INTERNATIONAL MARITIME ORGANIZATION

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MARITIME SAFETY COMMITTEE
85th session
Agenda item 17

MSC 85/INF.3
21 July 2008
Original: ENGLISH

FORMAL SAFETY ASSESSMENT

FSA – RoPax ships
Details of the Formal Safety Assessment

Submitted by Denmark

SUMMARY

Executive summary:	This document is related to document MSC 85/17/2 entitled "FSA – RoPax ships" and contains further details of the FSA study.
Strategic direction:	12.1
High-level action:	12.1.1
Planned output:	12.1.1.1
Action to be taken:	Paragraph 2
Related document:	MSC 85/17/2

Introduction

1 As referred to in document MSC 85/17/2 submitted by Denmark, a high level FSA application on RoPax ships has been performed. The reports providing further details on this study are contained in the annexes to this document:

.1 Annex I: Risk Analysis of RoPax Ships
.2 Annex II: Risk Control Options, Cost Benefit Analysis and Recommendations.

Action requested of the Committee

2 The Committee is invited to note the information provided in this document, in relation to its consideration of document MSC 85/17/2.

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ANNEX

ANNEX I

RISK ANALYSIS OF ROPAX SHIPS

ANNEX I – Risk Analysis

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1 Introduction

1.1 FSA – Step 2: Risk Analysis

The work is performed in accordance with the FSA Guidelines issued by IMO [1]. The objective of this study is to investigate the causes of hazards during RoPax operation and quantify, to the extent possible, their frequencies and consequences. Potential scenarios identified and prioritised during the RoPax HAZID work [2] are used for guidance. A high-level risk model is the principal outcome of this report, on the basis of which potential high risk areas are highlighted, which in turn would provide the foundation for carrying out the cost-effectiveness analysis and proposing suitable recommendations.

To build the high-level risk model, a combination of standard risk analysis techniques is utilised. A previous comprehensive study on the safety assessment of passenger RoRo vessels sailing in North West European waters, performed by DNV Technica [3, 4], is 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 studies and judgement.

1.2 Scope of Study

This study attempts to estimate the risk of loss of life among passengers and crew onboard RoPax ships, by calculating for each identified scenario the Individual Risk, the Potential Loss of Life – PLL and plotting the results on an F-N diagram. 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 (which is limited to accidental releases of small quantities of fuel and diesel oil or lubricants, black or grey water, etc.). Potential cost to the property (the vessel itself) after occurrence of any of the potential scenarios investigated is not attempted due to the fact that experience from past accidents demonstrates that this can vary significantly according to the particular circumstances of the accident. However, it is noted that this can well be a very significant cost; for example as reported in [5], the cost of capsize of the Herald of Free Enterprise was 79 million GBP (end of 1980s values), of which 25 million GBP represents the value of the vessel and its machinery, 32 million GBP compensation to bereaved and survivors and 10 million GBP damage to the image of the company and cost of remedial actions.

The overall scope of this high-level, generic risk analysis study is to investigate credible accident scenarios of a certain scale that may occur during RoPax operations. 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. The following operational phases considered during the HAZID session provide the range of operational phases that are taken into account in performing this study:

- Loading
- Departing quay
- Transit and navigation in coastal waters

- Transit in open sea
- Arriving at port, mooring and preparing for unloading
- Unloading

In this respect, 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.

2 Background

2.1 RoPax Industry

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.

2.2 Areas of Concern

Concern has been expressed about RoPax ships from the safety point of view, virtually ever since the first were introduced. The whole design concept is different from that of traditional ships because of the introduction of a number of elements which make RoPax ships unique.

The main areas of concern can be highlighted as follows:

Internal subdivision. Although RoPax vessels are all fitted with watertight subdivision below the freeboard deck (usually the main deck where cars and vehicles are carried), the huge undivided vehicle decks make it possible for water to enter very rapidly which can lead to the vessel capsizing due to the huge free surface created. Fire can also spread very quickly for the same reason.

Cargo access doors. The cargo access doors at the stern and bow of the ship represent a potential weak spot, as do the side doors with which some RoPax ships are equipped. Over the years such doors can become damaged or twisted, especially when the door also serves as a ramp.

Stability. Movement of cargo on the vehicle deck can affect the intact stability of the ship, causing it to list. The sudden inrush of water following damage to the hull or failure of watertight doors can be even more serious (and rapid). The fact that RoPax ships generally have a very large superstructure compared with other types means that they can be more affected by wind and bad weather.

Low freeboards. Cargo access doors are often very close to the waterline. This means that a defective trim or a sudden list, caused, for example, by the movement of cargo, can bring the access threshold below the waterline, resulting in a sudden inrush of water (if the door is open) which will in turn result in the list increasing and a possible capsizing of the ship.

Cargo stowage and securing. A list can cause cargo to break loose if it is not correctly stowed and secured. The problem is made worse because the crew of the ship cannot normally see how the cargo is stowed inside or on the trailer in which it is transported. The result can be increased list, the spillage of dangerous substances and, in extreme cases, damage to the hull and ship's structure.

Fire. Keeping tight operating schedules, which require high sailing speeds for short periods of time and manoeuvring at restricted waters and when berthing on a daily basis, necessitate extra caution for fires at the engine room. The presence of large undivided RoRo decks, which during sailing are secured, have the potential for uncontrolled fire spread. Also, RoPax carry large number of passengers at their accommodation areas, which also present extra fire risks.

Life-saving appliances. The high sides of many modern RoPax, pose problems regarding lifesaving appliances: the higher a lifeboat is stowed the more difficult to launch, especially if the ship is listing badly.

Crew. The factors referred to above indicate that RoPax are highly sophisticated ships which require very careful handling. This requires crew members to be highly trained.

2.3 Safety Regulations

The International Maritime Organisation has developed and adopted a series of regulations with special focus on RoPax characteristics. As can be seen from the list of areas of concern above 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.

2.4 World RoPax Fleet

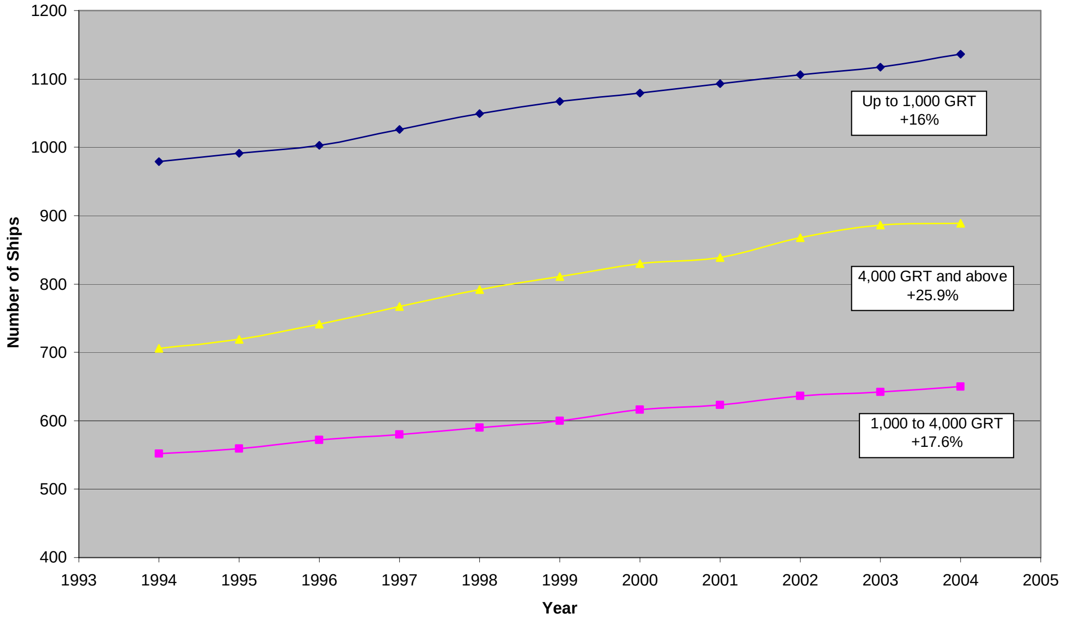
Table 1 shows the number and size distribution of the RoPax fleet world-wide, as of March 2006, according to Lloyds Register Fairplay (LRFP) data.

Table 1: Current RoPax Fleet, World-Wide Data, March 2006

GRT Ranges	Converting / Rebuilding	In Casualty / Repairing	In Service / Commission	Laid Up	To be Broken Up	Unconfirmed Ships	New Construction	TOTAL
Up to 1,000	2	4	1,163	8	2	0	17	**1,196**
1,000 to 4,000	0	8	656	7	0	0	16	**687**
4,000 and above	1	12	864	6	2	0	65	**950**
TOTAL	**3**	**24**	**2,683**	**21**	**4**	**0**	**98**	**2,833**

A first observation is that a great percentage of the fleet (42.2%) are ships of 1,000 GRT and below. Figure 1 illustrates the development of the world-wide RoPax fleet over the period 1994-2004.

Figure 1: RoPax Fleet Development, World-Wide Data, 1994-2004



Figures 2 and 3 illustrate the age distribution of RoPax ships. It can be deducted from these two graphs that newer ships are usually of bigger tonnage, as well as that the fleet, as absolute numbers and as tonnage, is ageing, a factor that may have significant safety implications.

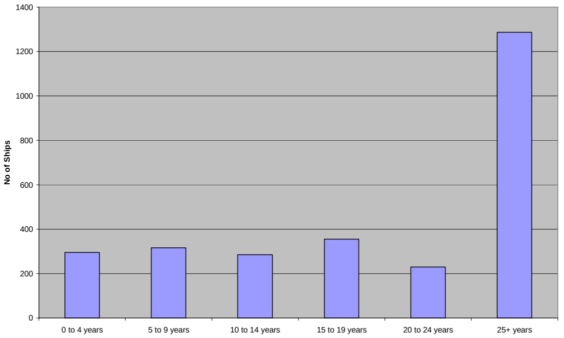


Figure 2: Age Distribution of RoPax Fleet (Number of Ships)

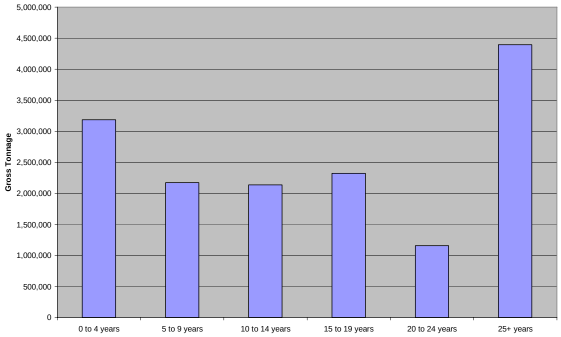


Figure 3: Age Distribution of RoPax Fleet (Gross Tonnage)

Finally, Table 2 shows the distribution of the maximum carrying passenger capacity of 1,153 RoPax vessels.

Table 2: World RoPax Fleet – Distribution of Passenger Carrying Capacity (2000) [6]

Group	**Number of Passengers**					
L_{OA} (m)	**Below 500**	**500 to 1,000**	**1,000 to 1,500**	**1,500 to 2,000**	**Above 2,000**	**TOTAL**
Below 100	162	192	56	4	1	**415**
100 – 120	33	67	62	15	7	**184**
120 – 150	22	93	100	53	23	**291**
150 – 180	23	49	25	33	31	**161**
Above 180	7	34	26	18	17	**102**
TOTAL	**247**	**435**	**269**	**123**	**79**	**1,153**

2.5 Reference Data

To carry out the risk analysis study for RoPax ships, a set of reference, generic data should be considered. As illustrated in Section 2.4 the distribution of sizes of the RoPax fleet is wide, hence it is considered that by selecting a RoPax ship with specific characteristics would greatly limit the analysis to be carried out. The following considerations/assumptions are made:

- RoPax ships of 1,000 GRT and below, are usually engaged on short crossings and passages and are often of an open-type configuration. A representative RoPax for a generic risk analysis study should be of a closed-type configuration and part of her trip is usually exposed to weather. On this basis, all RoPax ships of 1,000 GRT and below are excluded from this study.
- To distinguish between small and larger RoPax ships, two categories are initially considered: one of 1,000 to 4,000 GRT and one of 4,000 GRT and above. The purpose for this consideration is to investigate differences on accidents frequencies between small and larger RoPax.

- The distribution of number of passenger of Table 2, reproduced from [6], indicates an average maximum carrying capacity of around 1,000 passengers.

In carrying out risk estimations for Individual Risk, Potential Loss of Life (PLL) and producing the F-N diagram plot, the following assumptions are made:

- Different traffic loads indicate great fluctuations on the number of passengers carried, depending on the period of the year. Taking into account the average maximum carrying capacity of 1,000 passengers, traffic seasonality is assumed as follows:
    - 25% of trips carrying full passenger load (1,000 passengers)
    - 25% of trips carrying half of maximum passenger load (500 passengers)
    - 50% of trips carrying 75% of maximum passenger load (750 passengers)
- Crew onboard a RoPax is usually between 75 and 120. For the purpose of this study, a crew number of 100 is considered as an average.

3 Risk Criteria

In this section of the report risk criteria that will be used are outlined. A review of risk evaluation criteria has been carried out in another SAFEDOR task and is reported in the public Deliverable D4.5.2 [7], making use of previous work reported at IMO in [8]. In the following acceptance criteria for individuals (crew and passengers) and for the whole group of people (societal criteria) onboard a RoPax are discussed.

3.1 Individual Risk Criteria

Individual risk is the risk experienced by a single individual (passenger or member of crew) in a given time period, who, in our case, is exposed to hazards relating to RoPax operations. The individual risk is usually expressed as the frequency of an individual fatality per year. SAFEDOR Deliverable D4.5.2 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 in Table 3. On the basis of these criteria, Figure 4 below illustrates intolerable, ALARP and negligible risk levels for individuals.

Table 3: Individual risk criteria

Individual risk criterion	**Value**
Maximum tolerable risk for crew members	10^{-3} per year
Maximum tolerable risk for passengers	10^{-4} per year
Negligible risk	10^{-6} per year

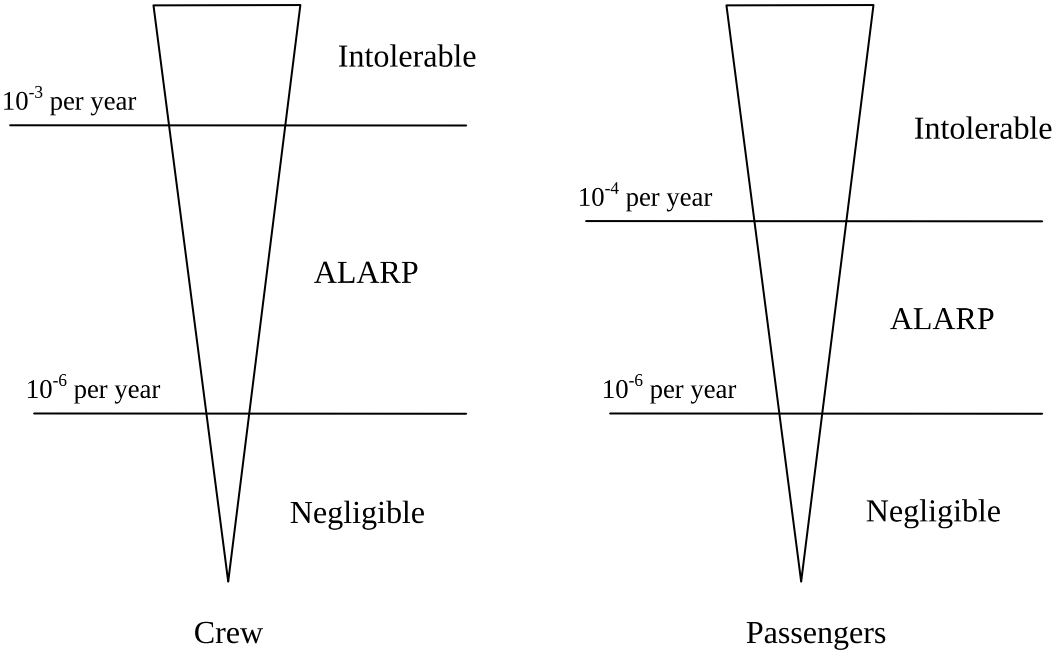


Figure 4: Individual risk criteria

In this study, average individual risks will be estimated on the basis of potential accident scenarios which form the generic risk model to be presented in this report. These estimations can then be weighted with different exposure expected for crew members and passengers, in order to determine risk acceptability or not.

3.2 Societal Risk Criteria

Societal risk is the total risk experienced by the whole group of people (passengers or crew members) travelling on a ship. It is usually plotted on an F-N log-log diagram which shows the relationship between the cumulative frequency F of incidents with N or more fatalities against the number of fatalities N.

Risk criteria on an F-N diagram distinguish intolerable, ALARP and negligible risk areas. The criteria are plotted on the basis of "anchor" points and a selected gradient (usually a slope of -1 is chosen, risk averse). Different activities and industry sectors will require different criteria to reflect the corresponding level of risk considered tolerable. Table 4 contains the anchor points for societal criteria suggested in SAFEDOR Deliverable D4.5.2 for RoPax vessels, using anchor points at N = 10. That report also states that these criteria have been derived on the basis of economic importance. Figure 5 illustrated the criteria lines using the anchor points of Table 4 and assuming risk averse perception (slope of the lines equal to -1).

Table 4: Societal criteria for RoPax

Anchor points for societal criteria	**Values**
Boundary between negligible and tolerable risk	(10, 10^{-4})
Boundary between tolerable and intolerable risk	(10, 10^{-2})

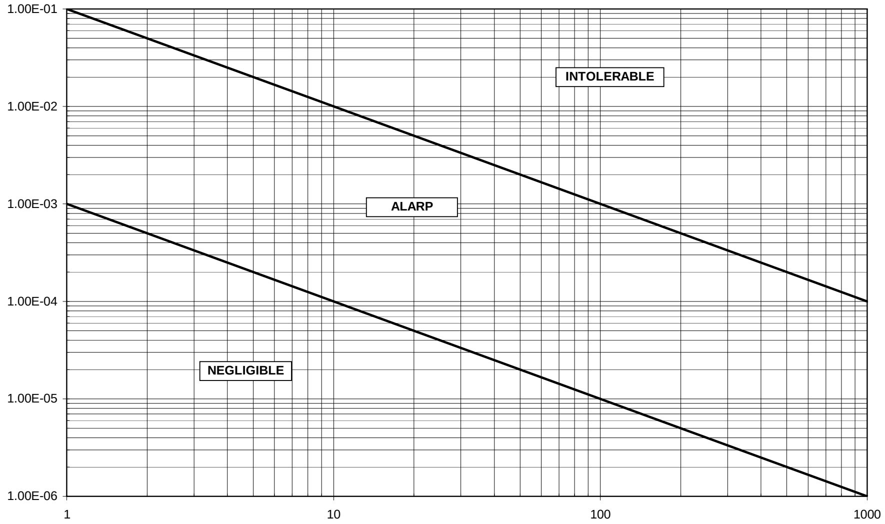


Figure 5: Societal criteria for RoPax vessels

4 HAZID Results

In SAFEDOR Deliverable D4.2.1 [2] a HAZID for RoPax has been carried out. Various RoPax operational phases were considered for which hazards, their causes and consequences were recorded and analysed qualitatively in a structured manner.

A risk register has been developed, comprising the most relevant hazards that may occur in RoPax operations. A total of 58 hazards were identified within the following operational phases and evaluated for their probabilities/frequencies and severity of potential outcomes:

- Loading (7 hazards)
- Departing quay (8 hazards)
- Transit and navigation in coastal waters (12 hazards)
- Transit in open sea (6 hazards)
- Arriving in port, mooring and preparing for unloading (6 hazards)
- Unloading (6 hazards)
- Bunkering, treatment of fluid and solid garbage (3 hazards)
- Emergency evacuation and drills (8 hazards)
- Other (2 hazards)

Based on subjective, qualitative estimates of their probabilities/frequencies and severity of potential consequences by the HAZID participants, the hazards have been ranked to derive a prioritised list of the most significant hazards. Table 5 contain the top-ranked hazards identified during the HAZID session. Of relevant is also Table 6, containing top-ranked hazards with high frequency of occurrence, but of low consequences.

Table 5: Top-ranked high-consequence 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**

Table 6: Top-ranked high-frequency hazards

No	Hazard	FI	SI	RI
8-2	Failure of evacuation equipment during an emergency	4.78	3.33	**8.11**
1-4	Collision between a car and the vessel or between two cars during loading	6.22	1.78	**8.00**
8-3	Human error and/or lack of training during an evacuation	4.56	3.22	**7.78**
4-3	Heavy ship movements due to weather while in open sea	5.89	1.11	**7.00**
1-2	Failure of loading equipment (gangways, ramps, cranes, etc.)	4.67	2.11	**6.78**
3-11	Own wash effect while navigating in coastal waters	5	1.44	**6.44**
9-2	Passengers misbehaving	4.44	2.00	**6.44**
1-1	Relative movement ship-shore while loading	4.89	1.11	**6.00**
1-5	Fire or explosion during loading	4.33	1.56	**5.89**
3-9	Bridge equipment generating too much information while navigating in coastal waters	4.22	1.56	**5.78**

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.

Section 5 of this report details a frequency analysis of available RoPax casualty data for the period 1994-2004, whilst Section 6 deals with the proposal of the corresponding high-level risk model for RoPax ships. The latter 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.

5 Casualty Data Analysis

This work is based on casualty 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). These two sources are considered the most comprehensive for casualty data and fleet-at-risk data, respectively. The reason for the selection of the said period is that the safety assessment study for passenger RoRo vessels carried out as part of the North West European Project [3, 4], covered the period 1978-1994, hence providing some reasonable basis of comparison of the corresponding safety records for the two periods.

5.1 LMIU Causes

LMIU casualty data are classified according to the initial causes described in Table 7:

Table 7: LMIU Classification of Accidents

Initial Cause	Code	Description
Collision	CN	Striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking underwater wrecks.
Contact	CT	Striking or being struck by any fixed or floating object, but not a ship or the sea bottom. This category includes striking drilling rigs/platforms, regardless of whether in fixed position or in tow.
Foundered	FD	Includes ships which sank as a result of heavy weather, vessel springing leaks, breaking in two, and not as a result of the other categories.
Fire/Explosion	FX	Accidents where the fire and/or explosion is the initial event reported (except where first event is hull/machinery failure leading to fire explosion).
Hull Damage	HL	Structural failure, holes, cracks, that can result in the ingress of water and/or loss strength and/or stability.
War Loss	LT	Encompasses damage or other incidents occasioned to ships by hostile acts.
Missing	MG	Ship whose fate is undetermined with no information having being received of conditions and whereabouts after a reasonable period of time.
Machinery Damage/Failure	MY	Machinery or equipment damage or failure which is not attributable to any of the other seven categories. Examples are lost rudder or fouled propeller.
Piracy	PY	
Wrecked/Stranded	WS	Includes ships reported hard and fast for an appreciable period of time and cases reported hitting or touching sea bottom. This category includes entanglement on underwater objects like wrecks.
Miscellaneous	XX	Includes ships which have been lost or damaged which, for want of sufficient information, or for other reasons, cannot be classified.

It is noted that the safety assessment study carried out as part of the activities of the Joint North West European project [3, 4], distinguished the following five initial causes: *collision* (as in Table 7), *grounding* (as having the same description of the category “wrecked/stranded” of Table 7), *impact* (as having the same meaning of the category “contact” of Table 7), *other flooding* (as having the same description of the categories “hull damage” and “foundered” of Table 7) and *fire/explosion* (as in Table 7). The definitions for the various initiating events as used in [3, 4] are reproduced in Section 6 of this report.

5.2 Casualty Frequency Analysis

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 for the reasons given in Section 2.5. Irrespective of this, given the great number of RoPax ships under 1,000 GRT (1,196 ships, according to LRFP data of March 2006), this casualty figure indicates serious under-reporting of casualties for RoPax ships under 1,000 GRT.

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.

Tables 8, 9 and 10 contain an analysis of the LMIU RoPax casualty data for the period 1994-2004, for RoPax of 1,000 GRT to 4,000 GRT, for RoPax of 4,000 GRT and above and for RoPax of 1,000 GRT and above, respectively. The data are also presented graphically on Figures 6, 7 and 8.

Table 8: Number of Incidents and Frequencies, RoPax 1,000 GRT to 4,000 GRT (1994-2004)

	# Incidents		% Total	% Serious	Frequency (per ship year)	
	Total	Serious			Total	Serious
Collision	53	4	18.6%	8.2%	8.01E-03	6.04E-04
Contact	62	8	21.8%	16.3%	9.37E-03	1.21E-03
Fire/Explosion	29	13	10.2%	26.5%	4.38E-03	1.96E-03
Wrecked/Stranded	48	14	16.8%	28.6%	7.25E-03	2.11E-03
Hull Damage	5	0	1.8%	0.0%	7.55E-04	0.00E+00
Foundered	0	0	0.0%	0.0%	0.00E+00	0.00E+00
Machinery damage/failure	75	10	26.3%	20.4%	1.13E-02	1.51E-03
Miscellaneous	13	0	4.6%	0.0%	1.96E-03	0.00E+00
TOTAL	**285**	**49**	**100.0%**	**100.0%**	**4.31E-02**	**7.40E-03**

Fleet at Risk (1994 – 2004)	**6,620**

Table 9: Number of Incidents and Frequencies, RoPax 4,000 GRT and above (1994-2004)

	# Incidents		% Total	% Serious	Frequency (per ship year)	
	Total	Serious			Total	Serious
Collision	141	16	18.4%	12.1%	1.59E-02	1.81E-03
Contact	131	13	17.1%	9.8%	1.48E-02	1.47E-03
Fire/Explosion	99	37	12.9%	28.0%	1.12E-02	4.18E-03
Wrecked/Stranded	100	33	13.0%	25.0%	1.13E-02	3.73E-03
Hull Damage	30	7	3.9%	5.3%	3.39E-03	7.91E-04
Foundered	2	2	0.3%	1.5%	2.26E-04	2.26E-04
Machinery damage/failure	214	21	27.9%	15.9%	2.42E-02	2.37E-03
Miscellaneous	50	3	6.5%	2.3%	5.65E-03	3.39E-04
TOTAL	**767**	**132**	**100.0%**	**100.0%**	**8.67E-02**	**1.49E-02**

Fleet at Risk (1994 – 2004)	**8,848**

Table 10: Number of Incidents and Frequencies, RoPax 1,000 GRT and above (1994-2004)

	# 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**

Fleet at Risk (1994 – 2004)	**15,468**

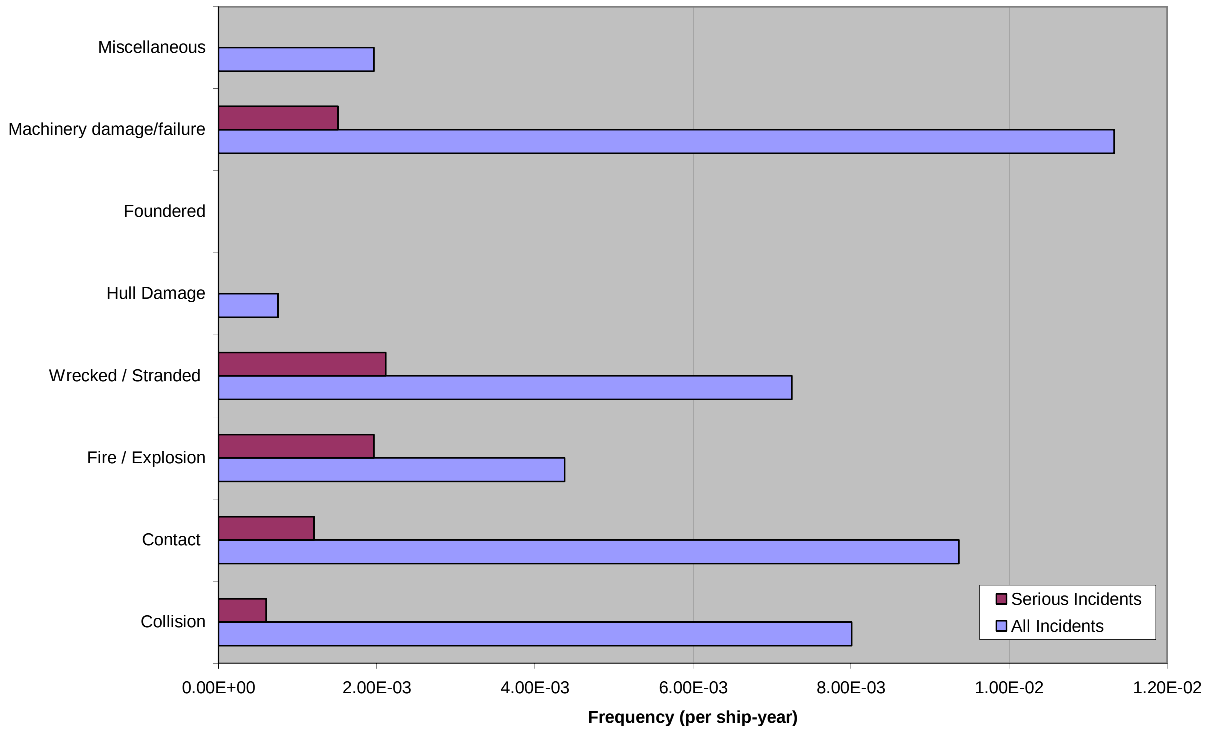


Figure 6: Frequency of Incidents, RoPax 1,000 GRT to 4,000 GRT (1994-2004)

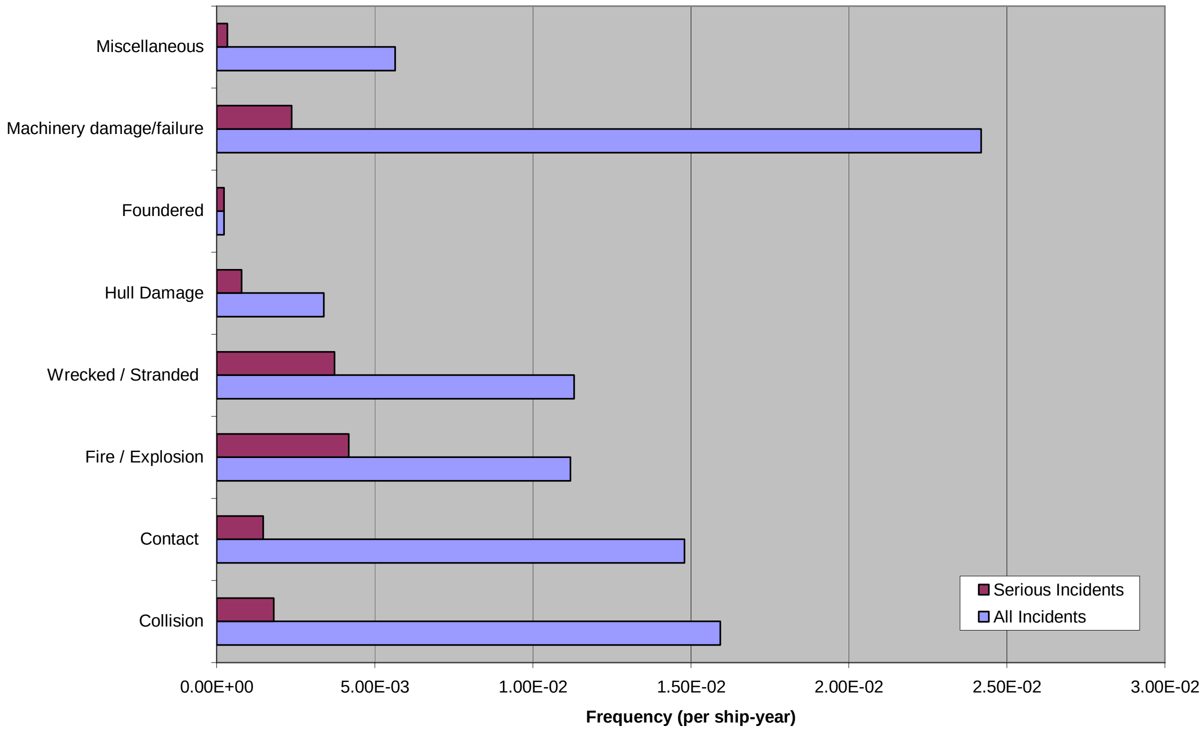


Figure 7: Number of Incidents and Frequencies, RoPax 4,000 GRT and above (1994-2004)

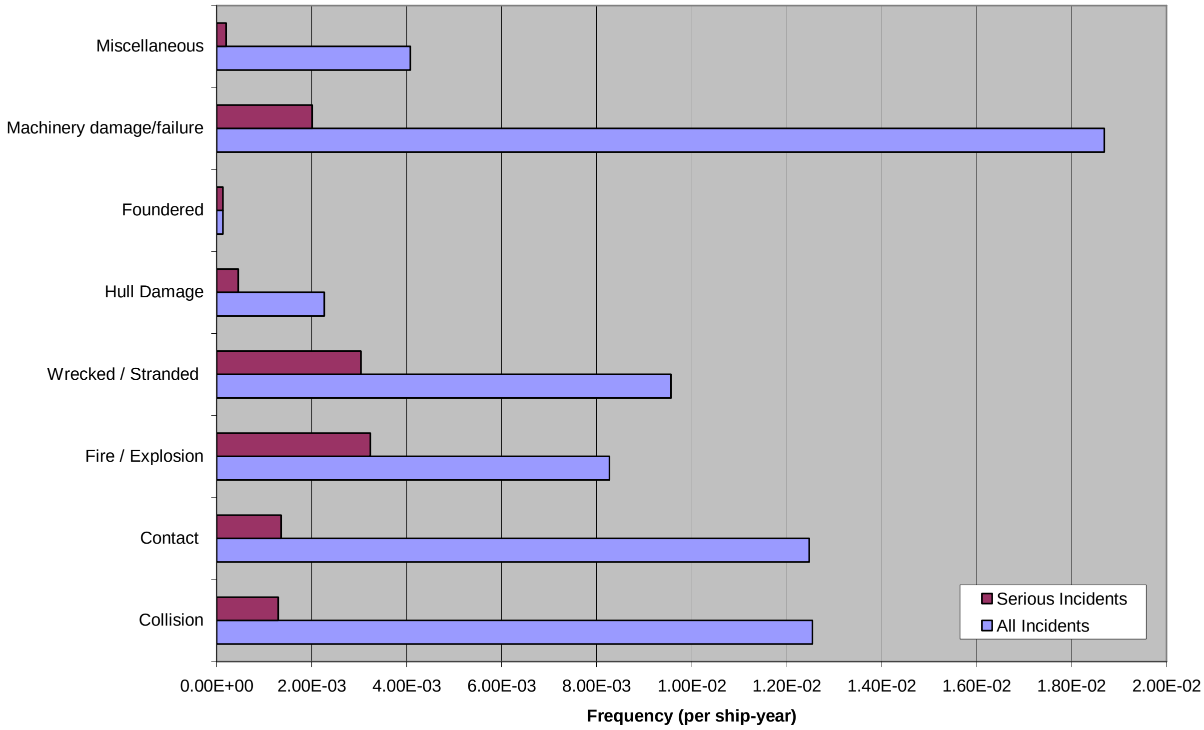


Figure 8: Number of Incidents and Frequencies, RoPax 1,000 GRT and above (1994-2004)

Other recent studies have also estimated accident frequencies, covering periods similar to the one analysed in this report. More specifically:

- In [10] the frequency of collisions for all passenger ships over 4,000 GRT for the period 1990-2000 was estimated as 5.16E-03 per ship year. Table 9 above indicates a collision frequency of 1.59E-02 per ship year, of which only 57% represent collisions under way, i.e. a frequency of collisions under way of 9.06E-03 per ship year.
- Similarly, [10] reports a frequency of groundings for all passenger ships over 4,000 GRT for the period 1990-2000 of 1.03E-02 per ship year. Table 9 above indicates a grounding frequency of 1.13E-02 per ship year.
- In [11] the frequency of serious fires for RoPax over 5,000 GRT for the period 1990-2002 was estimated as 1.90E-03 per ship year. Table 9 indicates a frequency of 4.18E-03 per ship year.

Taking into account the differences in reporting periods, different samples (importantly the fact that the figures presented in [10] refer to all passenger ships, including cruise ships and RoPax) and possibly different definitions of casualty categories and/or the way data are used, it can be considered that fair agreement exists with results of relevant studies.

5.3 Comparison with Previous Periods

A comparison with frequencies calculated in [3, 4] referring to North West European experience for the period 1978-1994 is attempted in this section. The following are the points that can be made:

- **Collision.** The frequency of collisions under way at North West Europe during the period 1978-1994 was 1.32E-02 per ship year. From Table 10 and considering that collisions under way represent only 63% of the total frequency, the frequency of collisions under way world-wide for the period 1994-2004 is estimated to be 7.88E-03 per ship year. This indicates a frequency reduction of **40%**.
- **Grounding.** The frequency of groundings at North West Europe during the period 1978-1994 was 2.00E-02 per ship year. From Table 10, the frequency of groundings world-wide for the period 1994-2004 is estimated to be 9.57E-03 per ship year. This indicates a frequency reduction of **52%**.
- **Impact.** The frequency of impacts at North West Europe during the period 1978-1994 was 4.90E-02 per ship year. From Table 10, the frequency of impacts world-wide for the period 1994-2004 is estimated to be 1.25E-02 per ship year. This indicates a frequency reduction of **74%**.
- **Flooding from other causes.** Comparison of corresponding data indicates no chance on this frequency.
- **Fire.** The frequency of fires at North West Europe during the period 1978-1994 was 1.00E-02 per ship year. From Table 10, the frequency of fires world-wide for the period 1994-2004 is estimated to be 8.28E-03 per ship year. This indicates a frequency reduction of **17%**.
- **Overall Frequency.** The overall frequency for all critical scenarios (collisions under way, groundings, impacts, flooding from other causes and fires) at North West Europe

during the period 1978-1994 was estimated to be 9.44E-02 per ship year. From Table 10, the overall frequency for these accident scenarios world-wide for the period 1994-2004 is estimated to be 4.05E-02 per ship year. This indicates an overall frequency reduction of **57%**.

Due to differences in reporting (LMIU started systematic collection of casualty data on 1994; before that mainly serious accidents were reported only) the frequency reductions calculated above should be used as for reference only. At any case, the estimated reductions provide a concise indication that safety has improved during the period 1994-2004.

5.4 Fatal Incidents

Table 11 contains a list of the 14 fatal incidents occurred world-wide during the period 1994-2004.

Table 11: 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

Table 12 presents the calculation for the potential loss of life during the period 1994-2004.

Table 12: PLL, RoPax 1,000 GRT and above, 1994-2004

	# Incidents	# Fatalities	PLL (per ship year)	%
Collision	2	7	4.53E-04	0.5%
Fire/Explosion	8	378	2.44E-02	25.6%
Wrecked/Stranded	1	94	6.08E-03	6.4%
Hull Damage	3	995	6.43E-02	67.5%
TOTAL	**14**	**1,474**	**9.53E-02**	**100.0%**

Fleet at Risk (1994 – 2004)	**15,468**

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[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

It is noted that the set of data of Tables 11 and 12 does not include the Al Salam Boccaccio 98 incident, which happened on 3 February 2006 with around 1,000 fatalities. Table 12 indicates a historical Potential Loss of Life (PLL) value of 9.53E-02 per ship year, on the basis of the date covering the period 1994-2004 (Table 11). Including the Al Salam Boccaccio 98 incident in a PLL calculation for the period 1994-2006, we obtain a figure of **1.35E-01 per ship year**.

Figure 9 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).

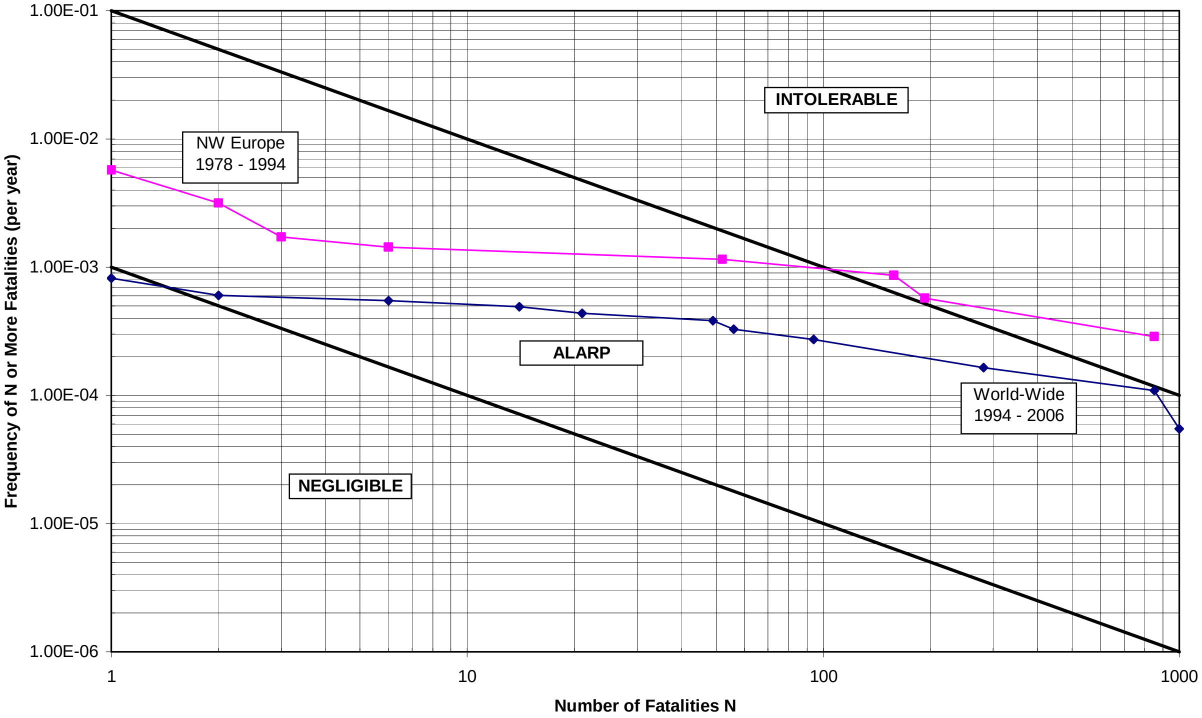


Figure 9: RoPax F-N Curve (Historical Risk)

6 Risk Model

This section describes the high-level risk model for RoPax operations. The risk model comprises event trees containing potential outcomes for the following initiating events:

1. Collision
2. Grounding (incidents classified by LMIU as “wrecked/stranded”)
3. Impact (incidents classified by LMIU as “contact”)
4. Other flooding (incidents classified by LMIU as “hull damage” or “foundered”)
5. Fire/explosion

This selection of initiating events is in agreement with the outcome of the HAZID work (described briefly in Section 4 of this report, and in detail in [2]). As it can be seen from the frequency analysis of Section 5, these initiating events provide a sufficient basis for the derivation of a complete risk profile for RoPax operations, since:

- All fatal incidents were initiated by one of these causes (Tables 11 and 12; also previous relevant studies, for example [3, 4, 12]).
- These five initiating causes represent 66.5% of all incidents and 81.2% of serious incidents recorded for the period 1994-2004 (Table 10). This is mainly due to the fact that incidents recorded as “machinery damage/failure” are not taken forward for further analysis and elaboration. Incidents recorded as such by LMIU did not develop to any subsequent accident of the five categories mentioned above. Extended time off-service for repair is the reason LMIU records a number of “machinery damage/failure” incidents as serious.

Potential outcomes (accident scenarios) for the five initiating events taken forward for analysis are based on the analysis carried out in the safety assessment study of the Joint North West European project [3, 4]. Since the risk model required by this study is at a high-level, this previous work is sufficient for this purpose. The event trees of that study are reproduced in Appendix 1, for ease of reference.

For clarity, definitions for the five initiating events considered within the high-level risk model are as follows, adopting to the accident classification of [3, 4]:

- **Collisions:** events where two vessels accidentally come into contact with each other. This may lead to sinking, grounding or to a fire on the vessel, but these are counted as collisions if this was the cause. This definition includes collisions between two ships under way, and also events sometimes known as “strikings”, where a moving ship strikes another ship at a berth.

- **Groundings:** cases where a vessel comes into contact with the sea bed or shore, including underwater wrecks. If the ship is struck fast, this is known as “stranding”. If the ship sinks, this is sometimes known as “wreck”. The category “wreck/stranded” used by LMIU is equivalent to the term “grounding” used in this study.

- **Impacts:** cases where a vessel comes into contact with objects other than ships, the sea bed or the shore. This includes impacts on berths, bridges and offshore platforms. It is known by LMIU as “contact”.

- **Other Flooding:** cases where water enters a ship for reasons other than collision, impact or grounding (treated separately). Some of these events are included by LMIU under the category “hull/machinery damage”. If the ship sinks, this is known by LMIU as “foundering”. The “other flooding” category is also taken to include weather damage, cargo shifting and intact instability events which would lead to flooding if the ship were to sink.

- **Fire/Explosion:** cases where fires and/or explosions occur for reasons other than collision, impact or grounding (treated separately).

In this section of the report, data used and assumptions made are presented on the event trees produced to reflect possible outcomes following collisions, groundings, impacts, flooding from other causes and fires. The latter section of the report presents the F-N curves resulting from the high-level risk model, together with results for individual risk.

6.1 Collision

Figure 10 presents the generic collision event tree based on world-wide experience of the period 1994-2004. Data used and assumptions made are as follows:

Collision Frequency

The overall frequency for collision incidents estimated in Table 10 for RoPax of 1,000 GRT and above is used, i.e. 1.25E-02 per ship year (1994-2004 world-wide experience).

Level 1

World-wide casualty data for RoPax indicate that during the period 1994-2004, of the 194 recorded collision casualties, 122 (63%) are collisions under way and the remaining 72 (37%) are strikings whilst at berth. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 2

Of the collisions under way involving RoPax ships during the period 1994-2004, 102 (84%) are recorded as minor incidents and the remaining 20 (16%) represent a serious casualty. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 3

The probability the vessel being the struck or the striking ship is assumed to be 50%-50%. This reflects a view that it is largely a matter of chance which is striking and which the struck ship, due to the unpredictable effects of last-minute manoeuvring. Furthermore, analyses of collision casualty data have concluded on the same probabilities [4].

Levels 4, 5 & 6

Of the serious collision casualties of RoPax ships during the period 1994-2004, 17 incidents represented impacts only, whilst in only 3 cases flooding did occur (in all of the latter the vessel remained afloat). No fire incident following a collision has occurred during the period 1994-2004, however, a very serious such incident has occurred prior to this period (the Moby Prince, which struck a tanker ship resulting in a fire killing 141 of the 142 people onboard).

To estimate the probability of flooding occurring on the struck ship following a serious casualty (Level 4), data from previous studies are used. In [10], two studies are quoted as providing estimations for this probability: in [13] the probability of flooding given collision is estimated as 38%, but the statistical basis for this is considered rather weak (the estimation was based on 16 collision incidents of passenger ships over 4,000 GRT). The second study [14], which reports on the analysis of the HARDER set of data of collision and grounding incidents for all types of ships, contains 508 collision records resulting in flooding of one or more compartments out of the 801 collision records in which the ship was identified to be struck, i.e. a probability of 63%. This latter result is in broad agreement with the result obtained in [15], where the probability of having a breach at the side of a RoPax was calculated to be 60%, using a collision structural model. On the basis of these considerations, a conditional probability of flooding of 50% is used.

To estimate Level 5 branch probabilities (flooding occurring on the struck ship following a serious casualty), results from the HARDER project are used. Attained Index of Subdivision calculations were carried out for a representative sample of 38 RoPax vessels [16]. The average obtained A value for this sample is 0.78, which can be used as the branch probability for the vessel to remain afloat, which its complement of 0.22 is used as the branch probability for the vessel to sink.

Due to limited experience during the period 1994-2004, branch probabilities used in [3, 4] are adopted for the remaining branches of the event tree at Levels 4 and 6. The North West European project study covered the period 1978-1994, where accident experience for these potential outcomes was also limited, and the branch probabilities used were based on judgement.

Risk Calculations

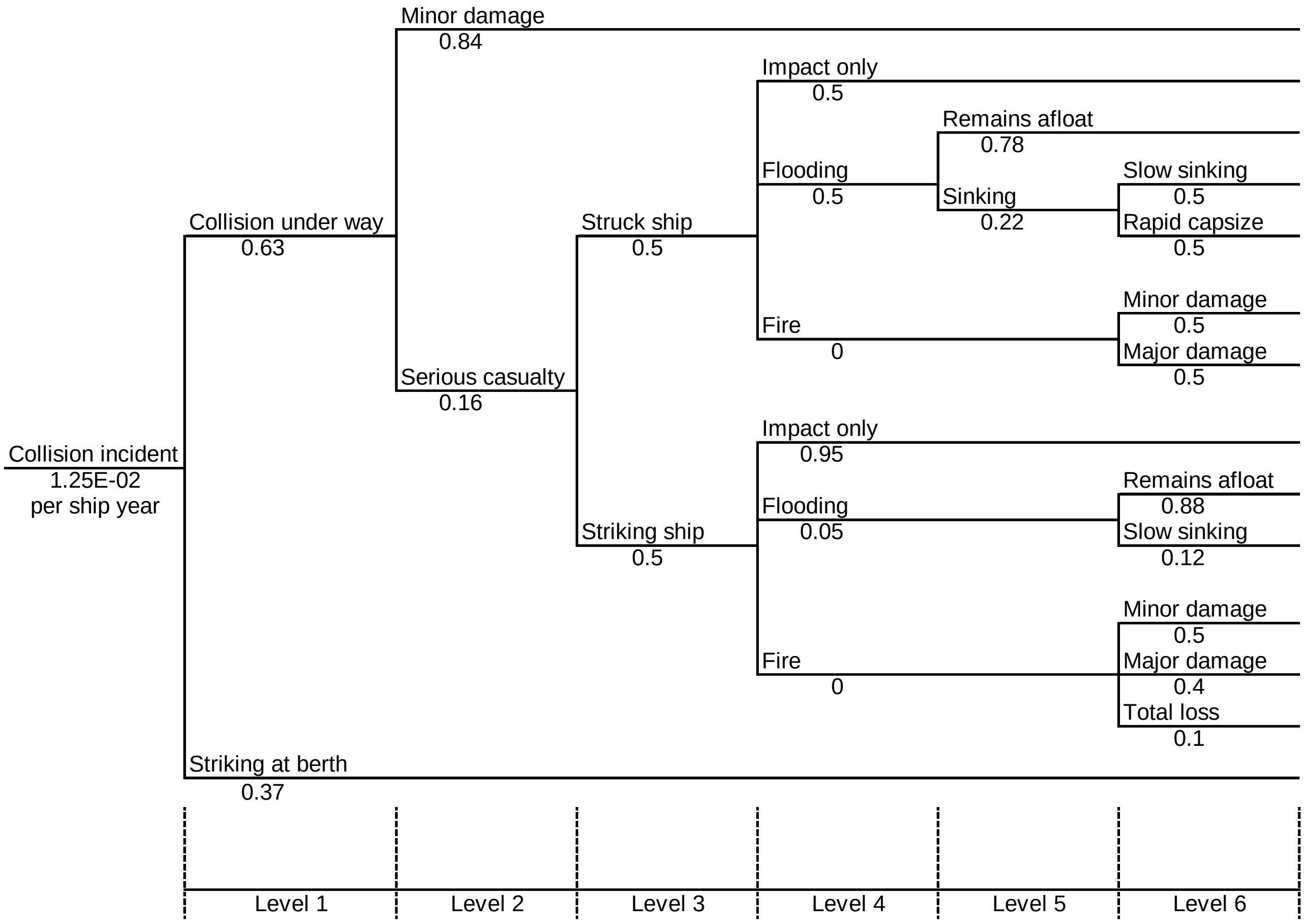
On the basis of the event tree of Figure 10, risk calculations for the outcomes of collisions have been carried out, as presented in Table 13.

Number of people at risk is as considered in the assumptions made in section 2.5 of this report, namely:

- Average maximum carrying capacity of 1,000 passengers, traffic seasonality assumed as follows:
  - 25% of trips carrying full passenger load (1,000 passengers)
  - 25% of trips carrying half of maximum passenger load (500 passengers)
  - 50% of trips carrying 75% of maximum passenger load (750 passengers)
- Crew number of 100 is considered as an average.

These calculations are carried out on the assumption of average fatality rates for the different potential scenarios, which have also been used during the North West European project study, namely a 12% fatality rate for flooding incidents leading to slow sinking and 66% for incidents leading to rapid capsize. Appendix 2 elaborates on the values assumed.

Figure 10: Generic Collision Event Tree



ID Code	Probability per collision	Frequency per ship year
C1	0.529200	6.62E-03
C2	0.025200	3.15E-04
C3.1.1	0.019656	2.46E-04
C3.1.2	0.002772	3.47E-05
C3.1.3	0.002772	3.47E-05
C4.1	0.000000	0.00E+00
C4.2	0.000000	0.00E+00
C2.3	0.047880	5.99E-04
C3.2.1	0.002218	2.77E-05
C3.2.2	0.000302	3.78E-06
C4.3	0.000000	0.00E+00
C4.4	0.000000	0.00E+00
C4.5	0.000000	0.00E+00
C5/C6	0.370000	4.63E-03
	1.000000	1.25E-02

Table 13: Risk Calculations for Collision Outcomes

1,100 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per collision)	PLL (per ship year)
C3.1.2	Serious collision, struck ship, flooded, slow sinking	8.66E-06	12	1.04E-06	132	1.14E-03
C3.1.3	Serious collision, struck ship, flooded, rapid capsize	8.66E-06	66	5.72E-06	726	6.29E-03
C3.2.2	Serious collision, striking ship, flooded, slow sinking	9.45E-07	12	1.13E-07	132	1.25E-04
				6.87E-06		7.56E-03

850 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per collision)	PLL (per ship year)
C3.1.2	Serious collision, struck ship, flooded, slow sinking	1.73E-05	12	2.08E-06	102	1.77E-03
C3.1.3	Serious collision, struck ship, flooded, rapid capsize	1.73E-05	66	1.14E-05	561	9.72E-03
C3.2.2	Serious collision, striking ship, flooded, slow sinking	1.89E-06	12	2.27E-07	102	1.93E-04
				1.37E-05		1.17E-02

Table 13 (Continued): Risk Calculations for Collision Outcomes

600 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per collision)	PLL (per ship year)
C3.1.2	Serious collision, struck ship, flooded, slow sinking	8.66E-06	12	1.04E-06	72	6.24E-04
C3.1.3	Serious collision, struck ship, flooded, rapid capsize	8.66E-06	66	5.72E-06	396	3.43E-03
C3.2.2	Serious collision, striking ship, flooded, slow sinking	9.45E-07	12	1.13E-07	72	6.80E-05
				6.87E-06		4.12E-03

6.2 Grounding

Figure 11 presents the generic grounding event tree based on world-wide experience of the period 1994-2004. Data used and assumptions made are as follows:

Grounding Frequency

The overall frequency for grounding incidents estimated in Table 10 for RoPax of 1,000 GRT and above is used, i.e. 9.57E-03 per ship year (1994-2004 world-wide experience).

Level 1

World-wide casualty data for RoPax indicate that during the period 1994-2004, 101 (68%) grounding incidents are recorded as minor incidents and the remaining 47 (32%) represent a serious casualty. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 2

Of the serious grounding casualties of RoPax ships during the period 1994-2004, 25 (54%) are recorded as incidents where no flooding occurred, 11 (23%) are incidents where limited flooding occurred (double-bottom only) and 11 (23%) where the most serious incidents where flooding above the double-bottom took place. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 3

Of the serious grounding casualties with extensive flooding taking place that happened on RoPax ships during the period 1994-2004, in 7 (64%) incidents the vessel run hard aground, whilst in the remaining 4 (36%) of the incidents the vessel floated free following grounding. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 4

Of the very serious grounding incidents for RoPax ships occurred during the period 1994-2004, in 3 cases the vessels remained afloat, whilst in just 1 case (Express Samina) the vessel capsized rapidly following the grounding incident. Due to this very limited experience, the branch probabilities at Level 4 obtained in the North West European project study [3, 4] are used for the purposes of the current study. The North West European project study covered the period 1978-1994, where accident experience for these potential outcomes was also limited, and the branch probabilities used were based on judgement.

Risk Calculations

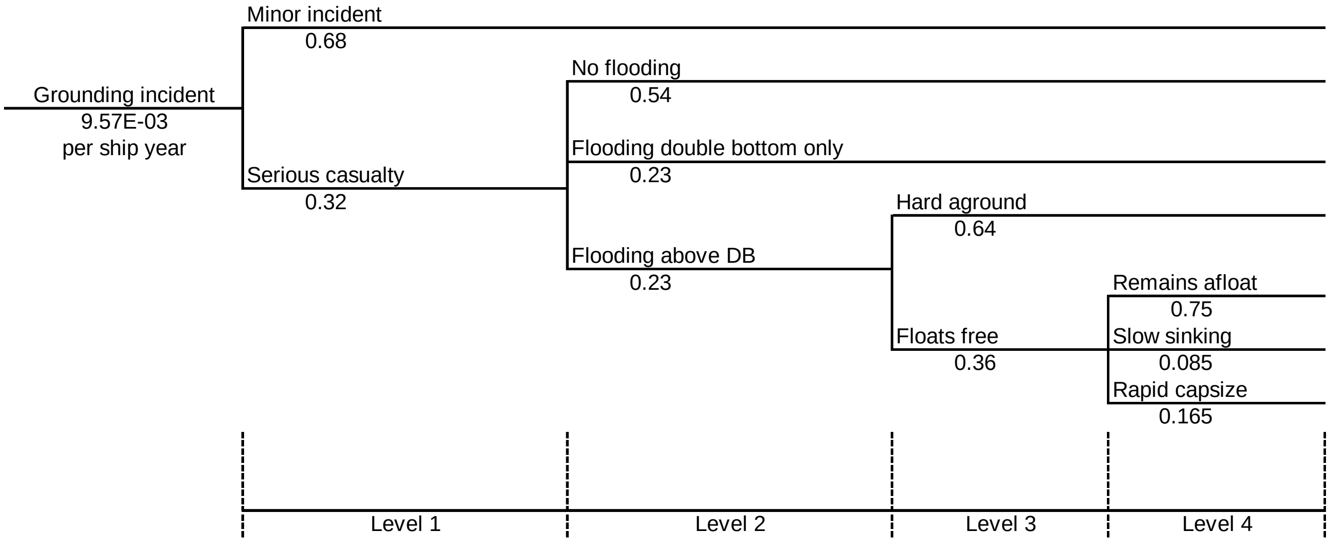
On the basis of the event tree of Figure 11, risk calculations for the outcomes of groundings have been carried out, as presented in Table 14.

Number of people at risk is as considered in the assumptions made in section 2.5 of this report, namely:

- Average maximum carrying capacity of 1,000 passengers, traffic seasonality assumed as follows:
  - 25% of trips carrying full passenger load (1,000 passengers)
  - 25% of trips carrying half of maximum passenger load (500 passengers)
  - 50% of trips carrying 75% of maximum passenger load (750 passengers)
- Crew number of 100 is considered as an average.

These calculations are carried out on the assumption of average fatality rates for the different potential scenarios, which have also been used during the North West European project study, namely a 12% fatality rate for flooding incidents leading to slow sinking and 66% for incidents leading to rapid capsize. Appendix 2 elaborates on the values assumed.

Figure 11: Generic Grounding Event Tree



ID Code	Probability per grounding	Frequency per ship year
G1	0.680000	6.51E-03
G1	0.172800	1.65E-03
G2	0.073600	7.04E-04
G3.1	0.047104	4.51E-04
G3.2.1	0.019872	1.90E-04
G3.2.2	0.002252	2.16E-05
G3.2.3	0.004372	4.18E-05
	1.000000	9.57E-03

Table 14: Risk Calculations for Grounding Outcomes

1,100 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per grounding)	PLL (per ship year)
G3.2.2	Grounding, float free, slow sinking	5.39E-06	12	6.47E-07	132	7.11E-04
G3.2.3	Grounding, float free, rapid capsize	1.05E-05	66	6.90E-06	726	7.59E-03
				7.55E-06		8.30E-03

850 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Rates	Ind. Risk (per year)	Fatalities (per grounding)	PLL (per ship year)
G3.2.2	Grounding, float free, slow sinking	1.08E-05	12	1.29E-06	102	1.10E-03
G3.2.3	Grounding, float free, rapid capsize	2.09E-05	66	1.38E-05	561	1.17E-02
				1.51E-05		1.28E-02

600 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Rates	Ind. Risk (per year)	Fatalities (per grounding)	PLL (per ship year)
G3.2.2	Grounding, float free, slow sinking	5.39E-06	12	6.47E-07	72	3.88E-04
G3.2.3	Grounding, float free, rapid capsize	1.05E-05	66	6.90E-06	396	4.14E-03
				7.55E-06		4.53E-03

6.3 Impact

Figure 12 presents the generic impact event tree based on world-wide experience of the period 1994-2004. Data used and assumptions made are as follows:

Impact Frequency

The overall frequency for impact incidents estimated in Table 10 for RoPax of 1,000 GRT and above is used, i.e. 1.25E-02 per ship year (1994-2004 world-wide experience).

Level 1

World-wide casualty data for RoPax indicate that during the period 1994-2004, 172 (89%) impact incidents are recorded as minor incidents and the remaining 21 (11%) represent a serious casualty. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 2

Of the serious impact casualties involving RoPax ships during the period 1994-2004, 16 (76%) are recorded as incidents where no flooding occurred, whilst 5 (24%) are incidents where flooding did occur. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 3

All the serious impact casualties with flooding taking place, for RoPax ships during the period 1994-2004, resulted in the vessel remaining afloat following the incidents. Due to the very limited experience, the branch probabilities at Level 4 obtained in the North West European project study [3, 4] are used for the purposes of the current study. The North West European project study covered the period 1978-1994, where accident experience for these potential outcomes was also limited, and the branch probabilities used were based on judgement.

Risk Calculations

On the basis of the event tree of Figure 12, risk calculations for the outcomes of impacts have been carried out, as presented in Table 15.

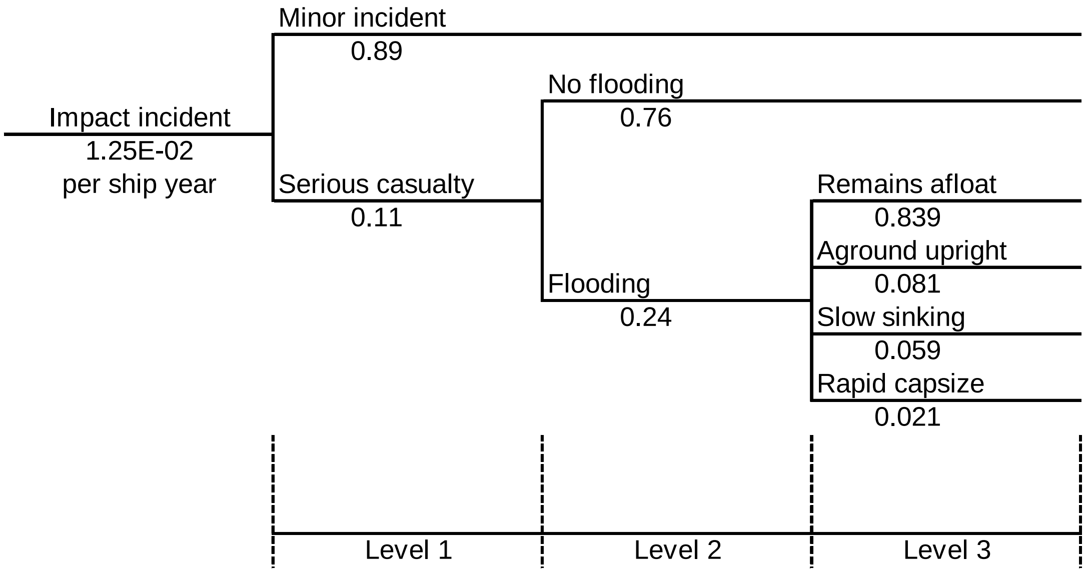
Number of people at risk is as considered in the assumptions made in section 2.5 of this report, namely:

- Average maximum carrying capacity of 1,000 passengers, traffic seasonality assumed as follows:
  - 25% of trips carrying full passenger load (1,000 passengers)
  - 25% of trips carrying half of maximum passenger load (500 passengers)
  - 50% of trips carrying 75% of maximum passenger load (750 passengers)

- Crew number of 100 is considered as an average.

These calculations are carried out on the assumption of average fatality rates for the different potential scenarios, which have also been used during the North West European project study, namely a 0.2% fatality rate for flooding incidents leading to slow sinking and 23% for incidents leading to rapid capsize. Appendix 2 elaborates on the values assumed.

Figure 12: Generic Impact Event Tree



ID Code	Probability per impact	Frequency per ship year
M1	0.890000	1.11E-02
M2	0.083600	1.05E-03
M3.1	0.022150	2.77E-04
M3.2	0.002138	2.67E-05
M3.3	0.001558	1.95E-05
M3.4	0.000554	6.93E-06
	1.000000	1.25E-02

Table 15: Risk Calculations for Impact Outcomes

1,100 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per impact)	PLL (per ship year)
M3.3	Impact, flooding, slow sinking	4.87E-06	0.2	9.74E-09	2	1.07E-05
M3.4	Impact, flooding, rapid capsize	1.73E-06	23	3.98E-07	253	4.38E-04
				4.08E-07		4.49E-04

850 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per impact)	PLL (per ship year)
M3.3	Impact, flooding, slow sinking	9.74E-06	0.2	1.95E-08	2	1.65E-05
M3.4	Impact, flooding, rapid capsize	3.47E-06	23	7.97E-07	196	6.77E-04
				8.16E-07		6.94E-04

600 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per impact)	PLL (per ship year)
M3.3	Impact, flooding, slow sinking	4.87E-06	0.2	9.74E-09	1	5.84E-06
M3.4	Impact, flooding, rapid capsize	1.73E-06	23	3.98E-07	138	2.39E-04
				4.08E-07		2.45E-04

6.4 Flooding from Other Causes

Figure 13 presents the generic flooding event tree based on world-wide experience of the period 1994-2004. Data used and assumptions made are as follows:

Flooding Frequency

The overall frequency for flooding incidents estimated in Table 10 for RoPax of 1,000 GRT and above is used, i.e. 2.39E-03 per ship year (1994-2004 world-wide experience).

Level 1

World-wide casualty data for RoPax indicate that during the period 1994-2004, 12 (32%) flooding incidents were due to wave damage, in 3 (9%) flooding occurred through open vehicle deck doors and 22 (59%) were incidents were flooding occurred below the vehicle deck. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 2

Of the flooding incidents that were due to wave damage for RoPax ships during the period 1994-2004, 2 (18%) happened through the bow door and 9 (82%) happened through ruptures on the vessel hulls. Of the flooding incidents that happened through open doors on RoPax ships during the period 1994-2004, 1 happened through the bow door and 2 through the stern door. These percentages are used as the branch probabilities of the respective scenarios in the event tree.

Level 3

In all cases but two (1 case of slow sinking and 1 case of rapid capsize), the vessels remained afloat following the flooding incidents that occurred on RoPax ships during the period 1994-2004. Due to the very limited experience, the branch probabilities at Level 4 obtained in the North West European project study [3, 4] are used for the purposes of the current study. The North West European project study covered the period 1978-1994, where accident experience for these potential outcomes was also limited, and the branch probabilities used were based on judgement.

Risk Calculations

On the basis of the event tree of Figure 13, risk calculations for the outcomes of floodings have been carried out, as presented in Table 16.

Number of people at risk is as considered in the assumptions made in section 2.5 of this report, namely:

- Average maximum carrying capacity of 1,000 passengers, traffic seasonality assumed as follows:
    - 25% of trips carrying full passenger load (1,000 passengers)

    - 25% of trips carrying half of maximum passenger load (500 passengers)
    - 50% of trips carrying 75% of maximum passenger load (750 passengers)
- Crew number of 100 is considered as an average.

These calculations are carried out on the assumption of average fatality rates for the different potential scenarios, which have also been used during the North West European project study, namely a 12% fatality rate for flooding incidents leading to slow sinking and 66% for incidents leading to rapid capsize. Appendix 2 elaborates on the values assumed.

Figure 13: Generic Flooding Event Tree

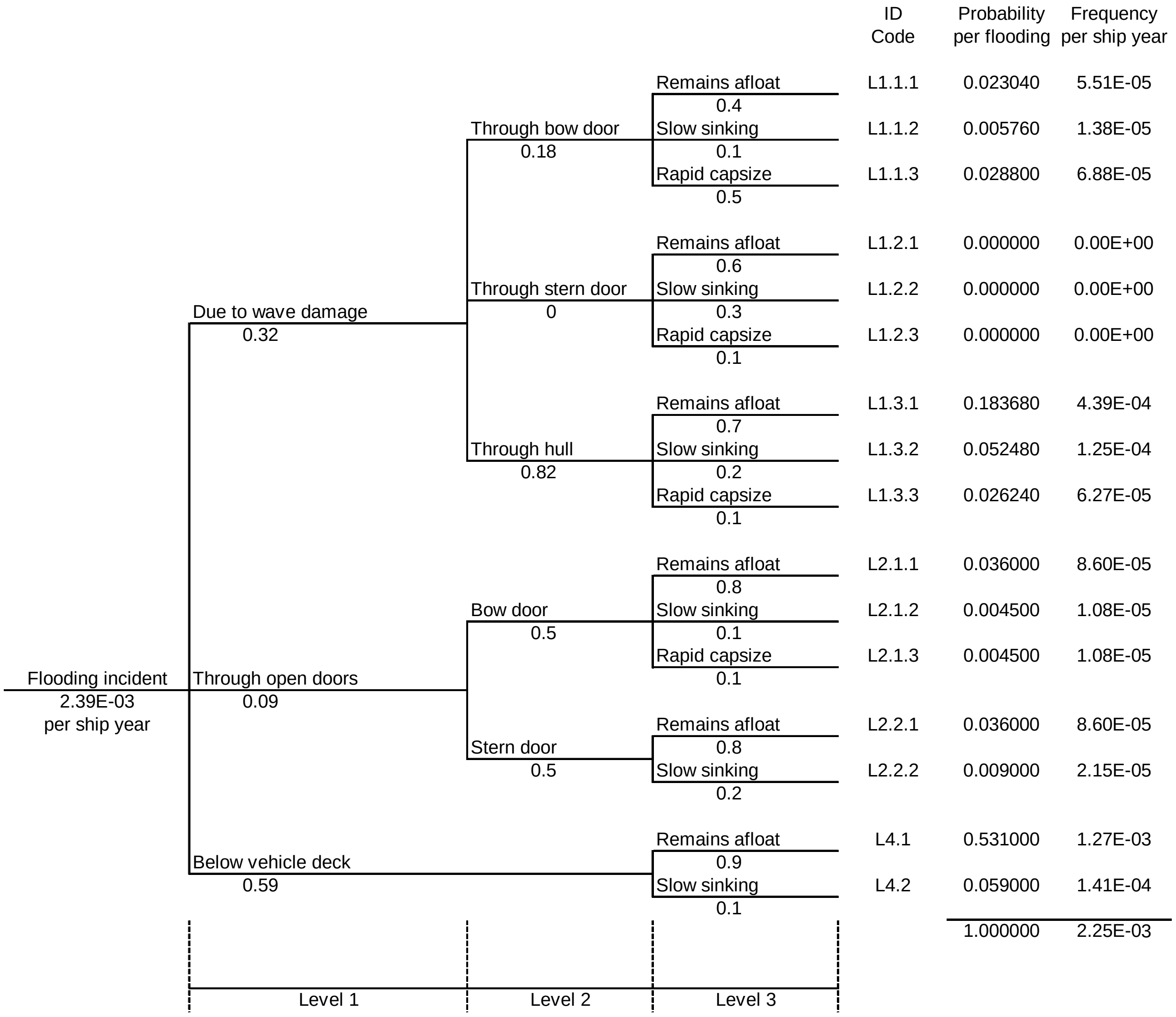


Table 16: Risk Calculations for Flooding Outcomes

1,100 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per flooding)	PLL (per ship year)
L1.1.2	Flooding through bow door due to wave damage, slow sinking	3.44E-06	12	4.13E-07	132	4.54E-04
L1.1.3	Flooding through bow door due to wave damage, rapid capsize	1.72E-05	66	1.14E-05	726	1.25E-02
L1.3.2	Flooding through hull due to wave damage, slow sinking	3.14E-05	12	3.76E-06	132	4.14E-03
L1.3.3	Flooding through hull due to wave damage, rapid capsize	1.57E-05	66	1.03E-05	726	1.14E-02
L2.1.2	Flooding through open bow door, slow sinking	2.69E-06	12	3.23E-07	132	3.55E-04
L2.1.3	Flooding through open bow door, rapid capsize	2.69E-06	66	1.77E-06	726	1.95E-03
L2.2.2	Flooding through open stern door, slow sinking	5.38E-06	12	6.45E-07	132	7.10E-04
L4.2	Flooding below vehicle deck, slow sinking	3.53E-05	12	4.23E-06	132	4.65E-03
				3.29E-05		3.61E-02

Table 16 (Continued): Risk Calculations for Flooding Outcomes

850 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per flooding)	PLL (per ship year)
L1.1.2	Flooding through bow door due to wave damage, slow sinking	6.88E-06	12	8.26E-07	102	7.02E-04
L1.1.3	Flooding through bow door due to wave damage, rapid capsize	3.44E-05	66	2.27E-05	561	1.93E-02
L1.3.2	Flooding through hull due to wave damage, slow sinking	6.27E-05	12	7.53E-06	102	6.40E-03
L1.3.3	Flooding through hull due to wave damage, rapid capsize	3.14E-05	66	2.07E-05	561	1.76E-02
L2.1.2	Flooding through open bow door, slow sinking	5.38E-06	12	6.45E-07	102	5.49E-04
L2.1.3	Flooding through open bow door, rapid capsize	5.38E-06	66	3.55E-06	561	3.02E-03
L2.2.2	Flooding through open stern door, slow sinking	1.08E-05	12	1.29E-06	102	1.10E-03
L4.2	Flooding below vehicle deck, slow sinking	7.05E-05	12	8.46E-06	102	7.19E-03
				6.57E-05		5.59E-02

Table 16 (Continued): Risk Calculations for Flooding Outcomes

600 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per flooding)	PLL (per ship year)
L1.1.2	Flooding through bow door due to wave damage, slow sinking	3.44E-06	12	4.13E-07	72	2.48E-04
L1.1.3	Flooding through bow door due to wave damage, rapid capsize	1.72E-05	66	1.14E-05	396	6.81E-03
L1.3.2	Flooding through hull due to wave damage, slow sinking	3.14E-05	12	3.76E-06	72	2.26E-03
L1.3.3	Flooding through hull due to wave damage, rapid capsize	1.57E-05	66	1.03E-05	396	6.21E-03
L2.1.2	Flooding through open bow door, slow sinking	2.69E-06	12	3.23E-07	72	1.94E-04
L2.1.3	Flooding through open bow door, rapid capsize	2.69E-06	66	1.77E-06	396	1.06E-03
L2.2.2	Flooding through open stern door, slow sinking	5.38E-06	12	6.45E-07	72	3.87E-04
L4.2	Flooding below vehicle deck, slow sinking	3.53E-05	12	4.23E-06	72	2.54E-03
				3.29E-05		1.97E-02

6.5 Fire/Explosion

Figure 14 presents the generic fire event tree based on world-wide experience of the period 1994-2004. Data used and assumptions made are as follows:

Fire Frequency

The overall frequency for fire/explosion incidents estimated in Table 10 for RoPax of 1,000 GRT and above is used, i.e. 8.28E-03 per ship year (1994-2004 world-wide experience).

Level 1

World-wide casualty data for RoPax indicate that during the period 1994-2004, 73 (64%) are fire incidents at machinery spaces, 14 (12%) incidents that happened on the vehicle deck and 27 (24%) incidents that occurred at accommodation spaces. The location for 14 incidents is not recorded (unknown). These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 2

Of the fire incidents that occurred in machinery spaces of RoPax ships during the period 1994-2004, 52 (71%) were incidents which did not escalate, whilst in the remaining 21 (29%) the fire did escalate. For fire incidents that happened on the vehicle deck of RoPax ships during the period 1994-2004, 10 (71%) did not escalate and 4 (29%) did so. The percentages for fire incidents that occurred in accommodation areas are 81% (21 incidents) and 19% (5 incidents) respectively. These percentages are used as the branch probabilities of the respective scenarios on the event tree.

Level 3

Of the fire incidents which happened in machinery spaces of RoPax ships during the period 1994-2004 and did escalate, in 12 cases evacuation of passengers and crew took place. There were fatalities in 2 of these cases, notably the case of Dashun, in which the fire got totally out of control and the vessel sunk in heavy seas, resulting in 282 people out of 304 onboard dying. A similar incident was that of Al Salam Boccaccio 98 which happened on 2006, resulting in 1,000 deaths out of 1,300 people onboard.

In all the cases of fires on the vehicle deck and accommodation spaces that did escalate on RoPax ships during the period 1994-2004, evacuation took place, with one incident of each category having fatalities associated with it.

Risk Calculations

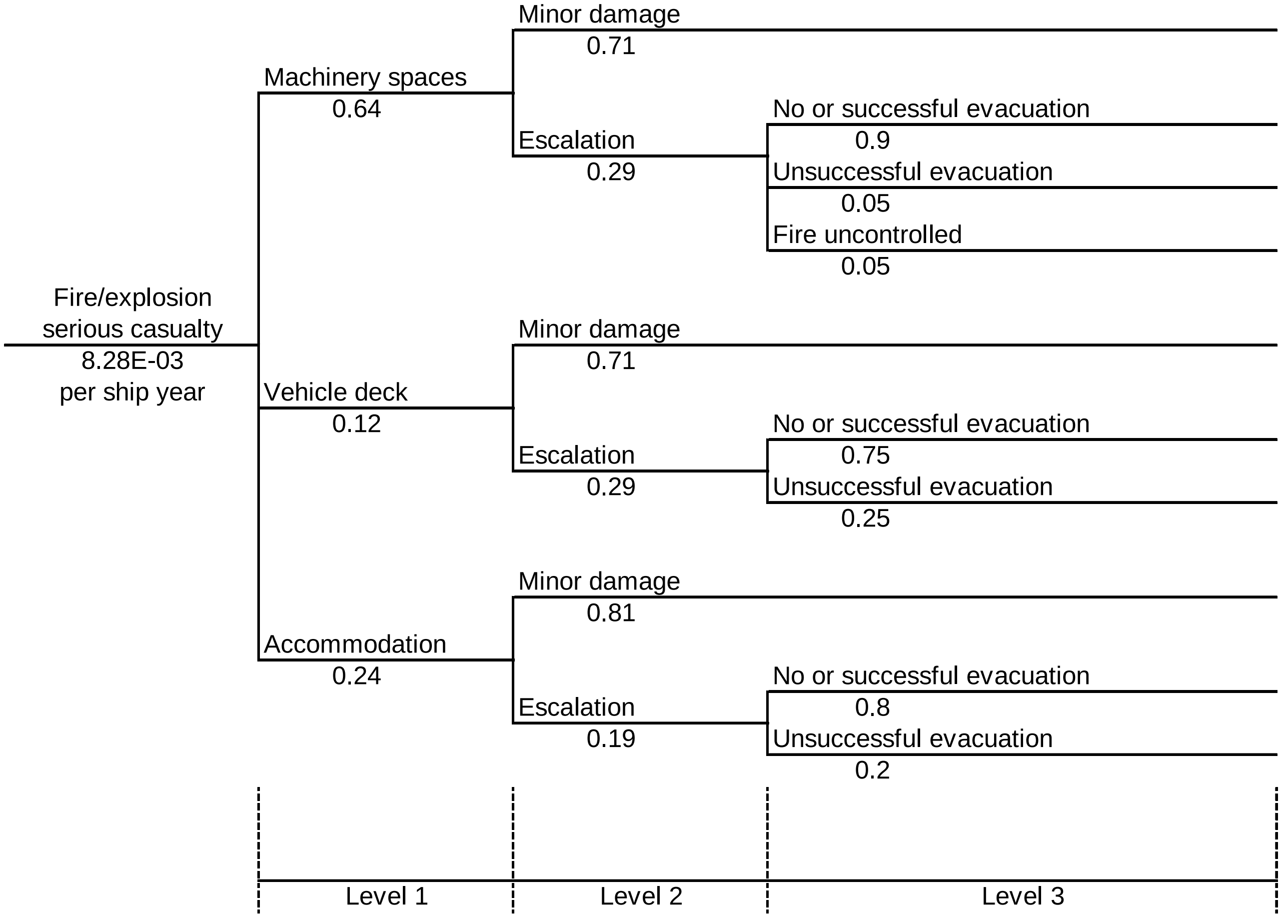
On the basis of the event tree of Figure 14, risk calculations for the outcomes of fires have been carried out, as presented in Table 17.

Number of people at risk is as considered in the assumptions made in section 2.5 of this report, namely:

- Average maximum carrying capacity of 1,000 passengers, traffic seasonality assumed as follows:
    - 25% of trips carrying full passenger load (1,000 passengers)
    - 25% of trips carrying half of maximum passenger load (500 passengers)
    - 50% of trips carrying 75% of maximum passenger load (750 passengers)
- Crew number of 100 is considered as an average.

These calculations are carried out on the assumption of average fatality rates for the different potential scenarios, which have also been used during the North West European project study. For major fire incidents in machinery spaces, a fatality rate of 0.7% is assumed. For major fire incidents on the vehicle deck and in accommodation for which the evacuation was not successful, a fatality rate of 8% is assumed. For the cases of engine room fires that went uncontrolled a fatality rate of 75% is used. Appendix 2 elaborates on the values assumed.

Figure 14: Generic Fire Event Tree



ID Code	Probability per fire	Frequency per ship year
F1.1	0.454400	3.76E-03
F1.2	0.167040	1.38E-03
F1.3	0.009280	7.68E-05
F1.4	0.009280	7.68E-05
F1.2	0.085200	7.05E-04
F2.2	0.026100	2.16E-04
F2.3	0.008700	7.20E-05
F1.3	0.194400	1.61E-03
F3.2	0.036480	3.02E-04
F3.3	0.009120	7.55E-05
	1.000000	8.28E-03

Table 17: Risk Calculations for Fire Outcomes

1,100 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per fire)	PLL (per ship year)
F1.3	Machinery space fire, unsuccessful evacuation	1.92E-05	0.7	1.34E-07	8	1.48E-04
F1.4	Machinery space fire, fire uncontrolled	1.92E-05	75	1.44E-05	825	1.58E-02
F2.3	Vehicle deck fire, unsuccessful evacuation	1.80E-05	8	1.44E-06	88	1.58E-03
F3.3	Accommodation fire, unsuccessful evacuation	1.89E-05	8	1.51E-06	88	1.66E-03
				1.75E-05		1.92E-02

850 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per fire)	PLL (per ship year)
F1.3	Machinery space fire, unsuccessful evacuation	3.84E-05	0.7	2.69E-07	6	2.29E-04
F1.4	Machinery space fire, fire uncontrolled	3.84E-05	75	2.88E-05	638	2.45E-02
F2.3	Vehicle deck fire, unsuccessful evacuation	3.60E-05	8	2.88E-06	68	2.45E-03
F3.3	Accommodation fire, unsuccessful evacuation	3.78E-05	8	3.02E-06	68	2.57E-03
				3.50E-05		2.97E-02

Table 17 (Continued): Risk Calculations for Fire Outcomes

600 people on board

ID Code	Outcome Description	Frequency (per ship year)	Fatality Percentage	Ind. Risk (per year)	Fatalities (per fire)	PLL (per ship year)
F1.3	Machinery space fire, unsuccessful evacuation	1.92E-05	0.7	1.34E-07	4	8.07E-05
F1.4	Machinery space fire, fire uncontrolled	1.92E-05	75	1.44E-05	450	8.64E-03
F2.3	Vehicle deck fire, unsuccessful evacuation	1.80E-05	8	1.44E-06	48	8.64E-04
F3.3	Accommodation fire, unsuccessful evacuation	1.89E-05	8	1.51E-06	48	9.06E-04
				1.75E-05		1.05E-02

6.6 Summary Risk Model Calculations

Table 18 summarises the calculations presented.

Table 18: 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 18. 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 15 presents the F-N curve calculated by the risk model.

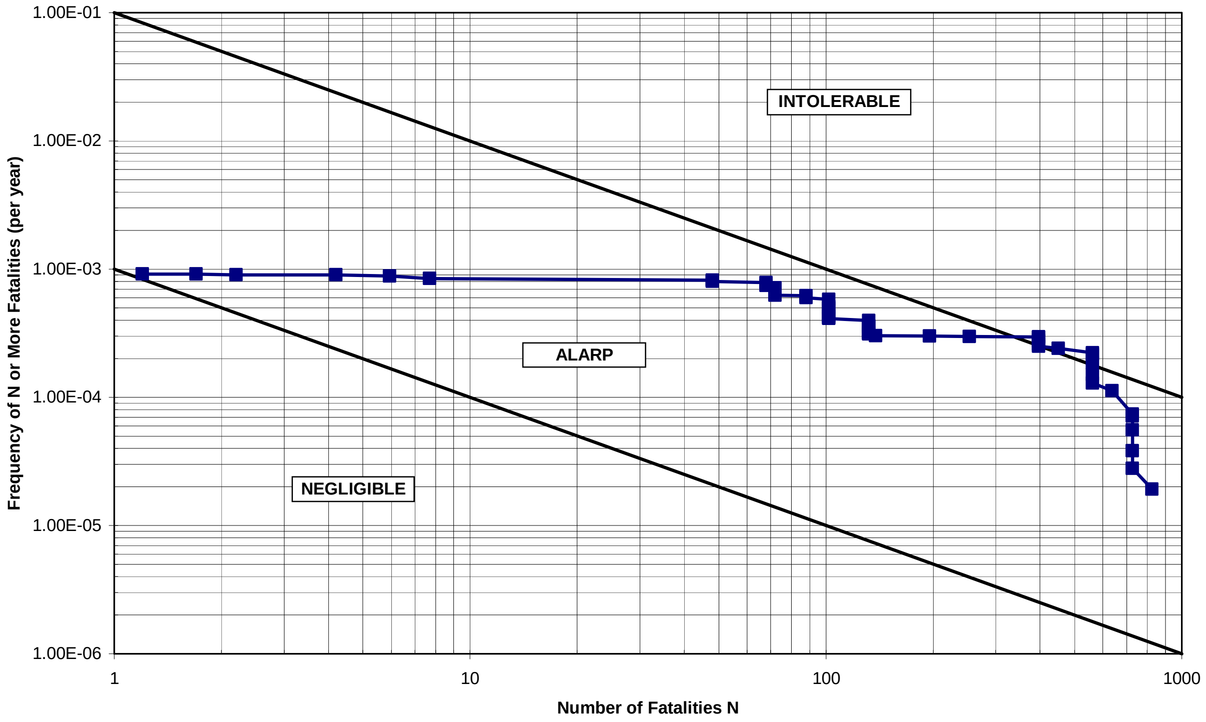


Figure 15: RoPax F-N Curve (Risk Model)

7 Conclusions

The risk analysis for RoPax reported in this document comprises a frequency analysis of world-wide casualty data covering the period 1994-2004, and the presentation of a high-level risk model for RoPax operations, which was developed on the basis of the said frequency analysis and previous studies.

The main conclusions of the study are the following:

- The frequency of *any* collision, grounding, impact, flooding from other causes or fire/explosion incident happening is 4.52E-02 per ship year (1 in 22 ship years; world-wide casualty data, 1994-2004). This breaks down as collision (28%), grounding (21%), impact (28%), flooding from other causes (5%) and fire/explosion (18%).
- The frequency of *a serious* collision, grounding, impact, flooding from other causes or fire/explosion incident happening is 9.50E-03 per ship year (1 in 105 ship years; world-wide casualty data, 1994-2004). This breaks down as collision (14%), grounding (32%), impact (14%), flooding from other causes (6%) and fire/explosion (34%).
- These figures are in general agreement with other published studies, covering periods contemporary to that of this study.
- There is significant reduction in the frequency of incidence occurrence. As an indication, comparison of the data above with data of the North West European Project on the Safety of Passenger RoRo Vessels (period 1978-1994) shows a reduction of **40%** of collision frequency, **52%** on grounding frequency, **74%** on impact frequency, **17%** on fire/ explosion frequency and **57%** on the overall frequency of these events.
- During the period 1994-2004 there have been 14 fatal incidents, resulting in 1,474 fatalities. The corresponding Potential Loss of Life is 9.53E-02 per ship year (approximately 134 fatalities per year). The figure is dominated by incidents involving flooding from other causes (67.5% of fatalities), followed by fire/explosion (25.6%) and grounding (6.4%) incidents.
- 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 (Figure 9 of the report).
- The frequency reductions estimated when comparing with previous periods provides a concise indication that safety has improved for the period 1994 onwards. This can be attributed to the application of contemporary rules and regulations and implementation of robust safety procedures in operating the vessels. However, risks are still high at the ALARP region, indicating more measures need to be taken.
- A high-level risk model is proposed, which includes a number of potential outcomes, considered to represent sufficiently the risk profile of RoPax operations. Section 6 of the report provides the details of the model, its results presented in Table 18 and Figure 15.
- Frequencies for the various accident scenarios considered were derived from accident experience of the period 1994-2004 and where this was not sufficient these predictions were based on previous studies (accident experience from earlier periods, relevant calculations or judgement). However, use of expert judgement was kept to a minimum.

- Risks are found to be high at the ALARP region, indicating the need for further risk control options to be assessed and recommended.
- Uncertainties in using the model refer mainly to the average fatality rates used for the various accident scenarios considered. In this study, these are based solely on past actual experience with RoPax vessels. This has proven inevitable, since no other feasible alternative was available for the wide range of accident scenarios considered.

8 References

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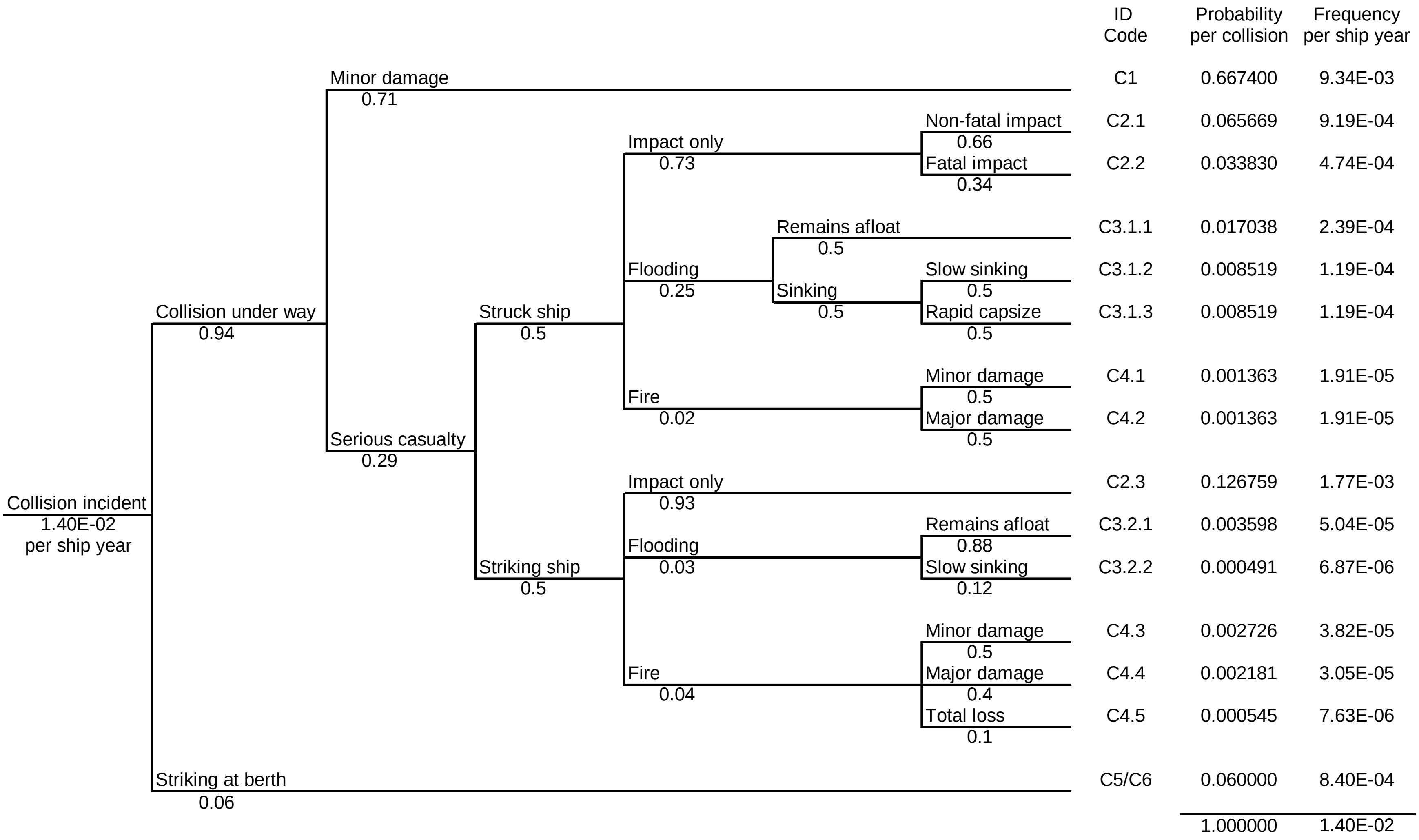
Appendix 1: Joint North West European Project

This appendix contains the generic events trees developed as part of the activities of the safety assessment study for passenger RoRo vessels of the Joint North West European project [3, 4].

The event trees contain potential outcomes of accidents scenarios under the headings of collision, grounding, impact, flooding from other causes and fire/explosion.

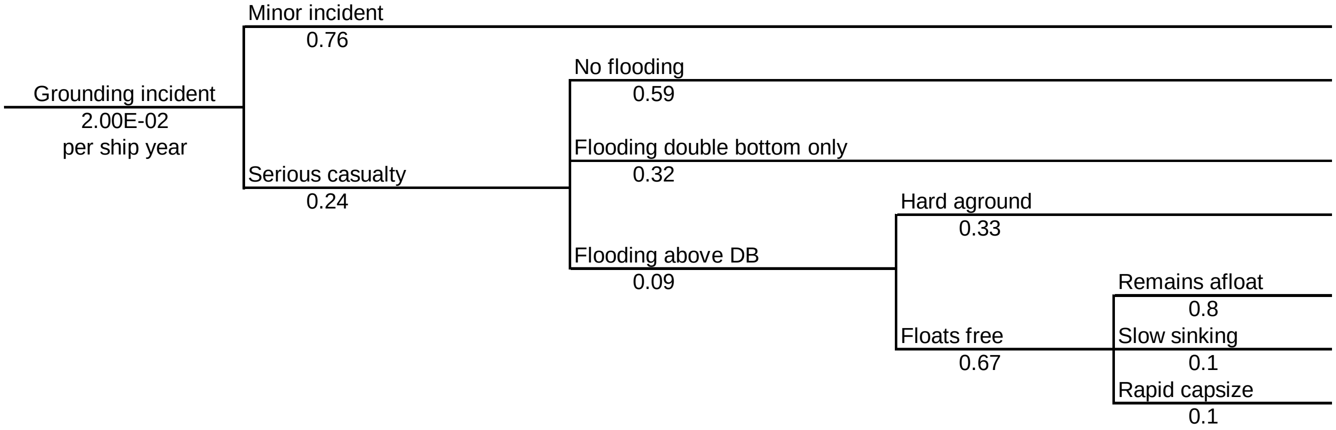
Figure A.1.1: Generic Collision Event Tree (North West Europe Experience, 1978-1994)



ID Code	Probability per collision	Frequency per ship year
C1	0.667400	9.34E-03
C2.1	0.065669	9.19E-04
C2.2	0.033830	4.74E-04
C3.1.1	0.017038	2.39E-04
C3.1.2	0.008519	1.19E-04
C3.1.3	0.008519	1.19E-04
C4.1	0.001363	1.91E-05
C4.2	0.001363	1.91E-05
C2.3	0.126759	1.77E-03
C3.2.1	0.003598	5.04E-05
C3.2.2	0.000491	6.87E-06
C4.3	0.002726	3.82E-05
C4.4	0.002181	3.05E-05
C4.5	0.000545	7.63E-06
C5/C6	0.060000	8.40E-04
	1.000000	1.40E-02

Source: Figure 6.1 of [3]

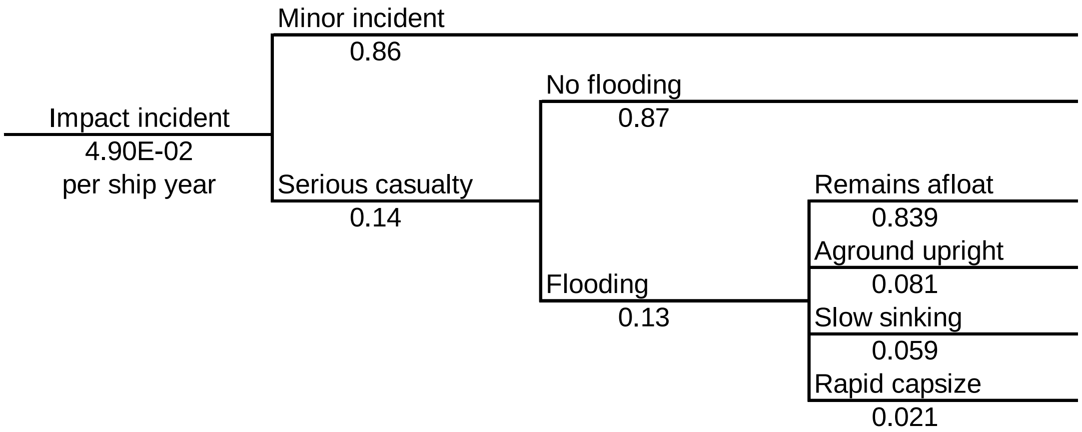
Figure A.1.2: Generic Grounding Event Tree (North West Europe Experience, 1978-1994)



ID Code	Probability per grounding	Frequency per ship year
G1	0.760000	1.52E-02
G1	0.141600	2.83E-03
G2	0.076800	1.54E-03
G3.1	0.007128	1.43E-04
G3.2.1	0.011578	2.32E-04
G3.2.2	0.001447	2.89E-05
G3.2.3	0.001447	2.89E-05
	1.000000	2.00E-02

Source: Figure 6.4 of [3]

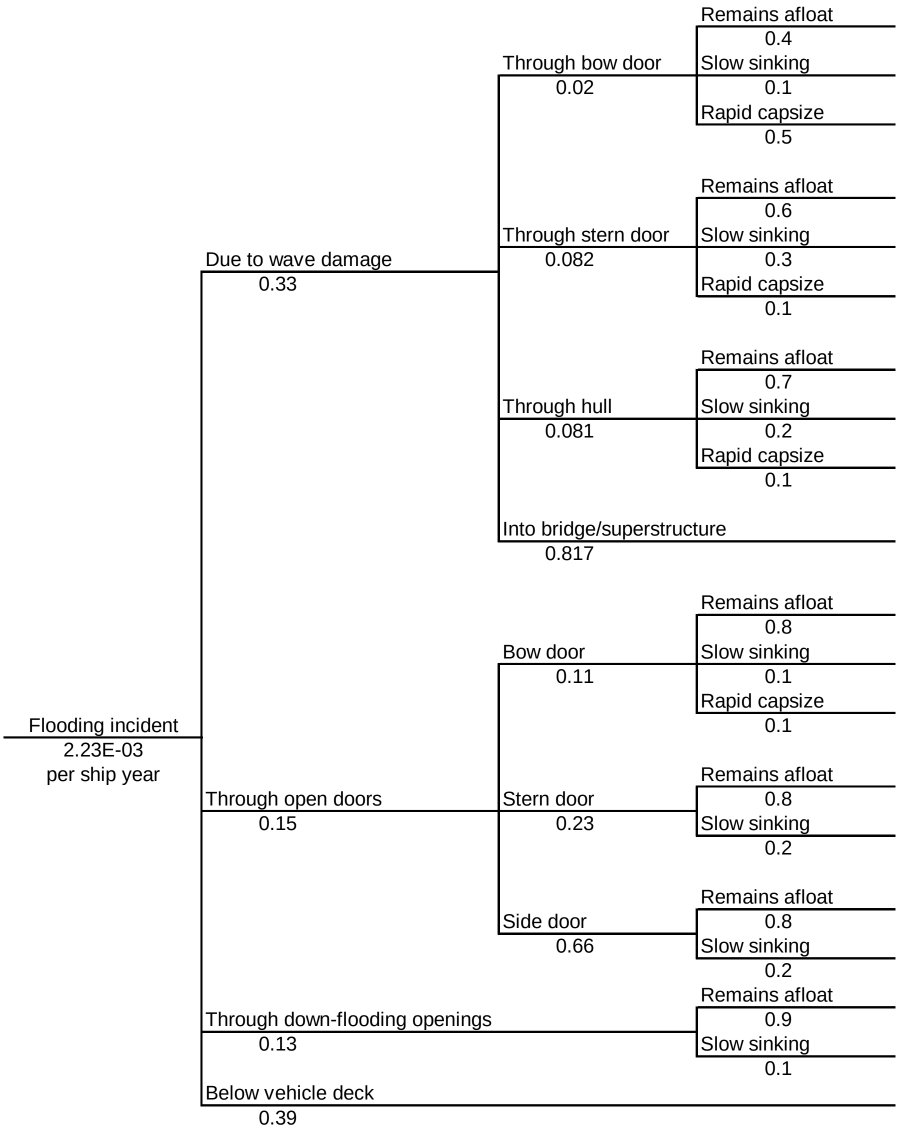
Figure A.1.3: Generic Impact Event Tree (North West Europe Experience, 1978-1994)



ID Code	Probability per impact	Frequency per ship year
M1	0.860000	4.21E-02
M2	0.121800	5.97E-03
M3.1	0.015270	7.48E-04
M3.2	0.001474	7.22E-05
M3.3	0.001074	5.26E-05
M3.4	0.000382	1.87E-05
	1.000000	4.90E-02

Source: Figure 6.5 of [3]

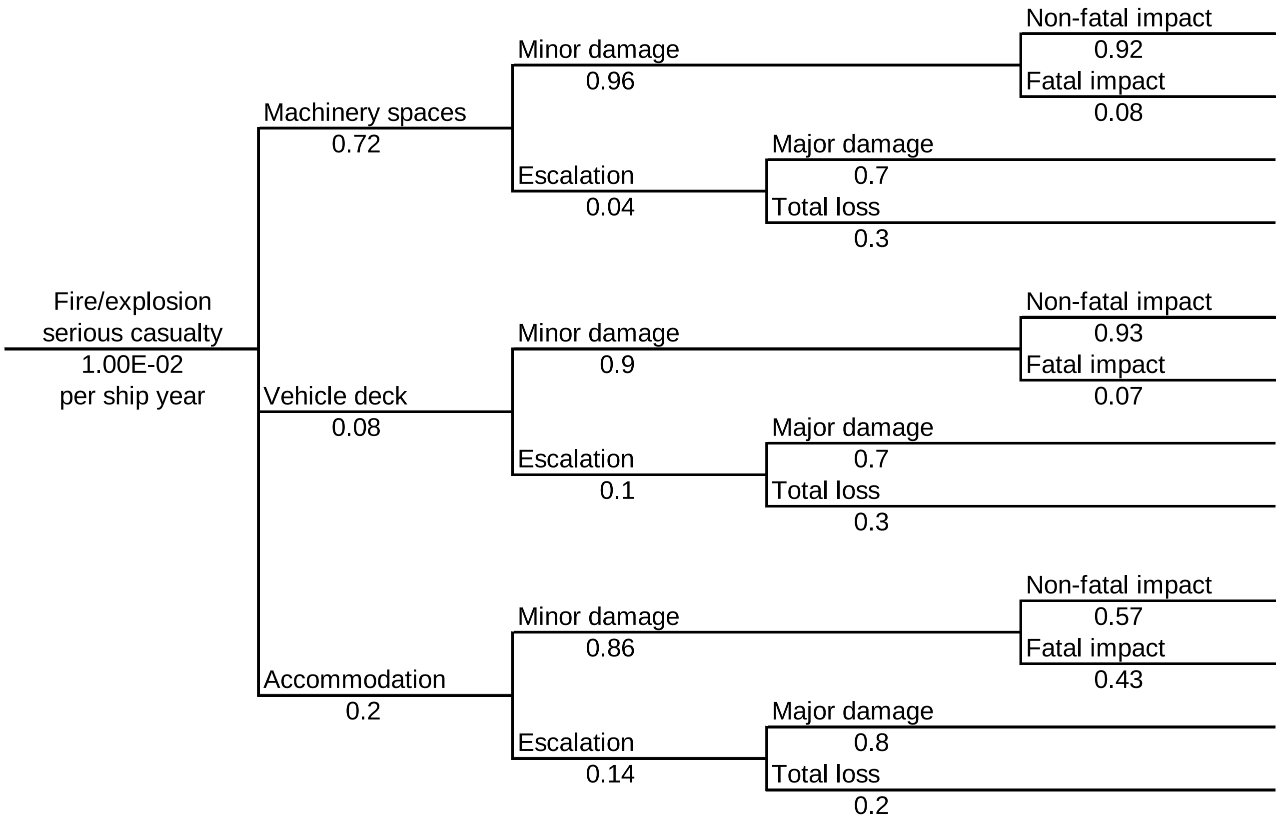
Figure A.1.4: Generic Flooding Event Tree (North West Europe Experience, 1978-1994)



ID Code	Probability per flooding	Frequency per ship year
L1.1.1	0.002640	5.89E-06
L1.1.2	0.000660	1.47E-06
L1.1.3	0.003300	7.36E-06
L1.2.1	0.016236	3.62E-05
L1.2.2	0.008118	1.81E-05
L1.2.3	0.002706	6.03E-06
L1.3.1	0.018711	4.17E-05
L1.3.2	0.005346	1.19E-05
L1.3.3	0.002673	5.96E-06
L1.4	0.269610	6.01E-04
L2.1.1	0.013200	2.94E-05
L2.1.2	0.001650	3.68E-06
L2.1.3	0.001650	3.68E-06
L2.2.1	0.027600	6.15E-05
L2.2.2	0.006900	1.54E-05
L2.3.1	0.079200	1.77E-04
L2.3.2	0.019800	4.42E-05
L3.1	0.117000	2.61E-04
L3.2	0.013000	2.90E-05
L4	0.390000	8.70E-04
	1.000000	2.23E-03

Source: Figure 6.6 of [3]

Figure A.1.5: Generic Fire/Explosion Event Tree (North West Europe Experience, 1978-1994)



ID Code	Probability per fire	Frequency per ship year
F1.1.1	0.635904	6.36E-03
F1.1.2	0.055296	5.53E-04
F1.2	0.020160	2.02E-04
F1.3	0.008640	8.64E-05
F2.1.1	0.066960	6.70E-04
F2.1.2	0.005040	5.04E-05
F2.2	0.005600	5.60E-05
F2.3	0.002400	2.40E-05
F3.1.1	0.098040	9.80E-04
F3.1.2	0.073960	7.40E-04
F3.2	0.022400	2.24E-04
F3.3	0.005600	5.60E-05
	1.000000	1.00E-02

Source: Figure 6.7 of [3]

Appendix 2: Fatality Rates

The fatality rates used in carrying out the risk calculations presented in this report are based on historical data of previous RoPax fatal accidents. Since a fatal RoPax accident is a very rare event, there is high uncertainty on the fatality rates used, however, currently there is no other alternative covering the wide range of accident scenarios this study covers.

For most of the accident scenarios the average fatality rates used in the safety assessment study for RoPax in North West Europe are utilised [3, 4]. These fatality rates had been derived on the basic of world-wide experience with fatal RoPax accident of the period up to 1996.

Table A.2.1 reproduces the fatality rates for all sinking/capsize accidents from [4]. It is noted that fatal incidents that have happened after 1996 (Table 11 of this report) do not significantly alter the fatality rates of Table A.2.1, hence these will be used for the purposes of this study.

Table A.2.1: Fatality Rates in Ferry Sinkings, reproduced from [4]

Vessel	Fatalities	Onboard	% Fatalities	Average % Fatalities
Fast aground/beached				
Hua Lien	0	104+	0	**0**
A Regina	0	213	0	
Slow sinking, shallow water				
Presidente Diaz Ordaz	1	508	0.2	**0.2**
Rapid capsize, shallow water				
European Gateway	6	70	9	**23**
Herald of Free Enterprise	193	539	36	
Slow sinking, deep water, prompt/accurate Mayday				
Skagerak	1	145	1	**2**
Wahine	51	735	7	
Saitobaru	0	238	0	
Zenobia	0	151	0	
Slow sinking, deep water, delayed/inaccurate Mayday				
Princess Victoria	134	172	78	**80**
Jan Heweliusz	52	63	83	
Rapid capsize, deep water				
Heraklion	217	264	82	**72**
Dona Josephina	199	414	48	
Salem Express	464	649	71	
Estonia	852	989	87	

Hence, the following assumptions are made for the average fatality rates to use in the various sinking/capsize scenarios considered in the current study:

- For collision and grounding scenarios we assume a fatality rate of 12% if they lead to slow sinking and a fatality rate of 66% if they lead to rapid capsize. These rates are based on actual experience with incidents happening in shallow water enough to prevent the ship sinking altogether, as reported in [4].

- For impact scenarios we assume a fatality rate of 0.2% if they lead to slow sinking and a fatality rate of 23% if they lead to rapid capsize. This assumption takes into account that impacts may only happen at shallow waters.
- For flooding from other causes scenarios a fatality rate of 12% is assumed for incidents leading to slow sinking and 66% for incidents leading to rapid capsize. These rates are based on actual experience with incidents happening in shallow water enough to prevent the ship sinking altogether, as reported in [4].

Table A.2.2 includes the average fatality rates for fire incidents assumed in [4].

Table A.2.2: Fatality Rates in Ferry Fires, reproduced from [4]

Vessel	Fatalities	Onboard	% Fatalities	Average % Fatalities
Fire on sea around vessel				
Moby Prince	141	142	99	**99**
Fire on vehicle deck				
Tampomas II	431	1,184	36	**36**
Chrissi Avgi	28	42	67	
Sweet Name	27	443	6	
Fire in accommodation				
Farah II	0	?	0	**8**
Scandinavian Star	158	482	33	
New Orient Princess	0	533	0	
Saray Star	0	79	0	
Fire in machinery spaces				
Nissos Rodos	0	158	0	**0.7**
Santa Ana	0	115+	0	
Aldonza Manrique	0	?	0	
Mazatlan	0	355	0	
Al-Qamar Al-Saudi Al-Misri	21	590	4	

The following assumptions are made for the average fatality rates to use in the various fire scenarios considered:

- For major fire incidents in machinery spaces, a fatality rate of 0.7% is assumed. This assumption is consistent with the fact that a fire in machinery spaces only affects limited number of the crew.
- For major fire incidents on the vehicle deck and in accommodation for which the evacuation was not successful, a fatality rate of 8% is assumed. This is based on the same assumption as for major fire incidents following a collision.
- For the cases of engine room fires that went uncontrolled a fatality rate of 75% is used. This is based on experience from two relevant accidents, Dashun and Al Salam Boccaccio 98.

ANNEX II

RISK CONTROL OPTIONS, COST BENEFIT ANALYSIS

AND

RECOMMENDATIONS

ANNEX II – Risk Control Options, Cost-Effectiveness Analysis and Recommendations

Table of Contents

1 Introduction

This document deals with Steps 3 to 5 of the Formal Safety Assessment (FSA) process as described in MSC/Circ.1023 and applied to the existing fleet of RoPax vessels larger than 1,000 GRT. The work utilises the results of Steps 1 and 2 reported in Annexes I and II, respectively.

In Section 2, an overview of the risk analysis results (FSA Step 2) is presented to consolidate the basis risk level. Four high-level Risk Control Options (FSA step 3) are discussed in relation to their risk reduction potential. Section 3 deals with the Cost-Effectiveness Analysis of the evaluated RCOs (FSA Step 4). Section 4 contains some recommendations made on the basis of risk reduction and cost-effectiveness considerations made in the present study for RoPax vessels.

It must be noted that high-level RCOs relate to focus areas where more detailed work should be undertaken; the range of measures that can form a specific RCO is only briefly discussed here, in line with the high-level nature of this FSA; therefore the Recommendations provided should be interpreted accordingly.

1.1 Objective

The objective of this work is to undertake a cost-effectiveness evaluation of the implementation of a series of Risk Control Options (RCOs) in order to improve the safety levels of RoPax ships (of 1,000 GRT and above). The current risk level was estimated with a risk model (event trees), presented in Annex II, and referred subsequently as the risk model. The model utilises worldwide casualty and fleet data for the period between 1994 and 2004. The same risk model is utilised in this report to produce risk reduction estimates after the implementation of the evaluated RCOs.

2 Risk Control Options

In this section, an overview of the risk analysis results (FSA Step 2) is presented with a view to consolidating the basis risk level. This is the basis for the formulation of 4 high-level Risk Control Options (FSA Step 3) and estimation of their associated risk reduction ΔR.

2.1 Overview of Risk Analysis Results

The basis risk level includes 5 accident categories: collisions, grounding (wrecked/stranded), impact (contact), other flooding (hull damage, foundered) and fire/explosions. The risk level is expressed and evaluated in terms of Individual and Societal Risk. The latter is expressed as the Potential Loss of Life (PLL, see Table 1) and illustrated with the FN curve (see Figure 2); generic risk acceptance criteria for RoPax ships, as detailed in Annex II, are used. The presented risk level relates to the following assumptions:

- Average maximum vessel capacity is 1,000 passengers and 100 crew
    - 25% of time, with a level of service of 100% (1,000 pax + 100 crew)
    - 50% of time with a level of service of 75% (750 pax + 100 crew)
    - 25% of time with a level of service of 50% (500 pax + 100 crew)

Table 1: Summary of Risk Analysis Results (Annex II)

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

Considerations made in Annex II indicate that the individual risk experienced by crew members and passengers is as follows:

- 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 3 crews rotate 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 who 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 (7.42 weeks per year at sea), 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).

On the basis of the figures above, it can be concluded that individual risk levels are within the ALARP region for both passenger (10^{-6} and 10^{-4}) and crew members (between 10^{-6} and 10^{-3}). In terms of the societal risk, Figure 1 and Figure 2 illustrate the calculated FN curve (see also PLL values in Table 1).

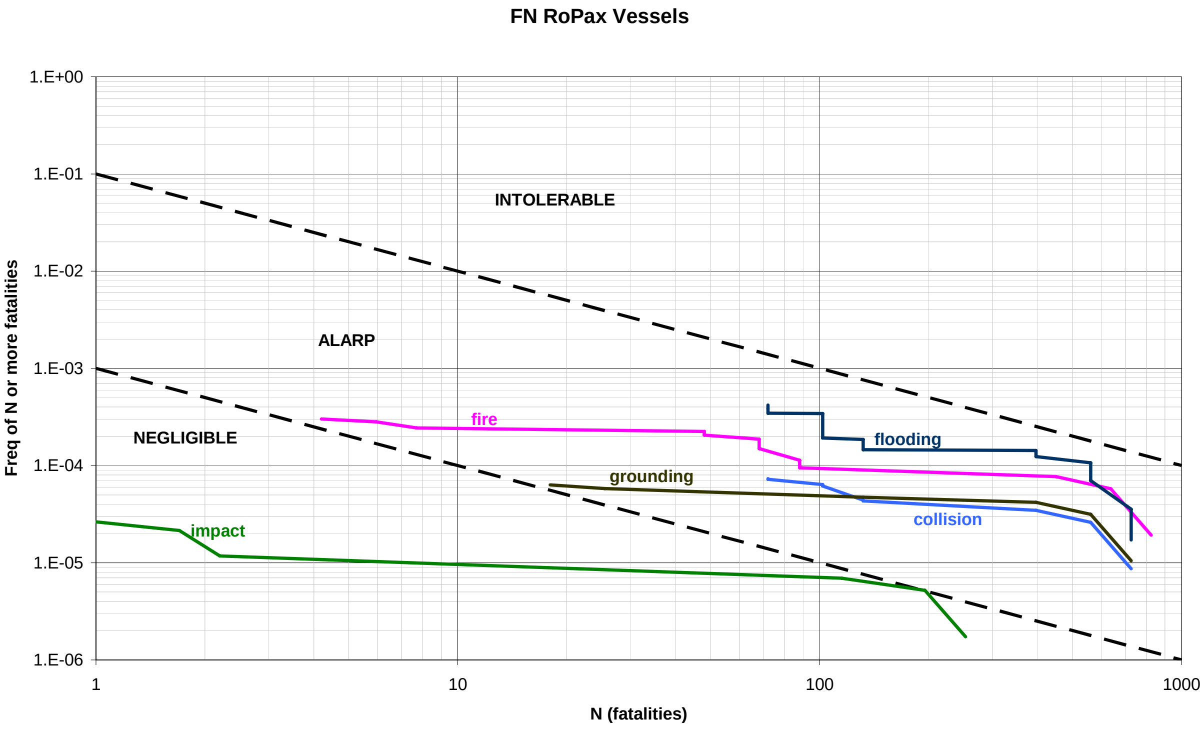


Figure 1: Societal Risk Level – Breakdown into Accident Categories

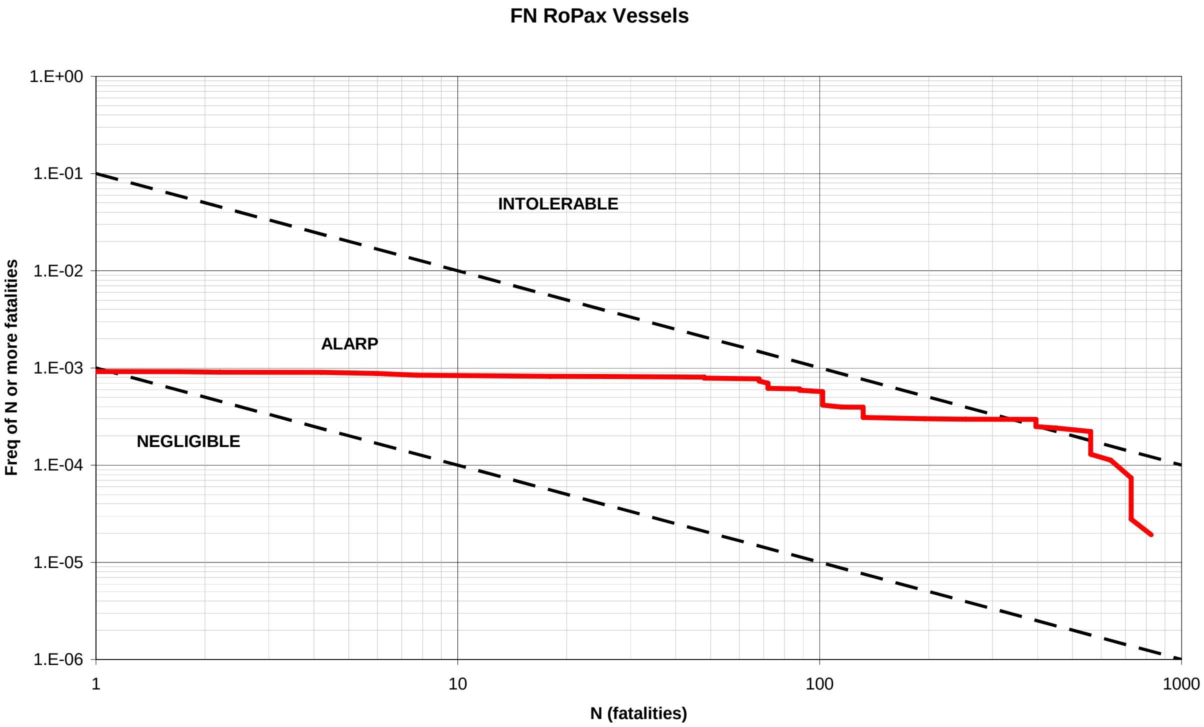


Figure 2: Societal Risk Level – TOTAL

The risk calculations suggest that, for RoPax ships, 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.

A mapping of the critical scenarios implicit in the risk model with known areas of concern for RoPax ships [2] is shown in Table 2. The following 'focus areas' (high-level RCOs) retain relevant and significant risk reduction potential for RoPax ships:

- **RCO1**: *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 ΔR_{max}=**39%**[1].

- **RCO2**: *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 ΔR_{max}=**73%**[2].

- **RCO3**: *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 ΔR_{max}=**27%**[3].

- **RCO4**: *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 ΔR_{max}=**100%**[4] 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.

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[1] $\Delta R = 39\% = 11\% + 12\% + 1\% + 0.32\times50\%$. All collision-, grounding- and impact-, as well as 32% of flooding-related accidents (due to wave damage in bad weather).

[2] $\Delta R = 73\% = 11\% + 12\% + 1\% + 50\%$. All collisions, groundings, impacts, and flooding-related accidents.

[3] $\Delta R = 27\%$. All fire/explosion- related accidents.

[4] $\Delta R = 100 = 11\% + 12\% + 1\% + 50\% + 27\%$. All accident categories.

Table 2: Mapping of Risk Model Critical Scenarios with Areas of Concern (as described in Annex II)

Event	**Id**	**Scenario**	**subdivision**	**cargo access doors**	**intact stability**	**low freeboard**	**cargo stowage**	**fire protection**	**LSA**	**crew**
Collision	C3.1.3	Serious collision, struck ship, flooded, **rapid capsize**	x							x / nav
	C3.1.2	Serious collision, struck ship, flooded, slow sinking	x						x	x / nav
	C3.2.2	Serious collision, striking ship, flooded, slow sinking	x						x	x / nav
Fire	F1.4	Machinery space fire, **fire uncontrolled**						x		x / mainten
Flooding	L1.3.3	Flooding through hull due to wave damage, **rapid capsize**	x							x / nav
	L2.1.3	Flooding through open bow door, **rapid capsize**	x	x						x / operat
	L1.1.3	Flooding through bow door due to wave damage, **rapid capsize**	x	x						x / nav
	L1.1.2	Flooding through bow door due to wave damage, slow sinking	x						x	x / nav
	L1.3.2	Flooding through hull due to wave damage, slow sinking	x						x	x / nav
	L2.1.2	Flooding through open bow door, slow sinking	x	x					x	x / operat
	L2.2.2	Flooding through open stern door, slow sinking	x	x					x	x / operat
	L4.2	Flooding below vehicle deck, slow sinking	x						x	x / systems
	G3.2.3	Grounding, float free, **rapid capsize**	x							x / nav
	G3.2.2	Grounding, float free, slow sinking	x						x	x / nav
Impact	M3.4	Impact, flooding, **rapid capsize**	x							x / nav

2.2 Improved Navigation Safety (RCO1)

This focus area includes better bridge management and improved navigational aids to prevent the incidence of collisions, groundings, impact and general damage in bad weather.

In this respect, RCOs considered in an FSA study on navigational safety for cruise vessels [4] can be considered here for information. The RCOs were selected to address three main hazards (further details can be found in Annex III of [4]):

RCOs to reduce the distraction level for the navigators:
- Onboard Safety and Security Center
- Automatic logging of information
- Two officers on the bridge

RCOs to liberate more time to observations:
- Electronic Chart Display and Information System (ECDIS)
- Automatic Identification System (AIS)
- Track Control

RCOs for improved human performance:
- Improved bridge design
- Improved navigator training
- Implementation of guidelines for Bridge Resource Management (BRM)

RCOs for improved technical performance:
- Navigation system reliability

In the (high-level) risk model presented in Annex II, the frequencies of accidents are directly calculated from statistical casualty data; hence it is not possible to explicitly investigate the impact of navigation-related measures on the resulting risk level. Furthermore, the available risk reduction estimates as published in [4] cannot be used as these relate to a different ship type and exposure profile to that considered in the present study.

In view of the above, it was decided to test the sensitivity of the risk level to different levels of frequencies of the accidents included in the risk analysis, referred to subsequently as the Incidence Rate (IR). The accident incidence rate can be reduced by introducing any or a combination of measures such as those listed above. The maximum risk reduction potential associated with RCO1 is ΔR_{max} = 39% (of the total PLL_{basis}) and relates to the following accidents categories:

- 100% of collisions (underway and at berth)
- 100% of groundings
- 100% of impact
- 32% of flooding (due to wave damage only)

As shown in Table 3, it has been assumed that the total frequency of occurrence (IR) of these four accidents categories can be reduced from 25% up to 100%. These values were introduced in the risk model and the resulting risk level (PLL) was used to estimate the actual risk reduction (ΔR). As can be noted, for example, an assumed reduction of the accident incidence rate of ΔIR=75% results in a reduction of the total PLL value of 29%; the resulting FN curve is illustrated in Figure 3.

Table 3: Risk Reduction from Improved Safety of Navigation (RCO1)

ΔIR % of Frequency	Frequency (per ship year)	Ind Risk (per year)	PLL (per ship year)	Averted fatalities per ship	ΔR % of PLL_{basis}
Frequency (basis)	4.52E-02	2.61E-04	2.22E-01	-	-
25%	3.63E-02	2.34E-04	1.99E-01	0.6	10%
50%	2.75E-02	2.09E-04	1.78E-01	1.3	19%
75%	**1.86E-02**	**1.84E-04**	**1.57E-01**	**1.9**	**29%**
100%	9.81E-03	1.59E-04	1.35E-01	2.6	39%

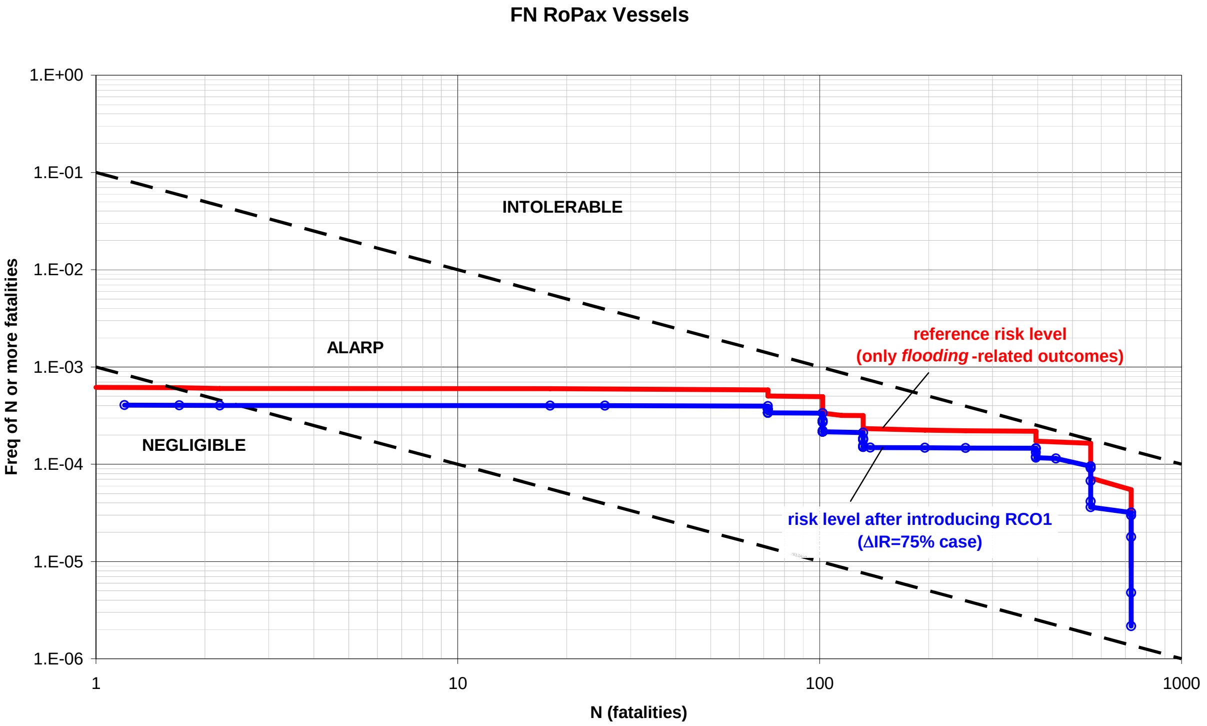

Figure 3: Societal Risk Associated with Navigation Related Outcomes (collision, grounding, impact and flooding accident categories included)

2.3 Improved Survivability to Flooding (RCO2)

Improved damage stability and survivability after flooding to avoid rapid capsize relates to the ability to stay afloat and upright for as long as necessary to allow for recovery of the vessel, safe continuation of the voyage or safe return to port, assistance to the vessel, or ultimately to allow for safe and orderly abandonment of the vessel.

Stability deterioration resulting from hull breach and subsequent flooding to internal compartments, had led in the past to major loss of life on RoPax ships (*MV Estonia, MV Jan Heveliusz, MV El Salam Bocaccio*, among others). Hence damaged ship stability is one of the fundamental areas of safety legislation as it deals with mitigating the consequences of water ingress related flooding.

The capsize mechanism of RoPax ships or any other ships with large un-subdivided horizontal spaces near the damaged waterline is associated with accumulation of water on deck due to wave action (see for instance [7] and [8]). The height of the water gradually increases until either a reasonably stable equilibrium level is reached where inflow is approximately equal to outflow for ships with sufficient reserve stability, or if stability is inadequate, the heeling moment of the water will cause the ship to capsize. On this basis, a number of measures are known to be beneficial for the stability of RoPax ships following water ingress. Among others, the following can be quoted from [8]:

- Fitting of buoyant spaces (additional reserve buoyancy) on the car deck or below the weather deck, as appropriate, along the ship sides. This would increase the GZ_{max} and decrease the heeling level due to water accumulated on deck.

- Use of down-flooding arrangements which counteract the accumulation of water on the vehicle deck, and if properly designed, can largely reduce or even eliminate this phenomenon.

- Application of sheer of the deck and/or trim of the ship to limit the extent of water accumulation on deck by increasing water outflow; this is of importance for midship flooding cases, the most detrimental for residual stability.

For new RoPax designs, the above three measures can be effectively incorporated without greater difficulties, taking the form of a lifebelt around the ship’s sides, leading to designs of unprecedented high levels of survivability [9]. A good illustration of the above measures on a RoPax design can be found in [10] where, the vessel was conceived with the philosophy of the ship functioning as “its own lifeboat”. Among the measures introduced in this design, efficient cross-flooding arrangements (for achieving symmetric flooding and avoiding excessive heel) as well as enclosed watertight side casings for providing reserve buoyancy up to the first accommodation deck, can be accounted for.

Essentially, there are several minor and major measures and combination thereof that can lead to high levels of stability in damage conditions. A non-exhaustive list of such design measures is included in the Appendix. Their effectiveness and hence their associated risk reduction potential would certainly vary even significantly from case to case as their success depend on many factors including among other, the design of the vessel, the functionality and performance requirements, and last but not least, the "talent" and ability of the designer.

As the results of risk analysis suggest, **rapid capsize** – as a consequence of various accident categories leading to various extents of flooding, is the main contributor to ship losses and the cause of a large number of fatalities. In this sense, during the concept design stages of a new ship project, in addition to 'conventional' (static stability) design methods for quantifying damage stability, the issue of verification of the survival time in cases of flooding would help to improve the survivability performance of the ship.

In relation to the above and for the purpose of the cost-effectiveness study, two high-level RCOs have been considered, leaving to the various specific measures and possibilities associated with them, open to the design case:

- RCO2a: relates to measures aimed at improving damage stability in a statutory sense only. The effectiveness of different measures is quantified on the basis of 'conventional' methods i.e. static stability calculations and it is expressed with the probabilistic Attained Index of Subdivision A. The explicit issue of the survival time is not directly addressed in Index A calculations, although the implicit ***s*** factor formulation encodes implicitly information on sea state as well as the time the vessel is expected to survive in specific damage conditions. It is expected that this RCO would lead to moderate increases of Index A , and that the associated costs are not major or significant.

- RCO2b: relates to improved damage stability as above, but the issue of the survival time is also directly and explicitly addressed with a performance-based approach (model tests and/or numerical simulations). This will ensure that the problem of ***rapid capsize*** is addressed for all possible flooding scenarios and it is not limited to collision damages. It is assumed that this RCO would lead to moderate increases of Index A and that in addition, its implementation would also lead to reduce the probability of rapid capsize (as opposed to slow sinking) in those situations in which the vessel "does not remain afloat". This RCO is meant to achieve high levels of survivability in line with the concept of "casualty threshold" and safe return to port [14] therefore the marginal costs associated with RCO2b are expected to be much higher than with RCO2a.

The risk reduction potential of all measures associated with improved damage stability and survival time, can be evaluated by assessing the impact of all related measures on the branch probabilities of the event trees constituting the (high-level) risk model. Accordingly, the maximum risk reduction potential associated with RCO2 is ΔR_{max} = 73% (of total PLL_{basis}) and relates to the following accidents categories:

- 100% of collisions (underway and at berth)
- 100% of groundings
- 100% of impact
- 100% of flooding

2.3.1 RCO2a (improved capability to “stay afloat”)

All possibilities and specific design solutions associated with implementing RCO2a would lead to varying degrees of improved stability after flooding. This increased level can be quantified in terms of Index A (as defined in the newly adopted SOLAS 2009 Chapter II-1 regulations), and the improvements would positively impact the probability of “staying afloat” in all ***collision*** and ***flooding*** events defined in the risk model.

The Required Index of Subdivision R for the representative RoPax vessel adopted in this study (see Section 3.1) is equal to R=0.735 and is a function of the subdivision length (L_s) and the number of persons the vessel is certified to carry. In the risk model, an Index A of 0.78 (average value of a sample of 38 RoPax vessels) has been used for the calculation of the basis risk. Since A>R, then the vessel complies with the probabilistic rules, and the same value of Index A is adopted here for consistency.

According to the concept behind the probabilistic framework, if a ship attains an Index A value of 0.78, it can be interpreted as meaning that in 78% of all potential collisions resulting in water ingress and flooding, the survival time would – theoretically at least – be 30 minutes[5] or more. This also means that the remaining 22% of the collisions, the time would be less than 30 minutes!

For a given damage case, the s factor formulation is assumed to reflect the percentage of cases the ship would survive for at least 30 minutes. Accordingly, if s=1.0, the mean survival time would tend to infinity, this is assuming of course that the current s factor formulation reflects appropriately the conditional probability that the ship will not capsize in a given critical sea state (further details can be found in [8]). In this respect, note the following comments with respect to the current ***s*** factor formulation as adopted in the SOLAS 2009 rules:

- The positive impact of many design measures to improve damage stability may not be reflected in the resulting Index A value (for more details see [12]).
- Recent studies [13] suggest that the ***s*** factor formulation eventually adopted in the SOLAS 2009 rules is based on a regression of data corresponding to conventional cargo ships, which would tend to overestimate (not conservative!) the probability of survival of RoPax (low freeboard) ships.

Consequently, it is not known with certainty whether the *s* factor formulation adequately reflects the true damage stability and the level of survivability of passengers ships, in particular of RoPax vessels.

Notwithstanding the above, for the purpose of this study, it can be assumed that Index A is a measure of damage stability and as such, any design measure introduced to increase Index A value, would lead to a higher probability of “staying afloat”. Thus, a systematic increase from A=0.78 (the basis level) up to A=0.99 is considered for estimating the range of risk reduction implied by implementing RCO2a. The impact on the specific branches of the event tree (ET, the risk model) is as indicated in Table 4. The results of sensitivity of the risk level to different

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[5] Duration of model tests on the basis of which the s factor formulation was derived [7]

values of Index A, (i.e. to different levels of success in the implementation of these measures) are presented in Table 5.

As can be noted, for example, if the vessel attains an Index A of 0.90, the resulting reduction of the total Potential Loss of Life (ΔR) is estimated at 44%; the breakdown into the considered accident categories is shown in Table 6 for the A=0.90 case. The resulting FN curve is illustrated in Figure 4. In the extreme case of A=0.99 the level of risk reduction of the total PLL in relation to the basis case can be as much as ΔR =63%.

Table 4: Impact of RCO2a (Index A=0.90 Case) on the Risk Model

Accident Category	**ET level 3**	**ET branch probability**		**change**
		basis	**new**	
Collision	Under way/serious/struck ship/flooding/remains afloat	0.78	0.9	15%
Grounding	Serious/flood above DB/floats free/remains afloat	0.75	0.9	20%
Impact	Serious/flooding/remains afloat	0.839	0.9	7%
Flooding	Wave damage/bow door/remains afloat	0.4	0.9	125%
	Wave damage/stern door/remains afloat	0.6	0.9	50%
	Wave damage/hull/remains afloat	0.7	0.9	29%
	Open doors/bow/remains afloat	0.8	0.9	13%
	Open doors/stern/remains afloat	0.8	0.9	13%
	Below car deck/remains afloat	0.9	0.9	0%

Table 5: Risk Reduction from Improved Damage Stability (RCO2a)

Index A		**Total Ind. Risk (per year)**	**Total PLL (per ship year)**	**averted fatalities per ship**	**Total ΔR % of PLL**
0.78	basis	2.61E-04	2.22E-01	-	
0.80	3%	2.01E-04	1.71E-01	1.5	23%
0.85	9%	1.73E-04	1.47E-01	2.2	33%
0.90	**15%**	**1.46E-04**	**1.24E-01**	**2.9**	**44%**
0.95	22%	1.18E-04	1.00E-01	3.6	55%
0.99	28%	9.55E-05	8.12E-02	4.2	63%

Table 6: Risk Reduction Breakdown after Improving Damage Stability (RCO2a - Index A=0.90 Case)

RCO2a A=0.90	**Frequency (per ship year)**	**Ind. Risk (per year)**	**PLL (per ship year)**	**ΔPLL (%)**
Collision	1.25E-02	1.27E-05	1.08E-02	54%
Grounding	9.57E-03	1.15E-05	9.82E-03	60%
Impact	1.25E-02	1.01E-06	8.62E-04	38%
Flooding	2.39E-03	5.04E-05	4.28E-02	62%
Fire	8.28E-03	7.00E-05	5.95E-02	0%
TOTAL	**4.52E-02**	**1.46E-04**	**1.24E-01**	**44%**

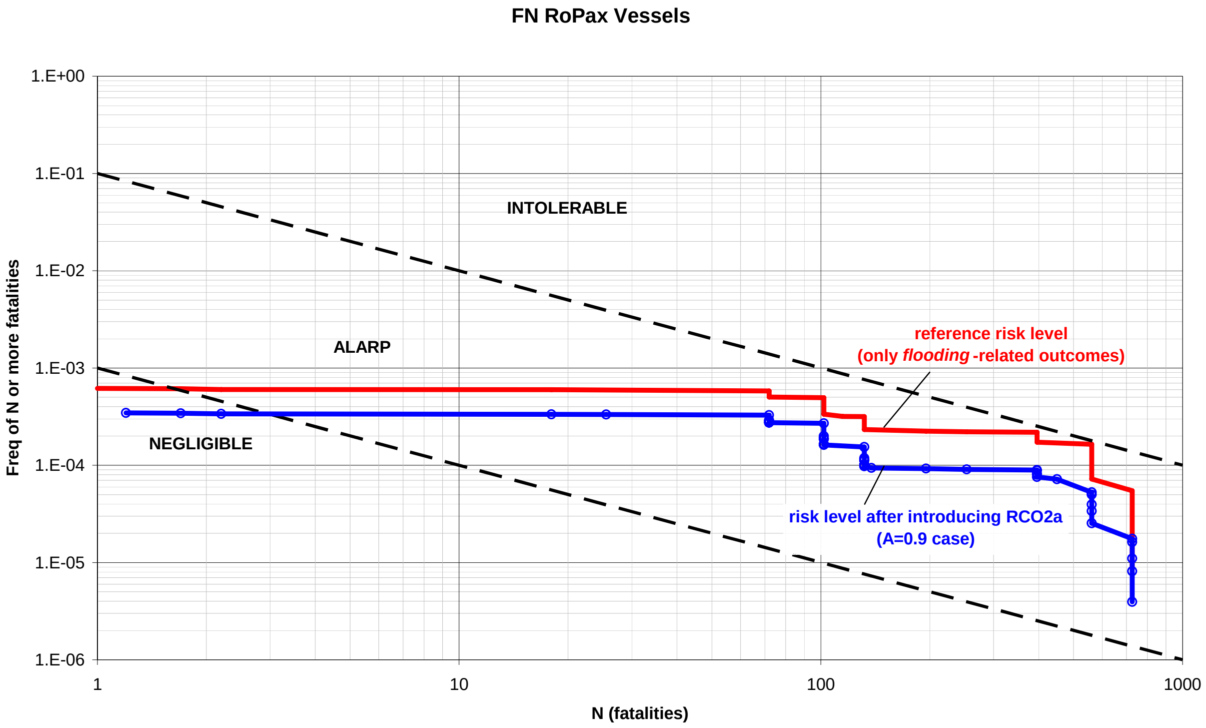

Figure 4: Societal Risk Associated with Flooding-Related Outcomes (collision, grounding, impact and flooding accident categories included)

2.3.2 RCO2b (improved capability to "stay afloat longer")

This RCO assumes that all measures implemented are much more effective in achieving the design goal of "stay afloat for longer"; it is expected that more effective measures can be designed if in addition to 'conventional' design verification methods based on static stability, state-of-the-art performance-based methods (numerical simulations) are utilised at early design stages for verification and systematic improvement of survivability performance not only for collision-related damages, but for a range of representative scenarios related to groundings, impact and other flooding scenarios. Modern performance-based methods are used for verification of structural strength, hull resistance, aerodynamic performance, evacuation, etc. There is no reason why in the 21st century, modern survivability analyses should not be utilised to design and verify one of the key safety ship design goals: "stay upright and afloat" for as long as necessary to recover the ship or eventually to allow for safe abandonment.

Obviously, the impact on survivability can also be expressed in terms of Index A, which is likely to be higher than that achieved in RCO2a, as there will be more cases for which the s factor is unity, hence survival time would tend to infinity. In addition to this, for all cases where the ship does not remain afloat, the proportion of 'slow sinking' to 'rapid capsize' is assumed also equal to the expected probability of survival (Index A). In this RCO the confidence in the "adequateness" of the s factor formulation implicit in Index A calculations is high.

The results of sensitivity of the risk level to different values of Index A, (i.e. to different levels of success in the implementation of these measures) are illustrated in Table 8. As can be noted, for example, if the vessel attains an Index A of 0.95, the resulting reduction of the total Potential Loss of Life (ΔR) is estimated at 62%; the breakdown into the considered accident categories is shown in Table 9 for the A=0.95 case. The resulting FN curve is illustrated in Figure 5.

Table 7: Impact of RCO2b (Index A=0.95 Case) on the Risk Model

Accident Category	ET level 3	ET branch probability		change
		basis	new	
Collision	Under way/serious/struck ship/flooding/remains afloat	0.78	0.95	22%
	Under way/serious/struck ship/flooding/sinking/slow sinking	0.5	0.95	90%
	/striking ship/flooding/remains afloat	0.88	0.95	8%
Grounding	Serious/flood above DB/floats free/remains afloat	0.75	0.95	27%
	/slow sinking	0.085	0.048	
Impact	Serious/flooding/remains afloat	0.839	0.95	13%
	/sinking	0.059	0.024	
Flooding	Wave damage/bow door/remains afloat	0.4	0.95	128%
	/slow sinking	0.1	0.05	
	Wave damage/stern door/remains afloat	0.6	0.95	58%
	/slow sinking	0.3	0.05	
	Wave damage/hull/remains afloat	0.7	0.95	36%
	/slow sinking	0.2	0.05	
	Open doors/bow/remains afloat	0.8	0.95	19%
	/slow sinking	0.1	0.05	
	Open doors/stern/remains afloat	0.8	0.95	19%
	Below car deck/remains afloat	0.9	0.95	6%

Table 8: Risk Reduction from Improved Damage Survivability (RCO2b)

Index A		Total Ind. Risk (per year)	Total PLL (per ship year)	Averted fatalities per ship	Total ΔR % of PLL
0.78	basis	2.61E-04	2.22E-01	-	
0.80	3%	1.54E-04	1.31E-01	2.7	40%
0.85	9%	1.32E-04	1.12E-01	3.2	49%
0.90	15%	1.14E-04	9.68E-02	3.7	56%
0.95	**22%**	**9.95E-05**	**8.47E-02**	**4.1**	**62%**
0.99	28%	9.12E-05	7.75E-02	4.3	65%

Table 9: Risk Reduction Breakdown after Improving Damage Survivability (RCO2b - Index A=0.95 Case)

RCO 2b A=0.95	Frequency (per ship year)	Ind Risk (per year)	PLL (per ship year)	ΔPLL (%)
Collision	1.25E-02	2.50E-06	2.13E-03	91%
Grounding	9.57E-03	1.05E-06	9.61E-04	96%
Impact	1.25E-02	1.10E-07	9.34E-05	93%
Flooding	2.39E-03	2.59E-05	2.20E-02	80%
Fire	8.28E-03	7.00E-05	5.95E-02	0%
TOTAL	**4.52E-02**	**9.95E-05**	**8.47E-02**	**62%**

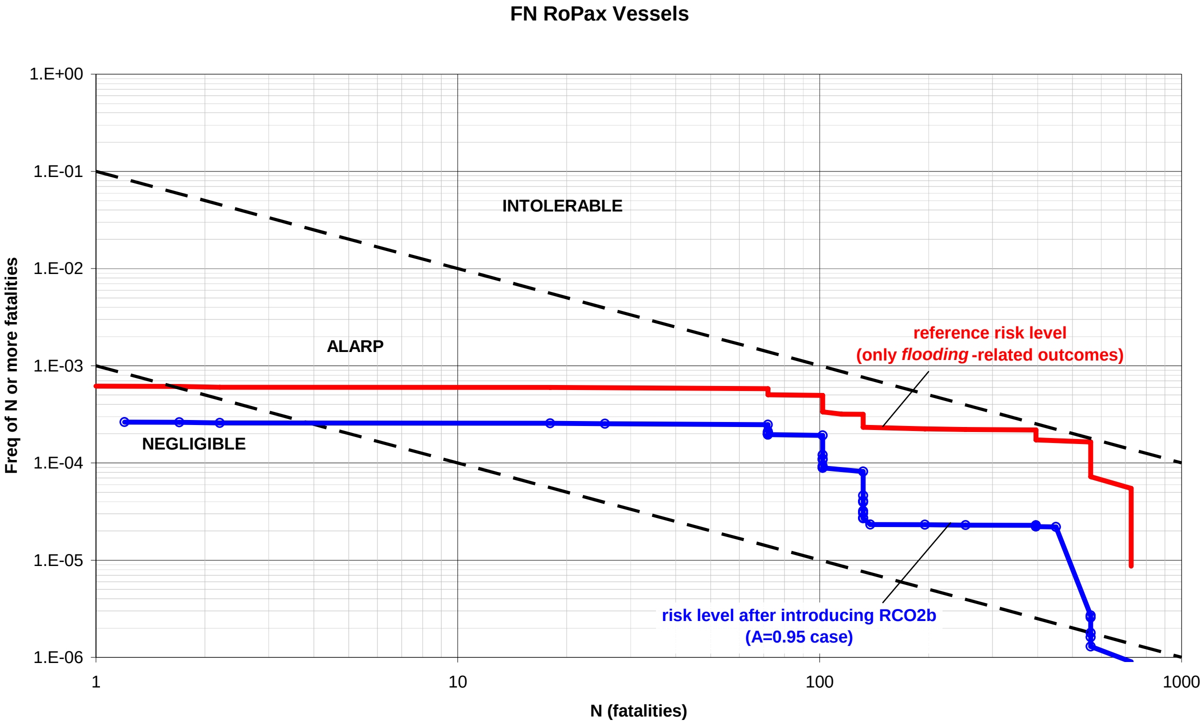

Figure 5: Societal Risk Associated with Flooding-Related Outcomes (collision, grounding, impact and flooding accident categories included)

2.4 Increased Survivability to Fire (RCO3)

Improved survivability to fire/explosion events relates to measures aimed at preventing <u>fire ignition</u> and protection of spaces to avoid <u>fire escalation</u> in case of fire. Based on historical casualty experience, for RoPax ships this should be mainly related to machinery, car deck and accommodation spaces, listed in order of priority.

Based on the results of the risk analysis, and the historical casualty experience with fires on RoPax ships, the following high-level RCOs can be considered:

- <u>RCO3.1</u>: This RCO relates to measures aimed at preventing fire ignition. These may be related to better operational procedures such as enhanced crew training, fire patrols, segregation of DG cargoes, etc. It can also be related to better materials (increase of fire ignition temperatures, fire growth potential, etc).

- <u>RCO3.2</u>: This RCO relates to measures aimed at improving fire suppression capabilities in machinery spaces. These may be related to measures such as water mist technology, CCTV monitoring, etc.

- <u>RCO3.3</u>: This RCO relates to measures aimed at improving fire suppression capabilities in car deck spaces. Reference is made to FP 51/3/2 and [19].

- RCO3.4: This RCO relates to measures aimed at improving fire suppression capabilities in accommodation spaces. These may be related to measures such as water mist technology, fire retardant materials, smoke extraction rates, CCTV monitoring, etc.

The maximum risk reduction potential associated with RCO3 is ΔR_{max} = 27% (of total PLL_{basis}). Risk Reduction considerations are made next.

2.4.1 RCO3.1 (improved fire prevention)

In the (high-level) risk model presented in Annex II, the frequencies of accidents are directly calculated from statistical casualty data; hence it is not possible to explicitly investigate the impact of specific fire prevention-related measures on the resulting risk level. Therefore, it was decided to test the sensitivity of the risk level to different levels of frequency of fire accidents (fire Incidence Rate, IR_{fire}). As can be seen in Table 10, a reduction in the overall frequency of fire/explosions would lead to a risk level reduction of 13%.

Table 10: Risk Reduction after Implementation of RCO3.1

ΔIR_{fire}	Frequency (per ship year)	Total Ind. Risk (per year)	Total PLL (per ship year)	Averted Fatalities per ship	Total ΔR (% of PLL_{basis})
0%	4.51E-02	2.61E-04	2.22E-01	-	-
5%	4.47E-02	2.56E-04	2.18E-01	0.1	1%
10%	4.43E-02	2.52E-04	2.15E-01	0.2	3%
20%	4.34E-02	2.45E-04	2.09E-01	0.4	5%
50%	**4.10E-02**	**2.24E-04**	**1.91E-01**	**0.9**	**13%**

2.4.2 RCO3.2 (improved fire suppression on machinery spaces)

Sensitivity of risk level (PLL) to variations in the probability of fire escalation in any of the machinery spaces is shown in Table 11.

Table 11: Risk Reduction after Implementation of RCO3.2

P(fire escalation |machinery spaces)	ΔP	Total Ind. Risk (per year)	Total PLL (per ship year)	Averted fatalities per ship	Total ΔR (% of PLL_{basis})
0.29	-	2.61E-04	2.22E-01	-	-
0.20	31%	2.41E-04	2.05E-01	0.5	7%
0.10	**66%**	**2.21E-04**	**1.88E-01**	**1.0**	**15%**
0.01	97%	2.03E-04	1.73E-01	1.4	22%

2.4.3 RCO3.3 (Improved fire suppression on vehicles decks spaces)

In this respect, a recent study commissioned by the UK MCA [19], concludes that “the combustible loading of vehicles on RoPax covered vehicle decks, in the event of fire, have the definite potential to exceed the suppression and control capabilities of suppression systems installed in accordance with IMO resolution A.123(V)”. The same report concludes further that existing evidence indicates that the same may be the case with systems installed in accordance with MSC/Circ.914. Among the recommendations, the study commissioned by MCA recommends further experimental research into vehicle deck fuel loading and the potential benefits of water mist (and other water-based systems).

Sensitivity of risk level (PLL) to variations in the probability of fire escalation in any of the machinery spaces is shown in Table 12. As can be seen, and in the light of the outcome of the study referred to above [19], the risk reduction potential is not significant at least in relation to machinery spaces. This however reflects the historical experience showing that only 12% of fires are originated in the car deck as opposed to 64% in machinery spaces; also in relation to risk to human life, this may not be the most critical, but it may be as critical in terms of property damage.

Table 12: Risk Reduction after Implementation of RCO3.3

P(fire escalation |vehicle spaces)	**ΔP**	**Total Ind. Risk (per year)**	**Total PLL (per ship year)**	**Averted fatalities per ship**	**Total ΔR (% of PLL_{basis})**
0.29	-	2.61E-04	2.22E-01	-	-
0.20	31%	2.57E-04	2.19E-01	0.0	1%
0.10	**66%**	**2.55E-04**	**2.17E-01**	**0.1**	**1%**
0.01	97%	2.54E-04	2.16E-01	0.1	2%

2.4.4 RCO3.4 (improved fire suppression on accommodation spaces)

Sensitivity of risk level (PLL) to variations in the probability of fire escalation in any of the accommodation spaces is shown in Table 13.

Table 13: Risk Reduction after Implementation of RCO3.4

P(fire escalation |accommodation)	**ΔP**	**Total Ind. Risk (per year)**	**Total PLL (per ship year)**	**Averted fatalities per ship**	**Total ΔR (% of PLL_{basis})**
0.19		2.61E-04	2.22E-01	-	
0.10	**47%**	**2.56E-04**	**2.18E-01**	**0.1**	**1%**
0.05	74%	2.55E-04	2.17E-01	0.1	2%
0.01	95%	2.54E-04	2.16E-01	0.1	2%

The impact of implementing RCO3.2-3.4 simultaneously (probability of fire escalation is assumed to be 10%, given a fire ignition event in any space aboard the ship) on the risk level is illustrated in Table 14 and Figure 6.

Table 14: Risk Reduction Breakdown after Introducing RCO3.2-3.4 Probability (Escalation|fire) = 10%

RCO 3.2-3.4 P(Escalation|fire)=0.10	Frequency (per ship year)	Ind Risk (per year)	PLL (per ship year)	ΔPLL (%)
Collision	1.25E-02	2.75E-05	2.34E-02	0%
Grounding	9.57E-03	3.02E-05	2.57E-02	0%
Impact	1.25E-02	1.63E-06	1.39E-03	0%
Flooding	2.25E-03	1.31E-04	1.12E-01	0%
Fire	8.28E-03	2.52E-05	2.14E-02	64%
TOTAL	**4.52E-02**	**2.14E-04**	**1.82E-01**	**17%**

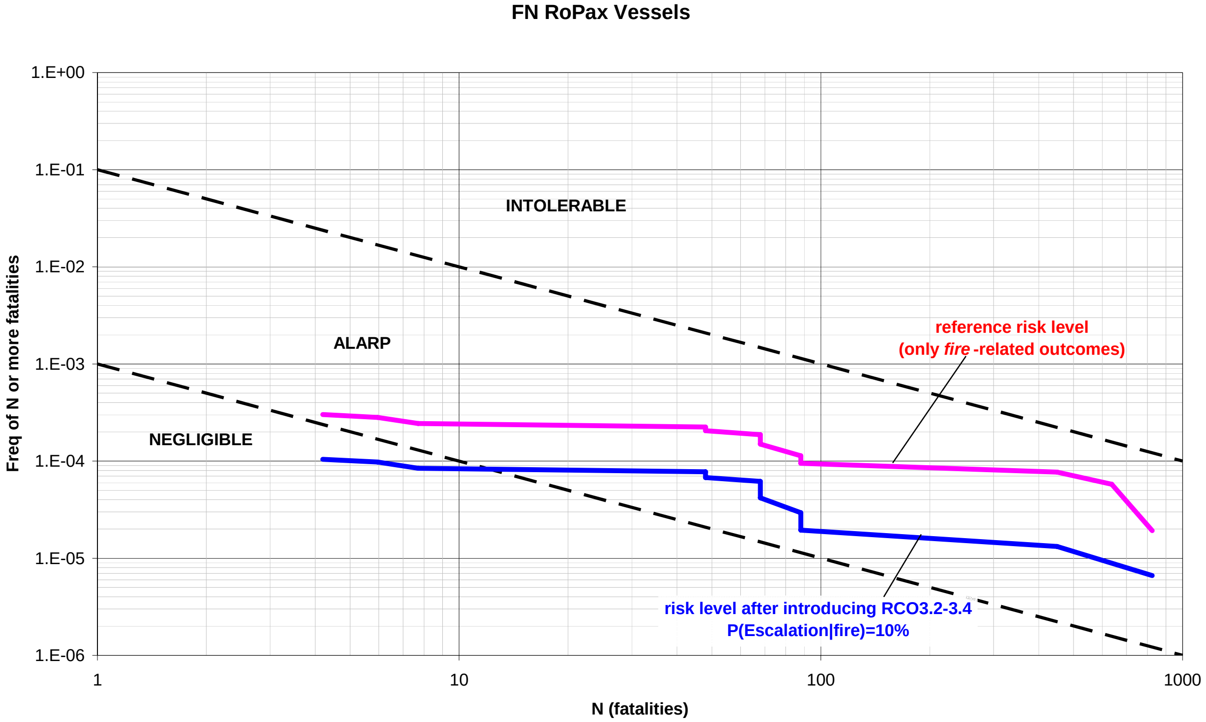

Figure 6: Societal Risk Level Associated with Fire-Related Outcomes

2.5 Improved evacuation arrangements (RCO4)

This RCO relates to all possible measures aimed at improving the abandonment success rate following any of the accident categories evaluated in the risk model, as indicated in Table 15 where, a reduction in the fatality rate FR of 50% is illustrated.

For water-ingress related events, such measures would be aimed at achieving low FR in all scenarios where there is "enough time" to abandon the vessel should the vessel needs to be abandoned. In this context, "enough time" refers to sufficient time for safely and orderly abandonment of the vessel. According to preliminary calculations provided in [19], a RoPax ferry with 1,000 passengers onboard could be evacuated within 60 minutes, the current IMO criterion for this size of vessel and the assumed survival time (vessel upright and afloat).

Table 15: Impact of RCO4 on Risk Model (ΔFatality rate=75%)

Accident Category	**ET scenario**	**ET branch probability**		**Change ΔFR**
		basis	**new**	
fire	Machinery/unsuccessful evacuation/fatality rate	0.7	**0.2**	75%
	Machinery/fire uncontrolled/fatality rate	75	**18.75**	75%
	Vehicle deck/unsuccessful evacuation/fatality rate	8	**2**	75%
	Accommodation/unsuccessful evacuation/fatality rate	8	**2**	75%
collision	Slow sinking/fatality rate	12	**3**	75%
grounding	Slow sinking / fatality rate	3	**0.75**	75%
impact	Slow sinking / fatality rate	0.2	**0.05**	75%
flooding	Slow sinking / fatality rate	12	**3**	75%

The sensitivity of risk level to fatality rate has been tested as indicated in Table 16. The societal risk is illustrated in Figure 7 for the case where the fatality rate is assumed to be reduced by 75% (risk reduction is ΔR = 33% of PLL_{basis}). The risk model does not account for risk (fatalities) in operational scenarios such as statutory training or during drills, which are known to be the largest contributors to the risk to crew members.

Table 16: Risk Reduction after Implementation of RCO4

Δ Fatality Rate	**Total Ind. Risk (per year)**	**Total PLL (per ship year)**	**Averted fatalities per ship**	**Total ΔR (% of PLL_{basis})**
basis	2.61E-04	2.22E-01	-	
25%	2.31E-04	1.96E-01	0.7	11%
50%	2.02E-04	1.72E-01	1.5	22%
75%	**1.74E-04**	**1.48E-01**	**2.2**	**33%**
100%	1.46E-04	1.24E-01	2.9	44%

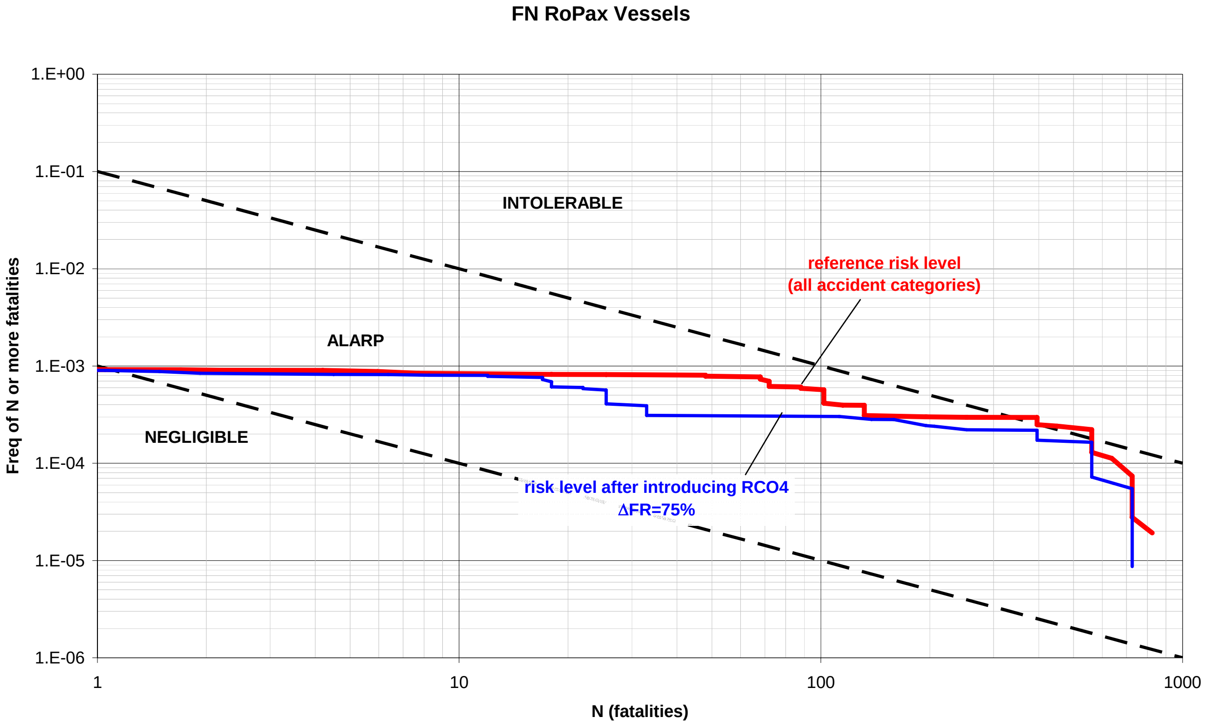

Figure 7: Societal Risk Level for All Accident Categories

3 Cost-Effectiveness Analysis

In this section, comparison of cost-effectiveness of each evaluated RCO is made on the basis of the Gross Cost of Averting a Fatality (GCAF). This index is defined as follows:

$$GCAF = \frac{\Delta C}{\Delta R}$$

where

ΔC	Marginal cost per ship associated with the introduction of a RCO over its lifetime (includes the initial capital costs and annual associated costs)
ΔR	Risk reduction per ship, in terms of the number of fatalities averted over the lifetime of the vessel, associated with the introduction of a RCO (see Section 2)

Marginal cost (ΔC) is calculated in Net Present Value (NPV) for the reference vessel described in Section 3.1 and assuming ship's service life (T_s) of 30 years and a discount rate (r) of 5%.

3.1 Definition of Generic Model / Ship System

For the purpose of evaluating the risk reduction potential (ΔR) and costs (ΔC) of the various RCOs considered, a representative reference ship has been selected, the main parameters of which are presented in Table 17. The parameters of the reference ship correspond to a RoPax vessel with capacity for approximately 1,000 passengers and 100 crew, consistently with the assumptions made in the risk analysis study (Annex II).

Table 17: Reference Ship for Evaluation of RCOs

Parameters	Value
Gross Tonnage, GT	25,000 tons
Length overall	180 m
Breadth	25 m
LSA Capacity Passengers Crew	1,100 1,000 100
No. cabins / 2 capacity No. cabins / 4 capacity	50 225
Total lane metres	1,900 m
Lightweight	12,000 tons

As the marginal costs are a function of the operational profile of the vessel, a specific profile was defined as summarised in Table 18. For consistency with the risk model assumptions, three operational profiles are considered: winter, spring/autumn and summer. The following additional assumptions are made:

- The vessel operates 356 out of 365 days per year (99% availability)
- The trip distance is 300 nm, travelled at average speed of 25 knots in 12 hours

Table 18: Reference Vessel Operational Profile

	season	**Low (winter)**	**Middle (spring / autumn)**	**High (summer)**
annual number of trips	No. service days	89	178	89
	Return trips / day (daily frq)	1	1	1
	Return trips per year	89	178	89
	Annual breakdown[6]	*25%*	*50%*	*25%*
pax / vehicle distribution	cars	90	150	301
	bus	5	8	3
	lorries	80	60	7
	trailer	100	90	40
loading profile	lane metres used	1885	1845	1454
	lane metres usage (% of max)	99.2%	97.1%	76.5%
	Pax (car&bus) / trip	420	690	993
	Pax (drivers) / trip	80	60	7
	Pax total / trip	500	750	1000
	Level of service[6]	*50%*	*75%*	*100%*

The cost-earning profile is shown in Table 19, based on the cost/revenue unit data presented in Table 20. From these considerations the following indicative cost considerations can be made:

The annual total revenue is estimated at EUR 18,440,000. Given the vessel's capacity parameters, the annual average revenue is as follows:

- EUR 42,475 per cabin
- EUR 4,117 per lane meter

After excluding the annual operational costs, estimated at approximately EUR 17,108,000, then the NET annual profit is as follows:

- EUR 731 per cabin
- EUR 605 per lane meter

The above figures will be used for making indicative estimates of the marginal costs associated with the implementation of design changes and alternatives affecting the layout and of course capacity of the vessel.

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[6] Assumption made in the risk model, see Annex II

Table 19: Reference Cost / Earning Profile for the Calculation of Marginal Costs

	season	winter	spring / autum	summer	annual sums
revenue profile	pax tiquets sale / trip	€ 15,686	€ 25,770	€ 37,086	
	pax onboard sales / trip	€ 2,500	€ 3,750	€ 5,000	
	cargo revenue (vehicles) / trip	€ 23,834	€ 22,727	€ 18,596	
	total revenue / trip	€ 42,020	€ 52,247	€ 60,682	
	revenue pax / season	€ 1,618,539	€ 5,254,486	€ 3,745,635	€ 10,618,660
	revenur cargo / season	€ 2,121,239	€ 4,045,459	€ 1,655,067	€ 7,821,765
	total annual revenue / season	€ 3,739,778	€ 9,299,945	€ 5,400,703	**€ 18,440,426**
				annual revenue per cabin	€ 42,475
				annual revenue per lane m	€ 4,117
cost profile	total distance (nm)	53400	106800	53400	
	fuel consumption (MT)	10680	21360	10680	sum
	fuel cost (EUR)	€ 1,281,600	€ 2,563,200	€ 1,281,600	€ 5,126,400
	crew wages	€ 2,990,400	€ 5,980,800	€ 2,990,400	€ 11,961,600
	maintenance				€ 20,000
				total annual cost	**€ 17,108,000**
				annual running cost per cabin	€ 41,744
				annual running cost per lan m	€ 3,512
					€ 1,332,426
				annual profit per cabin	€ 731
				annual profit per meter lane	€ 605

Table 20: Unit Cost Data [22]

pertaining to	item	value	units
design / construction	consultant hourly rate	90	EUR / hour
	price of steel work per hour (EU)	6,000	EUR / ton
	yard cost rate	20	EUR / hour
tickets prices	pax	37.4	EUR / person / trip
	Car (3 pax / 4 m)	52	EUR / vehicle / trip
	Bus (30 pax / 15 m)	196	EUR / vehicle / trip
	Lorry (1 pax / 15 m)	196	EUR / vehicle / trip
	Trailer (2.5 m)	33	EUR / vehicle / trip
onboard sales	car / bus pax	5	EUR / person / trip
	lorry driver	5	EUR / person / trip
operational cost	fuel	120	EUR / ton
	crew wages	280	EUR / day / person

3.2 Improved Navigation Safety (RCO1)

This section presents all cost and risk reduction considerations made to calculate the CAF values for evaluation of cost-effectiveness of measures associated with improved navigation safety.

3.2.1 Cost Considerations

Cost considerations follow the work presented in [4] but revised by a group of representatives from a RoPax operator to reflect the implementation on the reference RoPax ferry. As can be observed, the marginal cost (ΔC) of the various measures ranges from USD 19,000 to USD 9.7 million. The highest costs always relate to the lifecycle cost of having additional officers onboard. Initial and running costs of hardware-related measures are significantly lower.

3.2.1.1 Onboard safety and security centre

Considering that the bridge as a physical space is providing accommodation for navigation and the management of the overall operation of the ship, distraction of the crew can be avoided especially during difficult manoeuvres. This would require a secondary area, a "safety and security centre", that would be manned by one extra officer at all times and would provide functions such as decision support in hazardous situations in emergency (e.g. fire occurrences) and non-emergency situations, communication with the shore for issues other than navigation, etc.

The necessary size for such a centre would be equal to the size of three cabins. Additionally, it will have to be manned 24 hours per day in 3-hour shifts. That would require 3 officers on board and 3 officers standing-by ashore. The details of the calculations are presented in Table 21.

Table 21: Calculations for Setting Up a "Safety and Security Centre" Onboard

Initial investment for buying and installing equipment	$ 158,000
Officers' salary	$ 91,000
Number of officers (3 on board and 3 ashore, 3-hour shifts)	6
Cost per cabin (around a year for 70% utilisation)	$ 100,000
Number of cabins	3
Annual cost	$ 846,000
NPV	$ 9,682,085

3.2.1.2 Automatic logging of information (Electronic Log Book – ELB)

The Electronic Log Book is a relief measure for the officers on the bridge since it allows for spending more time with really important issues of navigation rather than with cumbersome tasks of manually noting details of the route, times of entering and leaving a harbour, etc. ELB is online with the rest of the navigation equipment on the bridge and it can register all the selected information from this equipment. It can further include soundings from vessel's tanks, alarms of various sources, etc. With all this information available in electronic form, communication with the shore offices is much more efficient and allows for proper instructions and detailed planning in case of emergency or trivial operations.

This measure would require installation of the system not only onboard the ship but also a similar supporting system ashore. The calculations are presented in Table 22.

Table 22: Cost Elements for the Implementation of Electronic Log Book (ELB)

Automatic logging of information (onboard)		$ 32,000
Automatic logging of information (ashore)		$ 8,000
Initial investment		$ 40,000
Annual maintenance / upgrade / update / service contract / annual licence cost		$ 500
	NPV	$ 45,629

3.2.1.3 Two officers on the bridge

IMO resolution A.890(21) defines minimum safe manning for navigation as being able to plan and conduct safe navigation, maintain a safe navigational watch, manoeuvre and handle the ship under all conditions and moor and unmoor the ship safely.

The intention behind this resolution is to allow one officer to focus on the navigation of own vessel and the other to focus on the surrounding traffic. This splitting of tasks reduces navigational risks more in comparison of having one officer to perform both tasks. In order to have the extra officer on board, for three shifts per day there have to be in total three more officers onboard which will occupy three cabins. Evidently, the three onboard officers should be supported by further three standing-by officers ashore for replacement.

Table 23: Breakdown of Costing for having One Extra Officer per shift On Watch

Officers' salary		$ 91,000
Number of officers (3 on board and 3 ashore, 3-hour shifts)		6
Cost per cabin (around a year for 70% utilisation)		$ 100,000
Number of cabins		3
Annual cost		$ 846,000
	NPV	$ 9,524,085

3.2.1.4 Electronic chart display system (ECDIS) - with and without track control

Instead of planning and displaying ship’s route on the traditional paper charts, the Electronic Chart Display and Information System (ECDIS) is available. It can provide live information of the position of the vessel in relation to shore side, navigational aids, charted objects, etc. Its implementation is appealing due to the way it allows officers to interact and its numerous information that can provide to the navigator. It has the potential to integrate with the radar system and the Automatic Identification System (AIS). As a result it can prove a very efficient mean of reducing involved risks substantially. Its implementation requires initial installation and an update package that will feed into the system all the new information regarding any area of interest (Table 24).

Table 24: Calculations for ECDIS Option

ECDIS (including backup arrangement)		$ 92,000
Chart update		$ 2,000
Initial investment		$ 94,000
Annual maintenance / service cost		$ 2,000
	NPV	$ 116,516

3.2.1.5 Automatic Identification System (AIS) - automation with radar

Automatic Identification System (AIS) is a system on the radar display, with overlaid electronic chart data, that includes a mark for every significant ship within radio range which indicates speed and heading. Each ship indicator reflects the actual size of the ship and by clicking on it the user can get access to information like ship name, course and speed, classification, call sign, registration number, etc. Evidently, AIS is becoming a very useful tool for situational awareness especially in situations of very dense traffic.

AIS implementation cost is restricted to the integration with the ARPA (Automatic Radar Plotting Aid) radar system (Table 25).

Table 25: Implementation of the AIS would entail only integration with the ARPA System

Integration of AIS with ARPA		$ 19,000
Annual maintenance / service cost		$ -
	NPV	$ 19,000

3.2.1.6 Track control system

The philosophy behind the track control is that a ship cannot run aground if the route is planned through navigable waters (before departure) and the ship follows this route [4]. Automatic real-time navigation is more precise and reliable than manual navigation, and leaves the navigation officer more time for monitoring instruments and ship traffic. The system can provide with automatic position information both for own ship and surrounding traffic using ECDIS and it can provide with grounding and collision avoidance instructions to the navigator. Its implementation includes some initial investment for the system and a small annual maintenance fee (Table 26).

Table 26: Cost Breakdown for the Track Control System

Track control system		$ 50,000
Annual maintenance / service cost		$ 200
	NPV	$ 52,252

3.2.1.7 Improved navigation training

STCW (Standards of Training, Certification and Watch-Keeping), [5], for seafarers is a safety convention adopted by IMO in 1978 and fully amended in 1995. STCW describes the minimum training of sea-going personnel should be subjected to seminars along with improvements in the navigators' training regarding advanced manoeuvring, crisis management, etc. All these elements can be safely implemented during training by taking advantage technical innovations, such as the use of simulators for training and assessment purposes which have been recognized. Simulators are mandatory for training in the use of radar and automatic radar plotting aids (regulation I/12 and section A-I/12 of the STCW Code). Crews on RoPax ships have to receive training in technical aspects and also in crowd and crisis management and human behaviour. According to STCW every master, officer and radio operator are required at intervals not exceeding five years to meet the fitness standards and the levels of professional competence contained in Section A-I/11 of the Code. This creates the need to train a number of officers in five-year intervals as presented in Table 27.

Table 27: Incurred Cost for Training Courses on Navigation Practices

Course fee		$	12,000
Board and lodging		$	500
Travel expenses		$	800
Number of officers to do the course			6
Ashore personnel to attend the course			1
Total expenses		$	93,100
Frequency of the course (years)			5
	NPV	$	264,859

3.2.1.8 Implementation of guidelines for BRM (Bridge Resource Management)

Within the maritime domain the only mandatory non-technical skills requirements are those of STCW Code, [5]. The minimum competence standards are specified in this code for crisis management and human behaviour skills for those senior officers who have responsibility for the safety of passengers in emergency situations, [6]. The 1995 amendments to the STCW include a requirement for training in bridge team procedures and techniques. The main focus areas are:

- To assist the ship master in managing the vessel's bridge team for each voyage so that personnel are rested, trained and prepared to handle any situation.
- To help the ship master recognize workload demands and other risk factors that may affect decisions in setting watch conditions.
- To ensure bridge team members are trained and aware of their responsibilities.
- To help bridge team members interact with and support the master and/or the pilot.

Officers onboard should attend seminars and presentations in a regular basis in order to familiarise themselves with procedures and techniques of CRM. These seminars are provided in intervals of 5 years. The details for the CRM implementation are presented in Table 28.

Table 28: Cost for Implementation of Crew Resource Management in Daily Operations

Course fee		$ 4,000
Board and lodging		$ 500
Travel expenses		$ 800
Number of officers to do the course		16
Ashore personel to attend the course		3
Total expenses		$ 100,700
Frequency of the course (years)		5
	NPV	$ 286,480

3.2.1.9 Navigation systems availability (systems duplication)

The navigational systems availability is primarily governed by 100% redundancy of all critical navigational systems. It is a SOLAS requirement that most of this equipment is duplicated in modern bridge arrangements and configurations. Exemption is the gyro compass and the GPS. As a result, this RCO is focusing in duplicating these two instruments.

Table 29: Cost for Systems Duplication

Gyro compass		$ 28,500
GPS		$ 8,000
Initial investment		$ 36,500
Annual maintenance cost		$ 3,000
	NPV	$ 70,273

3.2.2 Calculation of CAF

The results of calculations of CAF are presented in Table 30 and illustrated in Figures 8 and 9 for different assumptions related to accident incidence rate (IR) and consequently of risk reduction (see Table 3). As it can be observed, measures requiring additional crew (Officers) onboard result in CAF 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.

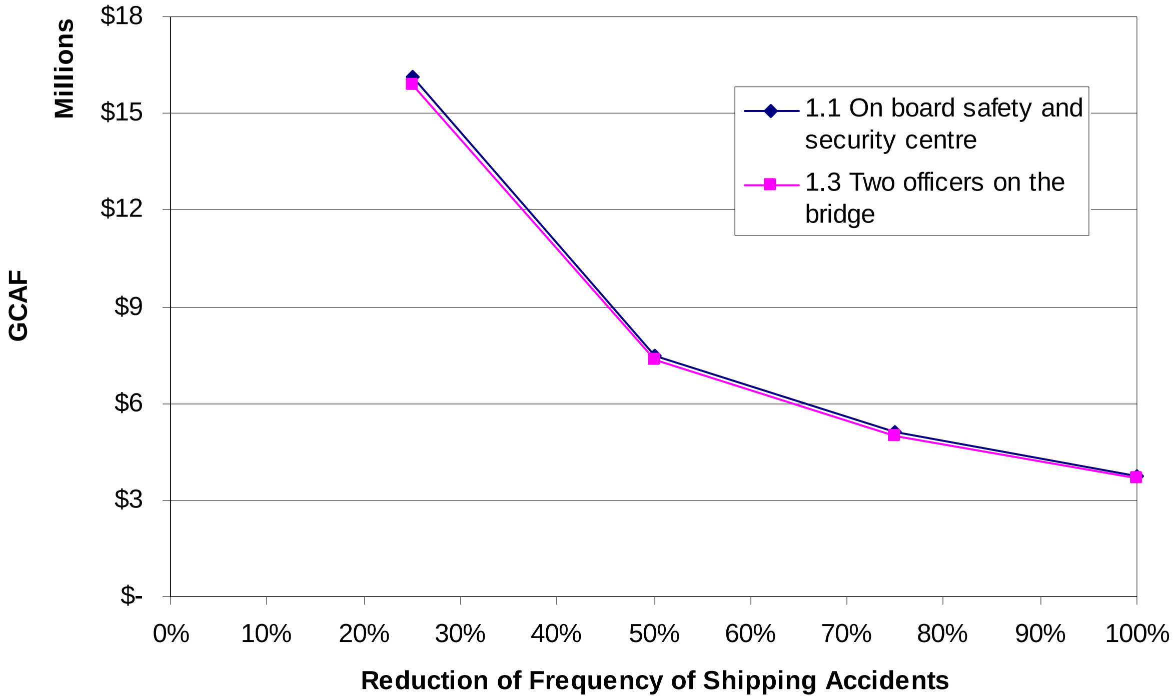

Figure 8: Sensitivity of GCAF to Effectiveness of Navigation Measures Requiring Additional Numbers of Officers Onboard

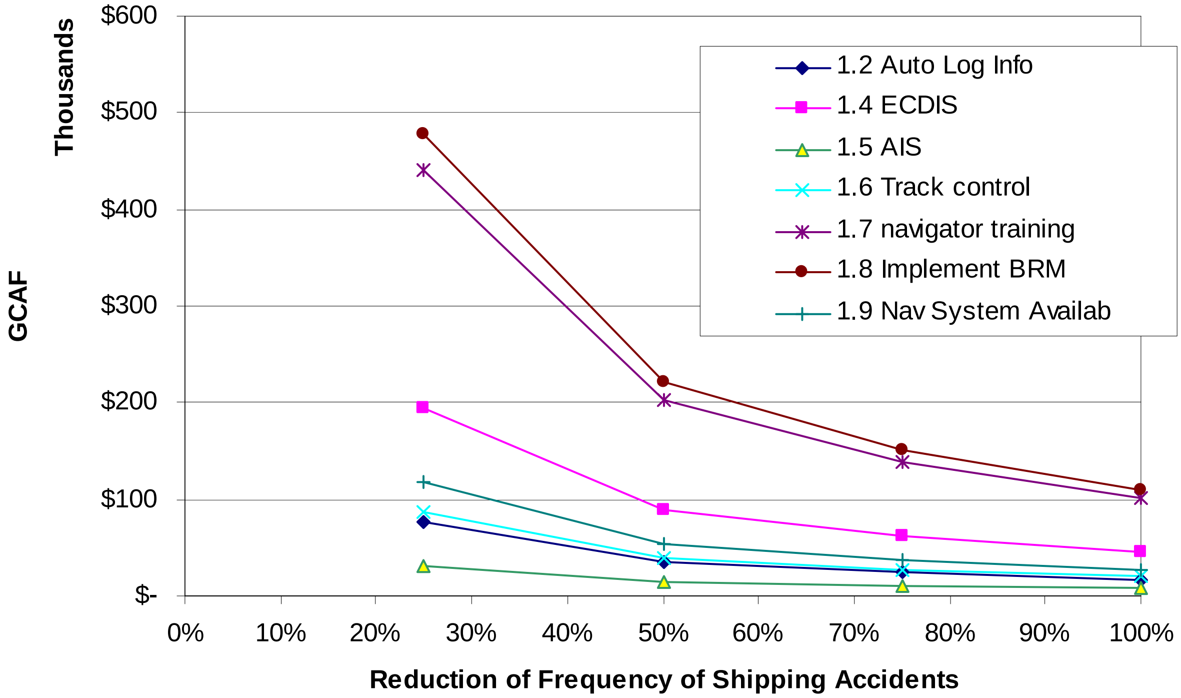

Figure 9: Sensitivity of GCAF to Effectiveness of Navigation Measures Not Requiring Additional Numbers of Officers Onboard

Table 30: CAF Results for Various Measures Related to Improved Safety of Navigation (RCO1)

RCO id	RCO Description	ΔC (in USD)	ΔIR - Reduction of accident frequency	PLL (per ship year)	ΔR (% of PLL)	Averted fatalities per ship	GCAF (USD)
1.1	On board safety and security centre	9,682,085	25%	1.99E-01	10%	0.6	16,136,808
			50%	1.78E-01	19%	1.3	7,447,758
			75%	1.57E-01	29%	1.9	5,095,834
1.2	Automatic Logging of Information	45,629	25%	1.99E-01	10%	0.6	76,048
			50%	1.78E-01	19%	1.3	35,099
			75%	1.57E-01	29%	1.9	24,015
1.3	Two officers on the bridge	9,524,085	25%	1.99E-01	10%	0.6	15,873,475
			50%	1.78E-01	19%	1.3	7,326,219
			75%	1.57E-01	29%	1.9	5,012,676
1.4	ECDIS	116,516	25%	1.99E-01	10%	0.6	194,193
			50%	1.78E-01	19%	1.3	89,628
			75%	1.57E-01	29%	1.9	61,324
1.5	AIS	19,000	25%	1.99E-01	10%	0.6	31,667
			50%	1.78E-01	19%	1.3	14,615
			75%	1.57E-01	29%	1.9	10,000
1.6	Track control system	52,252	25%	1.99E-01	10%	0.6	87,087
			50%	1.78E-01	19%	1.3	40,194
			75%	1.57E-01	29%	1.9	27,501
1.7	Improved navigator training	264,859	25%	1.99E-01	10%	0.6	441,432
			50%	1.78E-01	19%	1.3	203,738
			75%	1.57E-01	29%	1.9	139,399
1.8	Implementation of BRM guidelines	286,480	25%	1.99E-01	10%	0.6	477,467
			50%	1.78E-01	19%	1.3	220,369
			75%	1.57E-01	29%	1.9	150,779
1.9	Increased Navigation System Availability	70,273	25%	1.99E-01	10%	0.6	117,122
			50%	1.78E-01	19%	1.3	54,056
			75%	1.57E-01	29%	1.9	36,986

3.3 Improved Survivability to Flooding (RCO2)

This section presents all cost and risk reduction considerations made to calculate the CAF values for the evaluation of cost-effectiveness of measures associated with improved survivability to flooding.

3.3.1 Cost Considerations

The marginal costs associated with the various measures implied by introducing RCO2a and RCO2b, as described in Section 2.2, can vary significantly from ship to ship, depending on the size of the ship, the capacity, the internal layout, among others. This is related to the extent of possible utilisation of the available volumes and deck areas. In the case of a RoPax vessel, added volumes below the main deck (resulting for instance from an increase in beam) may be difficult to utilise economically.

Possible measures within the scope of RCO2 are discussed in Section 2.3. Examples of such measures from available general literature can be found in the Appendix. Therefore due to the high-level nature of this study, only indicative estimates of the order of magnitude of the costs associated with some of the measures discussed in Section 2 are provided here in Table 31 and Table 32. All the assumptions related to space utilisation and weight, are on the pessimistic side.

Table 31: Indicative Order of Magnitude of Marginal Costs ΔC associated with RCO2a

RCO 2a (A=0.95)				
stakeholder	**item**	**increase**	**units**	
owner	additional tons of steel (1% lightweight)	123.79	tons	
builder + yard	additional hours of design work	1000	h	
operator	Reduced lane metres	200	m	
operator	Reduced cabins	10		
stakeholder	**item**	**initial (capital) cost**		€ 792,759
owner	increased design costs (fixed price)	€ 15,000		
builder	increased design costs (fixed price)	€ 15,000		
owner	increased construction costs (due to added weight)	€ 742,759		
builder	increased construction costs (commissioning)	€ 20,000		
stakeholder	**item**	**annual (running) cost**		€ 129,327
owner	cost of reduced capacity (car deck space)	€ 121,015		
owner	cost of possible increased maintenance	€ 1,000		
owner	cost of reduced capacity (accommodation spaces)	€ 7,311		
Increase in cost PV		**$ 3,075,531**		€ 2,248,688

Table 32: Indicative Order of Magnitude of Marginal Costs ΔC associated with RCO2b

RCO 2b (A=0.95)

stakeholder	**item**	**increase**	**units**
owner	additional tons of steel (5% lightweight)	618.97	tons
builder + yard	additional hours of design work	5000	h
operator	Reduced lane metres	50	m
operator	Reduced cabins	10	

stakeholder	**item**	**initial (capital) cost**	€ 3,843,793
owner	increased design costs (fixed price)	€ 15,000	
builder	increased design costs (fixed price)	€ 15,000	
owner	increased construction costs (due to added weight)	€ 3,713,793	
builder	increased construction costs (commissioning)	€ 100,000	

stakeholder	**item**	**annual (runing) cost**	€ 38,565
owner	cost of reduced capacity (car deck space)	€ 30,254	
owner	cost of possible increased maintenance	€ 1,000	
owner	cost of reduced capacity (accommodation spaces)	€ 7,311	

Increase in cost NPV		**$ 5,850,952**	€ 4,277,950

3.3.2 Calculation of CAF

The results of calculations of CAF for RCO2a are presented in Table 33 and illustrated in Figure 10. For RCO2b, the results are presented in Table 34 and illustrated in Figure 11, for different assumptions related to risk reduction and cost. For illustration, assuming that the marginal cost of introducing RCO2a or RCO2b is between \$3M and \$6M, the resulting CAF value for an Index A of 0.9 (ΔA=0.12) is well below \$3M, the current IMO cost-effectiveness criterion,. An increase to A=0.95 would result in even lower CAF.

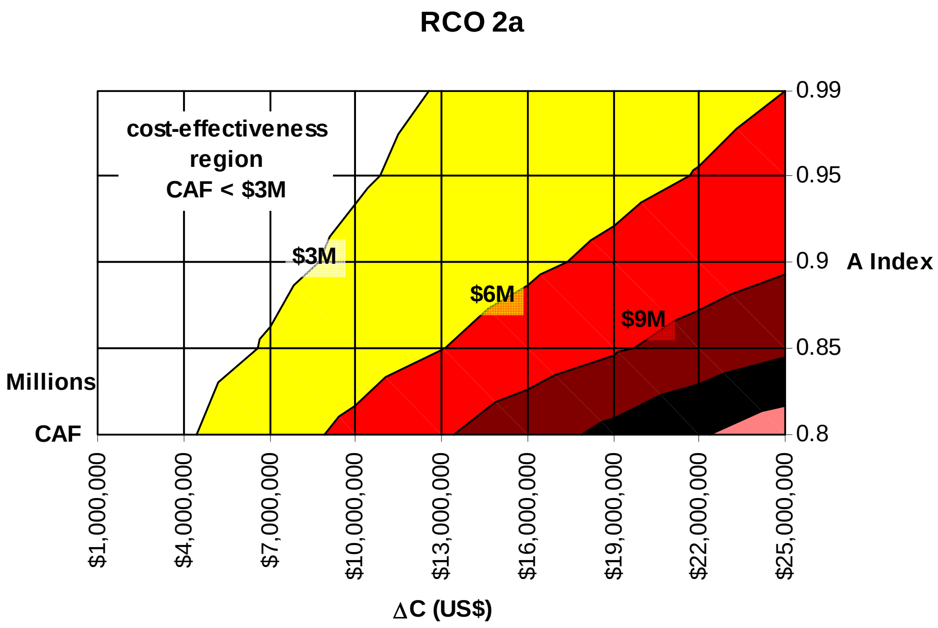

Figure 10: GCAF Sensitivity to Attained Index A and Cost Implications RCO2a: Measures Improving Damage Stability ("stay afloat")

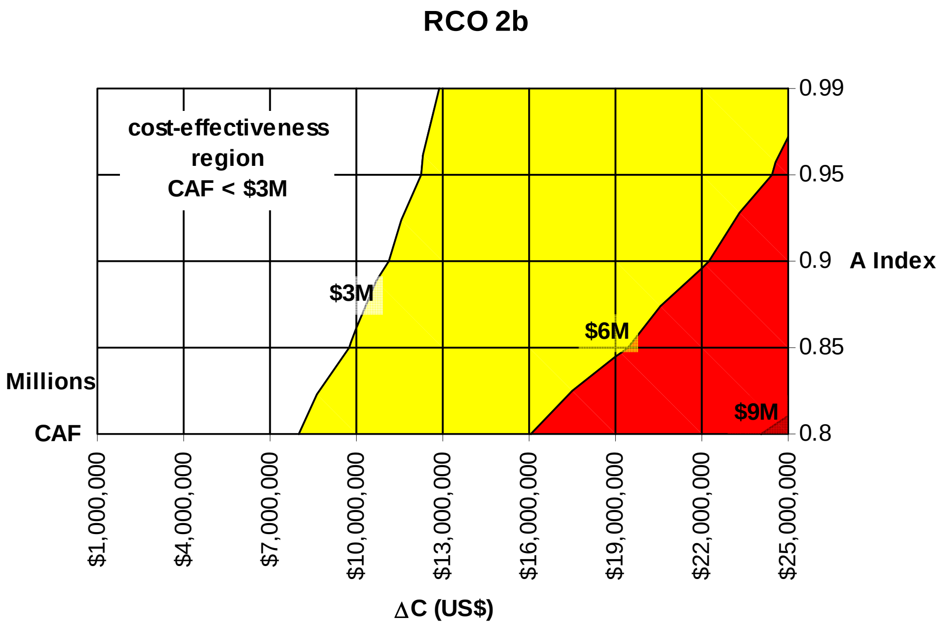

Figure 11: GCAF Sensitivity to Attained Index A and Cost Implications RCO2b: Measures Improving Damage Stability and Survival Time ("stay afloat for longer")

Table 33: CAF Sensitivity Results for RCO2a (Measures Leading to Improved Damage Stability)

RCO id	RCO Description	ΔC (US $)	Attained Index A	PLL (per ship year)	ΔR (% of PLL)	Averted Fatalities per ship	GCAF (US $)
2a	Various individual or combination of measures such 2.1-2.5 with ‘minor’ economic impact	4,000,000	0.80	1.71E-01	23%	1.5	2,684,352
			0.85	1.47E-01	33%	2.2	1,826,210
			0.90	1.24E-01	44%	2.9	1,379,012
			0.95	1.00E-01	55%	3.6	1,107,750
			0.99	8.12E-02	63%	4.2	957,130
2a	Various individual or combination of measures such 2.1-2.5 with ‘moderate’ economic impact	10,000,000	0.80				6,710,879
			0.85				4,565,524
			0.90				3,447,531
			0.95				2,769,374
			0.99				2,392,824
2a	Various individual or combination of measures such 2.1-2.5 with ‘major’ economic impact	16,000,000	0.80				10,737,407
			0.85				7,304,839
			0.90				5,516,050
			0.95				4,430,999
			0.99				3,828,519
2a	Various individual or combination of measures such 2.1-2.5 with ‘large’ economic impact	22,000,000	0.80				14,763,934
			0.85				10,044,153
			0.90				7,584,569
			0.95				6,092,624
			0.99				5,264,214

Table 34: CAF Sensitivity Results for RCO2b (Measures Leading to Improved Damage Stability and Survival Time)

RCO id	RCO Description	ΔC (US $)	Attained A index	PLL (per ship year)	ΔR (% of PLL)	Averted Fatalities per ship	GCAF (US $)
2b	Various individual or combination of measures such 2.1-2.5 with 'minor' economic impact	4,000,000	0.80	1.31E-01	40%	2.7	1,494,397
			0.85	1.12E-01	49%	3.2	1,234,227
			0.90	9.68E-02	56%	3.7	1,078,494
			0.95	**8.47E-02**	**62%**	**4.1**	**981,884**
			0.99	7.75E-02	65%	4.3	932,517
2b	Various individual or combination of measures such 2.1-2.5 with 'moderate' economic impact	10,000,000	0.80				3,735,992
			0.85				3,085,567
			0.90				2,696,236
			0.95				2,454,709
			0.99				2,331,292
2b	Various individual or combination of measures such 2.1-2.5 with 'major' economic impact	16,000,000	0.80				5,977,588
			0.85				4,936,907
			0.90				4,313,978
			0.95				3,927,535
			0.99				3,730,068
2b	Various individual or combination of measures such 2.1-2.5 with 'large' economic impact	22,000,000	0.80				8,219,183
			0.85				6,788,247
			0.90				5,931,719
			0.95				5,400,360
			0.99				5,128,843

3.4 Increased Survivability to Fire (RCO3)

This section presents all cost and risk reduction considerations made to calculate the CAF values for the evaluation of cost-effectiveness of measures associated with improved survivability to fire.

3.4.1 Cost Considerations

Due to the high-level nature of this study, detailed information on the specific RCOs and hence on the associated cost implications is not available. Therefore a sensitivity of the CAF value of different cost implication is being made for different levels of risk reduction. In this way, it is possible to determine the range of cost and risk reduction for which a measure can be regarded as being cost-effective.

3.4.2 Calculation of CAF

The results of cost-effectiveness are illustrated in Figure 12 to Figure 15 for various cost and risk reduction scenarios. If by introducing RCO3.1, the frequency of fire accidents (referred to as incidence rate, ΔIR_{fire}) can be reduced by 20% (corresponding ΔR=5%), any measure can be regarded as cost-effective if the marginal cost ΔC < $US 1.1M.

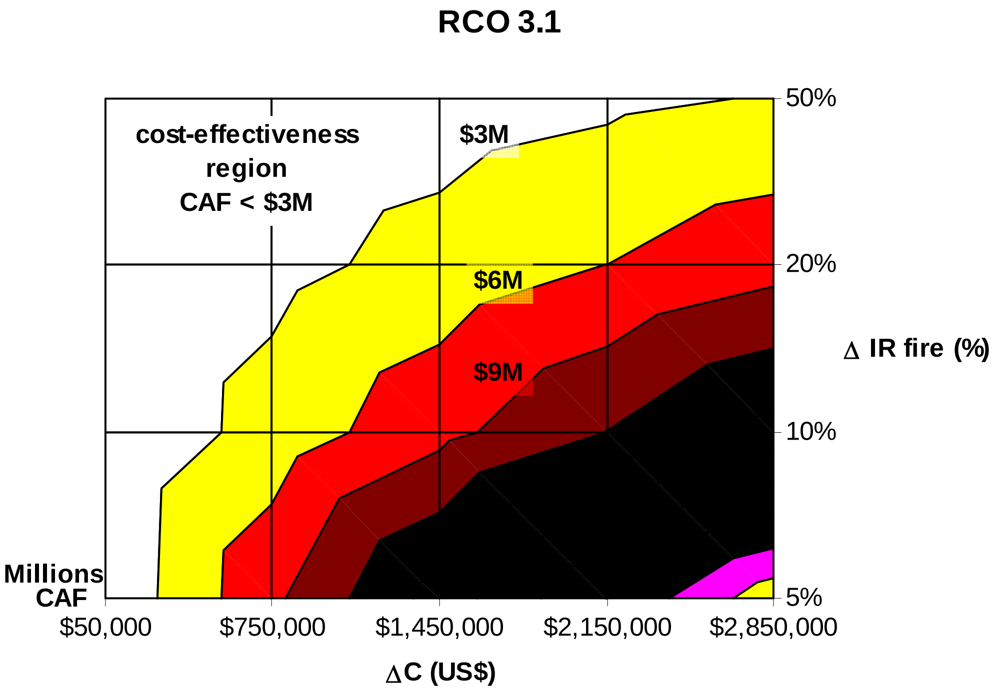

Figure 12: Sensitivity of CAF to Variations of Risk Reduction and Cost Implications RCO3.1 (Fire Prevention, Reduction in the Incidence of Fire and Explosions)

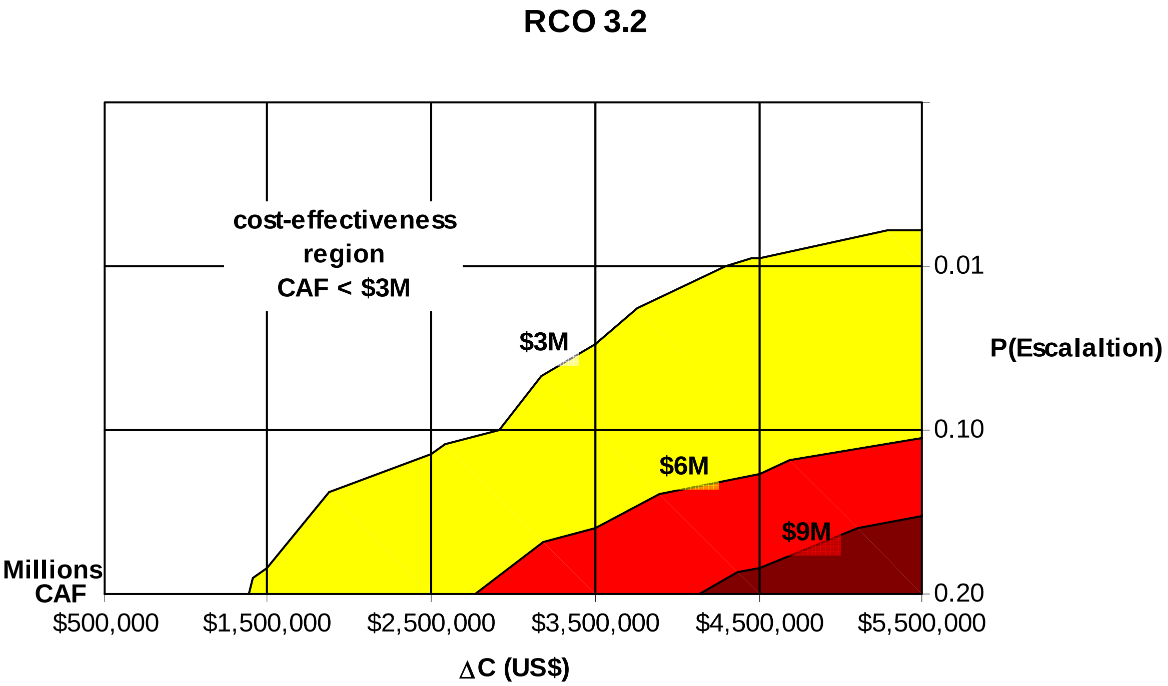

Figure 13: Sensitivity of CAF to Variations of Risk Reduction and Cost Implications RCO3.2 (Fire suppression in Machinery Spaces)

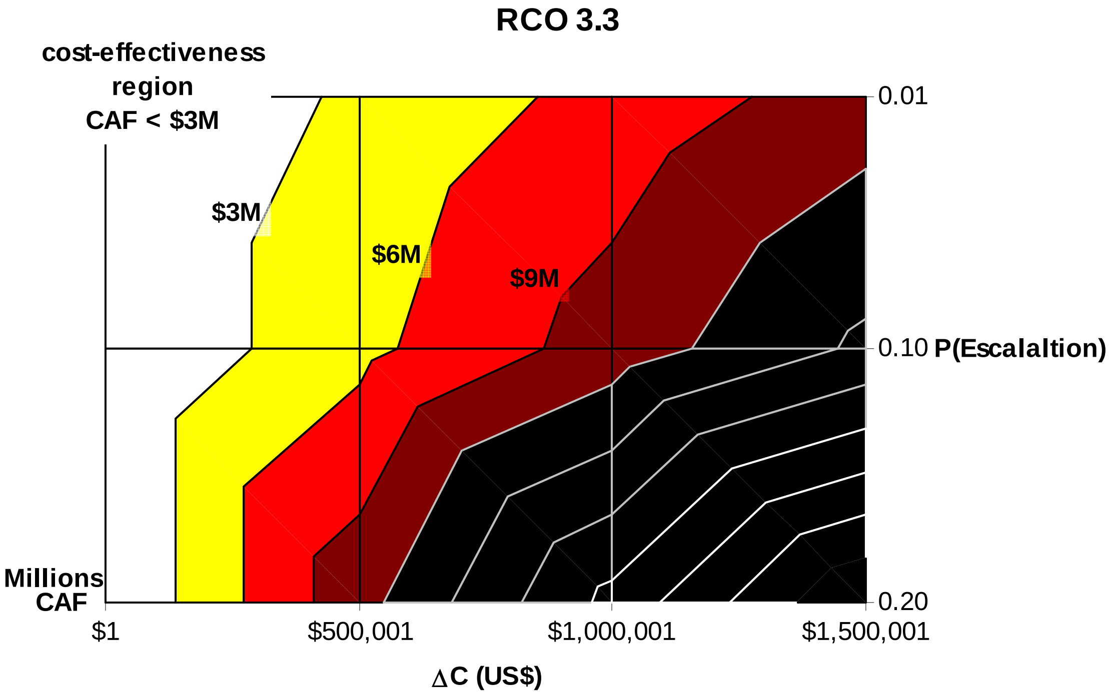

Figure 14: Sensitivity of CAF to Variations of Risk Reduction and Cost Implications RCO3.3 (Fire Suppression in Vehicle Deck Spaces)

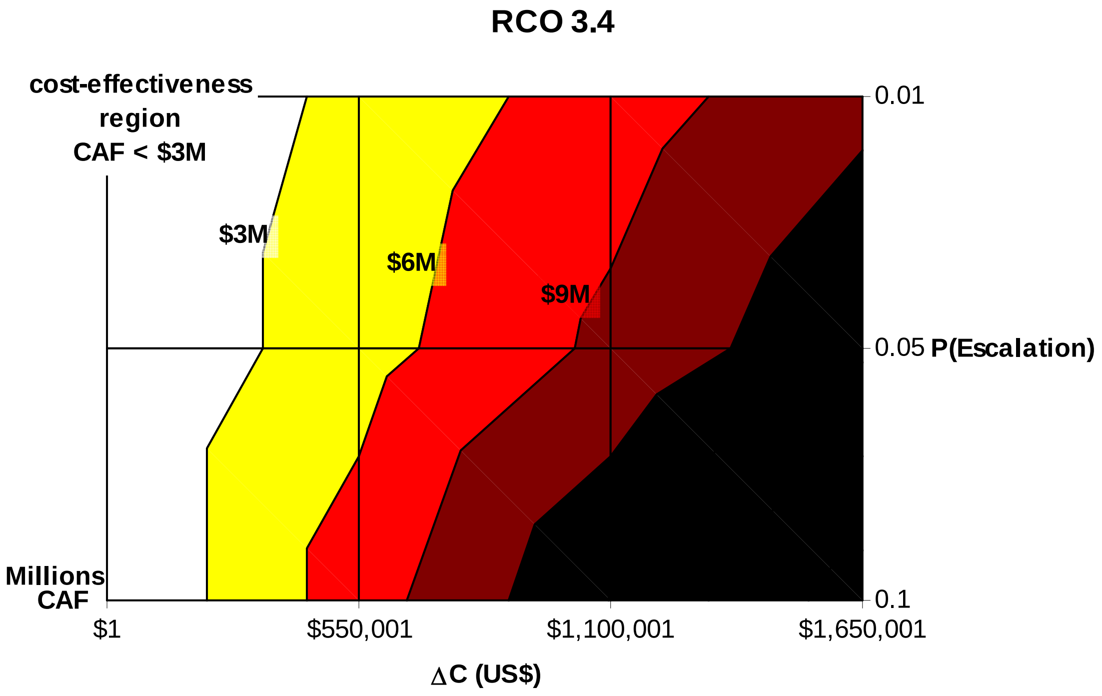

Figure 15: Sensitivity of CAF to Variations of Risk Reduction and Cost Implications RCO3.4 (Fire Suppression in Accommodation Spaces)

3.5 Improved evacuation arrangements (RCO4)

This section presents all cost and risk reduction considerations made to calculate the CAF values for the evaluation of cost-effectiveness of measures associated with improved survivability to fire.

3.5.1 Cost considerations

Due to the high-level nature of this study, detailed information on the specific RCOs and hence on the associated cost implications is not available. Therefore a sensitivity of the CAF value of different cost implication is being made for different levels of risk reduction. In this way, it is possible to determine the range of cost and risk reduction for which a measure can be regarded as being cost-effective.

3.5.2 Calculation of CAF

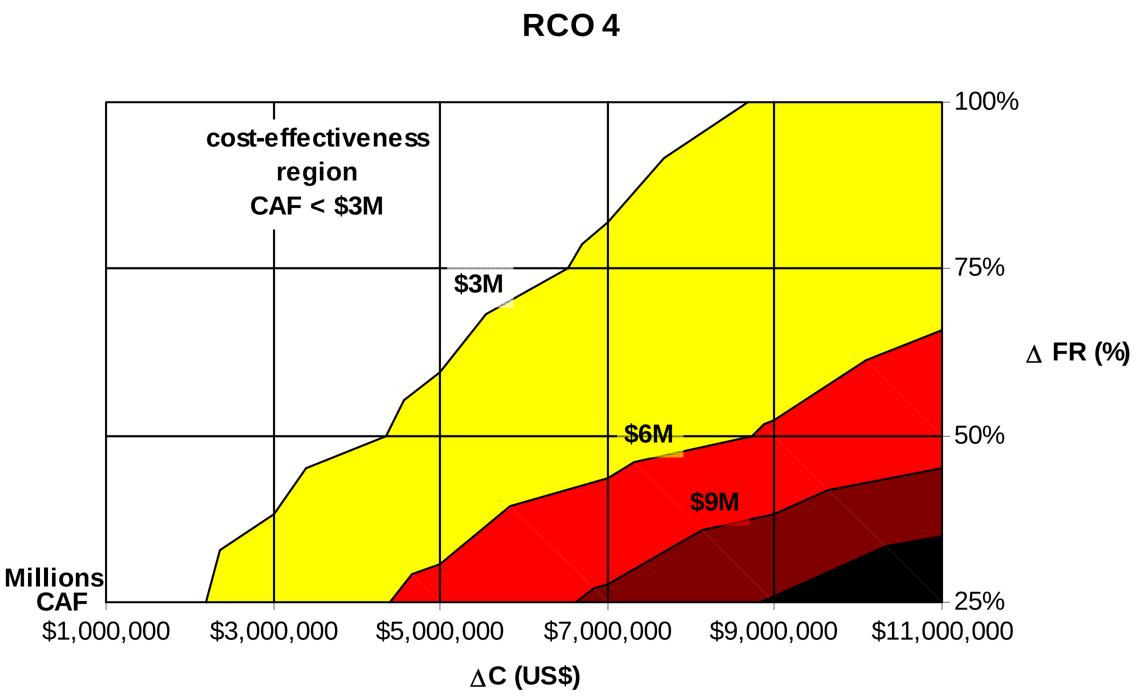

Figure 16: Sensitivity of CAF to Variations of Risk Reduction and Cost Implications RCO4 (Evacuation and Abandonment Arrangements)

4 Conclusions and Recommendations

The range of risk reduction potential for the measures evaluated in the present study is shown in Table 35.

Table 35: Summary of Results of Risk Reduction Estimation

RCO	**Description**	**Range of risk reduction (min - max) ΔR (% of basis PLL)**	**Most likely risk reduction level ΔR (% of basis PLL)**	**Priority**
RCO1	Measures related to better and safer navigation	10% - 39%	29%	3
RCO2a	Measures related to improved damage stability (conventional verification methods)	23% - 63%	44% (A=0.9)	2
RCO2b	**Measures related to improved damage stability and survivability (advanced verification methods) – more effective than RCO2a**	**40%-65%**	**62%** **(A=0.95)**	**1**
RCO3.1	Improved prevention of fire ignition	1%-13%	5%	6
RCO3.2	Improved fire protection (mainly suppression) in machinery spaces	7%-22%	15%	5
RCO3.3	Improved fire protection (mainly suppression) in vehicle decks spaces	1%-2%	1%	7
RCO3.4	Improved fire protection (mainly suppression) in accommodation spaces	1%-2%	1%	7
RCO4	Improved abandonment arrangements	11%-44%	22%	4

Based on risk reduction potential, the following RCOs should be recommended:

- Measures aimed at improving damage stability and survivability. Assuming that damaged ship survivability is ‘sufficiently’ reflected by the Attained Index of Subdivision (A), then the Required Index of Subdivision (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 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, this is outlined with a concrete proposal in [17].

- 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 above 0.9.

Implementation of all measures associated with the four RCOs evaluated in the present study, would lead to a significant reduction in the risk level. The resulting risk level is illustrated in Figure 17, equivalent to a risk reduction of ΔR = 90%.

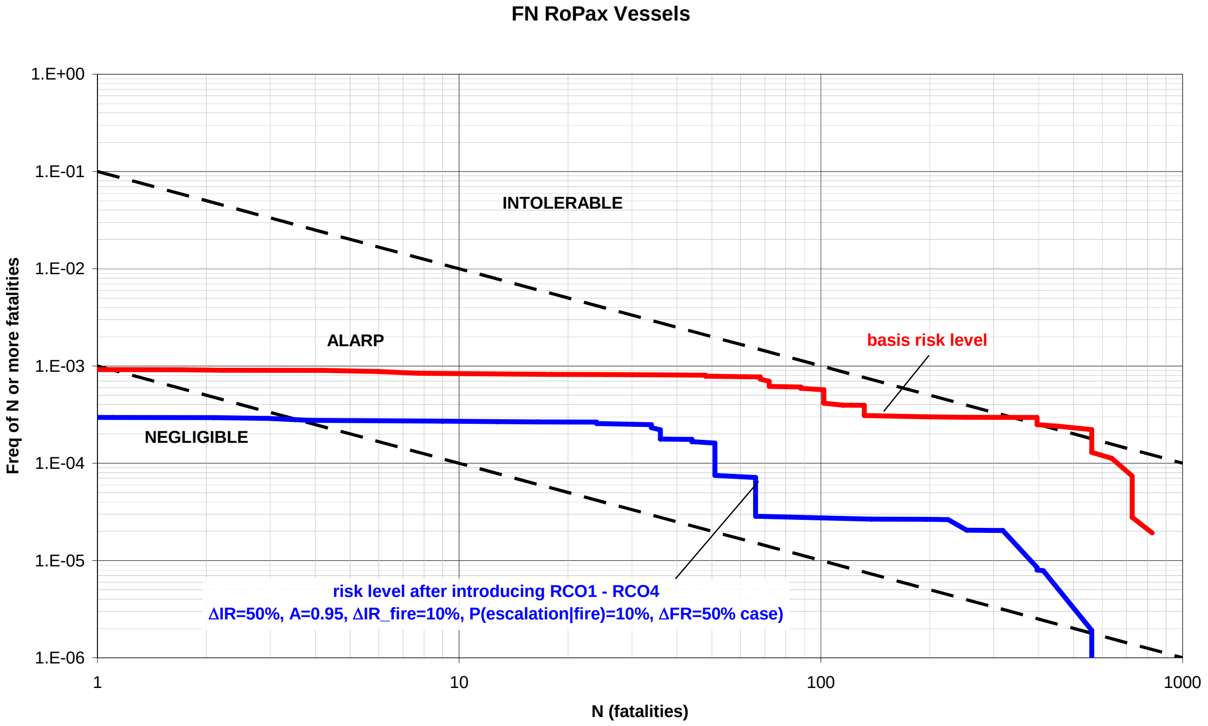

Figure 17: Societal Risk Level after the Introduction of RCOs 1-4

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Appendix: Possible measures aimed at improving damage survivability

The measures described subsequently are only indicative of the type of solutions and the extent of their associated impact on the design concept.

Increased GM

Increasing the metacentric height (GM) will increase residual stability after damage. The GM affects both the GZ (righting arm) and hence the amount of water on deck the vessel can sustain. Typical GM values are about 3.0 m and this can be increased to about 3.5 m, typically considered the maximum tolerable from comfort and sea-keeping considerations. Typically for a 0.5m increase in GM, the beam has to be increased by 1.5m. Other options for increasing GM consist of reducing capacity of upper cargo (vehicle) decks and in general reducing the size of the superstructure.

Increased Freeboard

Model testing and numerical simulation experience with the implementation of the Stockholm Agreement [11] shows that some RoPax vessels with large damage freeboard (in excess of 2m) possess extremely good damage survivability. Consequently, such ships would also display a very high Attained Index of Subdivision A. However increased freeboard deck results in higher centre of gravity (KG), which may require reductions of the size of the superstructure as well or increase of the beam to keep the GM constant. The effectiveness of this measure may be case specific.

Effective Cross Flooding Arrangements

Effective cross- and down- flooding arrangements allowing water to flood freely the entire compartment, with no air pockets and other obstacles delaying flooding. These arrangements are very important during intermediate stages of flooding, where, horizontal subdivision (in the vicinity of the flooded spaces) proves invariably detrimental. Thus efficient air escape pipes and down-flooding ducts could be incorporated to eliminate air cushions and/or multi free-surface of the floodwater, badly dangerous for the ship during transient flooding. This could be achieved by increasing double bottom height. Implementation of this measure may in some cases impact the tank arrangement by decreasing the available space for liquid storage.

According to regulations, these arrangements must provide complete equalisation within 10 minutes to be allowed for immediate flooding. If complete equalisation is done within one minute, then the damage may be regarded as instantaneous (not creating any unsymmetrical moment).

Less conventional (major) measures to improved damage survivability are discussed next, on the basis of published and available references.

Ro-Ro Deck with Shear and Camber (see [14])

This measure is aimed at preventing or limiting the extent of water accumulation on deck. The measure being evaluated here is based on an investigation published in [14], which aimed at having sufficient damage survivability for sea states up to 4m significant wave height (H_s) over the whole range of feasible loading conditions. The idea being advocated here is that of using a curved Ro-Ro deck, rather than a flat deck, with or without intelligent wash ports as a means of channelling the water on deck to flow out. Two alternatives are examined (see Figure 18):

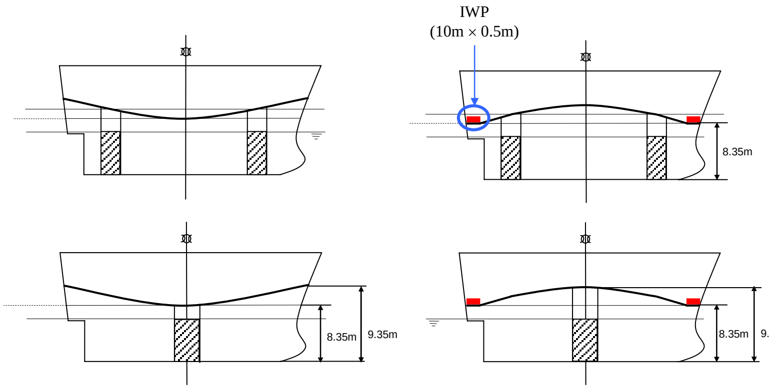
(i) Ro-Ro deck with positive sheer and positive camber (PSPC) and
(ii) Ro-Ro deck with negative sheer and negative camber (NCNS) together with intelligent wash ports (IWP).

According to this study, the perceived advantages offered by the PSPC idea include:

- In the case of midship damage any water finding its way on the Ro-Ro deck would tend to concentrate in the vicinity of the damage opening because of the fore-and-aft sheer on the deck and flow out.
- In the case of damage forward or aft, the increased freeboard resulting from the deck sheer will ensure that less water reaches the Ro-Ro deck and hence survivability will be improved. Normally, the ensuing trim forward or aft, following respective damages will be conducive to water accumulation towards the vicinity of the damage opening and hence to water egress from the deck.
- Irrespective of the damage location, the presence of positive deck camber potentially provides two additional benefits. Water may flow towards the intact side of the ship resulting in an increased damaged freeboard and hence enhanced survivability. If the ship is inclined towards the damage, the presence of camber in principle impairs water inflow whilst assisting water outflow.

Perceived advantages deriving from the NCNS idea include:

- Negative deck camber assists in water accumulating near the ship centreline and hence reducing the ship heeling. This is very important, as the damaged freeboard is a critical parameter affecting ship survivability.
- Negative deck sheer assists water flow towards the ship ends where the heeling effect is further reduced due to reduced beam. Additionally, by locating IWP's at the ends water can flow out.
- Negative deck sheer results in increasing damaged freeboards particularly amidships where the ship is the most vulnerable when damaged at this location without having to raise the whole deck which would adversely affect the overall stability of the ship.
- The presence of IWP's would give a Ro-Ro ship a chance in case of accidents similar to the *Herald of Free Enterprise* and the *Estonia* where bow damage with forward speed rendered capsize inevitable and catastrophic.



(i) PSPC (ii) NSNC+IWP

Figure 18: Curved Ro-Ro Deck Alternatives [14]

According to [14], with both alternatives, the survivability of the tested vessel is well above 4m sea state even at high KG values for midship damages, and significantly higher than what can be achieved with flat car decks.

Watertight Reserve Buoyancy (see [10])

This measure consists of introducing fully watertight side casings above the subdivision deck to provide a life belt in case of large scale flooding, making the vessel virtually "incapsizable", capable of staying afloat even in extreme (improbable) damages in the worst of environmental conditions. The extent of the lifebelt can vary from 1/5th to almost the full length of the vehicle deck and can have widths as low as 1.2m. Wider watertight spaces which make-up the Life Belt can be used to accommodate service spaces with vertical escape routes providing access to upper decks.

According to calculations on such solution provided by [19], in this way, the Index A of a large existing RoPax design can be increased from A=0.75 up to A=0.85 where, watertight spaces extent over 80% of length of car deck with 1.2m width, and the location and number of transversal watertight bulkheads is optimized to reduce weight. For new designs, the impact is expected to be much higher.

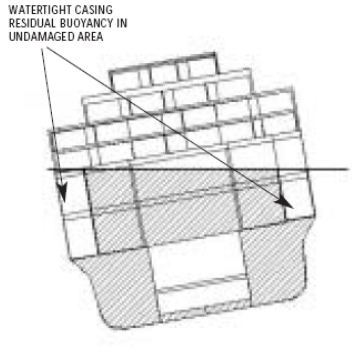


Figure 19: Example of Watertight Reserve Buoyancy (DESSO Project)

Furthermore, numerical simulations indicate exceptional survivability with the ship damaged at high sea states. It could be argued that in case of an accident leading to breaching of the hull and water ingress, staying onboard the vessel would be the safest alternative. This could be the basis for “abandoning” the use of lifeboats. The evacuation of the vessel can be performed fully with MES systems.