MARITIME SAFETY COMMITTEE
85th session
Agenda item 17

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# FORMAL SAFETY ASSESSMENT

## FSA – Cruise ships
## Details of the Formal Safety Assessment

**Submitted by Denmark**


**SUMMARY**

| | |
|---|---|
| ***Executive summary:*** | This document is related to document MSC 85/17/1 entitled "FSA - Cruise 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 85/17/1 |


## Introduction

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

.1 Annex I: Hazard Identification
.2 Annex II: Risk Analysis
.3 Annex III: Cost efficiency analysis, 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 85/17/1.

***

# ANNEX I

## HAZARD IDENTIFICATION

# ANNEX I - *Hazard Identification*

For brevity, the full Hazard Identification report has been omitted in this document. The full report is publicly available at the SAFEDOR public website at:

http://www.safedor.org/resources/index.htm under the heading "Documents"

# ANNEX II

## RISK ANALYSIS OF CRUISE SHIPS

# ANNEX II - *Risk Analysis*

## Contents

# Abbreviations

| | |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| CAF | Cost of Averting a Fatality |
| CBA | Cost Benefit Analysis |
| DNV | Det Norske Veritas (www.dnv.com) |
| FSA | Formal Safety Assessment |
| GNP | Gross National Product |
| GRP | Glass Reinforced Plastic |
| GRT | Gross Registered Tonnage |
| HAZID | Hazard Identification |
| HSC | Health and Safety Commission (UK) |
| HSE | Health and Safety Executive (UK) |
| IMO | International Maritime Organization (www.imo.org) |
| LRFP | Lloyds Register Fairplay accident database |
| LSA | Life Saving Appliances |
| LWFS | Lloyds World Fleet Statistics |
| NCAF | Net Cost of Averting a Fatality |
| RCO | Risk Control Option |
| SWIFT | Structured What-If Technique |

# 1 Introduction

The FSA for cruise ships – is described in three Annexes:

- Annex I – Hazard identification
- Annex II – Risk analysis
- Annex III – Cost benefit analysis and recommendations

This annex is the result of the Risk Analysis of the project, and will evaluate the cruise shipping's risk exposure from the main hazards identified in Annex I. This first section is a brief description of the methodology used in the above mentioned Annex.

This report is largely based on MSC Circ. 1023/MEPC Circ 392, 'Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process', IMO, 2002.

## *1.1 Hazard identification (Annex I)*

In the first phase, the Hazard Identification, the different hazards which define the risk environment for cruise shipping were identified. The methodology used to derive the hazards is described in detail in Annex I, but in short:

The identified risk picture was derived from historical statistics and workshops that identified hazards related to operation and design. Twelve (12) hazards were prioritized based upon their *frequency* of occurrence and severity of *consequence* which was measured in number of fatalities. The focus was on hazards with *high consequences* and *low frequency* rather than low consequences and high frequency.

The major hazards are represented by five main areas:

- Collision:
    - Officer on duty not watch-keeping
    - Failure of critical navigational aids (in fog)
    - Severe loss of functionality (e.g. loss of rudder/steering at full speed)
    - Lack of knowledge of navigating procedures
    - Misinterpretation of bridge information
- Grounding:
    - Similar to collision
- Contact:
    - Similar to collision
- Fire:
    - Arson - deliberate act resulting in a fire. Could be anywhere, anytime
    - Galley - deep fat fryers/greasy cooking appliances catching fire (due to overheating)
    - Engine room - flammable fluids on hot surfaces
    - Laundry - ignition of lint from tumble driers
    - Cabins - fire starts in cabin (cigarettes, candles, electrical equipment failure etc)
- Tender operation:
    - Tender boat failure - structural failure
    - Tender boat operations, in particular related to launching/retrieval

- Tender boat davit failure

The hazard identification work revealed that the tender boat operation, transporting passengers from the mother ship to the shore has inherent risks, mainly within the hazard areas mentioned above. However, the overall purpose of the project is to evaluate the operation and design of cruise ships, and not tender boat operation. Hence, tender boat operation is not analysed further.

## *1.2 Risk analysis*

In this document the hazards from Annex I are used to define the risk exposure. Risk is defined as the frequency of an event considered together with the associated consequence (which is expressed using the estimated number of fatalities). Risk is calculated using the product of the *frequency* of occurrence for an accident and the corresponding *consequence* (measured in terms of fatalities).

Risk analyses are carried out by estimating the frequency and consequence separately. The estimated *frequencies* are used as the initiating frequencies in the event trees. Frequencies for escalating events are then distributed throughout the event trees for a corresponding range of different *consequences*.

In Annex I the main hazards were identified. These hazards indicate areas where there is a potential for things to go wrong leading to a fault, either technically or through human error. The main purpose of the risk analysis, is to determine the frequency of these faults and determine the corresponding consequences, expressed as expected number of fatalities for each event.

Figure 1-1 below is added to illustrate the connection between a fault tree (frequency) and event tree (consequence). It should be read bottom up, illustrating how an initiating fault can cause a potential large scale accident.

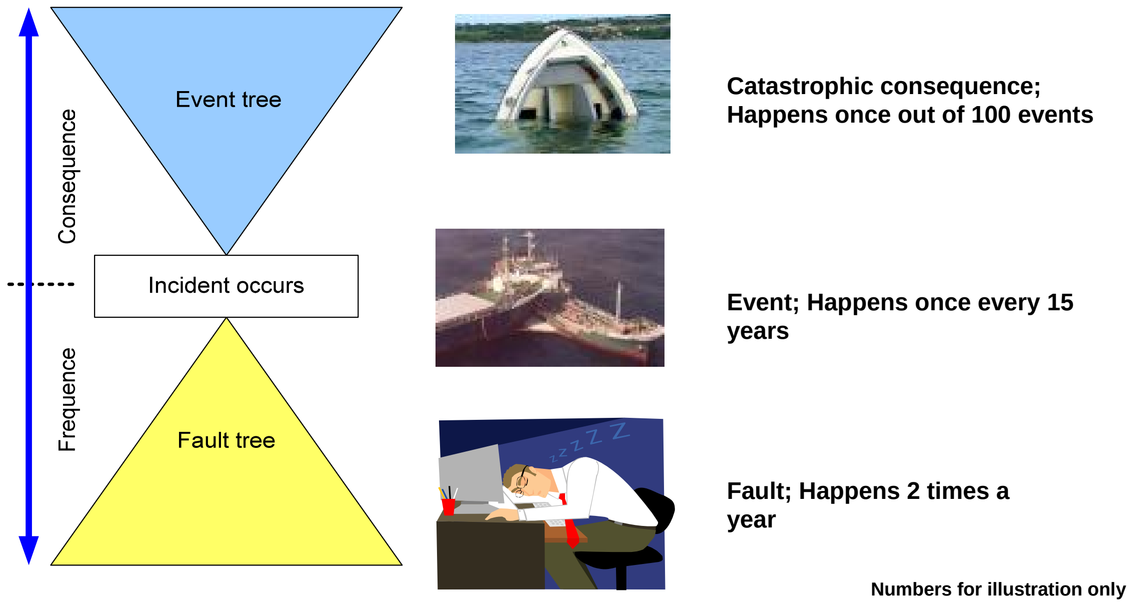


**Figure 1-1: The connection between fault and event trees**

Risks can be quantified by:

- Using past statistics,
- Risk modelling methods, or,
- A combination of the above two.

It should be noted that statistics only represent the past and do not take account of recent technical or operational developments, new requirements, or specific arrangements on the ship being analysed. Risk modelling is proactive and intends to determine the likelihood or consequence of future events. The disadvantage is that a risk model is only as good as the information put into it, and has to be structured correctly. It is important to use up-to-date and relevant statistical information in conjunction with risk models to ensure that the output is realistic.

Historical data will be used to derive accident frequencies. The frequencies will not be adjusted for the effect of new regulations and other factors which might have influenced the overall risk pictures over the last years. The accident frequencies will be applied to risk modelling through event tree distributions to help develop consequence estimations. The event trees have been developed based on hazid workshops; more about this in Section 7 of this report.

## *1.3 Cost benefit analysis and recommendations (Annex III)*

In the third part of the FSA, key risk control options (RCOs) will be identified. The RCOs will then be assessed through cost/benefit analysis using IMO recommended methods and criteria. The assessment will consist of two parts:

- Estimation of risk reducing effect of RCOs
- Evaluation of cost/benefits of RCOs

The risk may be reduced either through reduction of frequency or mitigation of consequence, or both. RCOs will be identified related to both frequency and mitigation. Where the risk is intolerable, RCOs will be recommended for implementation irrespective of their cost. Where the risk is tolerable, only cost effective RCOs according to IMO criteria will be recommended.

# 2 Uncertainties and assumptions

The results and numbers presented in this report are not to be interpreted as precise numbers, as there are several uncertainties in the presented statistical material, as well as assumptions and simplifications made during the risk modelling process.

## *2.1 Uncertainties*

The accident statistics are based on the LRFP (Lloyd's Register Fairplay) database. The database is one of the most extensive resources available for merchant ship accident information. The entries are recorded based on accident reports from Lloyd's agents throughout the world. However, there are at least two reasons to assume that the accident database is not complete:

- Not all (smaller) accidents occurred have been recorded.
- Not all accidents have been brought to the attention of the Lloyd's Register Fairplay agents and therefore not be recorded.

In general, low reporting produces relatively optimistic results with respect to accident frequency. Adding to this, for cruise ships, the number of entries in the LRFP database is rather low due to the small fleet size. This provides a limited statistical database for estimating the current risk level for the cruise industry. In addition the number and size of cruise ships are increasing significantly and the effect of this on accident frequency and consequence will not be evident until these vessels have operated for a period. It is a major point that the past risk picture does not necessarily represent what will occur in the future, and that future accident consequences may arise due to failures in areas other than the ones covered in this study, which has mainly been based on historical events.

Historically, few accidents have occurred with cruise ships. However, the lack of previous large scale accidents does not necessarily mean that a certain event cannot happen. The result from the modelling is therefore the best estimate on what is the actual risk level for cruise ships. In order to predict the present and future risk level it is not enough to look only in the rear-view mirror. Statistics, as a supplement to modelling, will, however, provide further confidence in estimated results.

This study considers fatalities on the vessel under consideration only, i.e. the cruise ship, and not fatalities on other vessels that might be involved in an accident.

The statistical data used for this report is covering a period of 15 years, from 1990 up to 2004. The rapid development of the cruise industry means that the most novel safety enhancing measures are not reflected in this study. This means that the assessed risk level for modern cruise ships in this study may be pessimistic. The cost-benefit effect of certain key RCOs will be evaluated using the IMO recommended methods and criteria.

## *2.2 Assumptions*

### 2.2.1 Assumptions on reference ship parameters

The risk assessment has been based on a modern “Post Panamax” cruise ship[1]. This vessel is assumed to represent an average vessel in the future world cruise fleet.

The following table summarizes the assumed ship parameters for this project:

Table 2-1 Reference ship parameters

| **Ship parameters** | **Value** |
|---|---|
| Size | 110,000 GRT |
| Speed | 22 knots |
| Passengers | 2,800 |
| Crew | 1,200 |
| Passengers + Crew | 4,000 |
| Length | 290 m |
| Draft | 8.5 m |
| Breadth | 36 m |

### 2.2.2 Assumptions on fleet size

The assumed size of the world cruise fleet is important for two reasons:

1. The statistics used in the risk modelling processes need to be applicable to the future world fleet of cruise ships.
2. Any results of risk modelling need to be expressed in realistic terms. If small ships, incapable of being involved in the large fatality events assumed in the study, are included in the assumed world fleet, the results will not show a realistic picture.

Hence, the following assumptions have been made:

1. Events for ships in the LRFP database below 20,000 GRT were not included in the input statistics because it was assumed that, on average, they were older and not representative of future cruise ships or not the vessels in focus here.
2. The decision was made to report results in terms of the number of years of operation of the current world fleet. Consequences assumed for the reference ship (maximum worst case consequence 4,000 fatalities) could only be incurred by a small proportion of the current world fleet. Therefore, to develop realistic estimations of numbers of fatalities that could be incurred in the current world fleet the following was carried out:
    a. Three (3) different sizes of ship were selected. These represented 3 ship size bands that, when summed, total the cruise fleet at the current time.

[1] A ‘Post-Panamax’ vessel is defined as a vessel where the beam of the hull is greater than 32.5 metres, and hence cannot pass through the Panama Canal.

i. Reference ship 01: A Post Panamax vessel which is expected to represent an average sized ship in the next 10 years. Data was taken from *M/S Carnival Conquest* for reference ship particulars.

ii. Reference ship 02: A Panamax vessel which is deemed to be the most common size for the larger Cruise operators. Data was taken from *M/S Costa Victoria* for reference ship particulars.

iii. Reference ship 03: A common size for smaller cruise operators. Data was taken from *M/S Norwegian Majesty* for reference ship particulars.

b. The numbers of fatalities in each consequence scenario in the event trees were then estimated for each ship size.

c. These estimations were incorporated into calculations in order to estimate fatality levels in the world cruise ship fleet. The selected ship parameters were as follows:-

**Table 2-2 World Fleet Cruise Ship Size Bands**

| **Reference Ship** | Reference Ship 01 | Reference Ship 02 | Reference Ship 03 |
|---|---|---|---|
| GRT | 110,000 | 75,200 | 40,876 |
| Persons on board | 4,000 | 2,728 | 2,080 |
| Ship size band | >90,000 GRT | 60,000 - 90,000 GRT | 20,000 - 60,000 GRT |
| Number of cruise ships in the world fleet falling within this band. | 30 | 53 | 89 |

### 2.2.3 Assumptions on frequencies

The accident frequencies are based on Lloyds Register Fairplay (LRFP) accident database which categories the accident with the following 3 labels:

- **Minor damage** - any event reported to LRFP and included in the database, not being categorised as serious casualty or total loss.
- **Serious casualty** - breakdown resulting in the ship being towed or requiring assistance from ashore; flooding of any compartment; or structural, mechanical or electrical damage requiring repairs before the ship can continue trading. In the LRFP context, serious casualty does not include total loss.
- **Total loss** - where the ship ceases to exist after a casualty, either due to it being irrecoverable (actual total loss) or due to it being subsequently broken up (constructive total loss). The latter occurs when the cost of repair exceeds the insured value of the ship.

In the database, there is an underreporting of accidents labelled “Minor damage” and this has lead to the fact that there are more “Serious casualties” than “Minor damages”. This is clearly not a correct picture of the real world, where it is normal to have more minor incidents happening than major incidents. The accident frequencies presented in the following is therefore based on the categories labelled: “Serious casualty” and “Total loss”, while the accident categorised as “Minor damages” has not been included, as the statistics are found to be unreliable. Hence it is assumed that the minor damages do not represent risk for personnel.

# 3 Cruise industry

The following short synopsis provides a brief background into cruising, current market trends and developments. It also provides background information relating to safety and security and an outlook on the future.

## 3.1 Markets, trends and development

Demand for cruising continues to grow faster than for any other type of mainstream holiday. Cruising is now a mainstream rather than the niche holiday choice, with an average annual passenger growth rate of 7 percent over the past decade.

Economic numbers for 2004 show passenger carryings increased more than 10 percent for a total of 10.85 million global cruise passengers.

North America continues to be the main source of passengers. U.S. residents totalled 8.3 million accounting for 77 percent of the industries global passengers.

A 2004 study sponsored by Cruise Lines International Association (CLIA) found that nearly 30 million Americans will likely cruise within the next three years, ref /1/.

The current world wide cruise fleet, above 4,000 GRT (~>100 m), stands at 264 ships (2004) whereas 172 of these ships are above 20,000 GRT, according to LRFP. For the purpose of this report, we have used ships above 20,000 GRT only.

With more ships, cruise lines are introducing new itineraries and expanding the choices of destinations, departures and cruise lengths.

## 3.2 Safety & security

The cruise industry's highest priority is to ensure the safety and security of its passengers and crew. During the past two decades, North American cruise lines have compiled the best safety record in the travel industry while transporting, entertaining and pampering more than 90 million people throughout the world.

Security measures have always been stringent, but increase in times of heightened alert. In 2004, ships and port facilities worldwide were subject to new international security regulations through the International Ship and Port Facility Security (ISPS) Code. All cruise ships are now in compliance with the ISPS Code, which requires all ships and port facilities worldwide to have formal security plans and processes in place.

All cruise ships are subject to various local, national and international rules and requirements relevant for safe operation and construction. The cruise ships must meet safety standards set by the International Maritime Organization enforced through the International Convention for Safety of Life at Sea (SOLAS). Cruise ships operating from U.S. ports are subject to U.S. federal and state regulations as well as periodic safety inspections by the U.S. Coast Guard. Personal health onboard is a prioritized issue onboard and in the USA this is handled by US Public Health. According to the U.S. Coast Guard, cruise ships operating from U.S. ports continue to be the safest form of mass transportation, ref /2/.

## 3.3 The future

Despite a series of major events around the world in recent years, the cruise industry has shown its resilience and ability to recover from difficult trading conditions, and the cruise market is recognised as the fastest growing sector of the UK travel industry, ref /3/.

New orders for large cruise ships continue for the industry's shipbuilders. The order-book for 2007 now stands at record heights in terms of the levels of investment being made by the industry and with occupancy levels at well over 100 per cent (i.e., increased occupancy in cabins with use of upper berths) across all the leading operators the industry may already be reaching its capacity limits. This suggests that further investment is probably needed if the industry wishes to continue the momentum that it has experienced over the last two decades and more. Continued globalisation will also assist in this process, with North American sourced tonnage increasingly moving back into Europe and other parts of the world, although home-porting by the industry look set to stay in North America for the foreseeable future. Growth in other markets, including the Far East, is also expected in the near future, ref /4/.

It is also of note that the vast majority of new orders are for the so called Post Panamax ships, with GRT of up to 170,000 carrying up to 5,000 passengers. At the time of this writing, Aker Finnyards, part of the Aker Yards industry group has been awarded the work for a record 220,000 GRT cruise ship from RCCL. The ship, a prototype developed under the project name "Genesis", will be delivered from Aker Finnyards in autumn 2009. The ship will have a capacity of 5,400 passengers.

These ships will challenge the industry to ensure and maintain the safety record that it currently has.

# 4 Tender boat operation

During the hazard identification phase, tender boat operation was highlighted as a potential problem and it was proposed that further risk analysis should be carried out on this subject. The main concerns highlighted from the Hazid (Annex I) are listed below:

1. Tender boat failure – structural failure
2. Tender boat operations, in particular related to launching/retrieval
3. Tender boat davit failure.

Tender boats are normally dual purpose crafts specially designed to operate as a tender or lifeboat. Their primary task from a safety perspective is as a lifeboat, but from a usage perspective they spend more time afloat in the tender mode. What follows is a short summary explaining the nature of tender boat operations.

## 4.1 Tender boat operation

Tender boat operation involves using a number of the ship's lifeboats to transfer passengers from the ship to the shore-side destination when the ship cannot berth alongside a quay. These may include inadequate size of berth for ship, inadequate draft requirements or merely due to the fact that the quay is already full to capacity. Obviously the situation is known well in advance and provisions are made to make sure all the necessary checks and preparations are carried out before the port of call.

Passengers are transferred from the ship using a ships tender/lifeboat to the shore-side destination. On modern cruise ships passengers embark the tenders from the tender embarkation platforms located on deck 3 just above sea level. On older vessels the passengers have to climb down an embarkation ladder. The embarkation ladder is in effect a gangway and not a rope ladder as implied. The launching and retrieval of the lifeboat is not carried out during the tender operation, and is only carried out by trained crew.

## 4.2 Tender boat structural failure

This should really be described as lifeboat/tender structural failure as these are the same thing. Damage to the GRP (Glass Reinforced Plastic) of a lifeboat can occur from hard landings with the ships side or shore-side quay. Lifeboats are subject to a rigorous testing and inspection regime and therefore structural damage to the boats is picked up quickly and repairs are usually undertaken onboard if minor, or at the next port of call. It is therefore extremely unlikely that damage to a lifeboat through hard landings will develop into a structural failure. Structural damage is most likely due to collision with another tender or vessel or through grounding in which the structural failure is often secondary to the incident. Incidents of this nature are rare. Occasional damage to canopies and windows due to heavy weather can occur, however.

### *4.3 Tender boat davit failures*

Again, the launching and retrieval of lifeboats using davits, falls and hook arrangements are not part of the tender operation. The boats are launched and prepared for the tender operation only by trained and experienced crew, during which only crew members are onboard.

There are many potential hazards inherent in tender boat operation although these are widely known to the crew and officers working onboard. There is a high level of training given to crew and a high safety culture onboard the ships. Therefore in practice although there is a high potential for accidents, there are few accidents involving tender boat operations due to the safety and management regimes carried out as best practice.

There have been a number of reported accidents relating to lifeboats and their launching and retrieval systems. The industry is currently looking into the commonly used systems and arrangements and endeavouring to develop better fail safe designs. However, the subject of LSA (Life Saving Appliances) are not a specific part of this FSA. Here potential hazards and mitigating measures for lifeboats/tenders will be discussed and developed further.

In summary, the tender boats' contribution to the overall risk level is qualitatively evaluated to be negligible. Arguments for neglecting the risk from tender boat operations are:

- No historic major events have occurred during tender boat operation.
- The potential for a large scale accident is very remote (short trips, competency of crew/safety regime, sheltered water).

For these reasons it has been decided not to model tender boat operations in this risk analysis.

# 5 Risk Evaluation Criteria

Before assessing the estimated risk of potential hazards onboard a cruise ship, an appropriate risk acceptance criteria for cruise ships should be established prior to, and independent of, the actual risk analysis. The following quote is taken from MSC 72/16: "The term risk acceptance is established in many industries and regulations; however, it is worth noting that the term itself can be misleading. The risk is not acceptable, but the activity might imply the risk to be acceptable because of the benefits."

It is therefore important to make the distinction between risk *tolerability* and risk *acceptability*:

The general public accept risk when they undertake an activity by choice even when the activity is hazardous (including driving cars), but will only *tolerate* risk that they perceive to be imposed on them (e.g. when travelling by train). By contrast, companies have to *accept* a level of risk relevant for their activities.

It could be concluded from the above that this document should be dealing with risk tolerability levels as opposed to risk acceptability levels as this reflects the fact that the risks inherent in cruise ship operation are imposed on individuals rather than accepted by them.

Some experts prefer to use the term "risk evaluation criteria" rather than "risk acceptance criteria". The terminology "risk evaluation" is the official term at IMO (FSA Guidelines) and reflects the observation that risks are not accepted; it is the decisions involving risks that are accepted because their benefits outweigh the risks.

This report will then use the term "risk evaluation criteria".

Risk evaluation criteria normally place the risk in one of three categories; unacceptable, tolerable and broadly acceptable. These categories are further described below, however, for further details refer to the IMO FSA Guidelines:

| | |
|---|---|
| Intolerable: | • Risk level is intolerable. Risks must be reduced irrespective of costs. |
| Tolerable (ALARP): | • Risk level is tolerable provided that risks are managed to ALARP (As Low as Reasonably Practicable). |
| | • Risks shall be reduced as long as the risk reduction is not disproportionate to the costs. |

| | | |
|---|---|---|
| | • | Need only to implement cost beneficial Risk Control Options (RCOs) |
| Broadly acceptable: | • | Risk level is negligible. Not necessary to consider RCOs. |

In the following the modelled risk level for cruise ships will be evaluated using risk evaluation criteria concerning individual risk and societal risk. The two terms are described in detail in the following sub chapters.

## *5.1 Individual risk*

Individual risk is defined in the HAZID as the frequency for an individual fatality per year. It is the likelihood that the most exposed crew member or passenger will die as a result of an accident or event onboard a cruise ship. This report only considers events related to ship operation. Personal accidents due to leisure activities and occupational risks are not considered to be within the scope of the report. As explained in Annex I the individual risk evaluation criteria are defined as:

**Table 5-1  Individual risk evaluation criteria**

| **Risk criteria** | **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 |

The individual tolerability criteria for crew members and passengers are plotted in a diagram to illustrate more clearly how the criteria defines intolerable, ALARP, and negligible risk levels, see Figure 5-1:

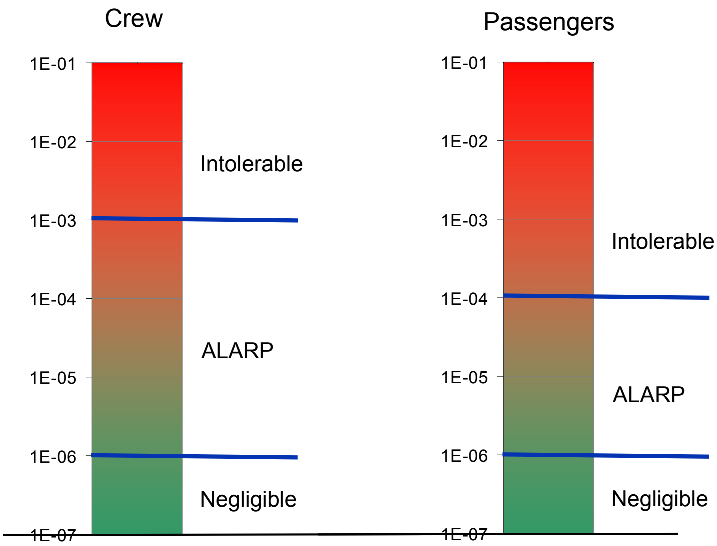


**Figure 5-1:  Individual risk evaluation criteria**

The criterion shows that higher risk is tolerable for crew members than for passengers. This is due to the fact that the crew members are exposing themselves voluntarily to the risk, and are gaining financial benefit from the operation of the cruise ship. The crew therefore accept the higher level of risk. Furthermore it should be noted that the crew members are more aware of their occupational inherent risks and have been trained to carry out their job responsibilities safely and effectively.

The upper/lower limits defining tolerable/negligible levels have been established based on values from Table 5-1. The above form the basic criteria and should be adhered to as a minimum standard, however it may not be uncommon for individual operators to impose a more stringent or demanding target.

## *5.2 Societal risk*

For some activities or projects of a large size with potential for multiple fatalities, a demand for other risk evaluation criteria additional to the criteria for individual risk may be required. This is referred to as societal risk, and is described further below.

### 5.2.1 Societal risk guidance

A societal risk criterion takes the possibilities of catastrophic accidents of major societal concern into account to ensure that the risks imposed on the society from the activity are controlled.

Depending on the system under consideration, both individual and societal risk evaluation criteria might apply. For large systems exposing a large number of people to risks, and where a large number of people are affected by possible accidents, societal risk evaluation criteria are deemed to be most appropriate by some parties.

Developing and justifying societal risk criteria is not as straightforward as for individual risk and there is continual debate as to whether the methodologies adopted are flawed. FN curves are however, a common way of presenting societal risk and are considered by some parties the best way of illustrating this data. A more thorough discussion around the use of FN curves is detailed in Appendix A.

The societal risk evaluation criteria used in this study is based upon the method presented in the IMO paper MSC 72/16, ref /5/, where the risk evaluation criteria may be associated with the economic importance of the activity. Calculations have been performed and results obtained using the method further described in Appendix A.

### 5.2.2 Societal risk evaluation criteria

The purpose of societal risk criteria is to limit the risks from ships to society as a whole, and to local communities which may be affected by ship activities. The societal risk evaluation criteria should reflect the importance of the activity to society. FN diagrams may be established as a way to illustrate societal risk. An FN curve displays the societal risk in a log log diagram, where number of fatalities (N) is given on the x-axis and the frequency per ship year for N or more fatalities is given on the y-axis.

The method for deriving societal risk evaluation criteria in this report is based on *IMO MSC 72/16 – Decision parameters including risk acceptance criteria,* ref /5/. The risk level is plotted as a cumulative function of consequence and frequency on a log-log graph. The area underneath the line is defined by the following expression which is commonly accepted by several parties (ref /6/, /7/, /8/):

$$F_1 = \frac{r * EV}{\sum_{N=1}^{N_u} \frac{1}{N}} \quad (1)$$

Where:

$F_1$= is the frequency of accidents involving one or more fatalities

$N_U$ is the upper limit of the number of fatalities that may occur in one accident.

r Number of fatalities due to transportation divided by contribution to GNP by transportation. It can be calculated as r = fatalities/$ GNP.

EV The economic value of the industry. In this case, the EV here is represented by a reference vessel and is derived from the income from cruise voyages.

The ALARP area can now be defined by use of formula (1). A more detailed background for the formula and values used in the calculation, are presented in Appendix A. The upper and lower limit for the ALARP area is presented in **Table 5-2**.

**Table 5-2 Limits for societal risk**

| Parameters for societal risk criteria | Value | Denomination |
|---|---|---|
| F upper (dotted line between ALARP and Intolerable) | $6.9\ 10^{-1}$ | fatalities |
| F lower (dotted line between ALARP and Negligible) | $6.9\ 10^{-3}$ | fatalities |

The FN diagram below is derived from the above tables and formulas. In the FN diagram, the risk evaluation criteria line will decrease with a factor of -1 on a log-log scale. Between the negligible/ALARP region and ALARP/intolerable region (acceptability criteria) there is two orders of magnitude difference.

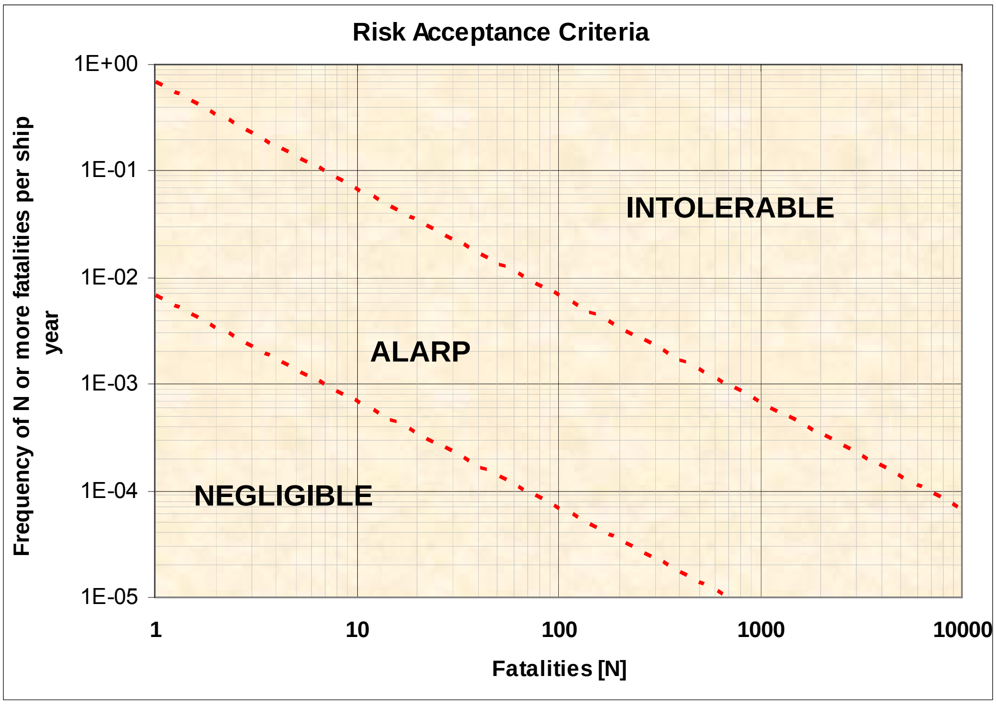


**Figure 5-2: Societal risk evaluation criteria**

The above FN diagram implies that, in general, society would find intolerable some 10 or more fatalities every 10 ship years (the borderline between ALARP and Intolerable), or 100 or more fatalities every 100 ship years or so. This does not imply that risks below this criteria line are acceptable. The implication is that cost benefit analysis can be applied, and that risks should be further reduced to As Low as Reasonably Practicable. However this diagram raises a question concerning the position of the criteria line between intolerable and tolerable.

The next step is to investigate whether the actual risk to which the cruise industry is exposed is within the ALARP (tolerable) or negligible area.

# 6 Accident frequencies

This section attempts to determine the accident frequencies of the hazardous events identified. The hazards are referred to as accident types. A short description of each accident type is provided below, followed by frequency calculations.

## 6.1 Accident type definitions

**Collision**

Striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking underwater wrecks.

**Contact**

Striking or being struck by an external substance but not a ship or the sea bottom. This category includes striking drilling rigs/platforms, regardless of whether in fixed position or in tow.

**Grounding**

Includes ships reported hard and fast for an appreciable period of time and cases of reported touching of the sea bottom. This category includes entanglement on underwater wrecks.

**Fire/explosion**

Where the fire and/or explosion is the first event reported (except where first event is hull/machinery failure leading to fire/explosion)

**Other**

Accident causes not fitting into one of the four above categories.

## 6.2 Accident frequency calculations

In order to determine the accident frequencies, fault trees can be used. A fault tree provides a structured system to model the final (top event) accident frequency from a set of initiating faults. However, in this FSA study, the fault trees models have not been used to determine the accident frequencies. Instead, the accident frequencies have been determined by use of historical accident data.

The fundamental way to calculate accident frequencies is to divide the number of accidents recorded in a given period by the corresponding exposure for that period.

$$\frac{Accidents\ reported\ during\ a\ period\ of\ x\ years}{Number\ of\ ship\ years\ acumulated\ during\ x\ years} = Incidents\ per\ ship\ year$$

Lloyds Register Fairplay (LRFP) accident database has been used as source for cruise accidents reported, while Lloyd's World Fleet Statistics (LWFS) has been used to derive the exposure of the cruise fleet. It should be noted that the number of accidents presented in this chapter does not include minor incidents, as previously discussed, as these are under-reported in the database.

### 6.2.1 Cruise ship exposure and accident trends

**Table 6-1** shows the cruise fleet development for vessels > 20,000 GRT since 1990. A ship year is defined as one ship sailing for one year. It should be noted that the number of large ships has increased during recent years. For the reasons of making a distinction between "smaller" cruise ships and "large" cruise ships, the following tables have been split into two category groups (20-60,000 grt and > 60,000 grt).

| Table 6-1 Cruise fleet 1990-2004 [in fleet year] | | | |
|---|---|---|---|
| **Year** | **20,000 - 60,000 GRT** | **> 60,000 GRT** | **Total (> 20,000 GRT)** |
| 1990 | 66 | 11 | 77 |
| 1991 | 66 | 11 | 77 |
| 1992 | 66 | 11 | 77 |
| 1993 | 66 | 11 | 77 |
| 1994 | 77 | 12 | 89 |
| 1995 | 81 | 17 | 98 |
| 1996 | 84 | 23 | 107 |
| 1997 | 82 | 27 | 109 |
| 1998 | 84 | 34 | 118 |
| 1999 | 88 | 35 | 123 |
| 2000 | 91 | 48 | 139 |
| 2001 | 94 | 57 | 151 |
| 2002 | 96 | 66 | 162 |
| 2003 | 92 | 74 | 166 |
| 2004 | 89 | 83 | 172 |
| **Total** | **1222** | **520** | **1742** |
| % | 70 % | 30 % | 100 % |

*Source: Lloyd's World Fleet Statistics, volume 1991-2005*

Statistics prior to 1990 are not thought to represent today's safety level for cruise ships. Also, the smallest ships in the fleet are not comparable to the reference ship (of 110,000 GRT). Thus, vessels below 20,000 GRT have been *excluded* when calculating the frequencies. Below, the accident records and fleet exposure are presented in tabular format. A table listing all the accidents is given in Appendix F.

| Table 6-2 Cruise ship accidents 1990-2004, by year [in number] | | | |
|---|---|---|---|
| **Year** | **20,000 - 60,000 GRT** | **> 60,000 GRT** | **Total (> 20,000 GRT)** |
| 1990 | 2 | 0 | 2 |
| 1991 | 2 | 0 | 2 |
| 1992 | 1 | 1 | 2 |
| 1993 | 1 | 0 | 1 |
| 1994 | 2 | 0 | 2 |
| 1995 | 3 | 1 | 4 |
| 1996 | 3 | 0 | 3 |
| 1997 | 4 | 0 | 4 |
| 1998 | 2 | 2 | 4 |
| 1999 | 5 | 4 | 9 |
| 2000 | 5 | 4 | 9 |
| 2001 | 6 | 2 | 8 |
| 2002 | 4 | 2 | 6 |
| 2003 | 7 | 5 | 12 |
| 2004 | 5 | 4 | 9 |
| **Total** | **52** | **25** | **77** |
| % | 68% | 32% | 100% |

*Source: Lloyds Register Fairplay (LRFP) accident database, volume 2005*

For cruise ships there are a total of 77 accident entries in LRFP from 1990-2004 for cruise ships > 20,000 GRT (in fact, there are 80 registered in LRFP, but some of these have been omitted because they occurred during construction, repair or sea trial, and by such they do not represent the normal operational mode for which the accident scenarios were identified). The 77 entries will be used in the accident frequency calculations.

As can be seen from above tables, compared to the number of vessels within each size segment, there is a relatively equal distribution of accidents for the large and the small size segment. Ships between 20,000 GRT and 60,000 GRT make up 70% of the exposure and 68% of the accidents, while vessels > 60,000 GRT makes up 30% and 32% respectively.

The table below has been compiled to show whether there has been an increasing or decreasing accident trend. The table takes into account the significant increase in the number of cruise ships that have entered the market during the last decade – particularly for vessels > 60.000 GRT. By doing so, we can conclude that the accident rate – measured in accidents per ship year – has shown an increasing trend during the last decade, albeit the last years has shown more positive signs:

**Table 6-3 LRFP Cruise ship annual accidents frequencies 1990-2004**

| Year | Ships > 20,000 GRT | | |
|---|---|---|---|
| | **Accidents** | **Ship years** | **Frequency [accidents / ship year]** |
| 1990 | 2 | 77 | 2.6E-02 |
| 1991 | 2 | 77 | 2.6E-02 |
| 1992 | 2 | 77 | 2.6E-02 |
| 1993 | 1 | 77 | 1.3E-02 |
| 1994 | 2 | 89 | 2.2E-02 |
| 1995 | 4 | 98 | 4.1E-02 |
| 1996 | 3 | 107 | 2.8E-02 |
| 1997 | 4 | 109 | 3.7E-02 |
| 1998 | 4 | 118 | 3.4E-02 |
| 1999 | 9 | 123 | 7.3E-02 |
| 2000 | 9 | 139 | 6.5E-02 |
| 2001 | 8 | 151 | 5.3E-02 |
| 2002 | 6 | 162 | 3.7E-02 |
| 2003 | 12 | 166 | 7.2E-02 |
| 2004 | 9 | 172 | 5.2E-02 |
| Total: | 77 | 1742 | 4.4E-02 |

The above data is illustrated in Figure 6-1 . The blue line is the plotted accident frequency for each year and the black line is the best-fitted trend-line to the data series.

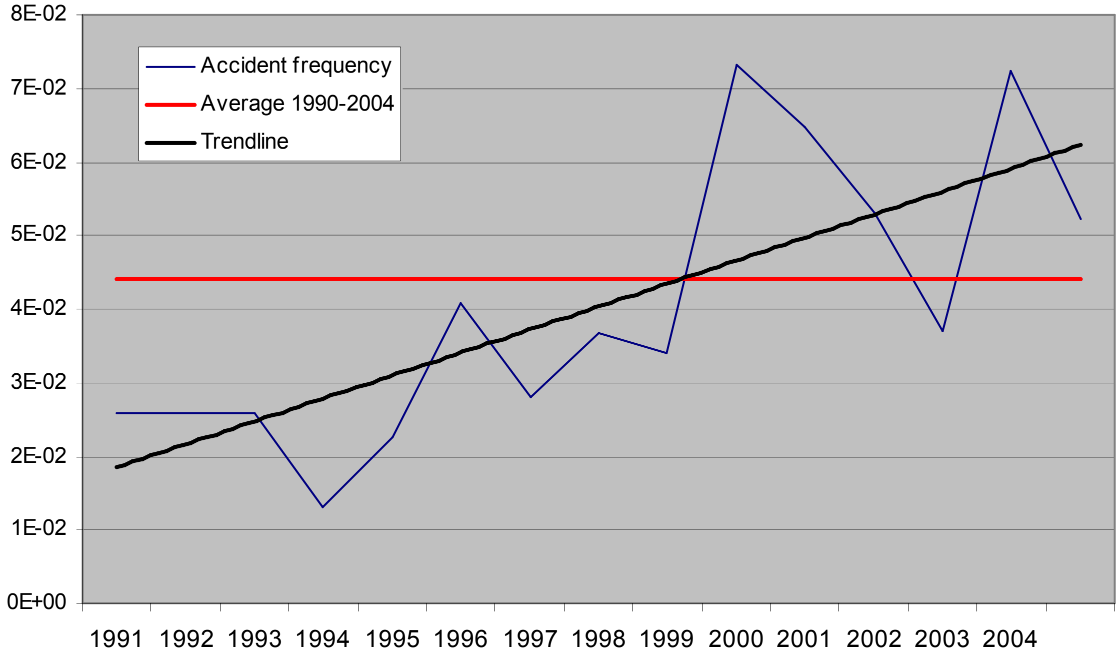


**Figure 6-1: Historic accident frequency, isolated year-by-year plot (per ship-year)**

### 6.2.2 Ship accidents by type

Finally, Table 6-4 shows accidents distributed on accident type.

**Table 6-4 Cruise ship accidents 1990-2004, by type**

| Accident type | 20,000 – 60,000 GRT | > 60,000 GRT | Total |
|---|---|---|---|
| Collision | 7 | 1 | 8 |
| Contact | 1 | 1 | 2 |
| Grounding | 13 | 4 | 17 |
| Fire/Explosion | 12 | 4 | 16 |
| Other | 19 | 15 | 34 |
| **Total** | **52** | **25** | **77** |
| % | 68% | 32% | 100% |

*Source: Lloyds Register Fairplay (LRFP) accident database, volume 2005*

The “Other” category covers mainly hull and machinery related incidents, where, historically, the number of fatalities has been low. The “Grounding” and “Fire/Explosion” categories dominate the list of relevant historical events. The “Other” category has not been further modelled in the study, as the statistics have been used directly.

### 6.2.3 Frequency calculation

Ships between 20,000 and 60,000 GRT, and ships > 60,000 GRT make up the accident history. By adding these two size segments, the historic accident input values will be 8 collisions, 2 contacts, 17 groundings, 16 fire/explosions, and 34 other accidents, mostly consisting of hull/machinery damage.

Similarly, the exposure has been 1,742 ships years (1,222 + 520) during the 1990-2004 period. 1,742 ship years will be used for the accident frequency calculations. The frequency calculations can be summarized as following:

| Table 6-5 Accident frequency calculations, vessels > 20.000 GRT | | | | | | |
|---|---|---|---|---|---|---|
| **Cruise ship** | **Collision** | **Contact** | **Grounding** | **Fire/Exp.** | **Other** | **SUM** |
| **Ships >20,000 GRT** | | | | | | |
| LMIS accidents recorded 1990-2004 | 8 | 2 | 17 | 16 | 34 | 77 |
| Ship years 1990-2004 [ship years] | 1,742 | 1,742 | 1,742 | 1,742 | 1,742 | 1,742 |
| **Cruise ship accident frequency [per ship year]** | **4.6E-03** | **1.2E-03** | **9.8E-03** | **9.2E-03** | **2.0E-02** | **4.4E-02** |
| Return period [no. of ship years per accident] | 218 | 871 | 102 | 109 | 51 | 23 |
| Number of fatalities, 1990-2004 | 0 | 0 | 0 | 21 | 1 | 22 |

The table shows how the number of accidents is divided by number of corresponding ships years to derive the accident frequencies for the different accident types. The calculated frequencies will serve as input to the event trees, where the consequences of the accidents are modelled.

It should be noted that, of the fire/explosion related fatalities, 16 of the 21 fatalities were onboard SS Norway (built 1961); four incurred onboard the Achillo Lauro (built 1947); one incurred onboard the Fairstar (built 1957).

The number of accidents with fatalities (only 4 accidents) is too few to represent any significant accident trend or picture.

## 6.3 Accident frequencies summary

The following numbers are the calculated accident frequencies for all four incident areas identified. *Grounding* has the highest frequency closely followed by *fire/explosion:*

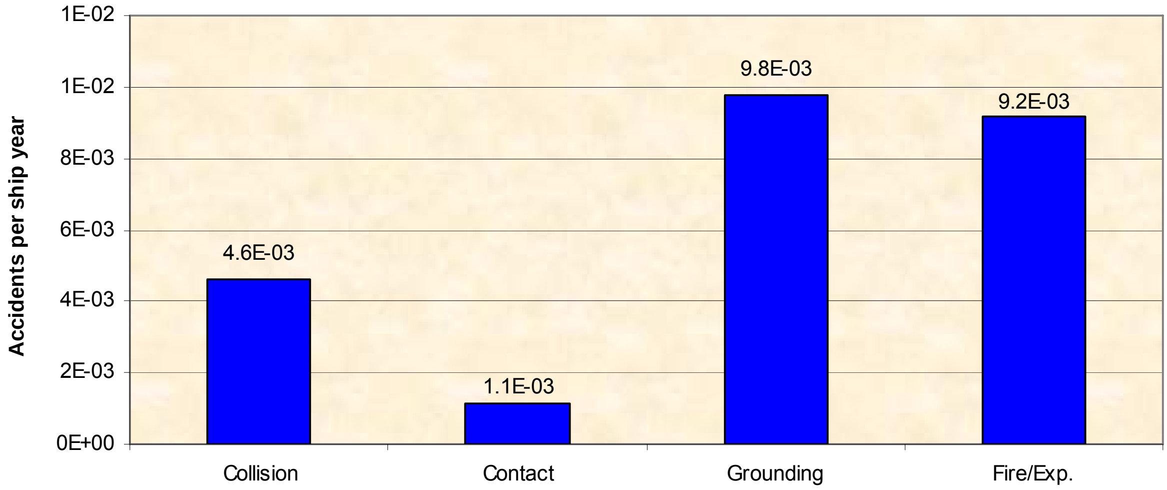


**Figure 6-2: Accident frequencies (vessels > 20,000 GRT)**

From a cruise operator's point of view, fire could be considered as the most likely event, however most of the fires incurred are either minor and self extinguished or are put out by cabin occupants. This type of fire incidents are rarely reported and are therefore not recorded in the LRFP database. The calculated frequencies in this report therefore do not include these minor scenarios and focuses on larger reported incidents. Again, most contact incidents are minor involving superficial damage rather than actual damage. Hence, the reason for the low accident frequency is due to the low number of reported incidents.

# 7 Accident consequences

This section contains consequence assessments of the accident scenarios. An accident can develop in different ways resulting in different consequences. The possible developments of the accident scenarios are modelled by use of *event trees*. Each branch in the event tree represents a possible escalation of the accident. To each sequence of events an expected number of fatalities are assigned.

By using the calculated accident frequencies as input to the event trees, the risk for each branch can be calculated as the frequency of a specific course of events occurring, multiplied by the severity of that course of events. The different courses of events (branches) are independent so that the sum of the risk for all the branches makes up the total risk for that accident type.

## *7.1 Consequence definition*

The consequence of an accident is defined as the *expected number of fatalities*, should that accident occur. In order to perform consistent and comparable consequence assessments, fixed bands of expected numbers of fatalities were defined. The bands were initially defined to suit the reference vessel of 110,000 GRT with a total capacity of 4,000 persons (crew + pax), see Section 2.2.

However, in order to develop a more accurate estimation of consequences for the current world fleet, the estimated number of fatalities was also estimated for a ship of 75,200 GRT and 40,876 GRT. A total of ten (10) bands of expected number of fatalities have been identified and are shown in the table below. The bands aim to cover the full range of accident severities, from a minor scenario to a catastrophic accident resulting in a large number of fatalities.

**Table 7-1 Fatality bands**

| Expected number of Fatalities | | | % of no of persons on board |
|---|---|---|---|
| **Ref Ship 01** | **Ref Ship 02** | **Ref Ship 03** | |
| **110,000 GRT** | **75,200 GRT** | **40,876 GRT** | |
| 0 | 0 | 0 | 0 % |
| 2 | 1 | 1 | 0,05 % |
| 5 | 3 | 3 | 0,125 % |
| 20 | 14 | 10 | 0,5 % |
| 100 | 68 | 52 | 2,5 % |
| 300 | 205 | 156 | 7,5 % |
| 800 | 545 | 416 | 20 % |
| 1600 | 1090 | 832 | 40 % |
| 3200 | 2182 | 1664 | 80 % |
| 4000 | 2728 | 2080 | 100 % |

It is important to note that, for local incidents (e.g., engine room or galley fire outbreak) involving small numbers of people, the total number of persons onboard will only have a minor impact on the numbers of fatalities. However, for other incidents due to the amount of people onboard there is an increased potential for a higher number of fatalities in a given accident. This effect has by the project team been assessed to be minor for the smaller accidents. It is only when whole ship events are modelled that the total numbers of persons is assumed to make an impact.

The most important scenarios to evaluate are those with potential disastrous consequences, resulting in a high number of fatalities. Thus the rationale behind the most severe fatality category is illustrated in Table 7-2. The remaining fatality categories have been identified in such a way that they best cover all possible scenarios of various severities.

It is important to note that the identified fatality bands only apply to the reference vessels defined for this study.

Each final event is connected to an estimated number of fatalities. The expected number of fatalities is selected from one of the ten possible bands, as defined in Table 7-1 above. This work has been carried out together with participants who were also involved in the Hazid groups.

**Table 7-2** provides an overview of a selection of major disasters on passenger vessels over the last 20 years. It is important to note that none of these accidents have occurred to cruise ships, but to ferries and RoPax ships. Similar statistics for cruise ships do not exist as there have been no such accidents with these vessels. The overview can still provide some useful information on the severity of disastrous events. One could argue that Estonia and Al Salam Boccaccio 98 are the two most relevant accidents to investigate when trying to learn how a worst case scenario possibly could occur. It is interesting to note that both the aforementioned vessels conformed to SOLAS regulations.

**Table 7-2 Sample comparison of some selected major passenger vessel disasters (for illustration)**

| Year | Vessel name | Ship type | Accident type | Persons on board | Fatalities | % fatalities (of total on board) |
|---|---|---|---|---|---|---|
| 1987 | HERALD OF FREE ENTERPRISE | RoPax | Capsize | 539 | 193 | 36 % |
| 1987 | DOÑA PAZ | Ferry | Collision | > 4000 | > 4000 | 99 % |
| 1994 | ESTONIA | RoPax | Capsize | 989 | 852 | 86 % |
| 2002 | JOOLA | Ferry | Capsize | 2000 | 1863 | 93 % |
| 2006 | AL SALAM BOCCACCIO 98 | RoPax | Capsize | 1408 | 1018 | 72 % |

Source: http://en.wikipedia.org/wiki/List_of_disasters#Ship_and_ferry_disasters, last accessed 21.02.06

Based on a qualitative evaluation it was first decided by the project participants that there could be approximately 80% fatalities in a *worst case scenario* involving a modern cruise ship. This was later found to be too coarse and therefore the following distribution was used for the worst case events, also based on **Table 7-2**:

- 40 % fatalities in 20 % of the total loss cases
- 80 % fatalities in 60 % of the total loss cases
- ~100 % fatalities in 20 % of the total loss cases

### 7.1.1 Event tree

An event tree starts with an initiating event, for example a collision. Numerous factors could influence the initiating event developing it into different end scenarios. The eventual outcome of each branch of the event tree is denoted an end-event. Each end-event represents a scenario that has been assessed separately with regard to an expected number of fatalities for passengers and crew on board their own vessel. Since the study aims to establish overall risk level for cruise ships, the event tree structure is kept at a high level in order to make the study manageable.

The expected number of fatalities modelled in the following event trees are representative for a 110,000 GRT cruise ship.

Estimated numbers of fatalities for two other sizes of vessels also representative of today's current fleet have also been derived and are used later in the results section to give an overall average number of fatalities that could be expected in the current world fleet. The method involved establishing the particulars of a reference vessel and determining the likely outcome in terms of fatalities for each scenario. As mentioned earlier in the report, the total number of persons on board is assumed to make an impact on the total numbers of fatalities only when whole ship events are modelled.

For each branch, a probability of occurrence of the particular outcome is estimated. The outcome probabilities are determined based on the input frequencies from Section 6 plus the various probabilities along the branches leading to the outcome. The probabilities along the branches are collected partly from previously acknowledged risk studies, and partly from project team members opinions derived from workshops.

In order to develop the event trees in this Section 7, workshops were organized where personnel with industry expertise on cruise ship navigation and collision, fire, and damage stability were gathered. Participants from DNV and Carnival contributed, and to add upon the credibility of work group opinions, results from earlier work on collision, cruise ship fire, and stability has been added when developing the branches in the even trees. These external sources are referred to directly after each event tree (Section 7.1.2 - 7.1.5).

There are three main areas of importance when designing an event tree:

1. Establish possible relevant outcomes or scenarios, of an accident. These are defined as the branches in the tree.
2. Establish *probabilities* for the different branches. These are defined as a probability distribution.
3. Attach a *severity* to each scenario. In this project severity is defined as the expected number of fatalities.

Four event trees have been designed, one for each accident category: Collision, Contact, Grounding, Fire/explosion.

The structure of the event trees is similar for the four scenarios modelled. By sticking to a similar level of detail when modelling all the hazards, a direct comparison between the hazards can be achieved.

**Evacuation** is indirectly factored into the event tree analysis by assuming a normal distribution of evacuation. That is, the analysis does not make assumptions for scenarios where evacuation may or may not be successful under certain defined conditions; rather it was assumed that, on average, evacuation will work according to procedures.

Hence the expected fatality figures in the event trees, and the corresponding frequencies, have not been adjusted to take into account the effect of evacuation, and evacuation fatalities are included in the accident categories.

The limited number of accidents for the cruise ship industry throughout the last couple of decades has been discussed elsewhere in this report, see Section 2.1. This will not be stressed again, but a lower sample number no doubt increases the sensitivity of the results.

### 7.1.2 Collision event tree

Input frequency for a cruise ship collision (4.6E-3), is calculated in Section 6 of this report. An event tree for collision has been developed and is illustrated in Figure 7-1; further details can be found in Appendix B:

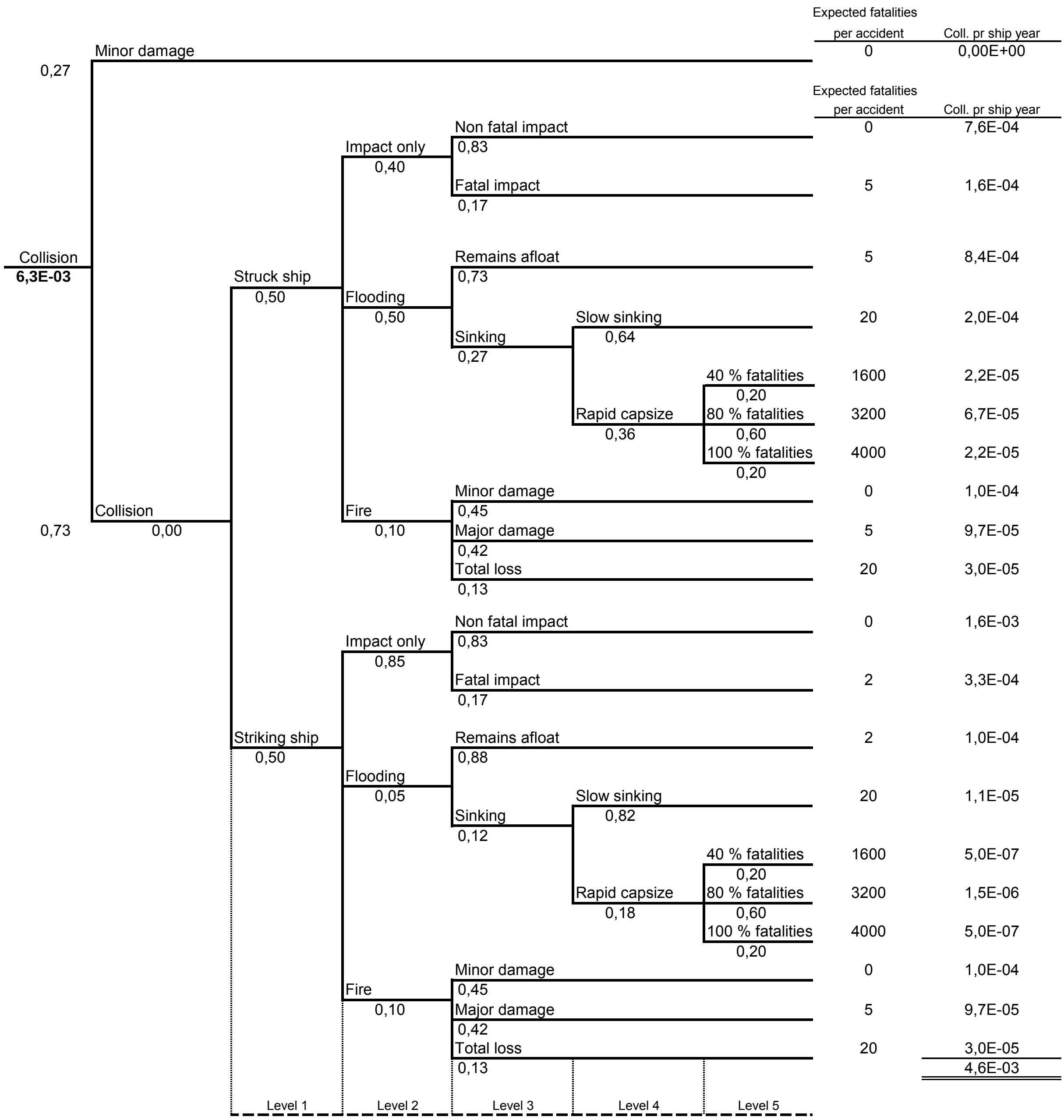


**Figure 7-1: Collision event tree**

An explanation to the various branches in the event tree follows suit:

### Level 1

The first branch separates between whether the cruise ship is the struck or the striking ship. Although the possible succeeding events will be the same for the two situations, there is a higher potential for fatalities on board when the cruise ship is struck by another ship. If the cruise ship strikes another, it will in most cases be with the bow first where there are no accommodation areas or crowded areas.

A potential hazard for the striking ship is sudden deceleration and jerking resulting in increased slips trips and falls. This hazard however will be limited due to the great mass of the vessel and the design deformation of the bow. On the other hand, if the cruise ship is the struck ship, it is likely to be along the shipside as this area is the largest. This area is packed with both accommodation and public areas, and forces in this direction may lead to penetration and flooding over several watertight bulkheads which in the worst case can result in capsize and total loss of the vessel.

The distribution between striking or struck ship is based on the assumption that two or more ships must be included, and in most cases both vessels are apportioned blame. The probability is set at 50/50.

**Level 2**

A typical collision between ships involves one ship striking another in the side with the bow first. As the bow is a fairly well protected area for most cruise ships, a low probability of flooding for the striking ship, only 5%, is assumed. The struck ship will typically sustain greater damage as the sides of the ship are structurally weaker. The chances of flooding are therefore considerably higher for the struck ship. A 50% chance of flooding is assumed for the struck ship /11/.

In addition, there is a probability of fire as a result of the collision impact. This is by project members' judgement (project participants) set to occur in one out of ten serious collisions.

**Level 3**

Whether the ship remains afloat or sinks depends on the number of watertight bulkheads the impact has penetrated. Typically if three or more bulkheads under the water line are flooded, the ship sinks. If flooding has occurred, the probability of remaining afloat has been estimated as 73% for a struck ship /11/. By the nature of the impact, the likelihood that a number of bulkheads under the waterline are ripped open is greater for a struck ship than for a striking ship. We therefore assume only a 12% chance that a striking ship will sink even when flooding has occurred.

The distribution for the fire event is based on LRFP statistics from 1990-2004.

**Level 4**

Whether the ship sinks slowly or rapidly is investigated in a previous FSA study for cruise navigation (ref /13/) which estimated a probability of 36 percent for rapid capsize if the ship was destined to sink. The fire which can occur due to collision may in worst case result in a total loss if it gets out of control.

**Level 5**

The number of fatalities if the vessel sinks rapidly is based on the numbers in **Table 7-2** and the discussion there after. To model the risk of collision, the said statistics are used to calibrate the expert judgement of the consequences of a collision followed by water ingress and a rapid capsize.

The information in Table 7-2 is included to provide some useful information on the severity of disastrous events. This information is only used as input to expert judgement on the percentage of fatalities in rapid capsizes.

**General comments to assessment of fatalities (right side of figure)**

If the collision only resulted in an impact, the only cause which results in fatalities would be the negative accelerations from the accident. No persons have died since 1978 due to drowning, flooding, or fire as a result of collision, only due to the impact, ref LRFP.

| COLLISION | | | |
|---|---|---|---|
| Ships in Band | Number of ships in band | Theoretical Fatalities per ship year | Theoretical Number of Fatalities per year in each band |
| Ref 01 (>90,000GRT) | 30 | 0,36 | 10,8 |
| Ref 02 (60,000-90,000 GRT | 53 | 0,25 | 13,2 |
| Ref 03 (20,000-60,000 GRT | 89 | 0,19 | 17,2 |
| Total | 172 | | 41 |

| Theoretical predicted fatalities per year in current world fleet | Theoretical predicted average number of fatalities per ship year | Theoretical predicted average number of ship years per fatality (current fleet) |
|---|---|---|
| 41 | 0,2 | 4,2 |

**Main results from the collision event tree**

- The large scale incidents (sinking, flooding and rapid capsize) with an estimated 80% casualty rate drive the results for the collision event tree. This is because the estimated numbers of fatalities is large and the estimated frequencies are not sufficiently low to compensate. Any change in the estimated likelihood or consequence of these large scale incidents will have a direct effect on the results of the risk modelling as this scenario is dominating
- These large scale incidents are estimated to occur with a frequency of once every 5,000 years per ship.
- The results can be expressed as one fatality due to collision every 4.2 ship years (return period).
- 41 fatalities (due to collision) per year for the cruise fleet (172 ships – considered in 3 size bands) (Note that this way of looking at risk as a yearly value can be misleading due to the large number of ship years between serious incidents).

### 7.1.3 Contact event tree

Input frequency for cruise ship contact (1.2E-03) is calculated in Section 6. Event tree for contact has been developed and is illustrated in Figure 7-2; further details can be found in Appendix C:

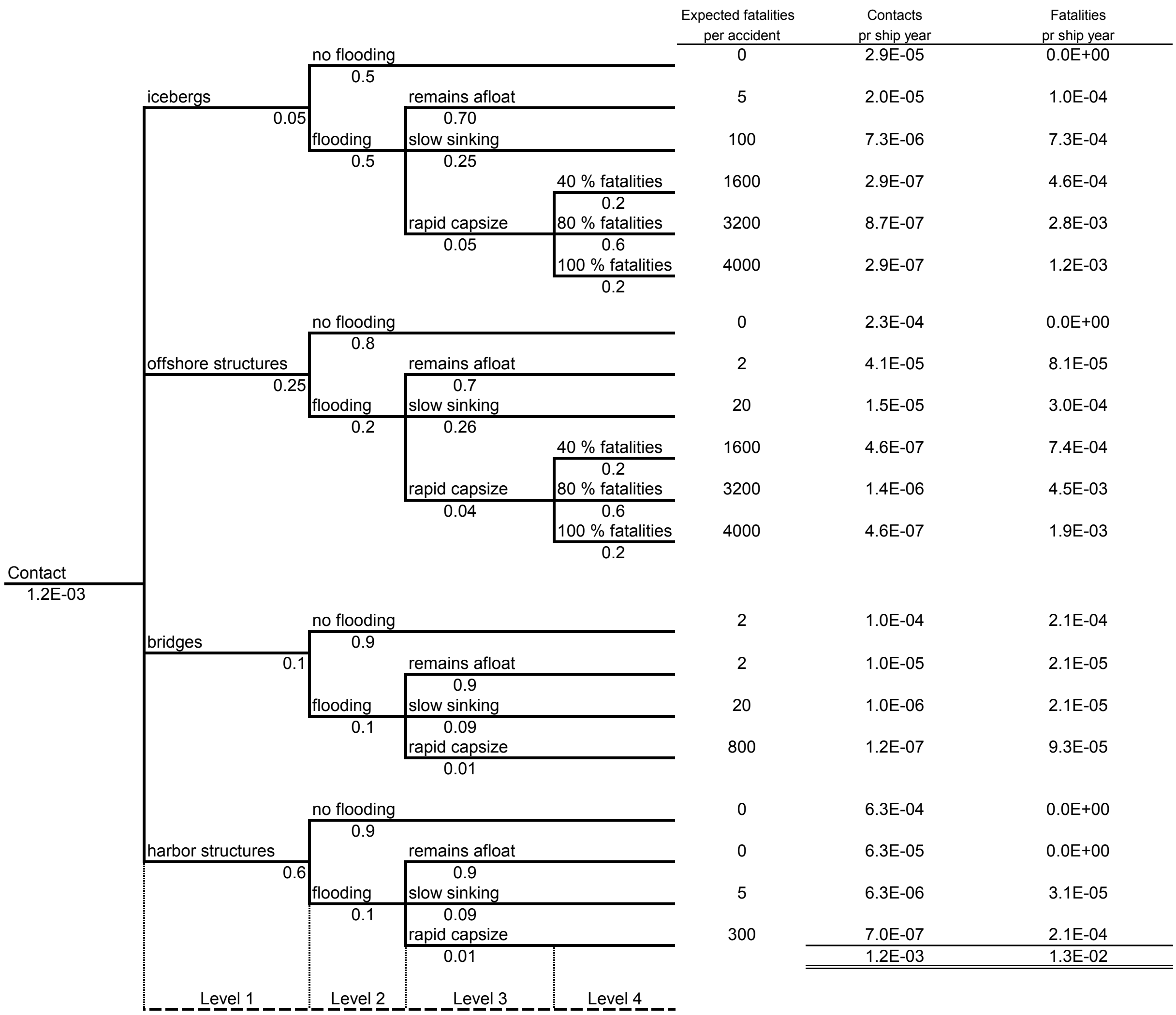


**Figure 7-2: Contact event tree**

An explanation to the various branches in the event tree follows suit:

**Level 1**

The serious casualty scenario is further divided into the four possible objects by which the ship can experience contact with. These are icebergs, offshore structures, bridges, and harbour structures. In order to obtain a large enough impact to cause serious casualty the cruise ship must have a certain speed. This is taken into consideration when defining the distribution between the four branches.

Icebergs represent a hazard, but the number of cruise ships presently sailing in ice infested waters is limited, yet increasing, and this increases the probability of this scenario (estimated by project participants to 0.05). The offshore structures are increasing in numbers, both as floating and fixed structures, and hence are modelled somewhat higher (estimated at 0.25) than the statistical data (LRFP) suggests. The offshore structures include drifting objects, such as containers and similar. Harbour structures are modelled approximately the same as the statistical number of serious contacts suggests, but somewhat lower (0.6).

**Level 2**

Contrary to bridges and harbour structures, impacts with offshore structures and icebergs will have an increased probability of penetration below water line resulting in flooding. Since offshore structures are often located in the middle of the sea, the probability for an impact with high speed is larger than for bridge impacts which are usually located where speed restrictions apply. Ice would also hit the cruise ship below water line. The probability figures at Level 3 are derived by the project group.

**Level 3**

The three scenarios developed from the flooding scenario represent the three typical events often used in similar projects. The Joint North-West European Project for RoPax ships (ref /14/) gives the overall probability of remaining afloat as 84% and rapid capsize as 2%, these numbers are referred to as a benchmark. For this event tree model, the probability of experiencing both slow sinking and rapid capsize for contact with icebergs and offshore structures has been increased compared to the overall numbers from ref /14/. For contact with bridges and harbour structures, the probability has been decreased compared to the overall numbers from ref /14/.

The consequences for sinking and capsizing due to contact with bridge or harbour structures have also been reduced. This takes into account the arguments mentioned above in level 3, along with the fact that the distance from shore is short and thus shore support is more available.

**Level 4**

The number of fatalities if the vessel sinks rapidly is based on the numbers in **Table 7-2** and the discussion there after. To model the risk of collision, the said statistics are used to calibrate the expert judgement of the consequences of a collision followed by water ingress and a rapid capsize.

The information in Table 7-2 is included to provide some useful information on the severity of disastrous events. This information is only used as input to expert judgement on the percentage of fatalities in rapid capsizes.

**General comments to assessment of fatalities**

Evidently, rapid capsize will lead to a high number of fatalities. The number of fatalities for icebergs and offshore structures are higher than for bridges and harbour structures due to the simple fact that collision with icebergs and offshore structures would occur in cold, open water.

Estimated consequences for 3 selected vessel bands

| CONTACT | | | |
|---|---|---|---|
| Ships in Band | Number of ships in band | Theoretical Fatalities per ship year | Theoretical Number of Fatalities per year in each band |
| Ref 01 (>90,000GRT) | 30 | 0.013 | 0.4 |
| Ref 02 (60,000-90,000 GRT | 53 | 0.010 | 0.5 |
| Ref 03 (20,000-60,000 GRT | 89 | 0.008 | 0.7 |
| Total | 172 | | 1.6 |

| Theoretical predicted fatalities per year in current world fleet | Theoretical predicted average number of fatalities per ship year | Theoretical predicted average number of ship years per fatality (current fleet) |
|---|---|---|
| 1.6 | 0.009 | 108.9 |

**Main results from the contact event tree**

- The large scale incidents (sinking, flooding and rapid capsize) with an estimated 80% casualty rate drive the results for the contact event tree. This is because the estimated numbers of fatalities is large and the estimated frequencies are not sufficiently low to compensate. Any change in the estimated likelihood or consequence of these large scale incidents will have a direct effect on the results of the risk modelling as this scenario is dominating

- A return period of 109 ship years per fatality (due to contact).
- 1.6 fatalities (due to contact) per year for the cruise fleet (172 Ships).

### 7.1.4 Grounding event tree

Input frequency for cruise ship grounding (9.8E-03) is calculated in Section 6. Event tree for grounding has been developed and is illustrated in Figure 7-3; further details can be found in Appendix D:

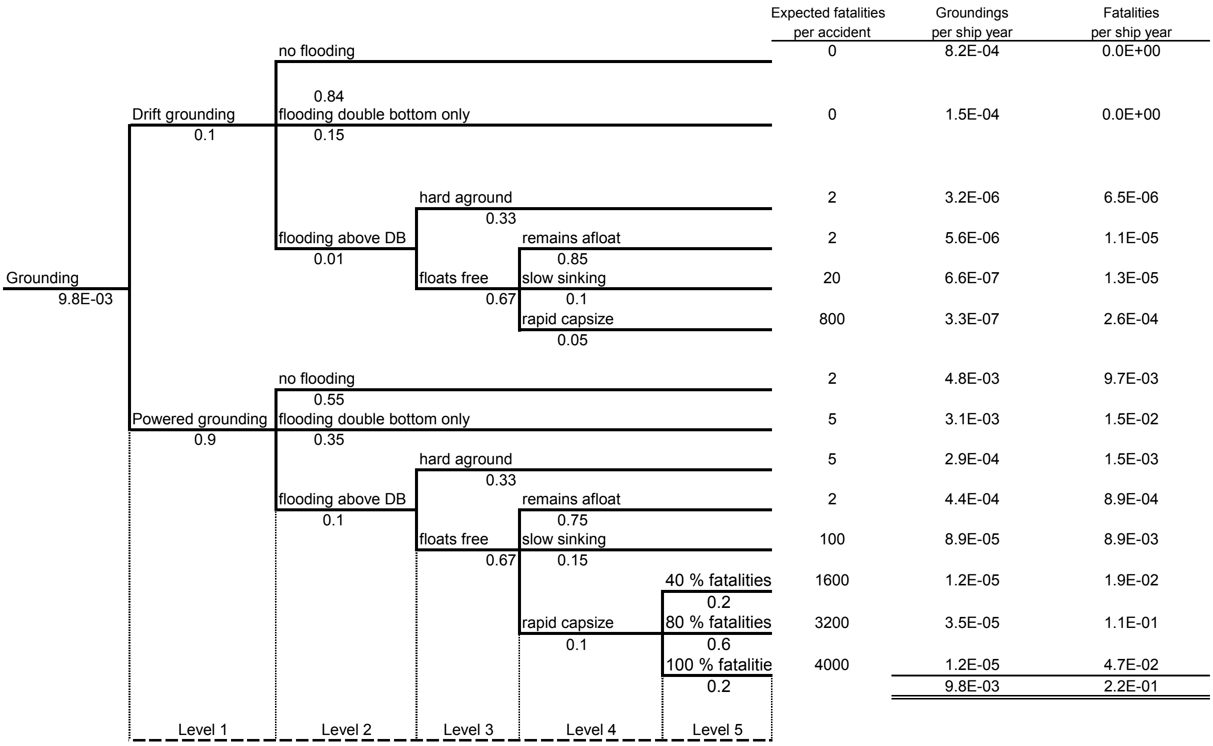


**Figure 7-3: Grounding event tree**

An explanation to the various branches in the event tree follows suit:

**Level 1**

Grounding is predominantly caused by navigation failure (“powered grounding”) or by propulsion, power or steering failure (“drift grounding”). A probability of 90% has been assigned where navigation failure is the dominant cause based on worldwide accident statistics in LRFP.

**Level 2**

Distribution among *no flooding, flooding double bottom only* and *flooding above DB* is based on Grounding event tree information from the HARDER project, ref /12/, figure 12.

**Level 3**

Distribution among *hard aground* and *floats free* is based on grounding event tree information from the Joint North-West European study (ref /14/).

**Level 4**

Distribution among *remains afloat, slow sinking* and *rapid capsize* is based on grounding event tree information from the Joint North-West European study (ref /14/). It is noted that the option of deliberately beaching the vessel to avoid sinking is not explicitly modelled, but is implicitly included in the probability of remaining afloat.

**Level 5**

The number of fatalities if the vessel sinks rapidly is based on the numbers in **Table 7-2** and the discussion there after. To model the risk of collision, the said statistics are used to calibrate the expert judgement of the consequences of a collision followed by water ingress and a rapid capsize.

The information in Table 7-2 is included to provide some useful information on the severity of disastrous events. This information is only used as input to expert judgement on the percentage of fatalities in rapid capsizes.

**General comments to assessment of fatalities**

In a *drift grounding* scenario the officers on board probably have time to react, slow down the speed by emergency anchoring, and prepare the crew and passengers for a potential impact.

In a powered grounding scenario, the speed, and thus the momentum, is high and the impact can surprise the navigating officer(s), leaving no or limited time to prepare or warn people on board of the impact.

Powered grounding is considered to be the worst scenario since continuing is likely to cause more damage to the length of the ships hull, and thus there is a higher potential to penetrate more compartments throughout the ships length. Most of the grounding events are not reported; hence the results are probably skewed.

Estimated consequences for 3 selected vessel bands

| GROUNDING | | | |
|---|---|---|---|
| Ships in Band | Number of ships in band | Theoretical Fatalities per ship year | Theoretical Number of Fatalities per year in each band |
| Ref 01 (>90,000GRT) | 30 | 0.22 | 6.5 |
| Ref 02 (60,000-90,000 GRT | 53 | 0.16 | 8.4 |
| Ref 03 (20,000-60,000 GRT | 89 | 0.13 | 11.6 |
| Total | 172 | | 26.5 |

| Theoretical predicted fatalities per year in current world fleet | Theoretical predicted average number of fatalities per ship year | Theoretical predicted average number of ship years per fatality (current fleet) |
|---|---|---|
| 26.5 | 0.2 | 6.5 |

**Main results from the grounding event tree:**

- A return period of 6 years per fatality (due to grounding) for the world fleet (172 ships)
- 26 fatalities (due to grounding) per year for the current cruise fleet (172 ships).

### 7.1.5 Fire event tree

Input frequency for cruise ship fire (8.9 $10^{-3}$ ), is calculated in Section 6. Event tree for fire has been developed and is illustrated in Figure 7-4; further details can be found in Appendix E:

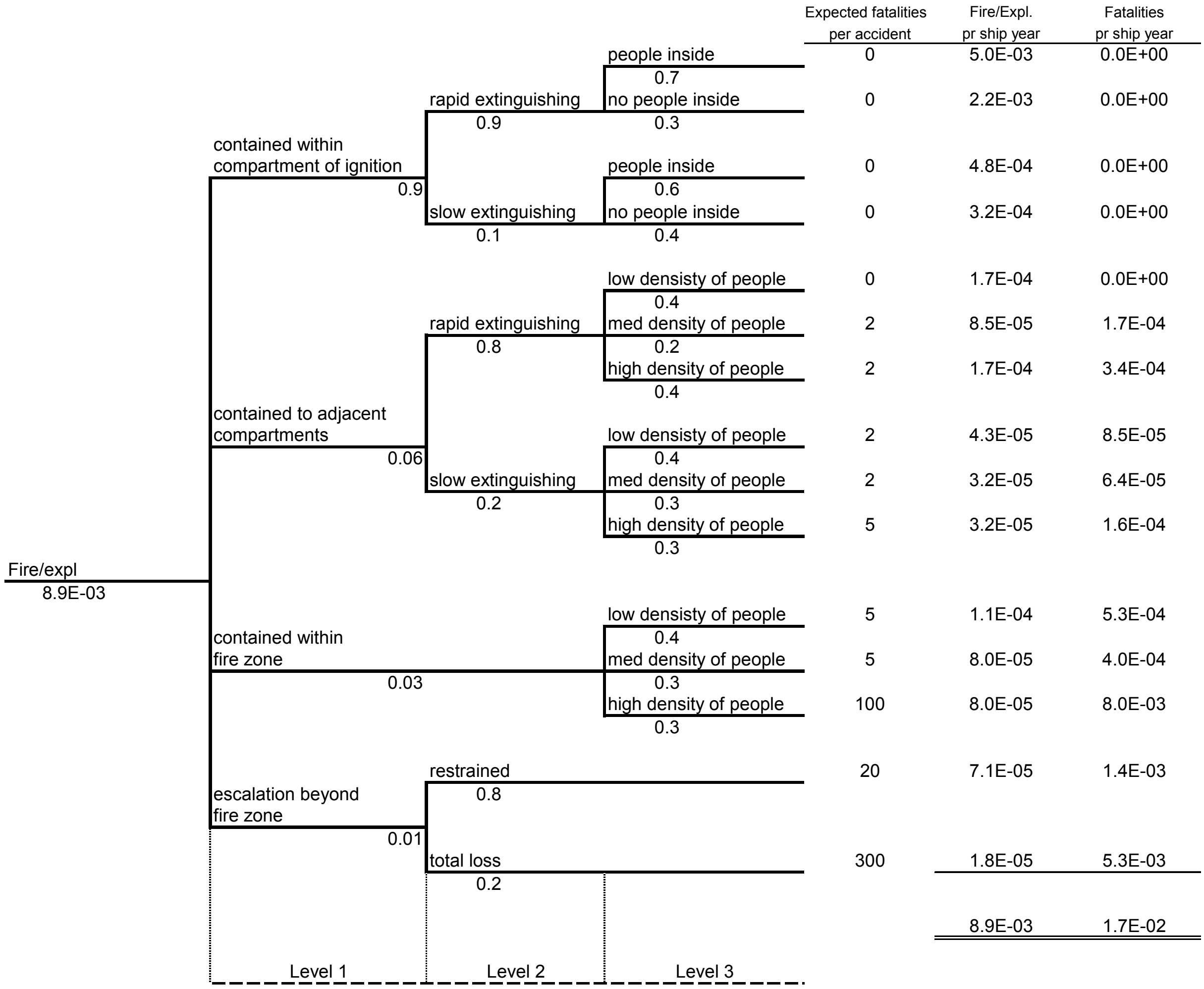


**Figure 7-4: Fire/explosion event tree**

An explanation to the various branches in the event tree follows suit:

### Level 1

The development and severity of the fire is divided into four groups:

a) The fire is contained within the room where the fire is initiated, or,

b) The fire develops into the surrounding compartments. These neighbouring rooms should represent less than 25 percent of the area within the fire zone, or,

c) When the fire is contained within the fire zone more than a quarter of the fire zone was affected by the fire, but other fire zones are not, or,

d) For the fire escalating beyond the fire zone, the branch options change. The events of such a fire are either that the fire is restrained or the situation ends in a total loss of the ship.

The probability figures have been derived by the project group which have extensive experience with similar fire risk projects for cruise ships.

### Level 2

The main concern after a fire has been initiated is the time for detection and suppression. The more time this process takes the higher the potential is for a large fire incurring fatalities.

For the fire scenarios where the fire is spreading to the neighbouring rooms the time of extinguishing is important and therefore distinguished between. If the fire is rapidly extinguished it means that the fire was less threatening than if the fire was hard to put out (slow extinguishing). For larger fires it is already given that the fire was severe and hard to put out and escalated beyond that point.

If the fire escalated beyond the fire zone, there are two options; either the fire is restrained and the ship is saved, or it will result in a total loss. The probabilities at Level 3 and 4 have been derived by the project group.

**Level 3**

In the three least severe fire scenarios, the fire affects a limited area of the ship only. The severity of these fires is therefore depending on the density of the people in these areas. The density of people is divided into three categories: low, medium and high density. A low density area would typically be in a machinery room, the laundry or a storage room; a medium density room would be the cabin areas and certain public rooms; a high density area would typically be the theatre, restaurant or certain other public rooms. The probability for having a small fire in a crowded area is relatively high for a cruise ship.

**General comments to assessment of fatalities**

Evidently, fires that reach beyond the fire zone or are contained within a fire zone, have a higher potential for fatalities than those contained within the compartment of ignition or adjacent compartment.

Estimated consequences for 3 selected vessel bands

| FIRE | | | |
|---|---|---|---|
| Ships in Band | Number of ships in band | Theoretical Fatalities per ship year | Theoretical Number of Fatalities per year in each band |
| Ref 01 (>90,000GRT) | 30 | 0.017 | 0.5 |
| Ref 02 (60,000-90,000 GRT | 53 | 0.015 | 0.8 |
| Ref 03 (20,000-60,000 GRT | 89 | 0.014 | 1.2 |
| Total | 172 | | 2.5 |

| Theoretical predicted fatalities per year in current world fleet | Theoretical predicted average number of fatalities per ship year | Theoretical predicted average number of ship years per fatality (current fleet) |
|---|---|---|
| 2.5 | 0.015 | 68.1 |

**Main results from the fire/explosion event tree:**

- A return period of 68 years per fatality (due to fire/explosion)
- 2.5 fatalities (due to fire/explosion) per year for the current cruise fleet (172 ships)

### 7.1.6 Summary of results from event trees (x4)

The event trees (7.1.2-7.1.5) can be summarized in the following table:

**Table 7-3 Summary of results from event trees**

| Cruise Ship | Collision | Contact | Grounding | Fire/Exp. |
|---|---|---|---|---|
| Fatality frequency [number of fatalities per ship year] | $2.4\ 10^{-1}$ | $9.2\ 10^{-3}$ | $1.5\ 10^{-1}$ | $1.5\ 10^{-2}$ |
| Return period per fatality [in ship years] | 4.2 | 108.9 | 6.5 | 68.1 |
| Estimated number of fatalities per year for the cruise fleet (172 ships) | 41 | 1.6 | 26.5 | 2.5 |

Table 7-3 shows that, *collision* and *grounding* represent by far, the highest risk for a cruise ship. It must be borne in mind that the original aim of the risk assessment for SAFEDOR was to clarify the risk of large consequence incidents. The results in the previous chapters clearly illustrates that large consequence incidents represent the highest risks for Cruise ships, which emphases the intention of the study.

It should be noted that the fatality figures are higher than statistical accident data and should be read as best estimates for the current fleet. It is logical that the fatality figures are higher than the statistics, as no large accident with hundreds or thousands of fatalities has happened in the cruise industry the last decades. The statistical material from which the figures have been derived is limited and models have had to be used. The sensitivity of the figures is correspondingly high.

The large scale incidents (sinking, flooding and rapid capsize) with an estimated 40-100% casualty rate drive the results for the collision and grounding event trees. This is because the estimated numbers of fatalities is so large despite the estimated frequency being low. Therefore, any change in the estimated likelihood or consequence of these large scale incidents will have a significant effect on the results of the risk modelling.

Risk is expressed in terms of a calculated number of fatalities per year in order to aid comparison between the different events. However, this way of looking at risk as a yearly value can be misleading since it implies that there will be casualties every year instead of there being a large number of ship years between serious incidents.

# 8 Risk Level

This section aims to present and explain the calculated risk level for individual risk and societal risk. The risk levels are illustrated together with the defined risk evaluation criteria and guidance from Section 5. Furthermore, the results are analysed and lessons learnt from the task are discussed and documented.

## *8.1 Individual risk level*

Individual risk levels can be derived from the ship risk level when knowing the number of crew and passengers. The table below details the number of passengers and crew onboard the three different size reference vessels. From the table, an estimated number of persons onboard the current world cruise fleet can be calculated and hence an estimated number of persons on an average size cruise ship can be derived.

**Table 8-1 Risk exposure for crew/pax**

| Selection of Representative Ships within 3 size bands | Selected Band for Group of Ships (GRT) | Numbers of Ships in Band | Representative Ship | GRT | Passengers | Crew | Total |
|---|---|---|---|---|---|---|---|
| Reference Ship 01 | >90,000 | 30 | Carnival Conquest | 110,000 | 2,800 | 1,200 | 4,000 |
| Reference Ship 02 | 60,000-89,999 | 53 | Costa Victoria | 75,200 | 1,928 | 800 | 2,728 |
| Reference Ship 03 | 20,000-59,999 | 89 | Norwegian Majesty | 40,876 | 1,460 | 620 | 2,080 |

| | No. of ships in each band | Ships complement (representative ship) | Total carrying capacity of each ship band |
|---|---|---|---|
| Number of persons onboard ships in current cruise fleet | 30 | 4,000 | 120,000 |
| | 53 | 2,728 | 144,584 |
| | 89 | 2,080 | 185,120 |
| | | Total | 449,704 |

| | Total No. of Ships | Total Capacity of Ships | Average no. of persons on each ship |
|---|---|---|---|
| Average number of persons on a ship representative of today's fleet | 172 | 449,704 | 2,615 |

| | Working period / stay onboard | Total exposure per ship year |
|---|---|---|
| Crew Exposure | Average 6 months onboard | 0.5 |
| Passenger Exposure | Maximum 2 weeks per year | 0.0385 |

The table above also details the assumptions made with regards to exposure to enable the average, individual risk for crew and passengers to be calculated.

The fatality frequencies, calculated from the event-trees in Section 7, are used as input to calculate the individual fatality frequencies for crew and passengers. Risk for crew and passengers have been modelled in a similar way, and no more sophisticated modelling has been used to differentiate between the crew and passenger risk exposure except for the fact that crew are onboard for a longer period (higher exposure). For the same reason, the calculation process does not differentiate between different categories of crew, i.e. all crew (deck, hotel and engine) are considered as one.

This is largely down to the assumption that for large scale accidents, with hundreds or thousands of fatalities, the difference in survivability for passengers, crew and different crew functions is small.

It should be noted that the calculations were carried out for a ship of 4,000 passengers. Further calculations were then carried out to take account of smaller bands of vessels in the current world fleet. It has been assumed that where small numbers of fatalities occur due to a local incident, the numbers of people on board do not impact on the numbers of fatalities. This assumption gives rise to a smaller number of people being exposed to the same risk level and a consequential rise in individual risk level in comparison to when the larger vessel was the sole reference vessel used. This further adds to the conservative results of the report, but is considered to be of minor importance.

| Table 8.2 Individual Risk Summary | | | | | | |
|---|---|---|---|---|---|---|
| **Hazard** | **Fatalities* [per ship year]** | **Individual Risk of Pax & Crew** [Fatalities Per Year]** | **Individual Risk for Pax*** [Fatalities Per Year]** | **Individual Risk for Crew**** [Fatalities per year]** | **Return period for passengers in years** | **Return period for Crew in years** |
| Collision | 2,4E-01 | 9,1E-05 | 3,5E-06 | 4,6E-05 | 280 000 | 22 000 |
| Contact | 9,2E-03 | 3,5E-06 | 1,4E-07 | 1,8E-06 | 7 400 000 | 570 000 |
| Grounding | 1,5E-01 | 5,9E-05 | 2,3E-06 | 2,9E-05 | 440 000 | 34 000 |
| Fire/explosion | 1,5E-02 | 5,6E-06 | 2,2E-07 | 2,8E-06 | 4 600 000 | 360 000 |
| **Sum of all incident causes** | **4,2E-01** | **1,6E-04** | **6,1E-06** | **8,0E-05** | **160 000** | **13 000** |
| Return period in years | 2,4 | 6 300 | 160 000 | 13 000 | | |

* From Table 7-3
** PLL - Fatalities divided by number of persons onboard an average size cruise vessel in current fleet
*** Individual risk for passenger & crew multiplied by average passenger exposure
**** Individual risk for passenger & crew multiplied by average crew exposure

From the table above it can be seen that the individual risk exposure to a crew member is $8.0\ 10^{-5}$ fatalities per crew year. This corresponds to one crew fatality approximately every 13,000 crew years.

Similarly, the individual risk exposure to a cruise ship passenger is $6.1\ 10^{-6}$ fatalities per year. This implies that a single fatality occurs approximately every 160,000 passenger years.
The individual risk level for crew and passengers is in the ALARP area, Figure 8-1. This means that according to the IMO guidelines the risk for crew and passengers should be reduced as long as the risk reduction is not disproportionate to the costs; i.e., only cost beneficial RCOs need to be implemented.

Risk reduction/mitigation is the focus of Annex III.

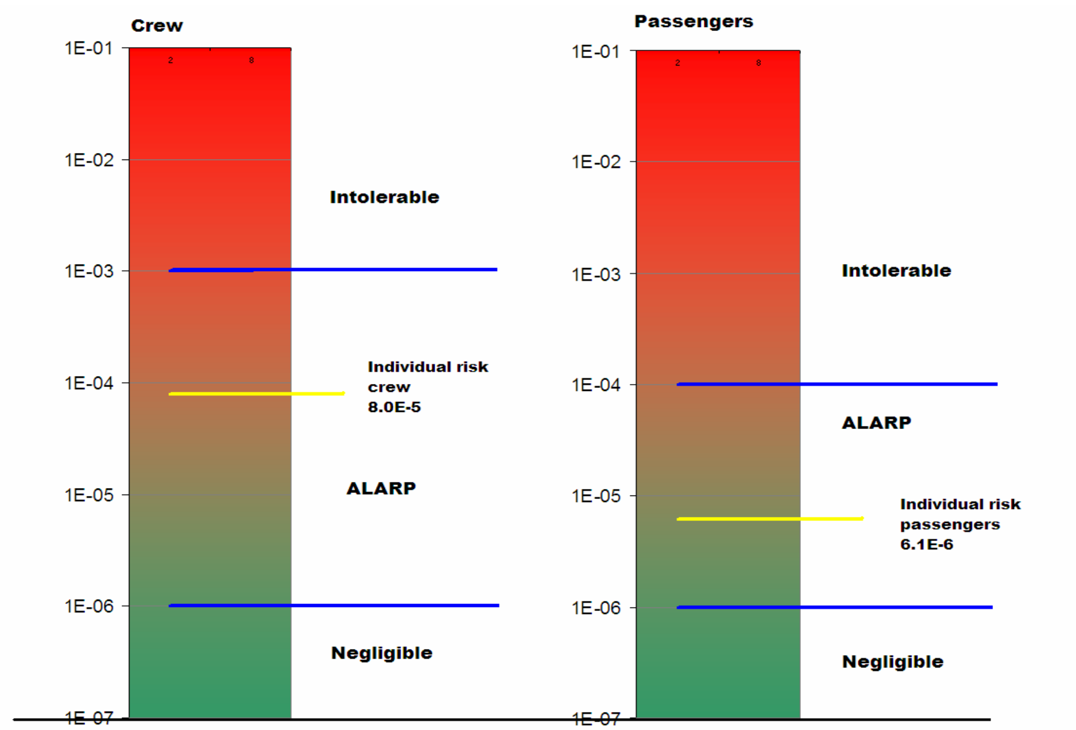


**Figure 8-1: Individual risk level**

## *8.2 Societal risk level*

Figure 8-2 illustrates the modelled risk level for cruise ships in an FN diagram. The risk level is calculated as *the sum* of the four accidents collision, contact, grounding and fire/explosion. The limits for societal risks were derived in Section 5.2. The risk level is within the ALARP region.

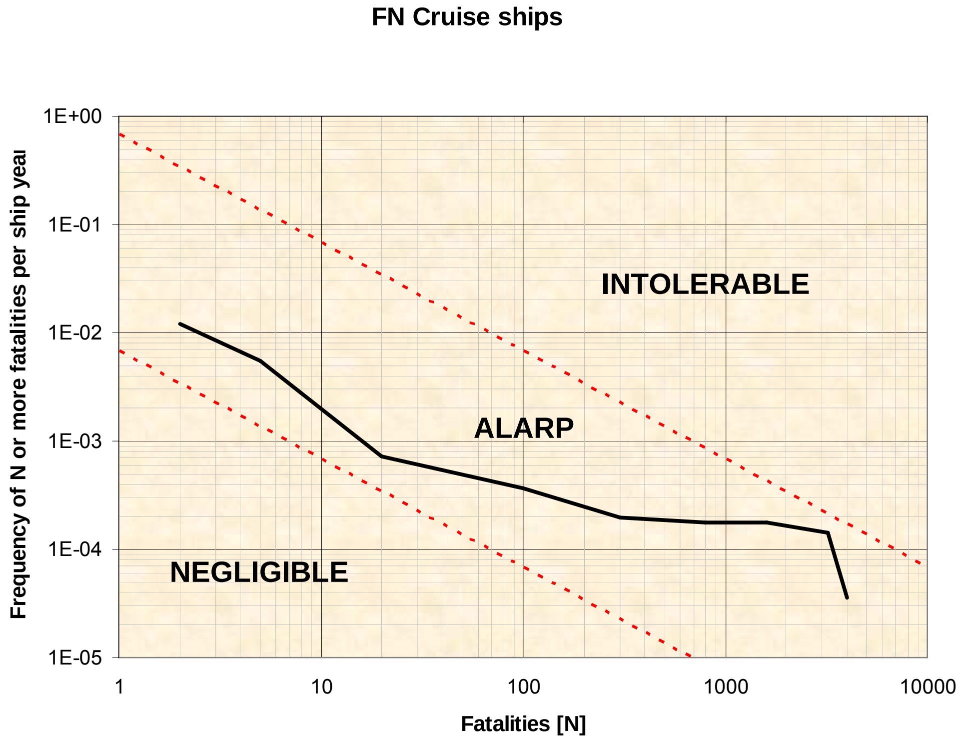


**Figure 8-2: Societal risk level**

Figure 8-3 shows the risk level split into the four accident types evaluated. From the figure it is evident that *collision* and *grounding* accidents are the main risk drivers, while *contact* and *fire/explosion* accidents do not contribute significantly to the overall risk picture.

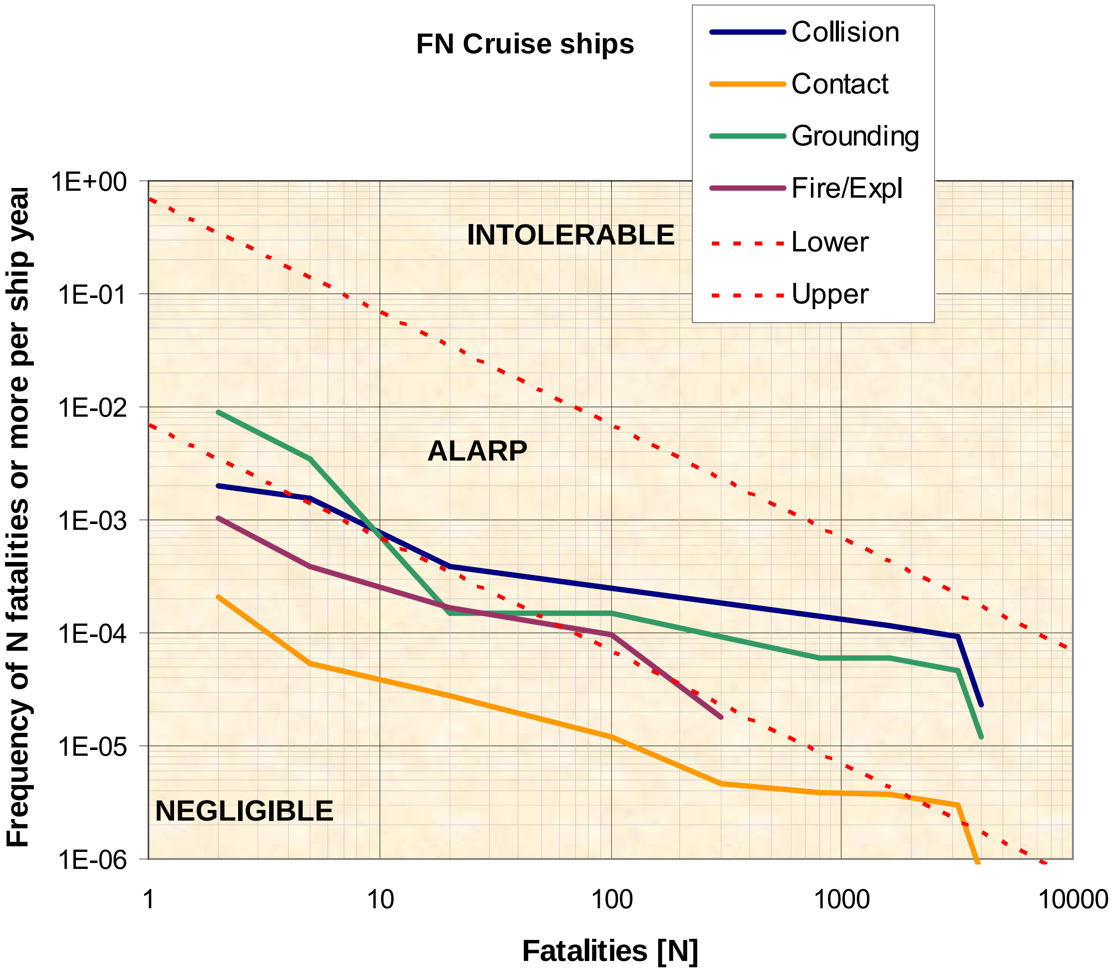


**Figure 8-3: Societal risk level – distributed on accident types**

# 9 Conclusion

In this last section the risk level is summarised, and interpretations of the results are provided. Table 9-1 summarizes the risk level per hazard type:

**Table 9-1 Risk Summary – per hazard**

| Hazard | Accident frequency | % of all accidents | Fatalities | % of all |
|---|---|---|---|---|
| | [per ship year] | | [per ship year] | |
| Collision | 4,6E-03 | 10 % | 2,4E-01 | 57 % |
| Contact | 1,2E-03 | 3 % | 9,2E-03 | 2 % |
| Grounding | 9,8E-03 | 22 % | 1,5E-01 | 36 % |
| Fire/Explosion | 8,9E-03 | 20 % | 1,5E-02 | 3 % |
| Others | 2,0E-02 | 44 % | 6,4E-03 | 2 % |

From table 9-1, the following conclusions can be derived:

- Almost half (44 %) of the accidents for cruise ships are events other than the four modelled hazards.
- However, the four modelled hazards accounts for 98% of the fatalities.
- Collision and Grounding together amounts to 93% of the fatalities (57% +36%).

Table 9.2 Individual Risk Summary

| Hazard | Fatalities* [per ship year] | Individual Risk of Pax & Crew** [Fatalities Per Year] | Individual Risk for Pax*** [Fatalities Per Year] | Individual Risk for Crew**** [Fatalities per year] | Return period for passengers in years | Return period for Crew in years |
|---|---|---|---|---|---|---|
| Collision | 2,4E-01 | 9,1E-05 | 3,5E-06 | 4,6E-05 | 280 000 | 22 000 |
| Contact | 9,2E-03 | 3,5E-06 | 1,4E-07 | 1,8E-06 | 7 400 000 | 570 000 |
| Grounding | 1,5E-01 | 5,9E-05 | 2,3E-06 | 2,9E-05 | 440 000 | 34 000 |
| Fire/explosion | 1,5E-02 | 5,6E-06 | 2,2E-07 | 2,8E-06 | 4 600 000 | 360 000 |
| **Sum of all incident causes** | **4,2E-01** | **1,6E-04** | **6,1E-06** | **8,0E-05** | **160 000** | **13 000** |
| Return period in years | 2,4 | 6 300 | 160 000 | 13 000 | | |

* From Table 7-3
** PLL - Fatalities divided by number of persons onboard an average size cruise vessel in current fleet
*** Individual risk for passenger & crew multiplied by average passenger exposure
**** Individual risk for passenger & crew multiplied by average crew exposure

Main conclusion from Table 9.2:

The individual risk levels are within the ALARP region for both for passengers and crew. This means that according to the IMO guidelines the risk for crew and passengers should be reduced as long as the risk reduction is not disproportionate to the costs.

**Conclusion from the event trees:**

- Smaller accidents with 2 to 5 fatalities can be expected every year in the current fleet of 172 ships. This corresponds well to historical data from LRFP (1990-2004).
- The vast majority of the risk lies within the large scale accident category (≥80% of ship's complement) due to the large numbers of estimated fatalities.

**Summary of conclusion**

- The risk level is within the ALARP region for crew and for passengers.
- Collision and grounding accounts for 93 % of the risk in terms of fatalities.
- Catastrophic accidents with large number of fatalities account for 85% of the risk although the frequency for such events is very remote.
- The next part of the FSA, Annex III, will focus on identifying key RCOs for large scale **collision** and **grounding** accidents.

Further conclusions

- The results are highly dependant on historic incident data and modelling of collisions and to a lesser extent groundings. Further research should be initiated to investigate whether the performance of a modern cruise ship is properly represented by these results. Currently work is ongoing to investigate the response of cruise ships to flooding following collision and grounding and the results of this work should be incorporated in this research.
- This study aims to be generic for the world fleet, and hence, the actual risk level for a specific ship will differ from the results given in this report.

# References


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/13/ *FSA large passenger ships – Navigational safety – Effective Voyage Planning for Passenger Ships,* NAV 51/10 of March 4, 2005, International Maritime Organization

/14/ *Joint North-West European Research Project - Safety Assessment of passenger/Roro vessels methodology Report*, DNV, 1997

/15/ *Transport Fatal accidents and FN Curves: 1967 – 2001 / HSE ISBN 0-7176-2623-7*

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*for use in the IMO rule-making process (MSC/Circ.1023−MEPC/Circ.392)*

# Appendices

## Appendix A – FN curves

The method for deriving societal risk evaluation criteria in this report is based on *The IMO consolidated FSA Guidelines* /15/. The following expression is a common starting point:

$$PLL_A = \sum_{N=1}^{N_u} N f_N \qquad (1)$$

Where:

$PLL_A$ is the average acceptable Potential Loss of Life, often based on the economic value of the activity and the risk associated with the persons involved.

$N_U$ is the upper limit of the number of fatalities that may occur in one accident. Here: 4,000 persons

$f_N$ is the frequency of occurrence of an accident involving *N* fatalities

$PLL_A$ for passengers is further defined as:

$$PLL_A = r * EV \qquad (2)$$

Where:

r Number of fatalities due to transportation divided by contribution to GNP by transportation. It can be calculated as r = fatalities/$ GNP. For the cruise industry this number is gathered from the aviation industry due to its large statistical database, and the aviation have many similarities to cruise industry, emphasising passenger safety which the cruise industry can compare itself to. This equals 4.8 fatalities / billion USD, ref/5/. (The numbers were originally in USD and converted to GBP by 2 GBP being 3 USD. Hence, varying exchange rates will change the results, the criteria lines and tolerability levels included). Crew risk evaluation criteria are not evaluated further here, only to mention that it is not considered as a transportation accident, but a work accident.

EV The economic value of the industry. In this case, the EV here is represented by a reference vessel and is derived from the income from cruise voyages. For the selected ship the annual economic value is calculated to be around USD 128 mill.

Through mathematical deductions, expression (1) can be converted to an equation describing a straight line in the FN diagram which corresponds to the average acceptable Potential Loss of Life (PLL). This leads to the following expression (3) for the accepted frequency of accidents involving one or more fatalities when defining the rate of inclination to -1, which is commonly accepted by several parties (ref /6/, /7/, /8/). By determining a steady rate of inclination the starting frequency can be calculated as a constant.

$$F_1 = \frac{PLL_A}{\sum_{N=1}^{N_u} \frac{1}{N}} \qquad (3)$$

Where:

$F_1$= is the frequency of accidents involving one or more fatalities

In the following tables the input values for the selected cruise ship are given.

**$F_1$ calculations**

| Input values | Parameter | Value | Denomination | Reference |
|---|---|---|---|---|
| To establish risk evaluation criteria for passengers | r | 4,778 | fat/1000MUSD | IMO MSC 72/16 |
| Economic value | EV | 128 | MUSD/year | Calculated, see details |
| Maximum fatalities | N | 4000 | fat | Project members decision |
| **Calculated values** | **Parameter** | **Value** | **Denomination** | |
| Sum 1/N | 1/N | 8,871 | [1 - 4000] | Calculated |
| Potential Loss of Life | $PLL_A$ | 0,611 | fat/year | Calculated |
| Tolerable one or more fat | F1 | 6,89E-02 | fat/year | Calculated |
| Upper boarder ALARP | $F1_{upper}$ | 6,89E-01 | fat/year | Calculated |
| Lower Border ALARP | $F1_{lower}$ | 6,89E-03 | fat/year | Calculated |

**EV calculations**

| *Input data* | | | Reference |
|---|---|---|---|
| Revenue for the fleet per year: | 9,727 | [1000 MUSD] | Carnival Corp. & PLC annual report 2004, page 4 |
| Number of ships in fleet | 76 | Ships | Carnival Corp. & PLC annual report 2004, page 4 |
| ***Calculations*** | | | |
| Revenue for an average ship | 128 | MUSD per year | Rev. fleet / number of ships in fleet |

### Appendix B – COLLISION event tree details

Table 1-Appendix B Collision event tree details (collision and fatality frequencies)

| Fatalities [per accident] | Fatalities [pr ship year] | Collision frequency [pr ship year] | Cumulative frequency [per ship year] |
|---|---|---|---|
| 0 | 0,0E+00 | 2,6E-03 | 4,6E-03 |
| 2 | 8,7E-04 | 4,3E-04 | 2,0E-03 |
| 5 | 5,9E-03 | 1,2E-03 | 1,6E-03 |
| 20 | 5,4E-03 | 2,7E-04 | 3,8E-04 |
| 100 | | | |
| 300 | | | |
| 800 | | | |
| 1600 | 3,7E-02 | 2,3E-05 | 1,1E-04 |
| 3200 | 2,2E-01 | 6,9E-05 | 9,1E-05 |
| 4000 | 9,1E-02 | 2,3E-05 | 2,3E-05 |

The FN curve is worked out based on the cumulative collision frequency for different fatalities per accident:

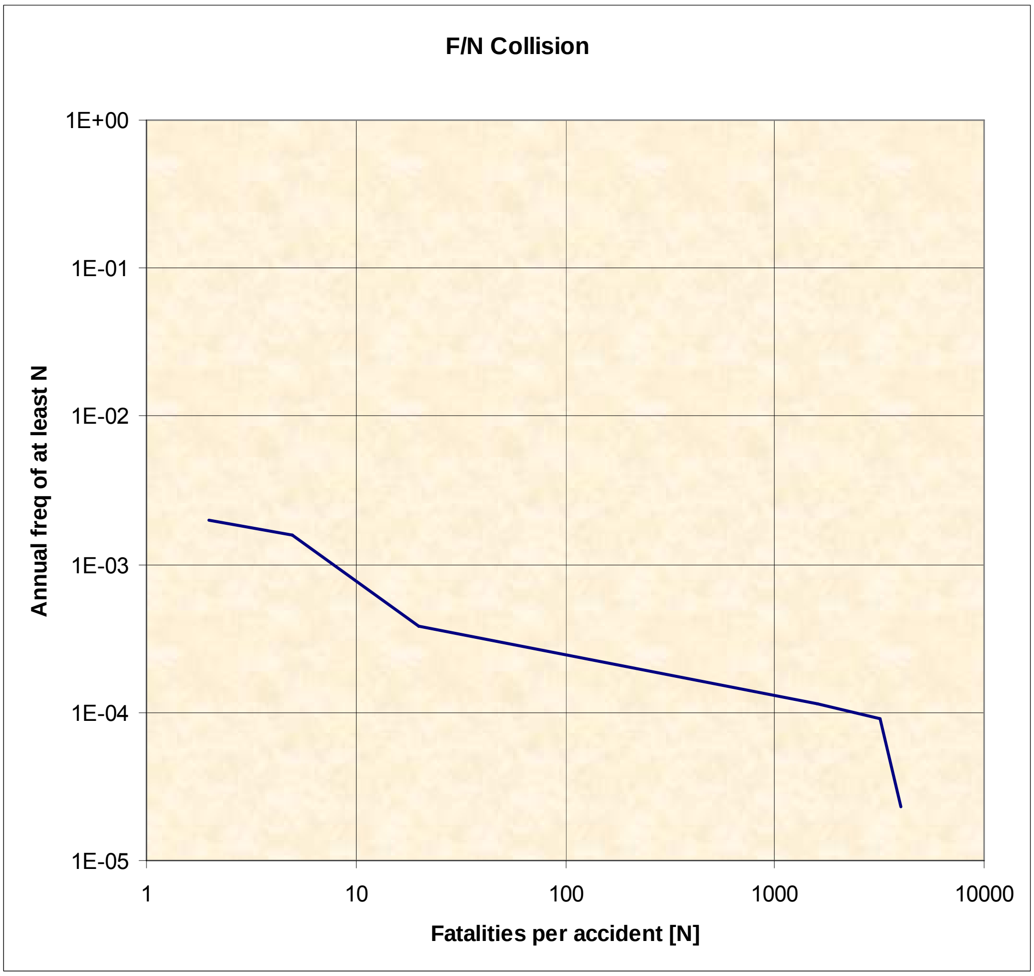


Figure 1-Appendix B  Collision FN curve

## Appendix C – CONTACT event tree details

| Table 1-Appendix C Contact event tree details (contact and fatality frequencies) | | | |
|---|---|---|---|
| Fatalities [per accident] | Fatalities [pr ship year] | Contact frequency [pr ship year] | Cumulative frequency [per ship year] |
| 0 | 0.0E+00 | 9.5E-04 | 1.2E-03 |
| 2 | 3.1E-04 | 1.6E-04 | 2.1E-04 |
| 5 | 1.3E-04 | 2.7E-05 | 5.5E-05 |
| 20 | 3.2E-04 | 1.6E-05 | 2.8E-05 |
| 100 | 7.3E-04 | 7.3E-06 | 1.2E-05 |
| 300 | 2.1E-04 | 7.0E-07 | 4.6E-06 |
| 800 | 9.3E-05 | 1.2E-07 | 3.9E-06 |
| 1600 | 1.2E-03 | 7.5E-07 | 3.8E-06 |
| 3200 | 7.2E-03 | 2.3E-06 | 3.0E-06 |
| 4000 | 3.0E-03 | 7.5E-07 | 7.5E-07 |

The FN curve is worked out based on the cumulative contact frequency for different fatalities per accident:

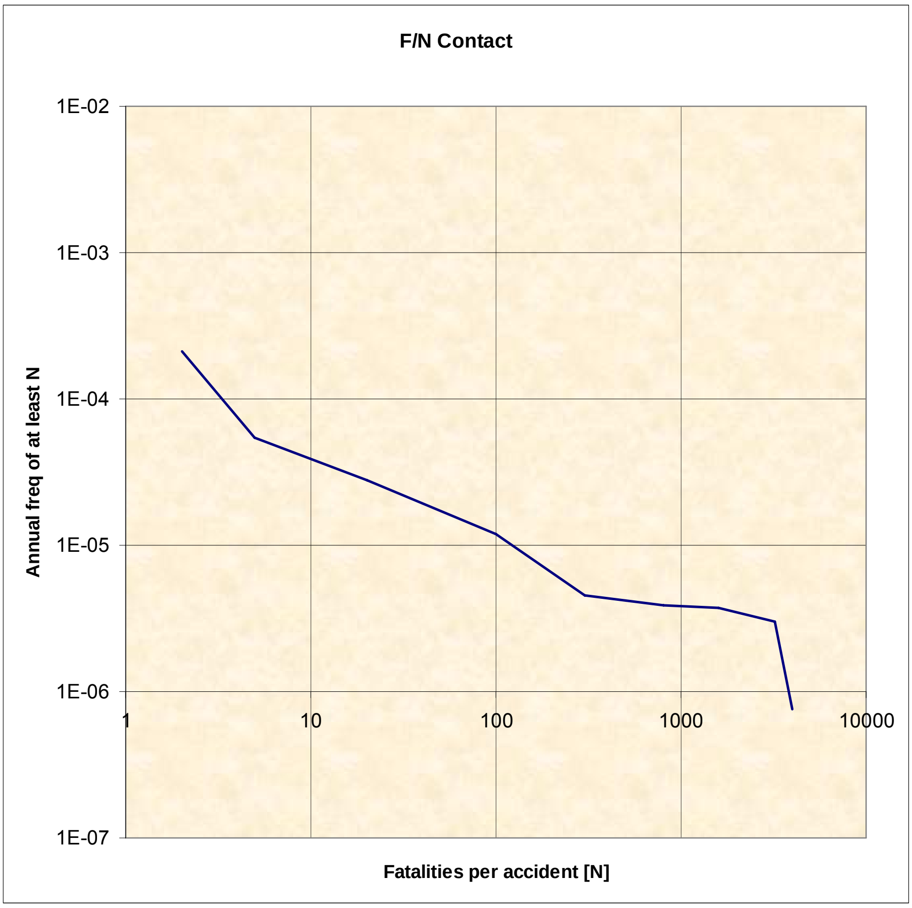


Figure 1-Appendix C Contact FN curve

## Appendix D – GROUNDING event tree details

Table 1-Appendix D Grounding event tree details (grounding and fatality frequencies)

| Fatalities [per accident] | Fatalities [pr ship year] | Grounding frequency [pr ship year] | Cumulative frequency [per ship year] |
|---|---|---|---|
| 0 | 0.0E+00 | 9.7E-04 | 9.8E-03 |
| 2 | 1.1E-02 | 5.3E-03 | 8.8E-03 |
| 5 | 1.7E-02 | 3.4E-03 | 3.5E-03 |
| 20 | 1.3E-05 | 6.6E-07 | 1.5E-04 |
| 100 | 8.9E-03 | 8.9E-05 | 1.5E-04 |
| 300 | 0.0E+00 | 0.0E+00 | |
| 800 | 2.6E-04 | 3.3E-07 | 5.9E-05 |
| 1600 | 1.9E-02 | 1.2E-05 | 5.9E-05 |
| 3200 | 1.1E-01 | 3.5E-05 | 4.7E-05 |
| 4000 | 4.7E-02 | 1.2E-05 | 1.2E-05 |

The FN curve is worked out based on the cumulative grounding frequency for different fatalities per accident:

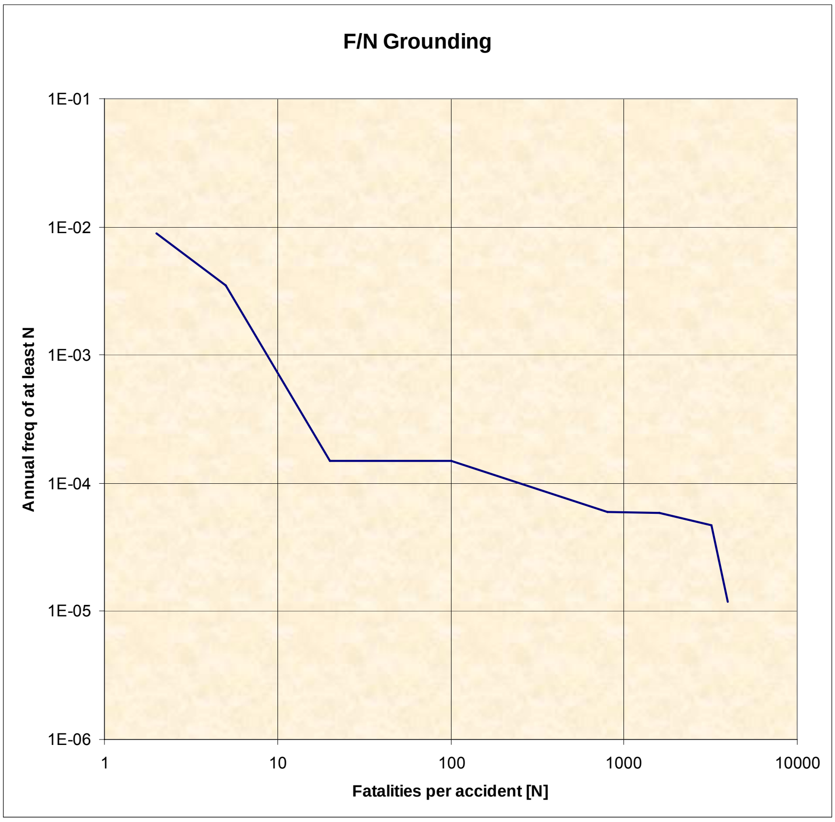


Figure 1-Appendix D Grounding FN curve

## Appendix E – FIRE/EXPLOSION event tree details

Table 1-Appendix E Fire/explosion event tree details (fire/expl. and fatality frequencies)

| Fatalities [per accident] | Fatalities [pr ship year] | Fire/expl. frequency [pr ship year] | Cumulative frequency [per ship year] |
|---|---|---|---|
| 0 | 0.0E+00 | 7.9E-03 | 8.9E-03 |
| 2 | 6.6E-04 | 6.5E-04 | 1.0E-03 |
| 5 | 1.1E-03 | 2.2E-04 | 3.9E-04 |
| 20 | 1.4E-03 | 7.1E-05 | 1.7E-04 |
| 100 | 8.0E-03 | 8.0E-05 | 9.8E-05 |
| 300 | 5.3E-03 | 1.8E-05 | 1.8E-05 |
| 800 | - | - | - |
| 1600 | - | - | - |
| 3200 | - | - | - |
| 4000 | - | - | - |

The FN curve is worked out based on the cumulative fire/explosion frequency for different fatalities per accident:

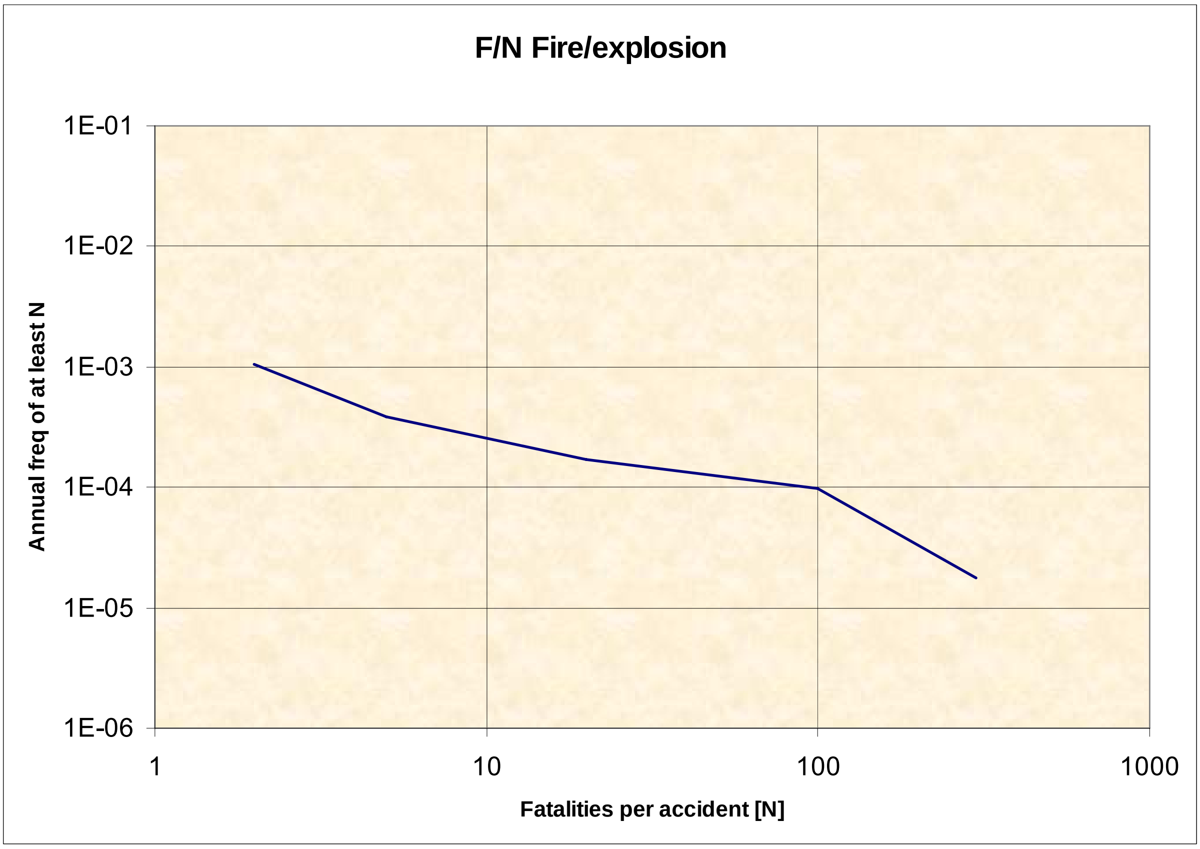


Figure 1-Appendix E Fire/explosion FN curve

## Appendix F – List of accidents

| Accident no | Year | Size [Grt] | Vessel name | Accident type | Number of Fatalities |
|---|---|---|---|---|---|
| 1 | 1997 | 25,611 | CONSTITUTION | CAPSIZE | . |
| 2 | 2000 | 31,793 | SEABREEZE I | CAPSIZE | . |
| 3 | 2000 | 32,327 | BELOFIN I | CAPSIZE | . |
| 4 | 2001 | 33,930 | SEA | CAPSIZE | . |
| 5 | 1992 | 37,012 | EUROPA | COLLISION | . |
| 6 | 1993 | 44,588 | NOORDAM | COLLISION | . |
| 7 | 1999 | 50,760 | THE TOPAZ | COLLISION | . |
| 8 | 1999 | 74,136 | NORWEGIAN DREAM | COLLISION | . |
| 9 | 2000 | 58,714 | BIG RED BOAT III | COLLISION | . |
| 10 | 2001 | 75,166 | ROYAL PRINCESS | COLLISION | . |
| 11 | 2003 | 21,010 | SILJA OPERA | COLLISION | . |
| 12 | 2004 | 23,292 | ENCHANTMENT OF THE SEAS | COLLISION | . |
| 13 | 2001 | 24,346 | EUROPEAN VISION | CONTACT | . |
| 14 | 2003 | 29,638 | COSTA VICTORIA | CONTACT | . |
| 15 | 1990 | 21,619 | FAIRSTAR | FIRE/EXPLOSION | 1 |
| 16 | 1990 | 23,478 | CRYSTAL HARMONY | FIRE/EXPLOSION | . |
| 17 | 1994 | 24,254 | ACHILLE LAURO | FIRE/EXPLOSION | 4 |
| 18 | 1995 | 24,474 | REGENT STAR | FIRE/EXPLOSION | . |
| 19 | 1995 | 24,803 | ALBATROS | FIRE/EXPLOSION | . |
| 20 | 1995 | 28,388 | CELEBRATION | FIRE/EXPLOSION | . |
| 21 | 1996 | 30,440 | SAGAFJORD | FIRE/EXPLOSION | . |
| 22 | 1996 | 35,190 | GOLDEN PRINCESS | FIRE/EXPLOSION | . |
| 23 | 1998 | 47,262 | ECSTASY | FIRE/EXPLOSION | . |
| 24 | 1999 | 47,262 | SUN VISTA | FIRE/EXPLOSION | . |
| 25 | 1999 | 48,563 | TROPICALE | FIRE/EXPLOSION | . |
| 26 | 1999 | 48,621 | ENCHANTMENT OF THE SEAS | FIRE/EXPLOSION | . |
| 27 | 1999 | 70,367 | NORWAY | FIRE/EXPLOSION | 8 |
| 28 | 2000 | 74,136 | CELEBRATION | FIRE/EXPLOSION | . |
| 29 | 2001 | 76,049 | NORDIC EMPRESS | FIRE/EXPLOSION | . |
| 30 | 2003 | 76,049 | NORWAY | FIRE/EXPLOSION | 8 |
| 31 | 1991 | 21,619 | SEAWARD | GROUNDING | . |
| 32 | 1992 | 21,667 | QUEEN ELIZABETH 2 | GROUNDING | . |
| 33 | 1994 | 28,430 | SALLY ALBATROSS | GROUNDING | . |
| 34 | 1995 | 31,793 | STAR PRINCESS | GROUNDING | . |
| 35 | 1996 | 32,753 | ROYAL VIKING SUN | GROUNDING | . |
| 36 | 1997 | 32,753 | ALBATROS | GROUNDING | . |
| 37 | 1997 | 32,753 | HORIZON | GROUNDING | . |
| 38 | 1998 | 40,132 | MONARCH OF THE SEAS | GROUNDING | . |
| 39 | 1999 | 46,052 | NORWEGIAN SKY | GROUNDING | . |
| 40 | 2000 | 46,087 | CAROUSEL | GROUNDING | . |
| 41 | 2001 | 46,087 | MISTRAL | GROUNDING | . |
| 42 | 2002 | 47,262 | OLYMPIA VOYAGER | GROUNDING | . |
| 43 | 2003 | 55,451 | MARCO POLO | GROUNDING | . |
| 44 | 2003 | 58,600 | MONA LISA | GROUNDING | . |
| 45 | 2003 | 59,652 | HOLIDAY | GROUNDING | . |
| 46 | 2004 | 69,153 | ASTOR | GROUNDING | . |

| Accident no | Year | Size [Grt] | Vessel name | Accident type | Number of Fatalities |
|---|---|---|---|---|---|
| 47 | 2004 | 69,490 | MONA LISA | GROUNDING | . |
| 48 | 1991 | 70,390 | FAIRSTAR | OTHER | 1 |
| 49 | 1997 | 73,817 | EDINBURGH CASTLE | OTHER | . |
| 50 | 1998 | 76,152 | EDINBURGH CASTLE | OTHER | . |
| 51 | 1998 | 76,522 | EDINBURGH CASTLE | OTHER | . |
| 52 | 1999 | 90,228 | ISLANDBREEZE | OTHER | . |
| 53 | 1999 | 90,228 | ORIANA | OTHER | . |
| 54 | 2000 | 90,228 | PARADISE | OTHER | . |
| 55 | 2000 | 90,228 | GRANDEUR OF THE SEAS | OTHER | . |
| 56 | 2000 | 90,228 | AURORA | OTHER | . |
| 57 | 2000 | 90,280 | CARNIVAL DESTINY | OTHER | . |
| 58 | 2001 | 91,740 | EUROPEAN VISION | OTHER | . |
| 59 | 2001 | 101,353 | GALAXY | OTHER | . |
| 60 | 2001 | 148,528 | INFINITY | OTHER | . |
| 61 | 2002 | 20,606 | VIKING SERENADE | OTHER | . |
| 62 | 2002 | 22,080 | CELEBRATION | OTHER | . |
| 63 | 2002 | 23,149 | STATENDAM | OTHER | . |
| 64 | 2002 | 24,391 | INFINITY | OTHER | . |
| 65 | 2002 | 24,803 | SUMMIT | OTHER | . |
| 66 | 2003 | 25,076 | OCEANBREEZE | OTHER | . |
| 67 | 2003 | 28,891 | COSTA ALLEGRA | OTHER | . |
| 68 | 2003 | 28,891 | PACIFIC SKY | OTHER | . |
| 69 | 2003 | 37,845 | LEGEND OF THE SEAS | OTHER | . |
| 70 | 2003 | 42,276 | MILLENNIUM | OTHER | . |
| 71 | 2003 | 46,052 | INFINITY | OTHER | . |
| 72 | 2004 | 46,811 | HOLIDAY | OTHER | . |
| 73 | 2004 | 47,276 | PACIFIC SKY | OTHER | . |
| 74 | 2004 | 63,524 | ROTTERDAM | OTHER | . |
| 75 | 2004 | 69,053 | INFINITY | OTHER | . |
| 76 | 2004 | 73,937 | NORWEGIAN STAR | OTHER | . |
| 77 | 2004 | 77,104 | QUEEN MARY 2 | OTHER | . |

# ANNEX III

## RISK CONTROL OPTIONS, COST BENEFIT ANALYSIS

## AND

## RECOMMENDATIONS

# ANNEX III - *Cost efficiency analysis, Recommendations*

# Contents

# 1 Introduction

The FSA for cruise ships – is described in three Annexes:

- Annex I – Hazard identification
- Annex II – Risk analysis
- Annex III – Cost benefit analysis and recommendations

This document contains the third and last Annex, to the FSA.

The results from the Annex I (hazard identification) /6/ and Annex II (risk analysis) (/4/) have been used as input information and modelling for this document.

## *1.1 Concretization of Task Description*

In the third Annex different risk control options (RCOs) will be identified to control the major risks identified. The RCOs will then be assessed through cost efficiency analysis using the standard IMO procedures and criteria for cost effectiveness. The assessment will consist of three parts:

- Identification of relevant risk control options
- Estimation of risk reducing effect of identified RCOs
- Evaluation of cost efficiency of RCOs

The risk is reduced either through reduction of frequency or consequence, or both. Only cost effective RCOs – i.e., when delta cost divided by delta risk is below the IMO predetermined value (cost effectiveness criteria) – will be recommended.

# 2 FSA Methodology

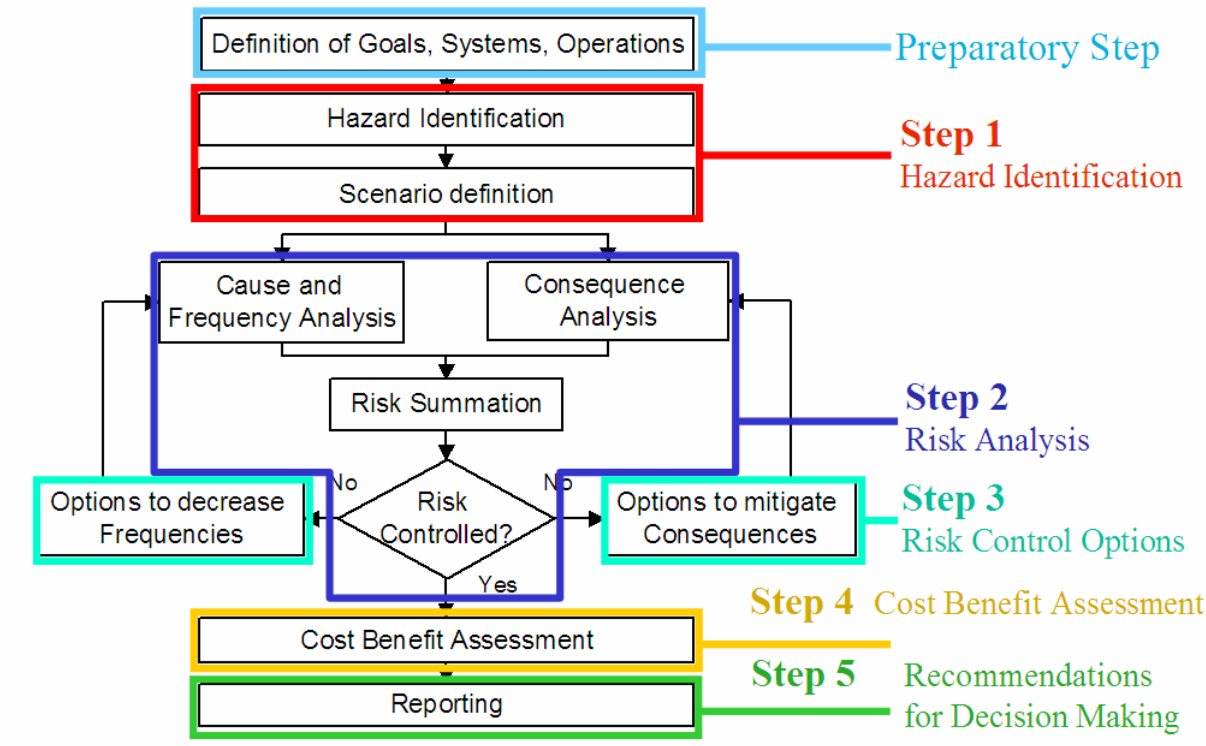


**Figure 1: The five steps of Formal Safety Assessment (from IACS FSA training course).**

Figure 1 shows the five main steps of the Formal Safety Assessment (FSA) approach, detailing what each step is comprised of and how the various steps are interrelated. This report is mainly related to the FSA steps 3, 4 and 5 but it is an iterative process to assess the risk reduction effect of identified risk control options. The total risk, defined as the combination of frequency and severity summed up over all identified accident scenarios may be controlled by a number of well-known or newly identified risk control options. Finally, the objective of the cost efficiency assessment step is to identify and rank the risk control options in order to determine the most cost efficient ones, i.e. those that provide most risk reduction in relation to cost. In order to compare single risk control measures or combinations of measures (risk control options) in a systematic and structured way, the risk models developed in Annex II (in accordance to step 2 of FSA) are used for re-evaluation of the total risk after implementation of risk control measures.

The following subsections are based on the IMO FSA Guidelines (/1/).

## *2.1 Risk Control options*

The purpose of Step 3 in Figure 1 is according to /1/ to propose effective and practical RCOs comprising the following four principal stages:

1. Focusing on risk areas needing control;
2. Identifying potential risk control measures (RCMs);
3. Evaluating the effectiveness of the RCMs in reducing risk by re-evaluating Step 2 (Figure 1) ; and
4. Grouping RCMs into practical regulatory options.

The purpose of focusing on risk areas is to screen the output of Step 2 (Figure 1) so that the effort is focused on the areas most needing risk control. The main aspects to making this assessment are to review the Risk levels, by considering the frequency of occurrence together with the severity of the outcomes. Accidents with an unacceptable risk level become the primary focus.

Structured review techniques are typically used to identify new RCMs for risks that are not sufficiently controlled by existing measures. These techniques may encourage the development of appropriate measures and include risk attributes and causal chains. Risk attributes relate to how a measure might control a risk, and causal chains relate to where, in the "initiating event to casualty" sequence, risk control can be introduced. RCMs should in general be aimed at one or more of the following:

1. Reducing the frequency of failures through better design, procedures, organizational polices, training, etc
2. Mitigating the effect of failures, in order to prevent accidents;
3. Alleviating the circumstances in which failures may occur; and
4. Mitigating the consequences of accidents.

The output from this step comprises:

1. A range of RCOs which are to be assessed for their effectiveness in reducing risk; and
2. A list of interested entities affected by the identified RCOs.

## 2.2 Cost Efficiency assessment

The purpose of Step 4 (Figure 1) as described in /1/ is to identify and compare the achieved risk reduction and benefits with the costs associated with the implementation of each RCO identified and defined in Step 3 (Figure 1). A cost efficiency assessment following the IMO procedure may consist of the following stages:

1. Consider the risks assessed in Step 2 (Figure 1), both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;
2. Arrange the RCOs, defined in Step 3 (Figure 1), in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;
3. Estimate the pertinent costs and benefits for all RCOs by reassessing the risk assuming the option under consideration is in place and comparing this risk level to the established base case;
4. Estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and
5. Rank the RCOs from a cost-efficiency perspective in order to facilitate the decision-making recommendations in Step 5 (Figure 1) (e.g. to screen those that are not cost effective or impractical). Costs should be expressed in terms of life cycle costs and may include initial setup, operating, training, inspection, certification, decommission etc. Benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, etc. and an increase in the expected operating life of ships. There are several indices used by IMO that express cost effectiveness in relation to safety of life such as Gross Cost of Averting a Fatality (GrossCAF) and Net Cost of Averting a Fatality (NetCAF).

The definitions of GrossCAF and NetCAF are:

$$GrossCAF = \frac{\Delta C}{\Delta R} \qquad NetCAF = \frac{\Delta C - \Delta B}{\Delta R}$$

Where:

$\Delta C$ is the cost per ship of the risk control option during the lifetime of the vessel.

$\Delta B$ is the economic benefit per ship resulting from the implementation of the risk control option during the lifetime of the vessel.

$\Delta R$ is the risk reduction per ship, in terms of the number of fatalities averted, implied by the risk control option during the lifetime of the vessel.

The output from this step comprises:

1. Costs and benefits for each RCO identified in Step 3(Figure 1) from an overview perspective;
2. Costs and benefits for those interested entities which are the most influenced by the problem in question; and
3. Cost effectiveness expressed in terms of suitable indices.

### *2.3 Recommendation for decision making*

The purpose of Step 5 (Figure 1) is to develop recommendations that can be presented to the relevant decision makers in an auditable and traceable manner. Those recommendations will be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable. IMO has recently published criteria to be used in rule making for GCAF and NCAF /10/ and to comply with IMO's requirements these values have been used to assist judgements about the effectiveness of RCO's in this work. While it is desirable for the IMO and Member Governments that propose new regulations or modifications to existing regulations to determine agreed risk evaluation criteria after wide and deep consideration, those used within an FSA should be explicit. The output from Step 5 (Figure 1) comprises:

1. An objective comparison of alternative options, based on the potential reduction of risks and cost effectiveness, in areas where legislation or rules should be reviewed or developed; and
2. Feedback information to review the results generated in the previous steps.

# 3 Risk Control Options

### *3.1 Results of 4.1.2; Risk Picture for the Cruise industry*

Risk is defined as the frequency of an event considered together with the associated consequence. In this project the risk is expressed using the estimated number of fatalities per ship year. The risk analysis performed in Annex II (/4/) defines the risk exposure for the cruise ships.

The accident statistics are based on the LRFP (Lloyd's Register Fairplay) database. The database is one of the most extensive resources available for merchant ship accident information. The entries are recorded based on accident reports from Lloyd's agents throughout the world. For cruise vessels, the number of entries in the LRFP database is rather low due to the small fleet size. This provides a limited statistical database for defining the current risk level for the cruise industry. It is a major point that the recent risk picture is not necessarily representative for the future, and that future accident consequences to some degree will arise in other areas than covered in this study, which has mainly been based on historical events. Historically, few accidents have occurred with cruise vessels. Zero incidents today however do not necessarily mean that a certain event cannot happen. The result from the modelling is therefore the best estimate on what is the actual risk level for cruise vessels. In order to predict the present and future risk levels it is not enough to look only in the rear mirror. Therefore statistics are used as a supplement to modelling to provide further confidence in the estimated results.

An analogy from aviation is presented to clarify the need for risk models: Concorde was, according to accident statistics, the safest commercial airplane in the world for over 20 years. Then, following the disastrous Paris accident in July 2000 the ratings dropped from no. 1 to no. 19. (http://www.airdisaster.com/statistics/) Following only one casualty, the new Concorde risk level is estimated to be 12.5 fatal incidents per 1 million flights. Compare this to 0.62 fatal incidents per 1 million flights for the more common Boeing 737. The point is this. Accident statistics can be very deceiving, especially when the statistics are based on small samples, as the case is with Concorde, or for that matter the large cruise vessels. It is essential to develop risk models to estimate the actual risk level of any system.

The risk is expressed as the expected number of fatalities per ship year for each of the following events: collision, grounding, contact and fire. The main characteristics of the cruise industry's risk exposure can be described in the following (excerpt from /4/):

- Smaller accidents with 2 to 5 fatalities can be expected every year in the current fleet of 172 ships. This corresponds well to historical data from LRFP (1990-2004).
- The vast majority of the risk lies within the large scale accident category (≥80% of ship's complement) due to the large numbers of estimated fatalities.
- The risk level is within the ALARP region for crew and for passengers.
- Collision and grounding accounts for 93 % of the risk in terms of fatalities.
- Catastrophic accidents with large number of fatalities account for 85% of the risk despite the low frequency for such events.

The large scale accidents are mainly results from collision and grounding accidents. This is due to the fact that a total loss is more likely to be initiated through a severe collision or grounding accident. These are low frequency, but very high consequence accidents. Although the possibility for a total loss is low the high consequence makes the final risk more significant than any other accidents. Fire is not a high risk scenario although the frequency is relatively high compared with collision and grounding. The consequence of most fires is, by comparison, more limited in terms of loss of life.

It should be noted, that the objective of this project is not only to pursue solutions dealing with high risk areas but to identify solutions with high risk reducing potential. This means that although fire only accounts for 3% of the risk, effective risk reducing measures should not be ignored for this scenario. However, the risks involved in collision and grounding accidents are far greater in absolute terms, and it is likely that these areas also hold the greatest risk reduction potential. It is therefore the intention of this sub-project to focus on risk reducing measures for collision and grounding accidents. For these accidents the record is at best limited and for the modern fleet such an accident has yet to occur, although some near misses are known (i.e. Norwegian Dream in 1999)

A closer look at the modelled event trees from Annex II reveals that the bulk of the risk originates from a very specific scenario within the collision and grounding accidents: water ingress leading to a rapid capsize.

## *3.2 Reference ship*

Calculations for both economic costs and benefits have been based on the same reference ship as in Annex II. The characteristics of this ship are presented in Table 1. This is a modern "Post Panamax" cruise vessel. This vessel is assumed to represent an average vessel in the future world cruise fleet. A relatively large cruise vessel was selected to represent the future standard cruise ship taking into consideration the growth of the cruise industry. This was done partly to avoid mixing vessels intended for transportation and vessels intended for recreation purposes, and partly to reflect a segment of the fleet in rapid growth.

All proposed RCOs will be evaluated based on an assumed implementation on a vessel as described in Table 1. However, when performing the stability calculations to evaluate the risk reducing effects of damage stability RCOs in this report, a slightly smaller ship was used (Table 2). This was done for convenience as the ship drawings and computerised models were readily available for the smaller vessel. Although smaller by 18% measured in gross tonnes (GT), the geometric dimensions of second vessel are not very different from the first, and it is the opinion of the project team that the stability assessments carried out for the second ship (Table 2) is representative for the first (Table 1).

| Table 1: Reference ship parameters | |
|---|---|
| **Ship parameters** | **Value** |
| Size | 110,000 GT |
| Passengers | 2,800 |
| Crew | 1,200 |
| Passengers + Crew | 4,000 |
| Length | 290 m |
| Draft | 8.5 m |
| Breadth | 36 m |

| Table 2: The specific ship used for stability calculations. | |
|---|---|
| **Ship parameters** | **Value** |
| Size | 90,000 GT |
| Passengers | 2,500 |
| Crew | 800 |
| Passengers + Crew | 3,300 |
| Length | 290 m |
| Draft | 8.5 m |
| Breadth | 32.2 m |

## 3.3 Identification of RCOs

Potential risk control options (RCOs) were identified in a process focusing on two approaches:

1. Review of previously examined RCOs: RCOs which had been evaluated in previous studies, but not found to be recommended for implementation were re-evaluated.
2. Identification of new RCOs. This was done by review of Annex I, by project members in a brainstorming sessions, and through interviews of experts in navigation, fire and stability and general industry experience. Experts from class and industry were consulted. (Ref. Appendix IV for names and positions).

Measures reducing accident consequence and measures reducing accident frequency were sought. From the identification process a long list containing all identified RCOs (Ref. Appendix I) was generated.

## 3.4 Screening of RCOs

To obtain a practicable number of RCOs to analyse in detail a screening process was initiated. The screening process eliminates those RCOs listed in Appendix I which are least likely to be cost effective according to the IMO procedures and criteria. This reduced the number of RCOs down to a manageable number for a more thorough analysis within the time frame allocated for this task. The screening process was performed through workshops with a panel of experts from class and industry.

The work done on RCOs identified in previous studies was reviewed with regard to both the risk assessment and the costs assessments. Industry best practise suggests that several of the RCOs could be effective at managing the risks, although the previous studies reached other conclusions based on cost effectiveness. These conclusions were examined to identify any erroneous assumptions. All these RCOs were analysed based on the suspicion of either a new risk picture or cost estimate. For those RCOs where neither of the aforementioned areas had any changes, the RCOs were rejected for further recommendation.

RCOs not previously examined were subjected to a standard screening process: The first step of the screening was to order the RCOs into a prioritized list using the following criteria:

1. Preventive options should have priority before mitigating options
2. Design options should have priority before operative measures
3. Passive systems should have higher priority than active systems

The rating of the RCOs "Estimated effect" was discussed in panels. The effect was evaluated through separating the different effects of the RCO and mapping them up against the relevant areas in the event trees of Annex II. Due to the conclusions of Annex II, focus was kept on the high consequence low frequency scenarios. RCOs related to so called "low risk" scenarios like fires initiated in galley, laundry room and cabins were given a lower priority. All RCOs were subjected to a crude estimation of the risk reducing potential, closely linked to the risks described in Annex II. Then, crude cost estimates were used to screen high effect RCOs.

After the initial rating, a sanity check was performed for the proposed RCOs. All RCOs should be:

- Manageable
- Practical
- Possible to implement

The result of the screening process was a short list of 4 RCOs deemed to be the most promising. There are two reasons why this list was kept short in comparison with other FSA studies, which often consider far more RCOs. Firstly, the cruise industry has a very high focus on safety, and much has been done in the past to secure the vessels. This is clearly reflected in the estimated fire risk, which is very low. This focus has resulted in several previous studies, covering various aspects of cruise industry risk, leaving few areas to be analysed. Secondly, the risk picture for the cruise industry is so dominated by a few scenarios, which together with the level of previous studies, narrows the focus considerably. In essence, two major considerations dominated the prioritisation. Firstly, the clear evidence from Annex II which focuses attention on high consequence collision and grounding accidents. This lead to an active search for RCOs intended for accident avoidance and RCOs for accident mitigation. Secondly, because previous studies /5/ has extensively analysed accident avoidance (aids to navigation), the focused narrowed to accident mitigation RCOs.

Most of the RCOs considered and discarded will not be discussed further. However, a few RCOs which were not analysed further are explicitly mentioned because they are of special interest. Appendix III describes the project team's deliberations regarding two RCOs deemed promising based on industry best practice, but which proved to be not cost effective.

Table 3 lists RCOs related to damage stability which were not analysed further. Damage stability is clearly a focus area based on the lessons from Annex II. However, damage stability calculations are complex and time consuming, and limitations in time and resources required a strict prioritisation of Stability RCOs. Hence, the four options listed below were not further analysed, but they are nevertheless recommended for further analysis as the risk reducing potential in this area is significant.

**Table 3: Stability RCOs not considered further, recommended for consideration in later studies.**

| No | RCO |
|---|---|
| 4 | Avoid longitudinal subdivision below bulkhead deck |
| 5 | Optimal position of transverse bulkheads |
| 6 | Effective cross flooding arrangements |
| 7 | Increased height of openings |

Also, a few RCOs on the list (Appendix I) have already been recommended to IMO for implementation. These are listed in Table 4. It is the opinion on the project team that the analyses on which these recommendations are made are sound, and that the results of Annex II encourage the implementation of these RCOs as they clearly demonstrate the need to avoid navigation related accidents. While no further work is done on these four RCOs in the current report, the project team confidently supports the recommendations stated in /5/.

| Table 4 RCOs recommended by NAV51/10 study (/5/). | |
|---|---|
| **No** | **RCO** |
| 39 | Improved bridge design (above SOLAS) |
| 30 | ECDIS - Electronic Chart Display and Information System |
| 33 | Increased Simulator Training for Navigators |

The above considerations result in a list of four RCOs which will be studied in detail, and evaluated for cost efficiency in the following chapter. The four RCOs to be evaluated are listed in Table 5, as well as a fifth and sixth option which are combinations of the other stability RCOs, which is also studied in detail.

| Table 5: RCOs selected for Cost – Efficiency Analysis | |
|---|---|
| **No** | **RCO** |
| 1 | Increased GM |
| 2 | Increased Freeboard |
| 3 | Reserve buoyancy high up and far out |
| 27 | Implementation of guidelines for Bridge Resource Management (BRM) |
| 1+3 | Combined Buoyancy and GM |
| 1+2+3 | Combined Buoyancy, GM and Freeboard increase |

# 4 Cost –Efficiency analysis

The RCOs listed in Table 5 are analysed in this chapter using the methods and criteria set out by IMO /1/, /10/. In addition to the descriptions in Appendix I, Table 6 presents details on the proposed damage stability RCOs and the alterations made for each RCO. The information in Table 6 is used in the following subsections to evaluate risk reduction, costs and benefits.

The cost and benefit of the RCOs will be spread over the lifetime of the vessel. Some RCOs might involve costs every year while others only involve costs at given intervals. In order to be able to compare the costs and benefits and calculate the NetCAF and GrossCAF, Net Present Value (NPV) calculations have been performed using the formulae as given below:

$$NPV = A + \frac{X}{(1+r)} + \frac{X}{(1+r)^2} + \frac{X}{(1+r)^3} + \ldots + \frac{X}{(1+r)^T}$$
$$= A + \sum_{t=1}^{T} \frac{X}{(1+r)^t}$$

Where:
X = cost or benefit of RCO any given year
A = Amount spent initially for implementation of RCO
r = interest rate

**Table 6: Stability RCOs, alterations to the original ship design.**

| Configuration | Subdiv. Length (m) | Breadth (m) | Freeboard depth (m) | Freeboard (m) | GM (m) | Attained Subdiv. index A | Cost factors | Benefit factors |
|---|---|---|---|---|---|---|---|---|
| As is (vessel in Table 2) | 285 | 32.2 | 10.7 | 2.2 | 2.0 | **0.80** | | |
| **RCO 1:** Increased GM 0.5 m | 285 | **32.7** | 10.7 | 2.2 | **2.5** | **0.85** | 1) | 2) |
| **RCO 2:** Increased freeboard 0.5 m | 285 | 32.5 | 11.2 | **2.7** | 2.0 | **0.85** | 3) | 4) |
| **RCO 3:** Reserve buoyancy on bulkhead deck | 285 | 32.2 | 10.7 | 2.2 | 2.0 | **0.836** | 5) | |
| **RCO 1+3:** Reserve buoyancy on bulkhead deck Increased breadth 1 m Increased GM 0.5 m One additional deck | 285 | **33.2** | 10.7 | 2.2 | **2.5** | **0.875** | 6) | 7) |
| **RCO 1+2+3: Increased Freeboard 0.5 m Reserve buoyancy on bulkhead deck Increased breadth 1m Increased GM 0.5 m 60% add. Deck** | 285 | **33.2** | 11.2 | 2.7 | **2.5** | **0.899** | 6) | 8) |

1) Increased steel weight 50-100 t
2) Increased deck area approx. 100 m2 per deck
3) Increased steel weight 50-100 t
4) Increased deck area approx. 60 m2 per deck
5) Reduced deck area approx. 2500 m2 on bulkhead deck
6) Increased steel weight 1200-1500 t
7) Increased deck area approx. 4500 m2
8) Increased deck area approx. 2500 m2

## *4.1 Risk reduction of selected RCOs*

### 4.1.1 Increased Freeboard

Freeboard is the distance from the water line to the freeboard deck of a fully loaded vessel; it is measured amidships at the side of the hull. For cruise ships the freeboard deck is normally taken as the bulkhead deck – the deck to which all transverse watertight sub-division is taken. Freeboard represents the safety margin showing to what draft a ship may be loaded under various service conditions. Further description of this RCO is included in Appendix I, and some details are given in Table 6 above.

The risk reduction is achieved through an increased attained damage stability index A. The new requirements (entering into force on January 1st 2009) call for a required stability index R = 0.8 for a ship as described in Table 2 (based on the calculation procedure of MSC 194(80) /8/, using the values of Table 2). This will be used as the base case performance.

Increasing the Freeboard by 0.5 meters will raise the index A from 0.8 to 0.85. These calculations are based on the work done in the HARDER project /9/, and implemented in MSC 194(80) /8/. Using the event tree developed in Annex II it is found that for the collision scenario this translates to a risk reduction of ΔR = 2.1 lives per ship lifetime[1]. Ship lifetime is assumed to be 30 years. Put in another way, this RCO is expected to save one life per ship every 14.3 years. Perhaps more important than focusing on the specific value for the estimated number of lives saved, is to realise the relative decrease in risk brought on by the increased value of A, and thus increased stability. Increasing the index A by 0.05 corresponds to increasing the probability of staying afloat by 5 percentage points. This is the same as reducing the probability of sinking after water ingress from collision by 25% (sinking in 20 out of 100 cases vs. sinking in 15 out of 100 cases). This scenario is in turn the dominant risk driver for large cruise ships, meaning the risk level on cruise ships is sensitive to changes in R.

As the subdivision index A does not directly relate to any other scenario than collision, the risk reducing effects of the selected RCO with regard to grounding and contact are more difficult to identify. In the current report no attempt to do so is made. While it is the firm belief of the project team that the current RCO will impact on the grounding scenario in particular, this effect is ignored in the current risk evaluation. This means that the estimated risk reducing effect of 2.1 lives per ship lifetime should be considered to be conservative.

### 4.1.2 Increased GM

GM is an expression for the relation between the height of a vessels centre of gravity, and its centre of buoyancy. Further description of this RCO is included in Appendix I, and some details given in Table 6. Increasing the GM by 0.5 meters will raise the attained damage stability index A from 0.8 to 0.85. Using the event tree developed in Annex II it is found that for the collision scenario this translates to a risk reduction of ΔR = 2.1 lives per ship lifetime. Ship lifetime is assumed to be 30 years.

This estimate should be considered to be conservative, as only the collision scenario is considered (see section 4.1.1).

### 4.1.3 Added buoyancy, high up and far out

A description of this RCO is included in Appendix I, and some details given in Table 6. Figure 2 and Figure 3 illustrate the implementation of the RCO. Adding buoyancy on the bulkhead deck will raise the index A from 0.8 to 0.836. Using the event tree developed in Annex II it is found that for the collision scenario this translates to a risk reduction of ΔR = 1.35 lives per ship lifetime. Ship lifetime is assumed to be 30 years.

As only the collision scenario is considered (see section 4.1.1), this estimate should be considered to be conservative. However, it should be noted that that this RCO has only been examined for its effectiveness related to an increase in A value. The implications on layout and other potential economic or safety hazards/risks have not been evaluated. For instance, the lack of outboard space on deck 4 may potentially lead to a collection of other risks – e.g. Machinery that is required to be put closer to passenger spaces, lack of management capability due to offices placed away from control stations, etc. This has not been evaluated in this report.

[1] The detailed calculation procedure is as follows. The probalility of a struck ship with flooding remaining afloat is set at 0.73 in level 3 of the Collision event tree. This probalility corresponds to the value of A, i.e. the fleet average A value is 0.73. To estimate the risk reduction accociated with the stability RCOs in the current study, a reference ship is being used for detailed calculations and the average value of 0.73 is replaced by the A value for the reference ship (0.8) to find the baseline risk level. The value of 0.8 is then replaced with the increased A value (Table 6) to find the reduced risk level.

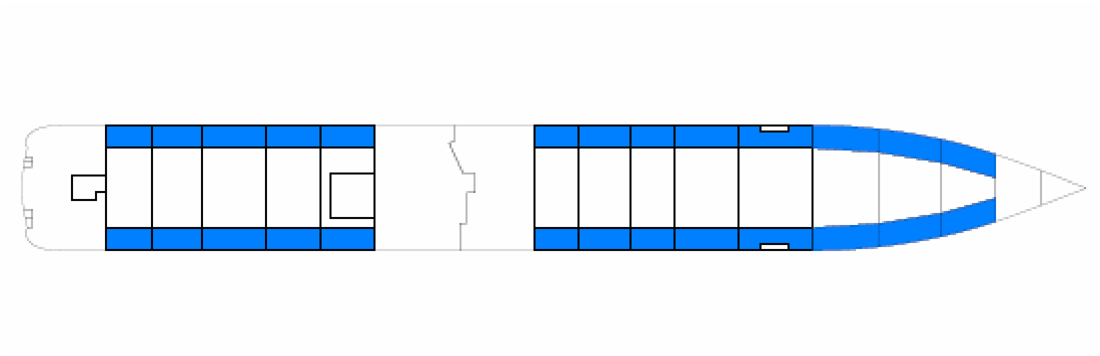

**Figure 2 Simplified bulkhead deck plan, illustrating the position of the added buoyancy compartments.**

**Figure 3  Approximate position of added buoyancy compartments. For illustration purposes only.**

### 4.1.4 Implementation of guidelines for Bridge Resource Management (BRM)

The effect of implementing enhanced Bridge Resource Management procedures is a reduction in accidents related to navigational errors. The risk models developed in Annex II (/4/) are not well suited to evaluate such an effect, as the models were not developed to evaluate the processes leading up to accidents such as grounding or collision. The reason for this is found in the objective statement of SAFEDOR :

"The risk modelling has been performed at high level in order to produce an overall risk picture for a generic cruise ship and the current world cruise fleet. However, in order for the FSA to provide value for an operator or designer as a practical tool for decision making in the design phase, more detailed risk models will be necessary"

However, extensive modelling of the events leading to grounding and collision was done in the FSA Large Passenger Ship Navigation study /5/. The focus of the two FSAs was different. For the FSA Large Passenger Ship Navigation study /5/ it was stated that:

"The most valuable output from a risk model is not the overall risk levels that are predicted by the model, but the structure itself and all the contributing factors that enables an understanding of the failure mechanisms and gives a quantified result whenever one of the input parameters is altered"

And

"The most important learning from the project is the understanding of the relation between the factors that contribute to grounding and collision. The most important use of the models will be as a tool to evaluate the effect of risk control options for new regulations"

Thus, the absolute level of risk was not of great importance in the FSA Large Passenger Ship Navigation study /5/, compared to the ability to asses the risk reducing effects of RCOs. Based on this it is believed that the risk reduction (in percent) estimated in the FSA LPS Nav study is accurate and applicable to the current study. While the risk reducing potential of the proposed RCOs will be calculated using the percentage of accidents avoided from FSA LPS Nav (/5/), the risk levels from this study will not be used. As the focus of the two studies is different, the initial risk level (which is to be reduced) is believed to be most updated in Annex II. Comparing the risk of fatalities, measured in terms of *per ship year*, (**Table 7**) it is seen that the risk estimate for SAFEDOR is 6.6 times higher for collision and 1.7 times higher for grounding. As for the sum of the risks, SAFEDOR is a factor 3.7 higher than FSA/LPS/NAV (/5/).

In conclusion, the potential risk reducing effect of the BRM RCO is estimated to be ΔR = 0.954 lives per ship lifetime (**Table 8**).

**Table 7: Comparison of risk estimates FSA/LPS/Nav /5/ and SAFEDOR (Table 9-1 in /4/)**

| RISK | | |
|---|---|---|
| (Fatalities per ship year) [1)] | SAFEDOR | FSA/LPS/NAV [2)] |
| Collision | $4.1\ 10^{-1}$ | $6.2\ 10^{-2}$ |
| Grounding | $1.5\ 10^{-1}$ | $8.8\ 10^{-2}$ |
| SUM | $5.6\ 10^{-1}$ | $1.5\ 10^{-1}$ |

[1)] 4000 people onboard
[2)] Adjusted to for comparison with SAFEDOR. Original figures for a 2000 pax vessel

**Table 8: Risk reduction for implementation of guidelines Bridge Resource Management (BRM)**

| | FSA/LPS/NAV Risk reduction /5/ | | SAFEDOR/Annex II Potential Loss of Lives [1)] | | SAFEDOR, Expected # SAVED LIVES [1)] |
|---|---|---|---|---|---|
| | Collision | Grounding | Collision | Grounding | Collision and Grounding |
| BRM | 3% | 6% | 18.6 lives | 6.6 lives | 0.954 lives |

[1)] Per ship, per lifetime, 30 years

Note also that the risk reducing effects of the BRM option under evaluation is limited to reducing the frequency of accidents, not the consequence. Although it may be argued that a well organised and efficient bridge crew could contribute to the safety in i.e. fire and evacuation scenarios it is evident from Annex II (Risk Analysis) that the bulk of the risk is associated with hull damage and rapid capsize, under which circumstances the bridge crew is unable to assist.

#### 4.1.5 Combined Buoyancy and GM

A solution combining *RCO 1: Increased GM* and *RCO 3: Added buoyancy high up and far out* is analysed. This solution involves adding reserve buoyancy on the bulkhead deck, as in RCO 3, as well as increasing the GM by 0.5 m as in RCO 1, by widening the ship. However, as adding buoyancy results in loss of cabin space, it would be very beneficial to be able to fit an additional deck to the ship to compensate for this. In the proposed solution this is achieved by increasing the breadth of the ship by 1 m (rather than 0.5 m as in RCO 1) to achieve a 0.5 m increase in GM when an additional deck is added (which in itself lowers the GM).

Adding buoyancy on the bulkhead deck and at the same time increasing GM by 0.5 m will raise the index A from 0.8 to 0.875. Using the event tree developed in Annex II it is found that for the collision scenario this translates to a risk reduction of ΔR = 2.85 lives per ship lifetime. Ship lifetime is assumed to be 30 years. This estimate should be considered to be conservative, as only the collision scenario is considered (see section 4.1.1). However, without an increase in length, there is an issue with fitting extra LSA (lifeboats), which are needed to serve the added passengers from the extra deck. This issue is not considered further in the current report.

### 4.1.6 Combined Buoyancy, GM and Freeboard increase

A solution combining *RCO 1: Increased GM*, *RCO 3: Added buoyancy high up and far out* and also *RCO 2: Increased Freeboard* is analysed. This solution involves adding reserve buoyancy on the bulkhead deck, as in RCO 3, increasing the freeboard as in RCO 2, and finally increasing the GM by 0.5 m as in RCO 1 by widening the ship. However, as adding buoyancy results in loss of cabin space, an additional deck is fitted to the ship to compensate for this. In the proposed solution this is achieved by increasing the breadth of the ship by 1 m (rather than 0.5 m as in RCO 1) to achieve a 0.5 m increase in GM when an additional deck is added. Because increasing the freeboard will lower the GM, the additional deck can only be 60% of what it would be without increased freeboard (because the 1 m increase in ship breadth is implemented to compensate for the freeboard and the extra deck).

Adding buoyancy on the bulkhead deck, increasing the freeboard and at the same time increasing GM by 0.5 m will raise the index A from 0.8 to 0.899. Using the event tree developed in Annex II it is found that for the collision scenario this translates to a risk reduction of ΔR = 3.75 lives per ship lifetime. This estimate should be considered to be conservative, as only the collision scenario is considered (see section 4.1.1). However, without an increase in length, there is an issue with fitting extra LSA (lifeboats), which are needed to serve the added passengers from the extra deck. This issue is not considered further in the current report.

## *4.2 Cost of implementing RCOs*

The direct costs of the measures have been divided into two parts: Initial costs and yearly costs over the lifetime of the vessel. The initial costs include all costs of implementing the measure, e.g. acquiring and installing equipment, additional construction costs and training of crew. During the lifetime of the vessel there might be additional costs at regular intervals in order to maintain the effect of the measure, e.g. equipment service and refreshment courses. The additional cost might be annual, but in some cases occur every two or five years.

### 4.2.1 Increased Freeboard

The cost of increasing the freeboard by 0.5 meters comes from adding more steel to the ship, with the associated added labour, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight is estimated as a minimum of 50 tonnes, and a maximum of 100 tonnes. The cost of the steel, including labour is estimated at $6,000 per tonne (Appendix II Cost Estimates). This gives a high estimate of $600,000 and a low estimate of $300,000. The high estimate of $600,000 is used in the calculations.

There are two main drivers for a vessel's resistance in water. Resistance due to the friction between hull and water, and resistance due to energy lost in wave generation from water being displaced as the hull passes through it. It can roughly be stated that frictional resistance is depending on wetted surface and speed. The wave resistance is depending on hull shape and speed. An increase in beam will result in an increased GM value and some additional wetted surface due to more steel weight. Due to the increased beam, the hull will to some degree increase its wetted surface. However this is countered by the reduction of its draft. It is thus assumed that the changes in displacement and wetted surface are insignificant. Using Guldhammer/Harvalds method gives a rough figure of the increase in resistance when holding all dimensions constant but the beam/draft ratio. It also gives a rough figure of resistance based on experience data from an extensive towing tank database. The method was however developed in the 1960's and the new hull design has a lower resistance than this method gives. However, since it is the difference between two different designs and not the full resistance this method can still be used. This gives a contribution to the wave resistance which results in 1% increase in total resistance. The relation between drag and fuel consumption is linear for small changes in drag, giving a 1% increase in fuel consumption due to the 1% increase in drag.

The annual total fuel consumption of the vessel is estimated at $ 17.1 million (Appendix II Cost Estimates). The fraction of this used for propulsion is 2/3 (the remainder is for power generation), meaning that the increase in fuel consumption amounts to 1% of $11.4 million or $ 114,000. At 5% interest, over 30 years, the net present value of this cost is $ 1,752,000.

In total, the estimated cost (steel and fuel) of increasing the freeboard by 0.5 meters is $ 2,352,000.

### 4.2.2 Increase GM

The cost of increasing the GM by 0.5 meters comes from adding more steel to the ship, with the associated added labour, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight is estimated as a minimum of 50 tonnes, and a maximum of 100 tonnes. The cost of the steel, including labour is estimated at $6,000 per tonne (Appendix II Cost Estimates). This gives a high estimate of $600,000 and a low estimate of $300,000. The high estimate of $600 000 is used in the calculations.

The increase in vessel breadth is estimated to cause a 1% increase in fuel consumption (details described in the previous section). The annual total fuel consumption of the vessel is estimated at $17.1 million (Appendix II Cost Estimates). The fraction of this used for propulsion is 2/3 (the remainder is for power generation), meaning that the increase in fuel consumption amounts to 1% of $11.4 million or $114,000. At 5% interest, over 30 years, the net present value of this cost is $1,752,000.

In total, the estimated cost of increasing the GM by 0.5 meters is $ 2,352,000. It is also worth noticing that increasing the GM will make the vessel stiffer and experience higher accelerations in roll, which may require increased lifting capacity of the stabilizers to maintain the level of comfort for passengers. This aspect is not considered further.

### 4.2.3 Added Buoyancy

The cost of adding buoyancy is associated solely with a reduction in available cabin space, assuming that the cost of any added steel needed to seal off buoyancy compartments is countered by the savings from not outfitting the same compartments with cabin interior. The proposed solution requires a loss of cabin space of 2,500 $m^2$. While there are no passenger cabins on the bulkhead deck as such, the loss of space on this deck will be transferred to other decks where cabin space will be reduced. The typical revenue of a cabin is $130,000 annually. Given a typical size of such a cabin at 15.6 $m^2$, this yields a typical revenue of $8,400 per $m^2$ (As argued in Appendix II Cost Estimates, bulkhead deck space should be valued higher than ordinary cabin space. However, lacking a structured approach to the valuation of this space, the value of $8,400 per $m^2$ is used in our calculations). Thus 2,500 $m^2$ of lost deck space translate to a reduction in annual revenue of $20,750,000 (8,400 ·2,500).

Over 30 years, at 5% interest, this amounts to a net present value of $320 million. Note that the uncertainty in pricing the lost space implies that the actual cost of adding the Added Buoyancy is likely to be higher than the presented estimate.

### 4.2.4 Implementations of guidelines for BRM

The cost of implementing enhanced BRM is related solely to the costs of training and educating officers. For each officer a course fee of $ 3,700 is estimated. Added to this is a cost of subsistence of $ 800 and travel expenses of $ 1,500. Also, the officer's salary is added estimated at $ 1,000 for the 5 day course.

Currently most cruise operators man their bridge's with two officers working a four hour shift. Therefore (6) six officers are used to continuously man the bridge. It is believed that the captain and staff captain should also attend the course. This brings the total to (8) eight persons. This number needs to be doubled to take into consideration the officers' leave plan. As an approximation, navigational deck officers are onboard for about half the year in total (3 months on, 3 months off).

This brings the total number of persons who ideally would want to attend the course to (16) sixteen, however this number currently does not include any junior ratings or key onshore personnel. It is debatable whether key onshore personnel are required to attend the course every five years, however adding the two quoted in the NAV 51/10 (/5/) study this brings the total number to (18) eighteen. It is debatable whether key onshore personnel should be included in the cost of this risk control option. In general, because of the ratio of ship navigators to shore operations managers it would not be practicable to send shore staff on every BRM course attended by sea staff. From discussions with the Carnival UK Fleet Personnel Training Manager it is understood that that Carnival UK currently does not send onshore staff to every BRM course. It is thus concluded to use 16 course attendees in the calculations. This number does not include any junior ratings or provision for any promotions or resignations.

The course has to be repeated every 5 years. It is assumed that not all officers take the course at the same time, and so the cost of 16 courses is thus spread evenly over 5 years. In all, this gives an annual cost of $22,400. At an interest rate of 5% over 30 years, the net present value (NPV) of the costs is $344,343.

### 4.2.5 Combined Buoyancy and GM

The cost of combining RCO 1 and RCO 3, i.e. increasing the GM by 0.5 meters as well as adding buoyancy on the bulkhead deck, comes from adding more steel to the ship, with the associated added labour, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight comes from widening the ship as well as from adding an additional deck, and is estimated as a minimum of 1,200 tonnes, and a maximum of 1,500 tonnes. The cost of the steel, including labour is estimated at $6,000 per tonne (Appendix II Cost Estimates). This gives a high estimate of $9,000,000 and a low estimate of $7,200,000. The high estimate of $9,000,000 is used in the calculations.

The increase in vessel breadth is estimated to cause a 2% increase in fuel consumption (by the same approach as described in the previous sections). The annual total fuel consumption of the vessel is estimated at $17.1 million (Appendix II Cost Estimates). The fraction of this used for propulsion is 2/3 (the remainder is for power generation), meaning that the increase in fuel consumption amounts to 2% of $11.4 million or $228,000. At 5% interest, over 30 years, the net present value of this cost is $3,500,000.

In total, the estimated cost of increasing the GM by 0.5 meters and adding buoyancy on the bulkhead deck is $12,500,000. This includes adding an extra deck to the vessel. It is also worth noticing that increasing the GM will make the vessel stiffer and experience higher accelerations in roll, which may require increased lifting capacity of the stabilizers to maintain the level of comfort for passengers. This aspect is not considered further. Note also that there are other cost implications to adding a further deck with increased weight and increased passenger complement, e.g. increased capacity requirements in Restaurant, toilets, cinemas, public spaces. It is also possible that taxation, docking costs, insurance and other cost factors are affected. These issues are not considered further in the current report.

### 4.2.6 Combined Buoyancy, GM and Freeboard increase

The cost of combining RCO 1, RCO 2 and RCO 3, i.e. increasing the GM by 0.5 meters as well as adding buoyancy on the bulkhead deck and increasing the freeboard, comes from adding more steel to the ship, with the associated added labour, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight comes from widening the ship as well as from adding an additional deck, and is estimated as a minimum of 1,200 tonnes, and a maximum of 1,500 tonnes. The cost of the steel, including labour is estimated at $6,000 per tonne (Appendix II Cost Estimates). This gives a high estimate of $9,000,000 and a low estimate of $7,200,000. The high estimate of $9,000,000 is used in the calculations.

The increase in vessel breadth is estimated to cause a 2% increase in fuel consumption (by the same approach as described in the previous sections). The annual total fuel consumption of the vessel is estimated at $17.1 million (Appendix II Cost Estimates). The fraction of this used for propulsion is 2/3 (the remainder is for power generation), meaning that the increase in fuel consumption amounts to 2% of $11.4 million or $228,000. At 5% interest, over 30 years, the net present value of this cost is $3,500,000.

In total, the estimated cost of increasing the GM by 0.5 meters, increasing the freeboard and adding buoyancy on the bulkhead deck is $ 12,500,000. This includes adding an extra deck to the vessel. It is also worth noticing that increasing the GM will make the vessel stiffer and experience higher accelerations in roll, which may require increased lifting capacity of the stabilizers to maintain the level of comfort for passengers. This aspect is not considered further. Note also that there are other cost implications to adding a further deck with increased weight and increased passenger complement, e.g. increased capacity requirements in Restaurant, toilets, cinemas, public spaces. It is also possible that taxation, docking costs, insurance and other cost factors are affected. These issues are not considered further in the current report.

## *4.3 Economic benefit of implementing RCOs*

The implementation of a RCO might have other benefits than reducing number of fatalities. These benefits could be reduced maintenance cost, reduced expected annual accident cost and reduced wet/dry dockings resulting in increased revenue. The reduced expected accident cost for each RCO has been found by accessing the potential risk reduction for each case, using the risk models developed in Annex II.

### 4.3.1 Increase Freeboard

The economic benefit of increasing the freeboard by 0.5 meters is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The increase in freeboard is associated with an increase in ship breath. This modest increase of 0.3 meters gives an increase in deck space of 60 $m^2$ on each affected deck. The typical revenue of a cabin is $130,000. Given a typical size of such a cabin at 15.6 $m^2$, this yields a typical revenue of $8,400 per $m^2$ (Appendix II Cost Estimates). Assessing the value of these extra square meters depends on how the space can be utilised. Naturally, 60 $m^2$ of added deck space does not translate to four added cabins of 15 $m^2$ each. It is therefore assumed pessimistically that only 10% of the added deck space is utilised. Furthermore it is assumed that the increase will affect 10 decks. In total, this gives an added annual revenue of $498,000 (8,400·60·0.10·10).

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased freeboard reduces the frequency of this event from 2.3 $10^{-4}$ per ship year to 1.7 $10^{-4}$ per ship year. As each such event involves the total loss of a $ 450 million vessel (Source: Carnival and ShipPax database 3.0, cd version 2005.3), the annual savings amount to $27,000.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $8.16 million.

### 4.3.2 Increase GM

The economic benefit of increasing the GM by 0.5 meters is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The increase in GM is associated with an increase in ship breath. This modest increase of 0.5 meters gives an increase in deck space of 100 $m^2$ on each affected deck. Assessing the value of these extra square meters depends on how the space can be utilised. The typical revenue of a cabin is $130,000. Given a typical size of such a cabin at 15.6 $m^2$, this yields a typical revenue of $ 8,400 per $m^2$.

Naturally, 100 $m^2$ of added deck space does not translate to six added cabins of 15 $m^2$ each. It is therefore assumed that only 10% of the added deck space is utilised. Furthermore it is assumed that the increase will affect 10 decks. In total, this gives an added annual revenue of $ 830,000 (8,400•100•0.10•10).

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased GM reduces the frequency of this event from 2.3 $10^{-4}$ per ship year to 1.6 $10^{-4}$ per ship year. Each such event involves the total loss of a $ 450 million vessel, therefore the annual savings amounts to $31,500.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $ 13.4 million.

### 4.3.3 Added buoyancy

Reduced accident costs are the only economic benefit from this RCO. The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased buoyancy reduces the frequency of this event from 2.3 $10^{-4}$ per ship year to 1.89 $10^{-4}$ per ship year. Each such event involves the total loss of a $ 450 million vessel, therefore the annual savings amounts to $18,600.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $ 286,000.

### 4.3.4 Implementations of guidelines for BRM

The benefit associated with implementing BRM is due to a reduction in all types of collision, contact and grounding accidents (not only total losses). This benefit was estimated in the FSA Large Passenger Ship Navigation study /5/, based on an average cost of collision, contact and grounding accidents. This benefit is assumed to be the same in the current study.

**Table 9: Accident frequency comparison between SAFEDOR and NAV 51/10 /5/.**

| Accident Frequency (per ship year) | SAFEDOR | NAV51/10 |
|---|---|---|
| Collision | 4.6 $10^{-3}$ | 4.2 $10^{-3}$ |
| Grounding | 9.8 $10^{-3}$ | 9.2 $10^{-3}$ |
| Contact | 1.1 $10^{-3}$ | 3.2 $10^{-3}$ |

Comparing the accident frequencies, used directly in the SAFEDOR study and for model calibration in NAV51/10, there is a good correlation (perhaps with the exception of contact, which is a minor risk contributor). This indicates that the major difference in the two studies lies in the estimation of accident consequences, which was not the focus of the NAV51/10 study:

> “The study focuses on frequency reduction, i.e. accident avoidance, and is not intended to cover recommendations for consequence reduction”

The benefits of implementing the navigation RCOs are thought to be adequately presented in NAV51/10. The calculations are based on average accident costs for accidents of all consequences. It may be that the number of total losses due to capsizing is underestimated (the fatality risk level indicates this), and consequently the benefits are underestimated. However, the benefits are not as sensitive as the number of expected total loss accidents and the risks to human life. The bulk of the benefit stems from avoiding more frequent accidents.

It is therefore decided to keep the benefit figures used in NAV51/10.

### 4.3.5 Combined Buoyancy and GM

The economic benefit of increasing the GM by 0.5 meters and adding buoyancy on the bulkhead deck is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The proposed solution involves adding an extra deck to the ship, which adds more space than the buoyancy elements subtracts. In sum, the solution gives 4,500 $m^2$ of added space. Assessing the value of these extra square meters depends on how the space can be utilised. The typical revenue of a cabin is $130,000. Given a typical size of such a cabin at 15.6 $m^2$, this yields typical revenue of $ 8,400 per $m^2$. It is not obvious how 4,500 $m^2$ of added deck space translate to a corresponding number of added cabins of 15 $m^2$ each. It is therefore assumed that only 50% of the added deck space is utilised. In total, this gives an added annual revenue of $ 18,900,000 (8,400•4,500•0.50). ‘

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased GM reduces the frequency of this event from 2.3 $10^{-4}$ per ship year to 1.44 $10^{-4}$ per ship year. As each such event involves the total loss of a $ 450 million vessel, the annual savings amounts to $38 700.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $291 million.

### 4.3.6 Combined Buoyancy, GM and Freeboard increase

The economic benefit of increasing the GM by 0.5 meters, increasing the freeboard by 0.5 meters and adding buoyancy on the bulkhead deck is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The proposed solution involves adding an extra deck to the ship, although this deck is only 60% of what it could be without the increase in freeboard, which adds more space than the buoyancy elements subtracts. In sum, the solution gives 2,500 $m^2$ of added space. Assessing the value of these extra square meters depends on how the space can be utilised. The typical revenue of a cabin is $130,000. Given a typical size of such a cabin at 15.6 $m^2$, this yields typical revenue of $ 8,400 per $m^2$. It is not obvious how 4,500 $m^2$ of added deck space translate to a corresponding number of added cabins of 15 $m^2$ each. It is therefore assumed that only 50% of the added deck space is utilised. In total, this gives an added annual revenue of $ 10,500,000 (8,400•2,500•0.50). ‘

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased GM reduces the frequency of this event from 2.3 $10^{-4}$ per ship year to 1.13 $10^{-4}$ per ship year. As each such event involves the total loss of a $ 450 million vessel, the annual savings amounts to $53 000.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $ 162 million.

# 5 Results & Uncertainties

| Table 10: Results | | | | | |
|---|---|---|---|---|---|
| | **Risk reduction ΔR** | **Cost[2)] ΔC** | **Benefit[2)] ΔB** | **GrossCAF** | **NetCAF** |
| | # of saved lives[1)] | $ | $ | $ | $ |
| RCO 1: Increased GM | 2.10 | 2 350 000 | 13 400 000 | 1 120 000 | - 5 260 000 |
| RCO 2: Increased Freeboard | 2.10 | 2 350 000 | 8 160 000 | 1 120 000 | - 2 770 000 |
| RCO 3: Added buoyancy | 1.35 | 322 800 000 | 286 000 | 239 100 000 | 238 900 000 |
| RCO 27: BRM | 0.95 | 344 000 | 540 000 | 361 000 | - 205 000 |
| RCO 1+3: Combined Buoyancy & GM | 2.85 | 12 500 000 | 291 000 000 | 4 390 000 | - 97 800 000 |
| RCO 1+2+3: Combined Bouyancy, GM and Freeboard | 3.75 | 12 500 000 | 162 000 000 | 3 340 000 | -39 900 000 |
| [1)] Per ship per lifetime, assumed 30 years<br>[2)] Net present value, 5% interest rate, 30 years | | | | | |

Note that the value of the risk reductions from each measure are not additive, i.e. implementing RCO 1 and RCO 27 simultaneously will not yield a risk reduction of equal to the sum of the two: 2.1+0.95=3.05. This is because the introduction of one RCO will lead to lower risk reductions for all preceding RCOs as the remaining risk reducing potential is reduced.

The results in Table 10 show that *RCO 1: Increased Freeboard*, *RCO 2: Increased GM* and *RCO27: Implementation of procedures for Bridge Resource Management* have low values for both GrossCAF and NetCAF compared to *RCO 3: Added buoyancy high up and far out*. The GrossCAF values are below $1M and the NetCAF values are negative. A negative NetCAF indicates that the RCO is beneficial in itself, i.e. the costs of implementing the RCO is less than the economical benefit of implementing it, regardless of how many lives that are saved. A GrossCAF value below $ 3M also indicates that the RCO should be implemented, according to the IMO criteria /10/ and /3/, /2/. The combinatory solution of RCO 1 and RCO 3 is also extremely cost efficient, due to the huge economic benefits involved. The combinatory solution of RCO 1, RCO 2 and RCO 3 is also highly cost efficient due to economic benefits, but is also close to meeting the $3m GrossCAF criteria due to very high risk reducing effect.

Table 11 shows that the results are not sensitive to fuel cost or steel weight. The conclusions rely on the most conservative estimates (using high fuel costs and high steel weights). The results are more sensitive to the degree of utilisation for added space. These conclusions are based on the assumption of a 10% utilisation (50% for the combined solutions). Table 11 demonstrates that the degree of utilisation must be well below 4% for the NetCAF values to be positive.

For the stability RCOs evaluated in this study, the results are conservative in the sense that none of the proposed designs have been optimised. The results demonstrate that even without a refinement of the design proposal the proposed measures are cost effective according to the IMO criteria. Furthermore, no estimation of risk reduction in relation to grounding accidents has been made. The actual risk reduction is thus likely to be higher than the figures used in the current calculations. This consolidates the robustness of the results for the example ship examined.

**Table 11: NetCAF sensitivity considerations to fuel consumption, steel weight and degree of utilisation of added space.**

| | Degree of utilisation of added space yielding NetCAF = 0 | NCAF[1)] |
|---|---|---|
| Increased Freeboard | ~ 2.5% | 0 |
| Increased GM | ~ 1.5% | 0 |
| Combined Buoyancy and GM | ~ 2% | 0 |
| Combined Buoyancy, GM and Freeboard increase | ~ 3.6% | 0 |
| | **Annual fuel cost** | |
| Increased Freeboard | 12 m $ | - 3 m $ |
| | 17 m $ [2)] | - 2.7m $ |
| Increased GM | 12 m $ | - 5.5 m $ |
| | 17 m $ [2)] | - 5.2 m $ |
| Combined Buoyancy and GM | 12 m $ | - 98.1 m $ |
| | 17 m $ [2)] | - 97.8 m $ |
| Combined Buoyancy, GM and Freeboard increase | 12 m $ | - 40.2 m $ |
| | 17 m $ [2)] | - 39.9 m $ |
| | **Added steel weight** | |
| Increased Freeboard | 50 t | - 2.9 m $ |
| | 100 t [2)] | - 2.7 m $ |
| Increased GM | 50 t | - 5.4 m $ |
| | 100 t [2)] | - 5.2 m $ |
| Combined Buoyancy and GM | 1,200 t | - 98.4 m $ |
| | 1,500 t [2)] | - 97.8 m $ |
| Combined Buoyancy, GM and Freeboard increase | 1,200 t | - 40.4 m$ |
| | 1,500 t [2)] | - 39.9 m $ |

[1)] Based on changing one input value, and leaving the rest unchanged. Does not account for any combined effects of changes.

[2)]Used in **Table 10** Results

# 6 Recommendations

As basis for the recommendations it is observed that:

- An RCO is considered cost-effective if the GrossCAF (Cost of Averting a Fatality) is less than $3M. This is the the IMO criteria /10/, and the value used in all decisions made following the

FSA studies submitted under Agenda Item 5, Bulk Carrier Safety, at MSC 76, December 2002 and suggested in MSC 72/16.

- As cost effectiveness is used as the decision criterion, it is required that large passenger ship risks are in the ALARP (As Low As Reasonably Practicable) area according to IMO. This is supported by the results of Annex II.

This study demonstrates that the RCOs listed in the upper part of Table 12 are cost-effective according to the IMO criteria for the example ship examined. Furthermore, the project team finds good reason to reiterate the recommendations made in the FSA study on large passenger ship navigation /5/, and these are included in the bottom part of Table 12.

**Table 12 RCOs recommended for further consideration at IMO**

| | |
|---|---|
| Based on current report: | |
| **No** | **RCO** |
| 1 | Increased GM |
| 2 | Increased Freeboard |
| 27 | Implementation of guidelines for BRM |
| 1+3 | Combined Buoyancy and GM |
| 1+2+3 | Combined Buoyancy, GM and Freeboard increase |
| Based on /5/: | |
| 39 | Improved bridge design (above SOLAS) |
| 30 | ECDIS - Electronic Chart Display and Information System |
| 33 | Increased Simulator Training for Navigators |

These RCOs with significant potential to reduce loss of lives are recommended for further detailed consideration. Some of these RCOs are already implemented on most cruise vessels (such as ECDIS). The measures are not yet required by IMO.

The results clearly indicate that the implementation of BRM procedures is cost effective according to the IMO methods and criteria. This measure has a negative NetCAF value and a GrossCAF value close to one tenth of the recommended upper limit. Also, the risk reduction in itself is significant, with close to one saved life per vessel per 30 years. *RCO 27: Implementation of procedures for Bridge Resource Management* is thus recommended for implementation on all cruise ships.

Also, the analysis shows that, for the particular example ship analysed both *RCO 1: Increased GM* and *RCO 2: Increased Freeboard* are cost effective, with GrossCAF at about one third of the IMO recommended upper limit, and with negative NetCAF which are shown to be robust (see Table 11). Although RCO 3: Added buoyancy high up and far out is not cost efficient in itself, a combination of this RCO 3 and RCO 1 as well as a combination of RCO 3, RCO 2 and RCO 1 proved to have potential. These combined solutions give the highest risk reduction for the example ship, giving a large negative Net CAF value. These solutions are recommended for further investigation, despite GrossCAF values above the IMO recommended limit. This analysis indicates that for the example ship the required subdivision index R could be raised from 0.8 to at least 0.90 in a cost efficient manner. However, the suggested specific solutions for increased damage stability are only indicative of what could be achieved, and it should be left to the designer to find a suitable way of meeting the required index. This means that if further detailed studies showed it justified then the subdivision index R might be able to be raised cost effectively The implementation of any specified measure, such as the RCOs evaluated in this report, should be left to the designer, the current report merely indicates ways in which a higher R could be provided.

A further consideration is the effect on cruise ship operation of a reduction in space on the bulkhead deck. This may have severe operating implications for cruise ships as this deck is used for many essential operational functions including passenger embarkation and disembarkation, security screening, loading of stores and baggage, storage of hotel stores (particularly food and beverages) and preliminary food preparation. The detailed effects of changes to the bulkhead deck layout on cruise ship operations have not been assessed in this study and need to be addressed in detail to calculate the full cost and truly assess the benefit of the proposed changes.

It is highly recommended to continue research in the area of damage stability along the lines suggested in this report, to firmly establish the highest level for R which is consistent with the current cost efficiency criteria used at IMO and consistent with the practical operation of individual cruise ships. In this connection it is also recommended for future work to investigate the use of lightweight structural materials for use in the superstructure of a cruise ship. This option has occurred to the project team very late in the work on this report, and is thus not included in the list of potential RCOs. Reducing the weight of the superstructure may be beneficial for the vessels stability. In future studies it is also recommended to analyse any effects the proposed RCO's may have on grounding accidents as this has been omitted in the current study.

With the introduction of the new probabilistic damage stability rules /8/ an increase in GM, and in some cases freeboard, is already being seen when compared to ships designed to the current regulatory regime.

In conclusion this study shows that for the particular design examined it appeared, within the constraints of the study, that there is potential for cost effective risk control options to reduce risk, according to IMO criteria. These include both operational and design changes to reduce the frequency of incidents and design changes to reduce their consequences. Before such design changes can be incorporated in individual ships more detailed studies related to the specific design, operation and costs of that ship would be needed. Continued research in this area is highly recommended.

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/8/ International Maritime Organisation (IMO), (2005): Resolution MSC 194(80), adopted on May 20 2005.

/9/ The HARDER project Information. Newsletter issued by SaferEuroro.org http://www.safereuroro.org/SEII_Newsletter_Issue_2_June_2004_RE1.pdf

/10/ MSC 83/INF.2 'Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (MSC/Circ.1023−MEPC/Circ.392)

# Appendix I Description of all considered RCOs

**Note: The numbering of the RCOs does not reflect any prioritisation between the RCOs.**

| # | **Area** | RISK CONTROL OPTION | Description | Previously Analyzed |
|---|---|---|---|---|
| **1** | Stability | Increased GM | Increasing the metacentric height (GM) will increase the residual stability after damage, thereby increasing the s-factor (probability of survival, given damage). Residual stability after damage will reduce the probability of rapid capsize in a damage scenario. Achieving an increase in GM can be done by either lowering the centre of gravity or increasing the beam of the vessel. The proposed solution is to increase the beam of the vessel. A wide hull will have greater righting forces at a heeling angle, compared to a slimmer hull, due to the larger volume of water displaced at the same angle. | |
| **2** | Stability | Increased freeboard | The higher the freeboard, the higher the v-factor, i.e. the damage from a collision is more likely to be below a watertight deck*. When fitting watertight decks the vessel will benefit from the cases where the damage is below the watertight deck. This is because intact watertight decks will contain vertical flooding. However, the increase in freeboard leads to a higher centre of gravity, and thus a lower metacentric height (GM). To keep the GM constant, the beam of the vessel is increased.<br><br>*) Note that decks on cruise ships are in practice not watertight. However, in this study one deck has been assumed watertight in all the design options considered. This is a simplification justified by the fact that this is a comparative study. If the design options had been modelled in full detail (i.e. without any completely watertight decks) all index values (A) would be lower than in the current study. This would, however, not influence the difference between the options, which is the objective of this study. | |
| **3** | Stability | Reserve buoyancy high up and far out | It is important that all reserve buoyancy is places as high up and as far out as possible. High up will reduce the probability of the reserve buoyancy being involved in a damage. Far out will give increased residual stability compared to the same buoyancy being placed more inboard. The proposed solution is to fit watertight compartments on the bulkhead deck. This will increase the righting forces at relatively large heel angles. | |
| **4** | Stability | Avoid longitudinal subdivision below bulkhead deck | Longitudinal subdivision below the bulkhead deck may have positive or negative effects, depending on their construction. The positive effect is protection of inner spaces, while the negative effect is creation of unsymmetrical heeling moments when damage to the wing compartment (longitudinal bulkhead not damaged). If fitted, the wing compartments should to the greatest extent possible be cross connected. Large, unsymmetrical wing spaces below the bulkhead deck should be avoided. | |
| **5** | Stability | Optimal position of transverse bulkheads | In any vessel, there exist an optimal number and position of watertight transverse bulkheads, given the restraints dictated by the operational features of the vessel. E.g. a two-compartment vessel is not better than the probability of having a 3-compartment damage. Increasing number of bulkheads will not increase the A-index if it is not leading to survival of some 3-compartment damages. | |
| **6** | Stability | Effective cross flooding arrangements | If cross flooding arrangements are fitted, they must provide complete equalization within 10 minutes to be allowed for intermediate flooding. If complete equalization is done within one minute, then the damage may be regarded as instantaneous (not creating any unsymmetrical moment). | |

| | | | | |
|---|---|---|---|---|
| **7** | Stability | Increased height of openings | Openings through progressive flooding may occur, will affect the stability after damage in two ways: - Any non-watertight openings below the damaged waterline will result in s=0 - Any unprotected opening will restrict the range of stability and thereby potentially reduce the s-factor. Increasing the height of openings may therefore increase the s-factor for those | |
| **8** | Stability | DCD - Damage Consequence Diagrams | Newbuild vessels to include the provision of damage consequence diagrams. In the event of damage to the ship, the DCD presents the impact the damage has on the ships stability. This information is presented in as clear a manner as possible, giving improved information to the master. | |
| **9** | Fire/ Evacuation | Self illuminating signs | Floor marking with lighting signs showing directions. This will ease the evacuation under low visibility and ensure that evacuation is guided in the right direction. | |
| **10** | Fire/ Evacuation | Evacuation notification system | Dynamic evacuation system which enables the bridge to manage the evacuation depending on where the fire is and where the large number of passenger is. The system will reduce the awareness time especially in cabin areas during night time. Important with redundancy and good procedures. | /7/ |
| **11** | Fire/ Evacuation | Outdoor stairways | Avoid internal stairways to reduce changes of smoke poisoning. Width is however most crucial. | /7/ |
| **12** | Fire/ Evacuation | Combustible materials requirements | Maximum allowable amount of combustible material within a zone. Defines the fire load of the area. Degree of flammability and toxicity of all installations, especially walls and floors. In cabins it is little combustible materials. | /7/ |
| **13** | Fire/ Evacuation | Regard sundeck as public space | It is not the same regulations towards requirements regarding flammable, combustible and toxicity of materials and furniture. Regarded as indoor vs. Outdoor due to overhanging roof. | /7/ |
| **14** | Fire/ Evacuation | Better emergency training of crew | Important, especially due to reduction of awareness time and flux in congested areas during evacuation. Make sure a proper spread on the rescue flow, use the emergency escape ways. Waitresses, gamblers and other personnel in contact with large amount of people must have good training in evacuation. "directional staging" | /7/ |
| **15** | Fire/ Evacuation | Distance to mustering area/ open deck | The distance to mustering area defines the evacuation time. As few turns, bottlenecks, cross roads, obstacles as possible. It is however difficult to improve on large cruise ships. | /7/ |
| **16** | Fire/ Evacuation | Ventilation system in corridors | Smoke extraction in certain areas together with high pressure escape ways will reduce the probability of fatalities due to smoke. It will however increase access to air for fire in the high pressure areas. | /7/ |
| **17** | Fire | Automatic shut down of fryers | Deep fat fryers have a high frequency of situations. Shut down equipment may fail. High temperature fat catches fire and a lid shutting out the fire can be used. All though the situation has a high frequency it has a low consequence. | |
| **18** | Fire | Installation of oil mist detectors | To install an oil mist detection system that will detect oil mist as it is being diffused into the atmosphere which will alarm long before it saturates the atmosphere to a danger level. It should be noted that steam and smoke have approximately the same particle size, so an oil mist detector should be able to detect these parameters if the right system is used - which is a bonus. The detectors are placed around the vessel in vulnerable areas where oil mist leaks are more likely to occur. The detectors are placed in the air stream that can normally be found by using a smoke generator. The route the oil mist usually takes is towards the turbocharger or the exit ventilation duct. Instalments in other areas than where it is required. | |
| **19** | Fire | Temperature monitoring (of hot surfaces?) | Using infrared cameras to monitor engine rooms and other areas with high temperature surfaces. Measuring devises is already required in several areas. | |
| **20** | Fire | Laundry exhaust ducts | Lint from dryers has a high flammability of occurrence but low consequence. Area of instalment and cleaning procedures are important factors. | /7/ |
| **21** | Fire | Correct maintenance in Engine Room | It is important with good procedures. Hot oil is highly flammable. Cleanliness and insulation on hot components. Good maintenance will reduce the frequency and consequence of a fire. | |

| | | | | |
|---|---|---|---|---|
| | | (proper cleaning) | | |
| **22** | Fire | Stricter smoking procedures | Some vessels may allow smoking in cabins and in dedicated areas. A non smoking policy on the whole vessel would reduce the number of fire out bursts. | |
| **23** | Fire | Key-card system to turn on el-system in cabin | The card would secure no electric apparatus having electricity when the cabin is empty. This will reduce electrical ignition sources (iron, TV, toaster, hair dryers and curling iron) and save energy. | |
| **24** | Fire | Mandatory FM-class | Enhanced redundancy in fire fighting systems, heat monitoring equipment, video monitoring in engine room. Thermographic surveys are to be conducted as part of a predictive maintenance program. A maintenance program will identify potential failure of components that could lead to equipment or component overload and possibly cause a fire to occur. | |
| **25** | Fire | Open Decks Fire Detection and Suppression | Newbuild vessels to incorporate the provision of fire detection and suppression in all high risk open deck areas. | |
| **26** | Navigation | Onboard Safety and Security Centre | The non-navigational functions could be reorganised into a continuously manned safety centre, located separately from the bridge. The centre could for example be located close to the hotel reception, which is already continuously manned.<br>The operation of such a centre would require one additional officer on watch at any given time. It is also needed to have space for repeaters and other equipment. The space required is here assumed to be the same size as one passenger cabin of the smallest size. | /5/ |
| **27** | Navigation | Implementation of guidelines for BRM | Bridge Resource Management (BRM) is designed to ensure efficient use of personnel and equipment during vessel operations. BRM is designed to reduce errors and omissions in bridge operations through a simple system of checks and delegation of duties. BRM system emphasises a coordinated effort among bridge personnel to ensure smooth, efficient and safe operation of the vessel. The implementation of BRM is assumed to involve some initial preparations of procedures to be followed and definition of relevant responsibilities. In addition, the bridge teams are assumed to go through a BRM course to assist the implementation. For communication and responsibilities that are connected to the onshore personnel, such training should also include key onshore personnel. | /5/ |
| **28** | Navigation | Two officers on the bridge | The manning in the cruise industry is most commonly to have two navigational officers on watch, and one extra watch in difficult or critical situations, e.g. congested areas. Typically, the tasks and responsibilities are clearly defined by having one officer to focus on navigating the vessel in the waters and one to focus on the traffic situation in the area or other tasks that have to be taken care of. The risk for navigational mistakes is reduced by having two officers compared to one officer on watch. | /5/ |
| **29** | Navigation | Automatic logging of information | SOLAS specifies the type and frequency of necessary entries into a vessel’s logbook. The task of manually entering data into the deck log book is somewhat time-consuming, and could result in distractions for the operating officer from his observation duties.<br>A number of the required entries into the deck log book could be done automatically, without interference of human presence, by adopting an electronic log book (ELB). Such a system is based on IT technology, and replaces paper versions of log books. ELBs will be online with most of the bridge’s navigational equipment and other vital sensors for the vessel’s operation, providing automatic entry of chosen online information, either continuously or on predetermined time intervals. | /5/ |
| **30** | Navigation | ECDIS | Electronic Chart Display and Information System (ECDIS) is a navigation aid that can be used instead of nautical paper charts and publications to plan and display the ship’s route, plot and monitor positions throughout the intended voyage. ECDIS is a real-time geographic information system. It is capable of continuously determining a vessel’s position in relation to land, charted objects, navigational aids, possible unseen hazards, and represents a new | /5/ |

| | | | | |
|---|---|---|---|---|
| | | | approach to maritime navigation. In daily navigational operations, it should reduce the workload of the navigating officers compared to using paper charts. It enables the navigator to have a continuous overview of the situation. | |
| **31** | Navigation | AIS (Integration with radar) | An Automatic Identification System (AIS) is designed to send and receive information between vessels. Current regulations, implemented mainly due to security reasons, require the information to be presented into an AIS display. The most common type of installed display (minimum required) provides three lines of data consisting of basic information of a selected target (name, range and bearing). Additional information regarding the target can be provided by scrolling. A huge amount of information received by the AIS is hidden behind the small display, and it is time consuming and distractive for the navigator to search for the information. By connecting AIS to the radar's ARPA (Automatic Radar Plotting Aid) function the information is easier accessible. Benefits deriving from the AIS-ARPA interface, will improve the navigator's ability to make early decisions based on real-time data, and avoid potential collisions. | /5/ |
| **32** | Navigation | Track control system | Track control and track keeping systems continuously compares the vessel's actual course, with the originally planned one. The route of the vessel is planned before departure and is entered in the track control system. In case a deviation occurs, an e.g. due to environmental force, the vessel is automatically corrected to follow the track. The philosophy for developing track control systems is that a vessel can not run aground if the route is properly planned and the ship follows the route for the entire voyage. Even though this is a powerful tool, the navigator has of course to ensure that the plotted track is actually followed. Implementation of track control systems will also liberate more time for the operating officer to monitor traffic conditions. | /5/ |
| **33** | Navigation | Improved Navigator Training | An example of improved navigator training is advanced ship manoeuvring, including training of crisis situations which can only be done safely in simulators. The training should be done with simulators to give a real life experience of the given situations and thus preparing the navigators in case they face a similar incident. | /5/ |
| **34** | Navigation | Navigation system reliability | The navigational systems availability is assumed mainly to be influenced by the redundancy of the navigational components. The navigational equipment, as required by SOLAS, is mostly redundant on standard bridges today. The important exceptions are the gyroscopic compass and the Global Positioning System (GPS). These items are not required to be duplicated and therefore they are most often not.<br>Improved navigational systems availability is here defined as installation of one extra gyroscopic compass and one extra GPS. | /5/ |
| **35** | Navigation | Automatic Collision Avoidance | Installation of automatic collision avoidance systems to vessels (a similar system in principal to that used for automatic air collision avoidance). | |
| **36** | Navigation | Automatic docking system | Automatic docking reduces the number of accidents in harbour, caused by human error | |
| **37** | Navigation | Slow speed DP system | Assists in manoeuvring at slow speed, in narrow waters, under the influence of high current and wind (e.g. Bosporus). | |
| **38** | Navigation | FLS - Forward Looking Sonar | To install real time FLS systems to vessels.<br>Vertical echo sounders show depth beneath the vessel. Forward looking sonar scans the view in front of the vessel and updates a screen several times a second to build up a picture of potentially hazardous obstructions. This system potentially allows the master to take evasive action should a situation occur. | |
| **39** | Navigation | Improved bridge design (above SOLAS) | In order to quantify "improved bridge design" and the degree of the upgrading, DNV's voluntary class notation NAUT-AW is used for description as input to the cost efficiency assessment. | /5/ |

# Appendix II Cost estimates

**Price of steel fitted on a cruise ship**

Two approaches to determining the price of steel fitted on a cruise ship have been considered. Initially, a price of $5,000 to $6,000 per ton was estimated (based on costs in Germany in 1990 and inflated).

A second approach is to use the price of manpower and un-fitted steel in combination. Limiting the evaluation to steel sections with some minor pre-outfitting (e.g. manholes, pipe supports, small ladders etc.), these figures depend on the average thickness of the steel (thin plates and high number of parts have a higher assembly cost per ton of steel) as well as the workshop facilities and welding procedures available in each shipyard. The range can be from 10 to 90 man hours per ton of steel. The lowest figures are typical of the central body of a tanker (flat sections, high thickness), the higher figures are typical of curved sections in the upper decks of passenger ships' superstructures. The average cost of one man hour may be different in different shipyards in Europe, but within the range of $55-$80 per hour.

The price of steel is set to $ 737 per ton (hot roller steel plate – Source “Steel on the net” November 2006 http://www.steelonthenet.com/) Using this information the price per tonne including labour range is calculated:

| Low | Average | High |
|---|---|---|
| $1,287.00 | $4,112.00 | $7,937.00 |

From the above information it is concluded that a typical figure for the primary structure of a cruise ship is $ 6000 per ton (for a vessel built at a European yard).

**Bunker cost over one year for a vessel**

Heavy fuel oil (HFO) costs approx $300 per ton – figures from Lloyd’s List 2006 (prices range from $267 to $375 depending on where the fuel is purchased, and fluctuations in time).

For a typical post Panamax cruise ship operating in the Caribbean during 2006 the fuel consumption was 56,900 tonnes per year. At $300 typical world wide price this yields an annual cost of $17.1 million

Considering a smaller vessel, the cost is lower. The following information relates to a cruise vessel of approximately 80,000 gross tonnes:

2006 Actual Consumption: 40,143 tonnes
2006 Average Price: 308.35 $ per ton
2006 Quantity Purchased: 41,914 tonnes

This yields an annual cost of $ 12.3 million.

Using this information the calculated annual fuel cost range for a vessel of approximately 100,000 gross tonnes is:

| Low | Average | High |
|---|---|---|
| $ 12 m | $ 15.5 m | $ 17 m |

In the current report, a large ship is assumed, with typical annual fuel consumption is 57,000mt per year and cost $17m.

Furthermore, the amount of fuel used for propulsion is 2/3 of total fuel consumption. The remaining 1/3 is for other uses.

**Financial loss/ square meter lost on bulkhead deck and the deck above**

A gross revenue $224 per ALBD (Available Lower Berth Day) was used in part two of the study (Annex II) to estimate revenue. However it might be more appropriate in this case to use net revenue $181 per ALBD which removes the revenue from carrying a passenger, e.g. airfares, that is passed on to third parties outside Carnival. Source for these figures - Carnival Corp and PLC 2005 Annual Report (http://library.corporate-ir.net/library/14/140/140690/items/187579/2005%20annual%20report.pdf )

A typical cabin on a post Panamax has a size of 15.6 $m^2$, excluding balcony. Assuming two beds per cabin and 360 operating days per year a revenue per square meter is found:

Gross revenue per $m^2$ = $ 28.72 per $m^2$ per day = $10,338 per $m^2$ per year
Net revenue per $m^2$ = $ 23.20 per $m^2$ per day = $8,354 per $m^2$ per year

It is concluded that the average value for the loss or gain of cabin space is $8,400 per $m^2$ per year.

Estimation of the value of bulkhead deck space is very difficult but on the basis "that this is the most valuable real estate on the ship" due to the essential operational functions carried out on this deck space must be considered more valuable than cabin space e.g. 50% more would be $12,600 per $m^2$ per year.

# Appendix III RCOs given special attention in screening process due to industry best practise

**No 26 Onboard Safety and Security Centre (Navigation)**

In the FSA study on large passenger ship navigation /5/, the RCO listed in Appendix I as *no 26: Onboard Safety and Security Centre* was analysed. The study concluded that, while providing a significant improvement in navigation risk due to a reduced distraction level on the bridge, the RCO was not cost efficient due to the high cost of the additional manning required.

Within the industry, an idea has emerged of a more cost-effective Onboard Safety and Security Centre than the one evaluated in the NAV51/10 study on large passenger ships (/5/). The "new" proposal is that the centre need not be continuously manned, as assumed in NAV51/10, but rather mobilised in an emergency. Such a centre is already considered best practise among some ship operators and has been implemented ahead of any IMO requirements.  It is a requirement of the SOLAS 2010 amendments.

This "new" onboard safety and security centre, which is only manned in emergency situations by off watch personnel, has much lower lifetime costs than the /5/ proposal. However, the risk reduction estimated in /5/ for the onboard safety and security centre is based heavily on the assumption that the centre is manned 24 hours a day, as the main risk reducing effect is to reduce the distraction level for the navigators on the bridge. If the centre is not manned continuously no such effect is achieved, and it must be viewed as an altogether different RCO.

As the main risk on a cruise vessel is the event of a collision followed by water ingress and sinking after rapid capsize it is not believed that a safety centre (manned after the collision) would be able to reduce the consequence of such an event. Measured against this risk the "new" onboard safety and control centre would not be cost effective when judged using current IMO methods even if the costs were much reduced.

However, this does not mean that such a centre serves no purpose. Cruise ship operating lines who have implemented safety centres prior to the new IMO requirement did so, as in their assessment safety centres, together with a minimum of two watch keeping officers on the bridge at all times provide an improvement in the safety of the vessel.

Due to the above reasoning, this RCO is not taken forward in the current study. While it is believed that the costs could be low if organised properly, and the economic benefits significant, the risk reducing potential if the centre is not continuously manned, in terms of saved human lives is low. An in-depth analysis is required to quantify these assumptions, and this is not prioritised in the current study.

**No 14: Better emergency training of crew (Fire/Evacuation)**

This option was examined in the FIRE EXIT project /7/, and found to be not cost effective. This conclusion was considered doubtful, and an examination of the FIRE EXIT report was initiated. However, the FIRE EXIT conclusion was found to be robust, based on sound judgement and up to date cost estimates, and therefore satisfactory to all project members. There was therefore no further reason to dispute the FIRE EXIT conclusion, and this RCO was thus not recommended for further study, or implementation in the regulations.

# Appendix IV Expert consultants

The project team has received input form a number of experts. These are listed below. The current report however, does not express the views and opinions of the listed experts explicitly, and the content of the report is the responsibility of the project team alone.

- Arve Lepsøe – DNV, Navigation expert
- Svein Erik Jacobsen – DNV, Fire expert
- Anders Tosseviken – DNV, Fire expert
- Olav Rognebakke – DNV, Hydrodynamics expert

A workshop was arranged at Carnival head offices in Southampton 27th October 2006. The workshop was used for discussing and screening RCOs. In addition to the project team, the following were present:

- Tom Strang - Carnival, Director, Maritime Affairs (Technical)
- Polly Morris - Carnival, Risk Analyst
- Tuula Aer – Carnival, Safety Manager

In addition the following experts provided input through the work in the HAZID sessions reported in Annex I

- Stuart Greenfield - Carnival, Director, Maritime Affairs (Operations)
- Chris Metson - P&O Cruises, Marine Safety Manager
- Timothy Wride - P&O Cruises, 1st Engineer Officer
- Chris Balls - Maritime Coastguard Agency (MCA, UK)
- Tore Baunan - DNV, Cruise/design expert, regulatory expert
- Giovanni Delise - Fincantieri, Ship Safety Department