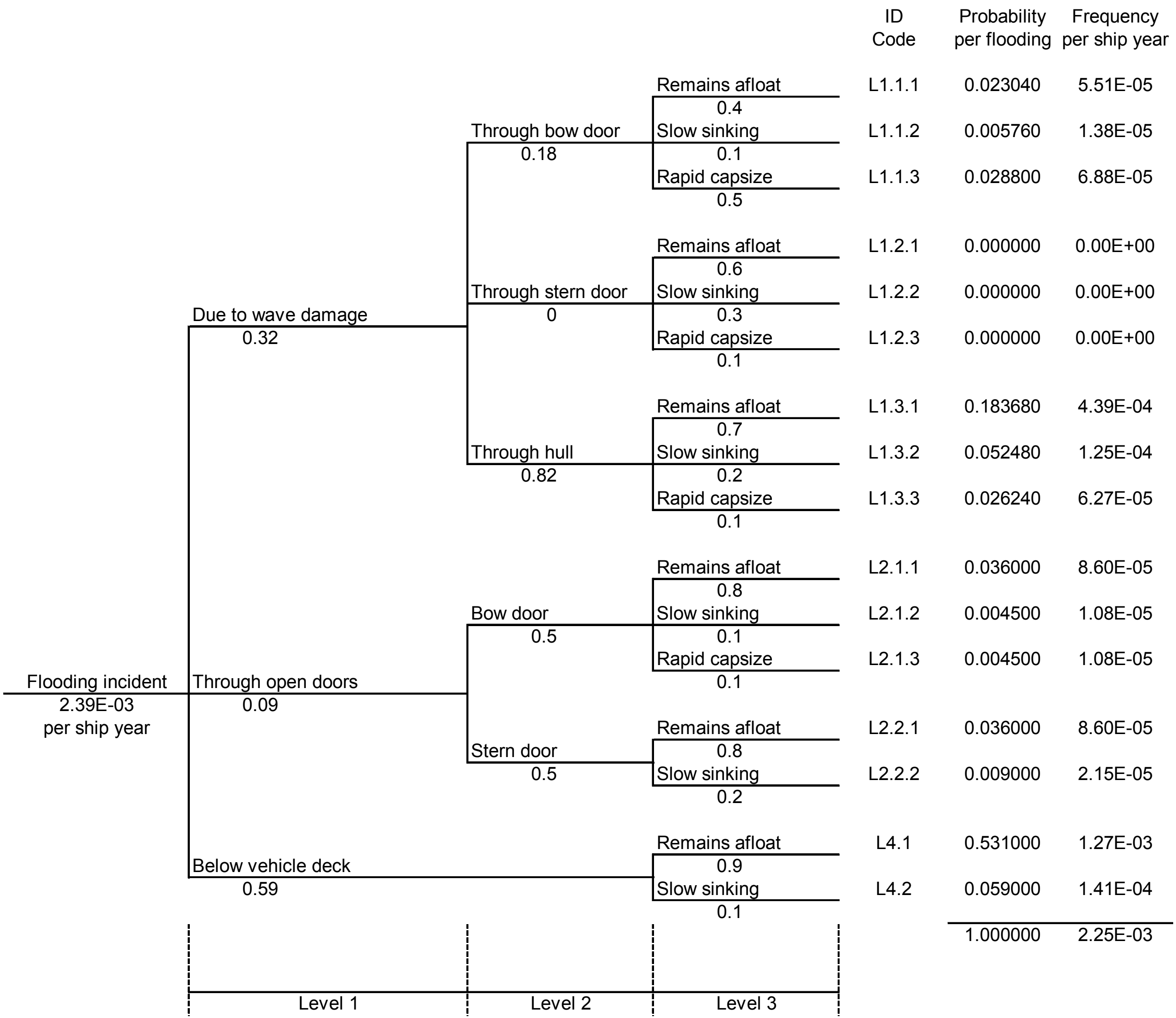

Figure 6: Generic Flooding Event Tree

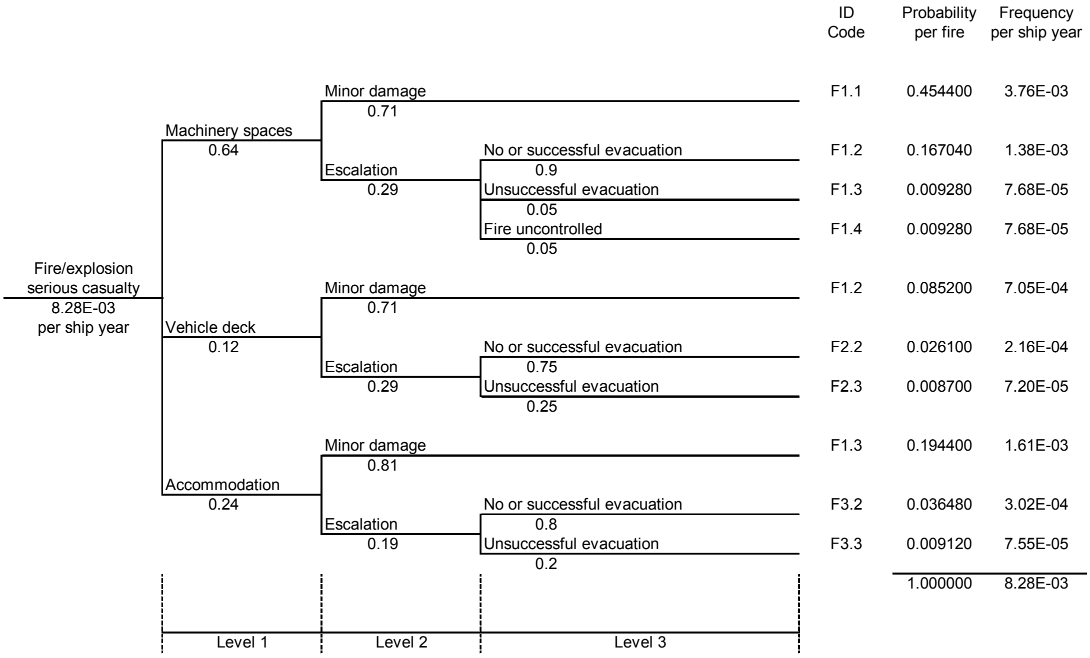

Figure 7: Generic Fire Event Tree

Assignment of branch probabilities in the event trees of Figures 3 to 7 was done using accident statistics for the period 1994-2004, results from past relevant research studies (such as the Joint North West European Project and the HARDER project) and, where necessary, expert judgement.

Table 3 provides a summary of the risk calculations carried out.

Table 3: Summary Risk Calculations (Risk Model)

	Frequency (per ship year)	Frequency (%)	Individual Risk (per year)	PLL (per ship year)	PLL (%)	Fatalities (per year)
Collision	1.25E-02	28%	2.75E-05	2.34E-02	11%	31
Grounding	9.57E-03	21%	3.02E-05	2.57E-02	12%	23
Impact	1.25E-02	28%	1.63E-06	1.39E-03	1%	2
Flooding	2.39E-03	5%	1.31E-04	1.12E-01	50%	148
Fire	8.28E-03	18%	7.00E-05	5.95E-02	27%	79
TOTAL	**4.52E-02**	**100%**	**2.61E-04**	**2.22E-01**	**100%**	**282**

The individual risk calculated by the risk model is **2.61E-04 per year**, assuming the vessel being at sea and a person being onboard for the full duration of the year, as recorded in Table 3. To provide an estimate of the individual risk experienced by crew members and passengers, the following considerations can be made:

- For crew members: assuming a 50-50 rotation scheme and that the vessel is at sea half of each day, the model predicts an overall individual risk for crew of **6.52E-05 per year**. If we assume 3 crews rotating on a vessel (this is not a widespread practice, but is valid for some positions onboard a RoPax) then the overall individual risk becomes **4.34E-05 per year**.

- For passengers: a passenger that spends 1 week per year travelling onboard a RoPax, experiences an individual risk **5.01E-06 per year**. For a RoPax sailing at sea for 12 hours per trip, the assumption of 1 week per year means that the passenger takes 7 return journeys a year. Considering a passenger that makes 1 such return trip a week, the individual risk becomes **3.72E-05 per year** (this estimation may be appropriate for a truck driver that travels regularly on a RoPax route).

Considering the figures above, it can be concluded that individual risk levels are within the ALARP region for both passenger and crew members.

Figure 8 presents the F-N curve calculated by the risk model.

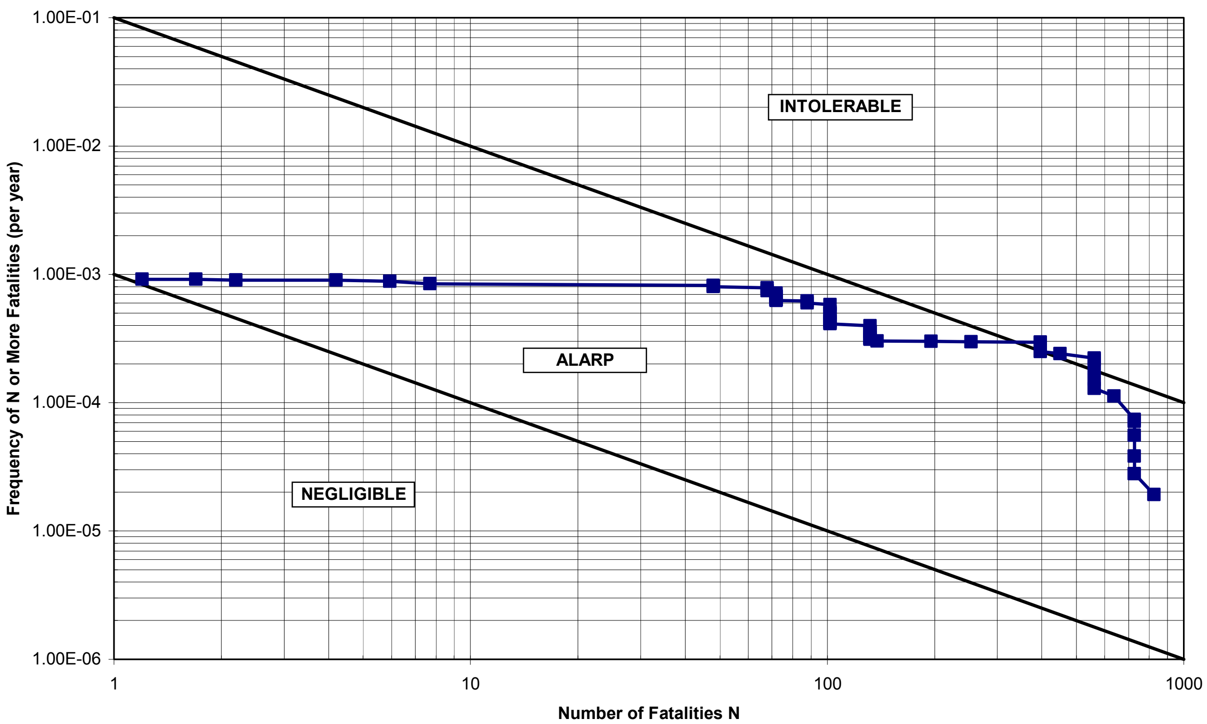

Figure 8: RoPax F-N Curve (Risk Model)

Uncertainties and assumptions

Most of the assumptions made would bias the results in a conservative way, with a very limited number being optimistic. The overall effect of the assumptions made is most likely conservative. Hence, the results from the risk analysis should be regarded as conservative estimates of the actual risk.

STEP 3 – Identification of risk control options (RCOs)
The results of risk analysis suggest that, for RoPax vessels, further risk reduction measures should be considered to reduce the overall societal risk level in particular with regards to high-severity scenarios. In this respect, the focus should be placed on flooding-, fire- as well as collision and grounding- related accidents, listed in order of priority. The following 'focus areas' (high-level RCOs) retain relevant and significant risk reduction potential for RoPax vessels:

- RCO 1: Improved navigation safety: this includes better bridge management and improved navigational aids to prevent the incidence of collisions, groundings and wave damage in bad weather. Maximum risk reduction potential is ΔRmax=39%.

- RCO 2: Improved damage stability and survivability after flooding, in particular to avoid rapid capsize: this relates to the ability to stay afloat and upright for as long as necessary to allow for recovery of the vessel, assistance to the vessel, or ultimately to allow for safe and orderly abandonment of the vessel. Maximum risk reduction potential is ΔRmax=73% .

- RCO 3: Improved fire prevention and protection: this relates mainly to prevention of fire ignition and protection of machinery spaces to avoid fire escalation. Maximum risk reduction potential is ΔRmax=27% .

- RCO 4: Improved evacuation arrangements: this mainly relates to measures aimed at preventing failures during the abandonment process and hence reducing the fatality rates in case of abandonment. Such failures can be due to human and/or technical -related factors. Maximum risk reduction potential is ΔRmax=100% although abandonment can only be accomplished in cases not related to 'rapid capsize'.

The risk reduction ΔR potential is given in reduction percentage in relation to the BASIS TOTAL risk (PLL) i.e. before introducing RCOs and including all accident categories.

STEP 4 – Cost-benefit assessment

In relation to RCO 1, the results of the analysis indicate that measures requiring additional crew (Officers) onboard result in GCAF values between \$3M - \$16M and thus, they should be considered carefully in relation to their risk reduction effectiveness. On the other hand, all measures that do not involve additional Officers onboard are well below the cost-effectiveness criterion (below \$0.5M), regardless of their actual risk reduction effectiveness.

In relation to RCO 2, the results of cost-effectiveness calculations (GCAF) for RCO 2a are illustrated in Figure 1. For RCO 2b, the results are illustrated in Figure 2; the figures show sensitivity of GCAF to different assumptions related to risk reduction and cost. The figures indicate that if the Required Index A for the representative ship is increased from 0.78 to 0.9, the measure is cost-effective if the total marginal cost associated with the stability upgrade is less than US$ 9M and US$ 11M for RCO 2a and RCO 2b, respectively. NCAF values are also lower than US$ 3M. Experience from Stockholm Agreement stability upgrades indicate that such cost can be significantly lower than US$ 9M.

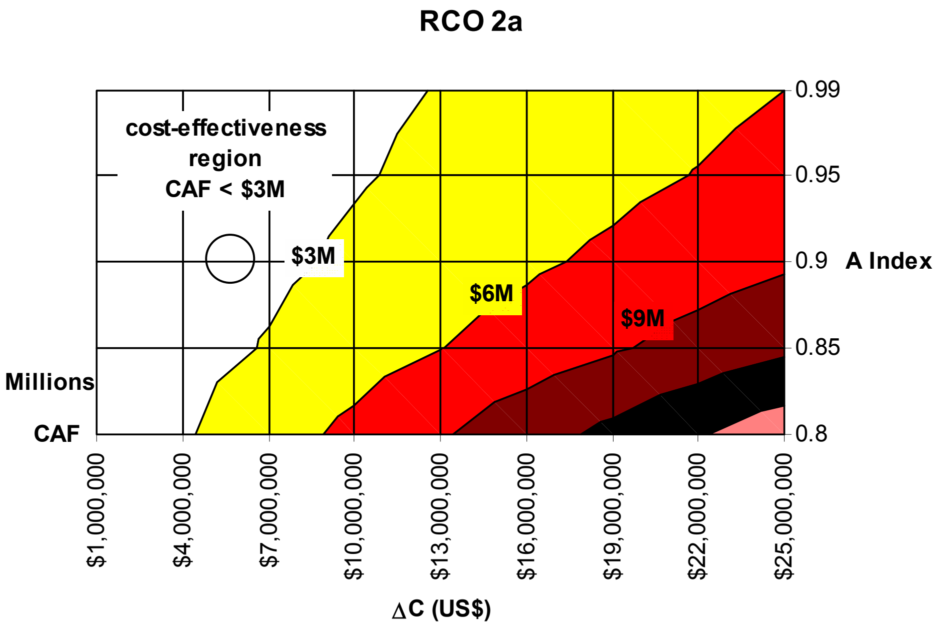

Figure 1: GCAF sensitivity to Attained index A and cost implications
RCO 2a: measures improving damage stability ("stay afloat")

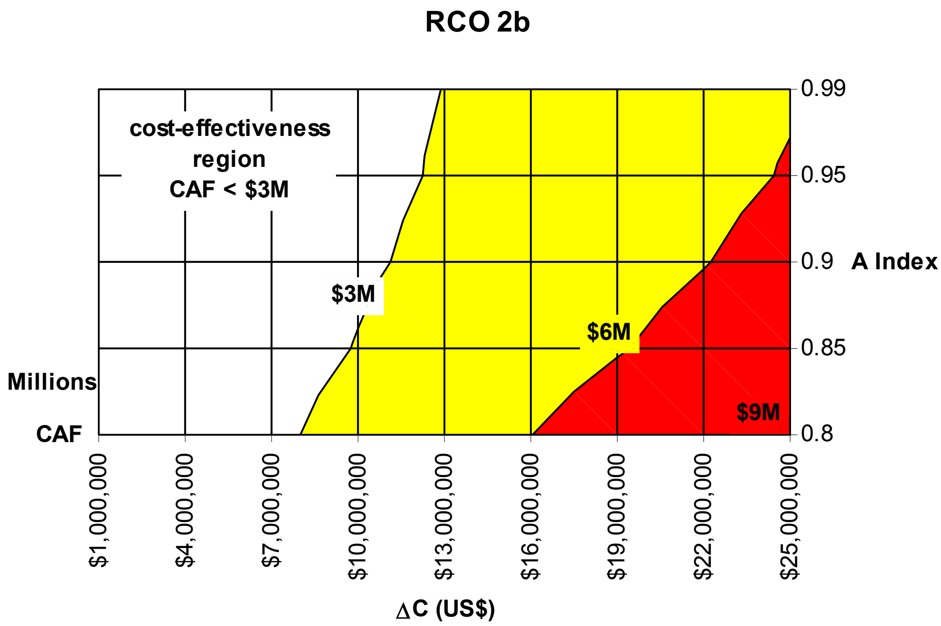

Figure 2: GCAF sensitivity to Attained index A and cost implications
RCO 2b: measures improving damage stability and survival time ("stay afloat for longer")

In relation to RCO 3, the analysis indicates that any measure that can lead to a 20% reduction in the annual frequency of fire accidents (RCO 3.1), can be regarded to be cost-effective if the total marginal cost of its implementation is less than $US 1.1M (see Figure 3).

Furthermore, any measure that can lead to a 66% in the conditional probability of fire escalation in machinery spaces (RCO 3.2), can be regarded cost-effective if the associated total marginal cost is less than US$ 3M (see Figure 4).

Furthermore, any measure that can lead to a conditional probability of fire escalation equal or less than 1 in 10, P(escalation)=0.1, in machinery spaces (RCO 3.2), car decks (RCO 3.3) and passenger accommodation spaces (RCO 3.4), can be regarded cost-effective if the associated total marginal cost is less than $3M, $0.75M, and $0.8M, respectively (see Figure 4 to Figure 6).

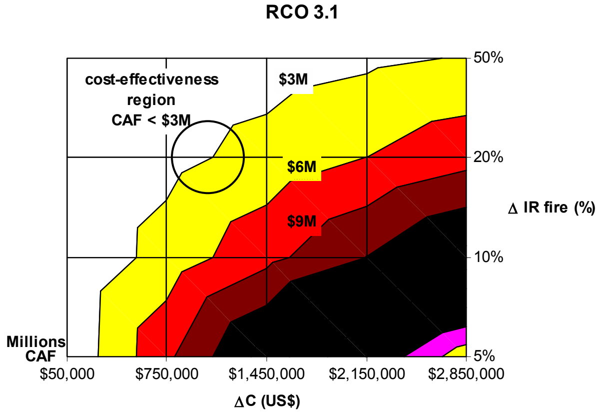

Figure 3: sensitivity of CAF to variations of risk reduction and cost implications RCO 3.1 (fire prevention, reduction in the incidence of fire and explosions)

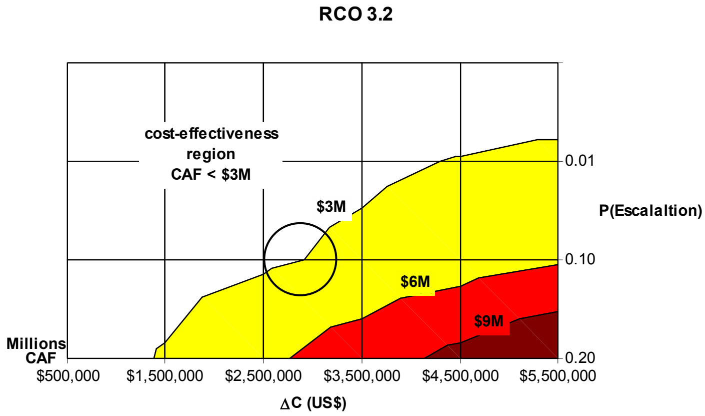

Figure 4: sensitivity of CAF to variations of risk reduction and cost implications RCO 3.2 (fire suppression in machinery spaces)

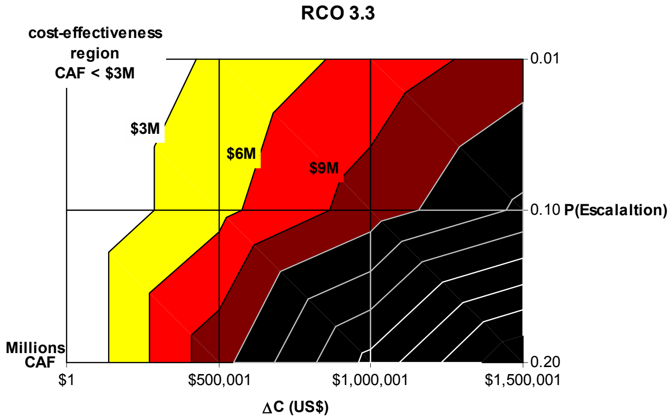

Figure 5: sensitivity of CAF to variations of risk reduction and cost implications RCO 3.3 (fire suppression in vehicle deck spaces)

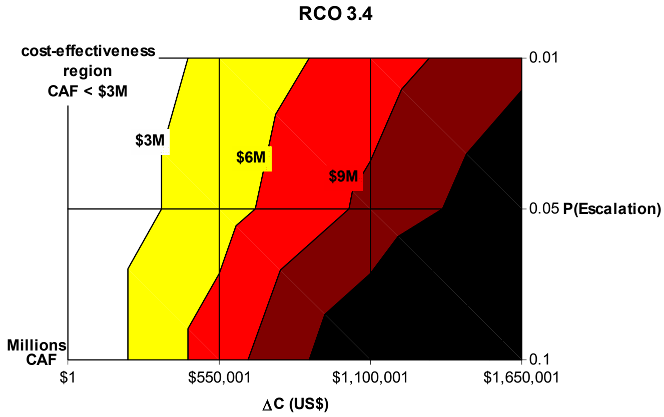

Figure 6: sensitivity of CAF to variations of risk reduction and cost implications RCO 3.4 (fire suppression in accommodation spaces)

In relation to RCO 4, the results of cost-effectiveness analysis indicate that any measure than can reduce the fatality rate but at least 50% in the event of abandonment, can be regarded as cost-effective if the associated total marginal cost is less than $4.2M approximately (see Figure 7).

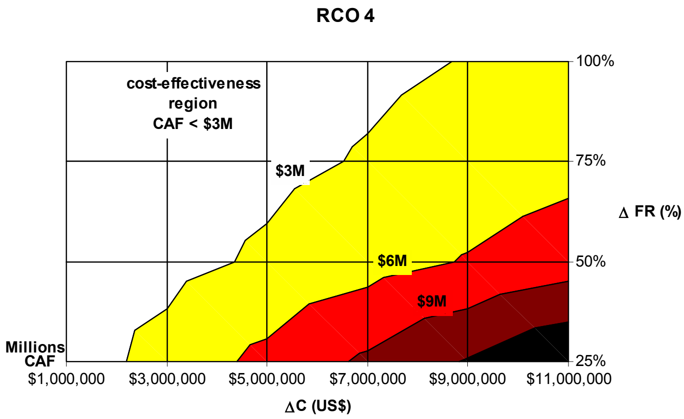

Figure 7: sensitivity of CAF to variations of risk reduction and cost implications RCO 4 (evacuation and abandonment arrangements)

STEP 5 – Recommendations

The range of risk reduction potential for the measures evaluated in the present study is shown in Table 1.

Table 1: Summary of results of risk reduction estimation (risk modelling, see Section 2)

RCO	Description	Risk reduction ΔR[2] (min-max)	Risk reduction ΔR (most likely)	Priority
RCO 1	Measures related to better and safer navigation	10% - 39%	29%	3
RCO 2a	Measures related to improved damage stability (conventional verification methods)	23% - 63%	44% (A=0.9)	2
RCO 2b	**Measures related to improved damage stability and survivability (advanced verification methods) – more effective than RCO 2a**	**40%-65%**	**62% (A=0.95)**	**1**
RCO 3.1	Improved prevention of fire ignition	1%-13%	5%	6
RCO 3.2	Improved fire protection (mainly suppression) in machinery spaces	7%-22%	15%	5
RCO 3.3	Improved fire protection (mainly suppression) in vehicle decks spaces	1%-2%	1%	7
RCO 3.4	Improved fire protection (mainly suppression) in accommodation spaces	1%-2%	1%	7
RCO 4	Improved abandonment arrangements	11%-44%	22%	4

Based on risk reduction potential, the following should be considered:

- Measures aimed at improving damage stability and survivability. Assuming that damaged ship survivability is 'sufficiently' reflected by the attained subdivision index (A), then the required subdivision index (R) should be increased so that for the average size ferry (1,100 persons onboard), the R index is above 0.9. When a ship attains an A value of A>0.9, it would mean that more than 90% of potential collisions would result in survival time of 30 minutes or longer. A high A value (>0.9) would also imply that there would be a larger number of damage cases with s=1.0, which, for a given damage case, implies infinite mean survival time ($t \rightarrow \infty$).

- Measures related to improved navigation have the same risk reduction potential as measures aimed at improving the success rate (hence reducing fatality rate) during abandonment scenarios.

In relation to the above recommendations, the following points are noteworthy:

- Although the current formulation of the required index R is supposed to be a measure of safety in line with current expectations, it does not explicitly relate to risk; it has been established on the basis of the attained index from a sample of existing vessels; thus the R index may not reflect the level of safety to be expected in the foreseeable future. An attempt to relate R more directly to safety would require the use of risk in its derivation.

---

[2] ΔR in % of basis PLL.

- The formulation of the s factor should be urgently revisited for passenger ships, including RoPax vessels, using relevant reference ships (RoPax) and using available performance-based methods.

Measures aimed at improving fire safety show the lowest – almost insignificant (1%-5%) – risk reduction potential. This may reflect the fact that the risk associated with human life is not as high as with flooding-related accidents. However these measures may possess a high risk reduction potential in relation to property.

Based on cost-effectiveness considerations, the following recommendations can be made:

- All measures aimed at improving navigation safety not requiring additional manning levels are well below the US$ 3M cost-effectiveness criterion and should be introduced.

- It is expected that the CAF value associated with the introduction of measures to improve survivability in flooded conditions is going to be well below the current cost-effectiveness criterion (US$ 3M), even for pessimistic assumptions of marginal costs. Hence it is strongly recommended that the required subdivision index R for RoPAx vessels be increased to levels at least or above 0.9.

Implementation of all measures associated with the four RCOs evaluated in the present report, would lead to a significant reduction in the risk level. The resulting risk level is illustrated in Figure 8, equivalent to a risk reduction of ΔR = 90%.

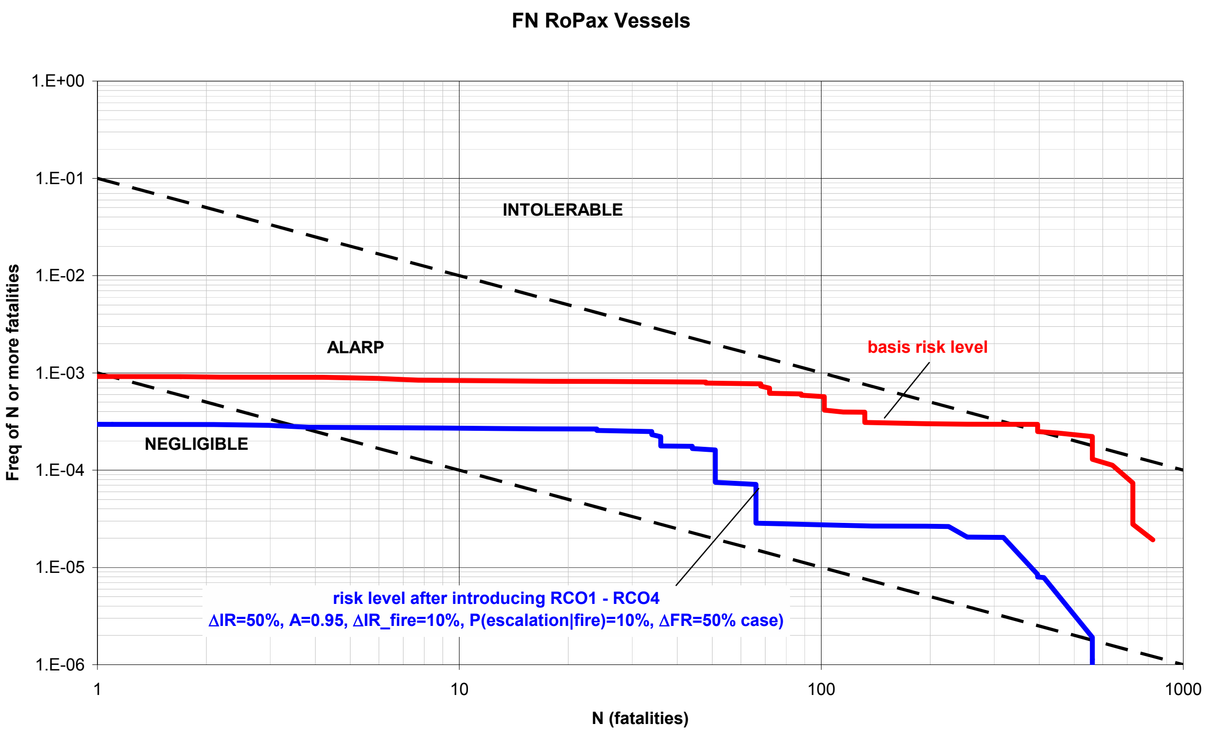

Figure 8: Societal risk level after the introduction of RCOs 1-4

6 FINAL RECOMMENDATIONS FOR DECISION MAKING

Based on the outcome of this FSA study, the following high-level risk control options show (in order of importance) the highest potential for risk reduction and are suggested for further consideration at IMO.

- Measures related to improved damage stability and survivability after flooding (RCO 2): This is particularly significant regarding ability to avoid rapid capsize as it relates to the ability of the vessel to stay afloat and upright for as long as necessary to allow for recovery of the vessel, assistance to the vessel, or ultimately to allow for safe and orderly abandonment of the vessel.

- Measures related to improved navigation safety (RCO 1): this includes better bridge management and improved navigational aids to prevent the incidence of collision, grounding and wave damage in bad weather.

- Improved evacuation arrangements (RCO 4): this mainly relates to measures aimed at preventing failures during the abandonment process and hence reducing the fatality rates in case of abandonment. Such failures can be due to human and/or technical factors. Note that abandonment cannot be accomplished in cases related to 'rapid capsize'.

- Improved fire prevention and protection (RCO 3): this relates mainly to prevention of fire ignition and protection of machinery spaces to avoid fire escalation.

In relation to the above findings, the following points are noteworthy:

- Although the current formulation of the Required Index R is supposed to be a measure of safety in line with current expectations, it does not explicitly relate to risk; it has been established on the basis of the Attained Index from a sample of existing vessels; thus Index R may not reflect the level of safety to be expected in the foreseeable future. An attempt to relate R more directly to safety would require the use of risk in its derivation.

- In view of this, it is strongly recommended to undertake further research in this area, without delay, targeting re-formulation and revision of the s-factor for passenger ships, including RoPax vessels, using relevant reference ships (RoPax) and available performance-based methods.

- Measures aimed at improving fire safety show the lowest – almost insignificant (1%-5%) – risk reduction potential. This may reflect the fact that the risk associated with human life is not as high as with flooding-related accidents. However, these measures may possess a high risk reduction potential in relation to property.

- Implementation of all measures associated with the four RCOs evaluated in the present study, would lead to a significant (≈ 90%) reduction in the risk level.

Based on the above and on cost-effectiveness considerations, the following recommendations may be put forward:

- Generic measures (deriving from suitable research) for adoption by IMO as requirements for increasing the required subdivision index R for RoPax vessels to levels consistent with current cost-effectiveness criteria and commensurate with the specialized operation of these ships. It is expected that CAF values associated with the introduction of measures to improve survivability in flooded condition would be well below the current cost-effectiveness criterion (US$ 3M), even for pessimistic assumptions of marginal costs.

- All measures aimed at improving navigation safety not requiring additional manning levels; they are all well below the US$ 3M cost-effectiveness criterion.

____