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Risk Acceptance Criteria and Risk Based Damage Stability, Final Report, part 2: Formal Safety Assessment

European Maritime Safety Agency

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Task and objective: This report includes a review of HAZIDs for passenger ships previously carried out, an updated collision risk model including uncertainty and sensitivity analysis, an assessment of the risk level of the current fleet, presentation of 5 sample ships subject to Cost Benefit Assessments and finally based on the achieved results suggestions on the level of the required index R.

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Reference to part of this report which may lead to misinterpretation is not permissible.

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1	2015-02-25	Initial issue	See list of authors	Apostolos Papanikolaou	Odd Olufsen
2	2015-02-27	Editorial corrections			

3	2015-06-29	Editorial corrections according to EMSA comments	Rainer Hamann	Anne Marie Kristensen	Odd Olufsen

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1 PREFACE

This report is a deliverable according to the Framework Service Contract Number EMSA/OP/10/2013. This is the third study commissioned by EMSA related to the damage stability of passenger ships. The previous studies focused on ro-ro passenger ships.

This study aims at further investigating the damage stability in an FSA framework in order to cover the knowledge gaps that have been identified after the finalization of the previous EMSA studies and the GOALDS project.

The project is separated in to 6 studies:

- Identification and evaluation of risk acceptance and cost-benefit criteria and application to risk based collision damage stability
- Evaluation of risk from watertight doors and risk based mitigating measures
- Evaluation of raking damages due to groundings and possible amendments to the damage stability framework
- Assessment of cost effectiveness or previous parts, FSA compilation and recommendations for decision making
- Impact assessment compilation
- Updating of the results obtained from the GOALDS project according to the latest development in IMO.

The project is managed by DNV-GL and is established as a joint project which includes the following organisations:

Shipyards/designer:

Euroyards representing: Meyer Werft, Meyer Turku, STX-France and Fincantieri

Knud E. Hansen AS

Operators:

Royal Caribbean Cruises

Carnival Cruises

Color Line

Stena Line

Universities:

National Technical University of Athens

University of Strathclyde

University of Trieste

Consultants:

Safety at Sea

Software manufacturer:

Napa OY

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4 ABBREVIATIONS

A: Attained index calculated in accordance with SOLAS 2009. Ch.II-1

ALARP: As Low As Reasonable Practicable

CN: Collision

CT: Contact

FD: Foundering

FSA: Formal Safety Assessment

FX: Fire/Explosion

GOALDS: **GOAL** based **D**amage **S**tability

GR: Grounding

GT: Gross tonnage

IACS: International Association of Classification Societies

IMO: International Maritime Organisation

LMIU: Lloyds Maritime Investigation Unit

POB: Persons on board

R: Required Subdivision Index in accordance with SOLAS 2009. Ch.II-1

SAFEDOR: Design, Operation and Regulation for Safety (EU FP6 project)

WOD: Water on deck

5 EXECUTIVE SUMMARY

A review of FSAs previously carried out in the SAFEDOR project for cruise and RoPax in addition to the FSA carried out for safety of navigation NAV49/INF.2 has been carried out. In addition, examination of data on accidents that have occurred since 2005, have been carried out focusing on collision and grounding. The sources for this additional investigation are the IHS-SeaWeb, IMO GISIS and EMSA's "Accident Investigation" summary reports. Analysis of causes and contrasting with causes included in the HAZIDs have been carried out when possible, however this has only been possible for a limited number of accidents. It is concluded that the causes included in the HAZIDS cover a much wider range of possibilities than which can be extracted from the accidents that have occurred. It is therefore concluded that the causes of the accidents occurred are also covered by the three HAZIDs that were carried out.

The risk for passenger ships of the types cruise, passenger, RoPax and RoPax-Rail was estimated. For this risk analysis two sample ship types were defined: Cruise comprising cruise ships and passenger ships, and RoPax comprising RoPax and RoPax-Rail. Risk models were developed based on the risk models developed in project GOALDS for the accident categories collision and grounding and models for fire & explosion and flooding (RoPax only) of SAFEDOR FSAs. The risk model for collision is completely reviewed and a new, combined model for grounding/contact has been developed.

The risk models has been updated by newly calculated initial accident frequencies for the period 2000 to 2012 and additional information derived from casualty reports. Casualty reports were selected in IHS Fairplay casualty database, Lloyds Maritime Investigation database and IMO GISIS (Global Integrated Ship Information System). The average accident frequencies have been calculated for the different accident categories and the two periods 1994 to 2012 and 2000 to 2012. For Cruise ships (cruise and passenger ships) the average accident frequencies of collision and contact accidents for 2000 to 2012 are higher than for the period 1994 to 2012. Further, it was observed that the average accident frequency for grounding of Cruise ships was highest for 1994 to 2012. A similar increase was observed for ship type RoPax and accident categories collision, contact, fire & explosion. As already mentioned in the GOALDS project, various potential causes for the observed increase exist, for instance changes in and stricter reporting/collecting casualty data by database providers. In general, this development is appreciated because the amount of information will increase in future and it is expected that this will improve the basis for this kind of investigation. However, the number of reports may also change the relation to accidents with significant impact on passenger safety and as to those with smaller impacts. Therefore, a carefully revisiting of existing risk models was necessary. Furthermore, as far as possible and meaningful, the effect of SOLAS 2009 damage stability requirements has been included in the updating of the risk models.

The risk to person on board (POB) has been estimated in terms of FN-diagram, PLL, fatalities per hour, fatalities per journey, fatalities per billion passenger hours and fatalities per billion passenger kilometres. This risk was calculated for the two sample Cruise ship sizes and the three RoPax sample ship sizes considered in the design optimisation. These ship sizes represented the ship sizes used currently. The human risk is calculated considering actual occupancy information.

The risk results are summarised and discussed considering the updated thresholds for the FN diagram as well as selected results from the analysis of risks for other modes of transport. For Cruise ships the main risk contributors are grounding/contact and collision. The risk to person on board of RoPax ships is dominated by grounding/contact and flooding.

Evaluation of risk as recommended in the FSA guidelines by FN diagram shows that the risk for Cruise ships was in the ALARP region[1]. Hence, ALAPRP process should be applied for reducing the risk as far as reasonable practicable, i.e. consider cost effective measures for implementation. For RoPax the risk in terms of FN diagram appeared partly in the intolerable risk region. However, not all the effects of possible compliance with the Stockholm Agreement provisions on this risk pattern have been herein considered. For both ship types the evaluation by FN diagram is significantly influenced by the updated thresholds for the risk regions (negligible – ALARP – intolerable) which are a factor of eight lower than the thresholds specified in MSC 72/16 (2000) typically used in risk evaluation of previous FSAs. In this context it is mentioned that the boundaries used for distinguishing between intolerable, ALARP and negligible risk should be regarded as benchmarks and not as strict criterion. This was also supported by the comparison to other means of transport based on billion passenger kilometres and billion passenger hours, which showed that RoPax vessels did not deviate considerably from other means of transport.

Section 12 includes the description of the sample ship developed to give the best possible distribution considering the world fleet of cruise/passenger ships and RoPax ships and the standards set forth by the current regulations. There is now one large cruise vessel, one small cruise ship, one large RoPax intended for operation in the Baltics, one smaller RoPax intended for operations in the Mediterranean, a smaller RoPax and finally a double ender ferry intended for operation on short international voyages. All ships have been designed in compliance with the applicable international regulations, and are designed for a described business case.

All sample ships have been subject to design modifications carried out for the purpose of improving the attained subdivision index A. The business case is kept unchanged when performing the design modifications. For all design modifications (Risk Control Option) a cost benefit assessment has been carried out. The design options that are found to be cost effective are taken into consideration for recommending the level of the required index R.

[1] Risk in ALARP region means that this risk is tolerable but not acceptable and therefore ALARP process should be applied to make it as low as reasonable practicable.

6 ABSTRACT

The report includes a review of FSAs previously carried out in the SAFEDOR project for cruise and RoPax in addition to the FSA carried out for safety of navigation NAV49/INF.2.

The risk analysis for passenger ships is summarised. This risk analysis is based on carefully reviewed and updated risk models for collision and grounding/contact as well as reviewed and updated models for fire & explosion and flooding.

Risk is calculated in terms of potential loss of life (PLL) per ship year for reference ship sizes (two Cruise and three RoPax vessel) using the updated risk models and average initial accident frequencies for the period 2000 to 2012.

The results are summarised and discussed. Evaluation of risk is carried out as recommended in FSA guidelines by FN diagram.

Sample ships developed in the project are presented. All sample ships have been subject to design modifications carried out for the purpose of improving the attained subdivision index A. For all design modifications (Risk Control Option) a cost benefit assessment is carried out. The design options that are found to be cost effective are taken into consideration for recommending the level of the required index R.

7 INTRODUCTION

This report is the final report prepared in accordance with the tender specification and the project proposal. This report covers all subtasks of the Task 1 on “Risk acceptance criteria and risk based damage stability”

Included in this report is a review of the HazIds carried out in the SAFEDOR project as well as NAV.49/Inf.2. Records of accidents that have taken place since these studies were carried out are investigated to confirm the validity of the identified causes for accidents, primarily focusing on collision and grounding.

The risk of persons on board of passenger ships was in focus of different investigation for instance the FSAs carried out on cruise ships and RoPax vessels within the research project SAFEDOR. Additionally, studies of single risk contributors were carried out in order to determine and evaluate risk mitigating measures considering limited number of causes, for instance GOALDS which was dedicated to damage stability.

This task of EMSA III project is focused on determining the risk of passenger ships using already existing risk models. In order to determine the overall risk of persons on board of the ship types Cruise (including passenger ships) and RoPax (including RoPaxRail), the risk models as developed in GOALDS or in SAFEDOR are updated. This update incorporates into risk estimation the effects of latest IHS Fairplay data on casualties and fleet development, as well as of SOLAS-2009 (SOLAS damage stability) requirements. The investigation is carried out using a statistical sample of ships of the IHS Fairplay database that follows the same selection criteria, for instance with respect to ship size, year of construction etc., as specified in GOALDS project.

For determining the updated initial accident frequencies, the historical evolution of casualties over the last decades has been investigated and proper times intervals have been specified, which are regarded to be representative for the fleet status of today. The risk is calculated for reference ship sizes regarded to be representative for the current world fleet (three cruise ships and three RoPax) using updated risk models and initial accident frequencies equal to the average of the period 2000 to 2012.

For discussion of the risk, we are introducing and determining various risk terms like potential loss of life (PLL) per ship year, FN diagram, fatalities per hour, fatalities per journey, fatalities per billion passenger kilometres or fatalities per billion passenger hours. Risk is also discussed by comparing it with respect to tolerability using the FN diagram and updated values for specifying the regions of intolerable, ALARP and negligible risk. Furthermore, the risk is compared to the risk of other transport means in terms of fatalities per billion passenger kilometres and fatalities per billion passenger hours.

8 METHOD OF WORK

This risk analysis of passenger ships, i.e. cruise ships, passenger ships, RoPax and RoPaxRail, aiming on the development of updated damage stability requirements for these ship types if justified by cost-benefit assessment is based on the process outlined in the Formal Safety Assessment (FSA) guidelines (MSC 83/INF.2, 2007; MSC-MEPC.2/Circ.12, 2013) 1. The main steps of this process are shown in Fig. 8-1.

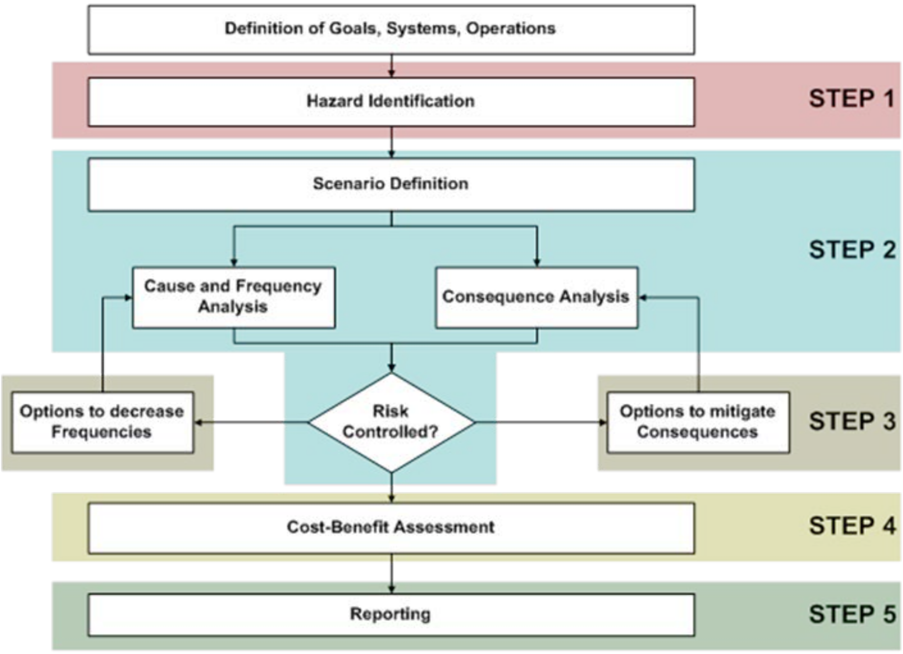


Fig. 8-1 Flow chart of FSA process

8.1 HazId

Typically, hazard identification is performed for identification of major hazards influencing the risk and causes of these hazards. In this project the results of previous HazIds were reviewed.

8.2 Risk Analysis

The risk analysis is based on an investigation of accident statistics for passenger ships as well as development of risk models using event tree (ET) methodology. The risk to people on passenger ships is estimated by developing risk models distinguishing between typical accident categories. All risk models are realised using the software Decision Suite from Palisade©. Risk models are based on the models developed in the FSA on cruise ships (MSC 83/INF.2, 2008), **2** and RoPax (MSC 83/INF.3, 2008) **3** as well as on the partly EU funded research project GOALDS 4. The main objective of this project is the identification of new cost beneficial damage stability requirements. Therefore, the risk models for the accident categories collision, contact and grounding are reviewed in detail. To evaluate the current risk of passenger ships with respect to tolerability the risk by other accident categories is also taken into consideration. These risk models are updated by means of historical data.

In accordance with previous FSAs, risk of passenger ships is quantified on basis of historical data as well as expert judgement, e.g. initial accident frequencies are calculated on basis of reported accidents and fleet at risk. Casualty reports are taken from IHS Fairplay database. For collision, contact and grounding accidents information of IHS Fairplay database are supplemented by information from IMO GISIS (Global Integrated Ship Information System) investigation reports. All IHS Fairplay casualty reports have been reviewed and transferred to a new database in order to allow more specific statistical investigation. GISIS investigation reports provided detailed information on accident causes. This information is used to developed risk models towards accidents causes using fault tree (FT) method.

8.3 Risk Evaluation

In the risk analysis (step 2 of FSA process, Fig. 8-1) the risk of passenger ship operation is quantified with respect to persons on board, i.e. crew and passenger. The risk of person on board is calculated in terms of potential loss of life (PLL) as well as other values. Risk is also evaluated by means of societal risk (F-N diagram) as well as characteristic values used in other industries, e.g. fatalities per billion passenger km.

The societal risk is evaluated using FN diagram with updated risk areas (intolerable – ALARP – negligible). The procedure followed to derive the FN criteria is described in Appendix D of part 1 of the final report 5. It is explained in the IMO FSA Guidelines (IMO, 2013) 1 , and in MSC 72/16 (2000) 6. The basis for this approach is a benchmark against the airline industry. The airline industry was chosen because of the good statistical data and the generally excellent safety record. Based on the IATA Annual Reports for the period 2007 to 2013 the number of fatalities per $billion revenue from passenger transport are determined (Fig. 8-2).

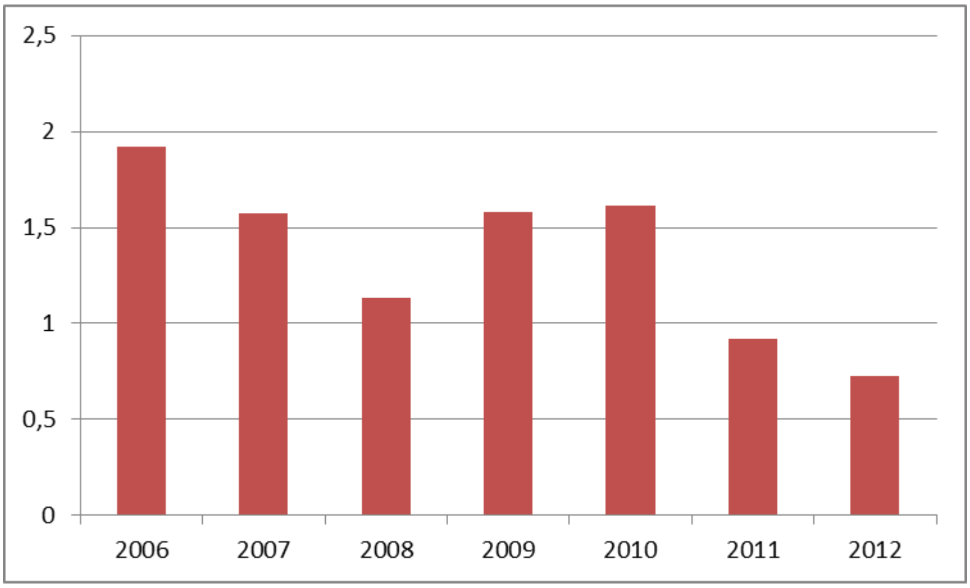


Fig. 8-2 Fatalities per $billion in revenue for the international airline industry (IATA Members)

The figure from the last annual report available was 0.73 fatalities per $billion (all numbers from IATA (2013)). The indication was a rather steady decline from the 5.7 fatalities per $billion referred to in MSC 72/16 (2000), which was based on the annual report IATA (2000). Since there seems to be this steady decline, the 2012 data is used for the benchmark.

For passenger ships, there is no organisation following up the trends like IATA does for airlines. The source of information is, therefore, annual reports from RoPax and Cruise operators. It was decided to use data for RoPax operators to establish the benchmark. This was the same approach as used to establish the FN diagram in IMO (2000). By studying annual reports from

RoPax operators in the Baltic, North Sea, the English Channel and the Mediterranean it was established that the revenue per passenger-year is about $0.05 million. In this number the contributions from tax-free sales on-board had been removed from the revenue.

An FN Curve based on the information above was therefore suggested for N = 1,000 passengers on board. This could be used as a general benchmark for passenger ships, see Fig. 8-3. For further details, see Appendix D of Part 1 of the report.

It should be emphasised that these curves should only be used as benchmarks, and not as absolute criteria. For example, if ships with very large numbers of passengers turned out to be associated with risks in the intolerable area according to this curve, this is an indication that it is likely to be easy to identify cost effective risk control options, and such risk control options should be implemented according to the criterion for Value for Preventing Fatalities (VPF).

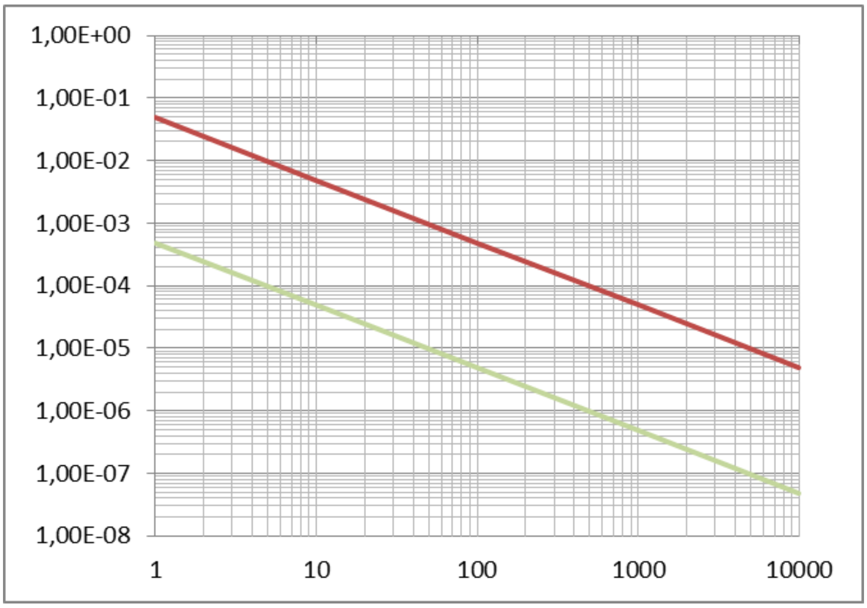


Fig. 8-3 FN criteria for passenger ships: Intolerable limit (red), Negligible/Broadly acceptable (green)

8.4 Risk Control Options

The aim of step 3 of the FSA process (Fig. 8-1) is the identification of measure reducing the risk. The focus of this investigation is damage stability of passenger ships and hence only risk control options that mitigate the consequences of water ingress after collision, contact or grounding accidents are investigated.

9 REVIEW AND UPDATE OF SAFEDOR HAZID

9.1 Introduction

According to the project description; subtask 2(a) objectives are to:

- Review HAZIDs carried out for cruise ships and for RoPax as part of the activities of the SAFEDOR project, as well as the HAZID carried out for the Navigation Safety of Large Passenger Ships project (NAV49/INF.2) Ref./7/.
- Examine data and information of accidents occurred since carrying out these HAZIDs with a view to take onboard any relevant information and confirm the validity of the HAZID studies.

9.2 Review of HAZIDs

The purpose of the SAFEDOR HAZIDs was to establish, at a high-level, the main risks related to cruise and RoPax ship operation and design, and as such, they include hazards relating to all types of incidents.

On the other hand, the purpose of the NAV49/INF.2 HAZID was to identify hazards to safe navigation to be implemented for large passenger ships, and as such, mainly focusing on collision and grounding incidents.

For each hazard identified, causes, consequences, current safeguards and recommendations for potential future safeguards are included in detailed risk registers. A review of the main findings of the three HAZID studies mentioned is included in this part of the report.

9.2.1 SAFEDOR Cruise Ship HAZID

This HAZID is reported in SAFEDOR deliverable "SAFEDOR-D-04.01.01-2005-10-31-DNV-HAZID" 7. The purpose of the HAZID was to establish, at a high-level, the main risks related to cruise ship operation and design. Two brainstorming workshops were organised by gathering panels of different cruise industry experts, as follows:

- The first workshop, held on 21-22 March 2005, focused on the daily operation of cruise ships. The workshop was moderated and recorded by DNV risk experts. The experts' team comprised 5 members, and included technical and operational directors of maritime affairs, marine safety manager and first engineer officer, as well as a risk analyst from Carnival and P&O Cruises. A total of 84 hazards were identified relevant to cruise ship operations, distinguished in the following phases: planning of voyage (18 hazards); arrival/departure to/from port (10 hazards); voyage at open sea (13 hazards); tender operations (15 hazards); emergency operations (19 hazards); common for all modes of operation (6 hazards); other (3 hazards).
- The second workshop, held on 13-14 September 2005, focused on cruise ship design. This workshop was also moderated and recorded by DNV risk experts. The experts' team comprised 5 members and was more design-focused, and included technical risk analysts from Carnival, a flag state representative (MCA), an expert from the ship safety department of a shipyard (Fincantieri) and a cruise/design and regulatory expert from DNV. A total of ***34 hazards*** were identified focusing in particular on

flooding and structural integrity, split in the following categories: collision (13 hazards); fire/explosion (13 hazards); contact (7 hazards); grounding (1 hazard).

The first workshop focused on high-frequency and low-consequence incidents (i.e., occupational incidents, tender operations, etc.), while the second workshop focused on low-frequency and high-consequence incidents (collision, grounding, etc.). It should be mentioned, as highlighted in the HAZID report that collision, grounding and fire/explosion hazards identified in the first workshop, were re-visited and further analysed in the second workshop.

The experts participating in the second workshop provided their assessment of the importance of the hazards identified, which resulted in a ranking of the most important collision/grounding and fire/explosion hazards. Ranking of hazards was carried out using the standard 7 x 4 risk matrix proposed in the IMO FSA guidelines.

The following are the ***five major collision/grounding hazards*** identified by the experts:

1. Officer on-duty not watch-keeping
2. Failure of critical navigational aids (in fog)
3. Severe loss of functionality (e.g. loss of rudder/steering at full speed; failure of shaft bearings)
4. Lack of knowledge of navigating procedures
5. Misinterpretation of bridge information

A list of the next five hazards (*with lower risk*) was also provided:

- Collision between two ships (cruise-other) where cruise ship is not at fault
- Wrong pilot intervention
- Lack of interpersonal communication on bridge
- Severe loss of functionality (e.g. loss of power, blackout, etc.)
- Contamination of fuel tanks

The following are the ***five major fire/explosion hazards*** identified by the experts:

1. Arson – deliberate act resulting in a fire (could be anywhere, anytime)
2. Galley – deep fat fryers, greasy cooking appliances catching fire (due to overheating)
3. Engine room – flammable fluids on hot surfaces
4. Laundry – lint from tumble driers catching fire
5. Cabins – fire starts in cabin (cigarettes, candles, electrical equipment failure, etc.)

A list of the next five hazards (with lower risk) was also provided:

- Hot work procedures (including engine room)
- Mooring deck (mooring ropes catch fire)
- Bunkering – leakage whilst bunkering, ignition through sparks, etc.

- Theatre (front stage and backstage) – hot lights and flammable materials
- Storage areas – self ignition (chemical reactions)

9.2.2 SAFEDOR RoPax HAZID

This HAZID is reported in SAFEDOR deliverable "SAFEDOR-D-04.02.01-2005-10-31-LMG-HAZID" 8. The purpose of the HAZID was to establish, at a high-level, the main risks related to RoPax ship operation and design.

A brainstorming workshop was organised for this purpose on 13-14 June 2005. The workshop was chaired by an experienced risk analyst from LMG Marin and moderated by personnel from the Ship Stability Research Centre and Safety at Sea. The experts' team comprised 8 members covering a wide spectrum of required expertise: naval architect from the basic design office of a shipyard (FSG), a principal surveyor from a class society (DNV), an FSA expert from a flag state (MCA) and five personnel from a RoPax operator, Color Line (new building director, safety manager, naval architect, superintendent, quality assurance/safety superintendent). Specific sessions of the workshop were also attended by further three Color Line personnel (technical director, captain and chief officer), as their expertise was required.

The workshop comprised a series of separate sessions to facilitate identification of hazards occurring during distinct phases of RoPax operation. The eight phases of operation considered are the following, with the associated number of hazards identified: loading (7 hazards); departing quay (8 hazards); transit and navigation in coastal waters (12 hazards); transit in open sea (6 hazards); arriving in port, mooring and preparing for unloading (6 hazards); unloading (6 hazards); bunkering and treatment of fluid and solid garbage (3 hazards); emergency evacuation and drills (8 hazards); other and ordinary hazards (6 hazards).

A total of 62 hazards were identified, with their causes, consequences, current safeguards and potential mitigating measures recorded in a risk register. The HAZID has been conducted based on generic characteristics and features of RoPax ships.

The experts participating in the workshop provided their assessment of the importance of the hazards identified, in terms of their anticipated frequencies and consequences, which resulted in a ranking of the most important hazards. Ranking of hazards was carried out using the standard 7 x 4 risk matrix proposed in the IMO FSA guidelines.

The ***top-ranked high-consequence hazards*** are the following:

1. Failure of evacuation equipment during an emergency
2. Fire in accommodation while in open sea or navigating in coastal waters
3. Human error and/or lack of training during an evacuation
4. Collision with other ships while in open sea or navigating in coastal waters
5. Fire on vehicle deck while unloading due to accumulation of fuel spills during journey
6. Fire in machinery spaces while in open sea or navigating in coastal waters
7. Evacuation arrangements and plans not as effective as designed for
8. No or reduced visibility and high toxicity due to smoke during evacuation

9. Evacuating following a fire or explosion

10. Grounding while navigating in coastal waters

A list of top-ranked high-frequency hazards were also produced, which, however, is not included in this review as the focus of this project is on collision and grounding.

9.2.3 Navigation Safety of Large Passenger Ships (NAV49/INF.2) HAZID

This HAZID was part of an FSA study on the navigation safety of large passenger ships 9 sponsored by the Norwegian Shipowners Association, the Norwegian Maritime Directorate, Kongsberg Maritime Ship Systems and DNV with an objective to identify risk control options related to safe navigation to be implemented for large passenger ships.

The HAZID workshop took place on 20-22 November 2002. The workshop was facilitated and recorded by experienced DNV personnel, and the experts' team comprised 6 members covering a wide spectrum of required expertise: officer on large cruise ships (from RCCL); expert on marine electronics equipment (from Kongsberg Maritime Ship Systems); two DNV nautical surveyors with previous experience as navigator and deck officer, both educated in marine engineering and nautical science; a senior and a principal nautical surveyor from the Norwegian Maritime Directorate, with previous experience as ship masters.

A total of 45 hazards were identified during brainstorming, classified under five main issues determinant for performance on the bridge of a large passenger ship regarding navigation safety, namely: company culture (11 hazards); navigator (7 hazards); procedures, rules and regulations (9 hazards); technical systems (11 hazards); user interface (6 hazards); other (1 hazard).

For each of these identified hazards causes, consequences, current safeguards and recommendations for potential future safeguards were made. The focus was kept on powered grounding, collision and grounding accident scenarios.

The experts contributed their ranking of the most important/critical of the hazards identified. The following list is the hazards ranked as most important to the industry:

1. Level of destruction when the OOW is performing his/her tasks
2. INS/IBS (Integrated Navigational System / Integrated Bridge System) failure (including software)
3. Poor bridge design and physical work conditions
4. Misjudgement of traffic situations
5. OOW unfamiliar with vessel/bridge

9.2.4 Review Comments

The main conclusions from this review are the following:

- All three HAZIDs followed the well-established SWIFT (Structured What IF Technique) approach, a structured form of identifying hazards, their causes, consequences, current and potential future safeguards. At the start of all HAZIDs the participants decided on the sessions required for the HAZID (for example, for the cruise ships and RoPax, the HAZIDs were divided in sessions corresponding to phases of operation; for the Navigation Safety study, the HAZID was divided in sessions corresponding to areas of importance for navigational safety). This resulted in well-organised and structured brainstorming sessions.

- The duration of the brainstorming sessions, number of experts and complementarity of their expertise, facilitation and recording are considered to be satisfactory and adequate for the purpose intended.
- The HAZIDs on cruise ships and RoPax are done at a high-level addressing the needs of the high-level SAFEDOR FSA studies that were part of. This reflects on the hazards identified which mainly associate with consequences of accidents and their mitigation. On the other hand, the HAZID on navigation safety of large passenger ship, as having very specific focus, resulted in hazards mostly related to prevention of accidents relating to navigation safety. In this respect, the risk registers of the three studies can be considered as complementary to each other. Evidence of this are the similarities of hazards identified as most important in the three studies, as reviewed above.

9.3 Updating of HAZIDs

The second objective of subtask 2(a) is to examine data and information of accidents occurred since carrying out these HAZIDs with a view to take onboard any relevant information and confirm the validity of the HAZID studies.

The current project deals with hazards associated with collision, grounding and contact. Since the earlier HAZIDs cover experience until the end of 2005, the updating of HAZIDs will be carried out with the use of information from accidents occurred from the beginning of 2006 and onwards.

For this purpose, the relevant subset of accident data of subtask 2(b) of the project is utilised, namely, in carrying out an analysis of causes of total losses and serious accidents classified as collisions, groundings, and contacts involving cruise ships and RoPax from the beginning of 2005 and onwards to verify the validity of the HAZIDs undertaken.

9.3.1 Approach Adopted

The approach adopted in carrying out this work comprises of the following steps:

- Examine data and information of accidents occurred since carrying out these HAZIDs in 2005 with a view to take onboard any relevant information and confirm the validity of the HAZID studies.
- Focus is placed on collision and grounding incidents, as this is the objective of the EMSA III project.
- Contrast and compare causes, consequences and safeguards of collision and grounding incidents occurred from 2005 and onwards with the causes, consequences and

safeguards, as included and documented in the two HAZIDs of the SAFEDOR project and the NAV49/INF.2 HAZID.

For this purpose, the accident dataset of the risk analysis work of Task 1 of this project is used. The following sources of accident details and descriptions are utilised:

- IHS-SeaWeb (www.sea-web.com)
- IMO's GISIS (Global Integrated Shipping Information System) database
- EMSA's "Accident Investigation" summary reports from accident investigations carried out by National Authorities, as published in EMSA's website (www.emsa.europa.eu)

EMSA III Task 1 Dataset

The dataset contains the number of collisions and groundings (2005 onwards) as shown in the below Table 9-1:

Table 9-1 EMSA III accident dataset

Ship Type	Collisions	Groundings
Cruise Ships	20	17
Passenger Ships	0	2
Passenger/Cruise Ships	1	3
	21	**22**
Passenger-RoRo Ships (Vehicles)	5	8
RoPax Ships	50	24
RoPaxRail Ships	2	0
	57	**32**

9.3.2 IHS-SeaWeb Records – Analysis

With reference to the causes of accidents, the following is the information which can be retrieved from these records:

- Ship status: moored/anchored; manoeuvring; manoeuvring without assistance; on voyage
- Weather: good visibility and good weather; calm weather/seas; heavy weather (wind, waves); hurricane, etc.; fog, mist, poor visibility; freezing conditions
- Location: in port, harbour or dock, at quay; estuary/river; canal; restricted waters; shipyard, dry dock; at sea

It is noted that for a very limited number of records, there is mention of mechanical/electrical failure of equipment as contributing cause to the incident.

Regarding accident consequences, the following details are mentioned in the records:

- Number of people injured, fatalities
- Structural damage to the ship and location of damage (in some records also mentioning if the damage was above or below the waterline)
- Occurrence of flooding
- Environmental pollution (in some records also mentioning amount and type of oil spilled)
- Severity of damage – assistance given (by tugs or other ships), need for repairs, time out of service, total loss
- Some evacuation process details
- Recovery and salvage operations

In conclusion, causes included in IHS-SeaWeb are at a very high-level, only location and status of the ship at the time of incident and the weather conditions are recorded systematically. The following are specific comments in contrasting the HAZIDs with the information included in the IHS-SeaWeb database:

- The HAZIDs include a very wide array of accident causes; the causes mentioned in the IHS-SeaWeb records have been examined in sessions comprising the HAZID workshops, as operational phases.
- There is no mention of the effects of the human factor in the IHS-SeaWeb records.
- The IHS-SeaWeb records are more complete with reference to consequences, as included in the HAZIDs risk registers.

9.3.3 GISIS and EMSA Records

In order to obtain more detailed information in relation to detailed causes of the accidents being reviewed, particularly with reference to the effect of the human factor, additional relevant information is reviewed.

The IMO (GISIS Global Integrated Shipping Information System) database and records retrieved from the EMSA website are used in order to obtain a more comprehensive overview of the causes of the collisions and grounding occurred after 2005.

The GISIS database contains only a limited number of incidents, as shown in the below Table 9-2 :

Table 9-2 IMO GISIS database

Ship Type	Collisions	Groundings
Cruise Ships	0	3
Passenger Ships	0	1
Passenger/Cruise Ships	0	0
	0	**4**
Passenger-RoRo Ships (Vehicles)	1	1
RoPax Ships	10	5
RoPaxRail Ships	1	0
	12	**6**

Additional details (summary reports from accident investigations carried out by National Authorities) obtained from EMSA's website for 6 of the collisions and 1 grounding for RoPax are also used.

9.3.4 Details of Analysis

The following tables 6-3 through 6-7 include the accidents for which the causes are contrasted with causes as included in the three HAZIDs under review.

Table 9-3 Accidents - *Cruise Ships*

Ship Name	Incident	Remarks
Sea Diamond	Grounding, 05/04/2007	No mention of causes
Astor	Grounding, 15/05/2009	
Costa Concordia	Grounding, 13/01/2012	

Table 9-4 Accidents - *Passenger Ship*

Ship Name	Incident	Remarks
Ocean Nova	Grounding, 17/02/2009	No mention of causes

Table 9-5 Accidents - *Passenger-RoRo Ships (Vehicles)*

Ship Name	Incident	Remarks
Nuraghes	Collision, 21/06/2006	No mention of causes
Ile de Groix	Grounding, 28/07/2008	no mention of causes

Table 9-6 Accidents - *RoPax Ships*

Ship Name	Incident	Remarks
Panstar Dream	Collision, 03/11/2005	No mention of causes
Finnsailor	Collision, 13/11/2005	
Olympia Palace	Collision, 07/12/2005	No mention of causes
Mercandia IV	Collision, 11/09/2006	EMSA summary report
Pride of Bruges	Collision, 13/11/2007	EMSA summary report
Skania	Collision, 17/02/2009	EMSA summary report
Gotland	Collision, 23/07/2009	No mention of causes
Scottish Viking	Collision, 05/08/2010	
Stena Feronia	Collision, 07/03/2012	EMSA summary report
Nils Holgersson	Collision, 03/05/2012	EMSA summary report
Hamnavoe	Grounding, 16/05/2006	
Stena Danica	Grounding, 10/01/2008	No mention of causes
Pride of Canterbury	Grounding, 31/01/2008	EMSA summary report
Princess of the Stars	Grounding, 21/06/2008	No mention of causes
Isle of Arran	Grounding, 28/03/2009	

Table 9-7 Accidents - *RoPaxRail Ships*

Ship Name	Incident	Remarks
Schleswig-Holstein	Collision, 24/08/2009	EMSA summary report

Appendix A contains all the details of the reports available from the IMO GISIS database and also the additional information obtained from EMSA's "Accident Investigation" summary reports. Appendix A also contains full details of the contrasting between the causes of the accidents and possible causes included in the HAZIDs.

As an example, Table 9-8 below shows the contrasting of the causes of the Costa Concordia incidents with causes included in the HAZIDs.

Table 9-8 Costa Concordia causes vs causes included in HAZIDs

Causes of Costa Concordia Incident Extracts from IMO GISIS Record	Causes included in HAZIDs
• Illusion of control • Distraction caused by presence of additional persons on the bridge and a mobile telephone call • Insufficient bridge resource management • Lack of appropriate large-scaled chart • Insufficient position monitoring	SAFEDOR Cruise HAZID, Workshop II risk register. Hazard on "Grounding" – ship at full speed hitting hard sea-bottom (rock), as causes the following are mentioned: navigational equipment, updated and appropriate sea-charts, trained and competent officer on watch. Another section of the SAFEDOR Cruise HAZID is on "Emergency Operations" with hazards included 5.1 "crew ability/training", 5.3 "crew behaviour/reaction/emergency handling", 5.7 "knowledge of emergency procedures", 5.14 "ship movement (list/trim)"; etc.
	Hazards included in NAV49/INF.2 • No. 1 – "OOW distractions", one of the causes mentioned is "human: telephone calls, other crew members, passengers" • No. 10 – "poor company policy/culture" • No. 19 – "communication between navigators, misunderstandings" • No. 32 – "large vessels, difficult to manoeuvre" A number of hazards relating to use of bridge equipment: No. 15 "incorrect use of equipment", No. 29 "poor quality of equipment"
Some passengers jumped into the water and swam to safety, but there were delays in getting others into life boats, especially as the vessel had by then rolled over onto her side and many of the lifeboats were inaccessible	Hazards 8-1 and 8-2 of the SAFEDOR RoPax HAZID refer to emergency evacuations when the ship is trimmed and heeled and to evacuation equipment failure. It should be highlighted that hazard 8-2 was the top-ranked hazard in this HAZID. The causes for these hazards included in the HAZID are: difficulties in launching lifeboat and MES; slow reaction/awareness by passengers; inappropriate assistance to passengers from crew; lack of plans, training and experience; poor maintenance; lack of training; faulty equipment; too extreme heel and trim; human error.
Some reports indicated that the ship had also suffered a major electrical fault	NAV49/INF.2 – Hazard No. 30 "technical failure of power supply" SAFEDOR Cruise HAZID –under the "planning, departure/arrival & voyage" section, HAZARD A is "black-out"
• Error in judgement; Inappropriate choice of route • Insufficient risk assessment and passage planning	The SAFEDOR Cruise HAZID includes a whole section for hazards relating to Voyage Planning. We can highlight the following hazards included: 1.4 – navigational failure with causes mentioned "unreliable electronic charts" 1.8 – crew resource management 3.7 – human error – two of causes included are inappropriate watch changeover and complacency

On the basis of the analysis carried out, we can derive the following conclusions:

- Analysis of causes and contrasting with causes included in the HAZIDs only possible for a very limited number of accidents (2 cruise ship groundings; 8 RoPax collisions; and 3 RoPax groundings).
- Causes included in HAZIDs, as the result of brainstorming, cover a much wider range of possibilities when compared with the causes of accidents occurred.
- Due to the very little data available, quantitative analysis of causes cannot be performed, hence it is not possible to make exact comparisons with the ranking of hazards included in the HAZIDs. In any case, the rankings provided in the HAZIDs appear to be appropriate and corresponding to the nature of causes analysed in this subtask.
- From this analysis, it can be concluded that the causes of the accidents occurred are included as causes in the three HAZIDs reviewed, hence the latter can still be considered valid.

10 RISK ANALYSIS

The focus of this project is to provide the basis for updating damage stability requirements for passenger ships based on risk analysis and evaluating risk control options with respect to their cost-benefit. Following FSA guidelines application of cost-benefit requires that the risk is in the area of tolerable risk and should be minimized by means of ALARP process (making risk as low as reasonable practicable). Whether the prerequisite for applying ALARP process is fulfilled can only be verified on basis of a quantitative risk analysis considering all relevant risk contributors.

In this section the development of the quantitative risk model for passenger ships is summarised, i.e. for the ship categories Cruise and RoPax as specified above. The risk analysis is based on quantitative of risk models developed in form of event trees (ET) and were realised using the software Decision Suite from Palisade©. Typically risk models are developed based on high-level event sequences covering the main events influencing the consequences and subsequently the risk. Such high-level event sequences cover the main parameters between incident or accident and consequence influencing the consequences, for instance the location of an incident or the success of consequence mitigating measures. The high-level event sequences used for developing the risk model are described in the first part below.

In the following section the basis for the quantification of the risk models with respect to fleet at risk and casualty reports is briefly summarised. More detailed information can be found in Annex B and Annex C.

This section closes with a representation of the quantitative risk models for the different accident categories considered and distinguishing the ship categories Cruise and RoPax.

Risk of passenger ships was already in focus of several research work, in particular the FSAs for cruise and RoPax ships as well as in the project GOALDS. This project continues the work of the previous investigations and therefore the risk model for passenger ships is based on previous studies that were reviewed and updated as appropriate.

10.1 High-Level Event Sequence

Typically, risk models were developed based on high-level event sequences that specify major ramifications in the sequence between accident and consequences. In the following the high-level event sequences are summarised for both ship types and all accident categories characterising the risk for both ship types under consideration.

The high-level event sequence for collision is shown in Fig. 10-1. This event sequence was developed for both ship categories Cruise and RoPax in the GOALDS project 4 and is used also for this investigation because it is regarded to adequately describe the development of collision accidents. The consequences of collision accidents highly depend on whether the ship is striking or struck. Typically, for striking ship damages to hull occurred but they are limited to the bow area. Even if water ingress occurs, the damage stability is not reduced. The situation is different for ships struck. When a ship is struck it may lose its stability and sink. All measures to limit the consequences for person on board strongly depend on the area of accident, i.e. the operational area. When accident occurs close to the shore the reaction time for SAR is low compared to accident far from shore line. Hence, fatality rates for accidents close to shore should be lower. The following two nodes of the event sequence focus on the prerequisites for sinking, i.e. water ingress and loss of stability.

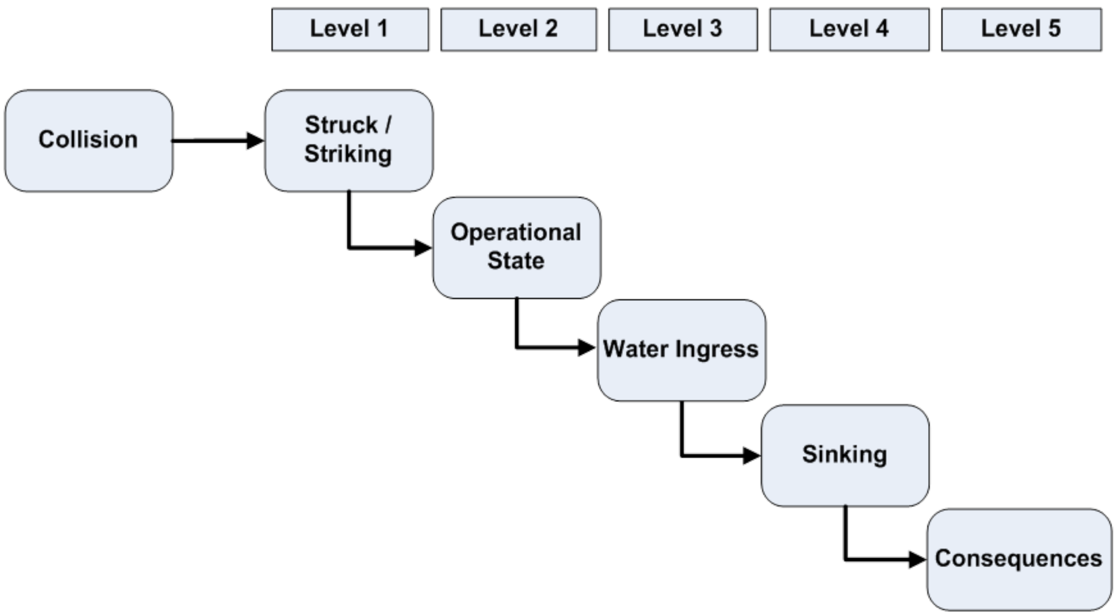


Fig. 10-1 High-level event sequence for collision of Cruise and RoPax (based on GOALDS)

One of the objectives of this investigation is the adequate consideration of contact accidents and their impact on damage stability. Grounding accidents are defined by IMO as stranding or grounding, or hitting/touching shore or sea bottom or objects. Contact accidents should cover striking any fixed or floating object other than considered under collision or grounding. As long as both lead to water ingress the further escalation can be quite similar, i.e. contact as well as grounding can lead to sinking of the vessel. In particular the consideration of so-called raking damages is of higher importance.

Therefore, the high-level event sequence and the risk model for grounding accidents need to be revisited. The high-level event sequence for grounding accidents for both Cruise and RoPax ships (Fig. 10-2) considers the following events:

1. Area of Operation. Two alternatives are foreseen: the accident takes place either within or outside a Terminal Area. In the latter case, Limited Waters and Open Sea are combined in one area (Other) and treated together, since it is expected that the consequences of a grounding accident would be similar in both areas.
2. Area of the hull in contact with the sea bottom. The following two alternatives are considered: the ship touches the sea bottom with the bottom or the side of the hull surface.
3. Type of the sea bottom (Hard/Soft). In case the ship touches the sea bed with the side of the hull surface, the sea bottom is assumed always hard; therefore the corresponding node in the risk model is omitted.
4. Hull breach (Yes/No). In case of soft bottom, the probability of hull breach is set equal to zero. In case of hard sea bottom, the probability of hull breach is calculated based on the available data from grounding accidents.
5. Water Ingress (Yes/No). In case of a hull breach due to bottom damage (type B00), water ingress takes place with a probability of 100%, therefore the corresponding node in the risk model is omitted. In case of a hull breach due to side damage (type S00), water ingress might take place or not, depending on the position of the lower limit of the breach with respect to the water line.
6. Staying aground (Yes/No). If immediately after the accident the ship stays aground, then no fatalities are assumed.
7. Afloat (Yes/No). If the ship does not stay aground, two alternatives are considered: a) it may remain afloat, with a probability assumed equal to the corresponding A-Index or, b) it may sink or capsize, with a probability assumed equal to 1-A .
8. Consequences. In case the ship sinks or capsizes, the number of fatalities is calculated as a percentage of POB (Persons on Board).

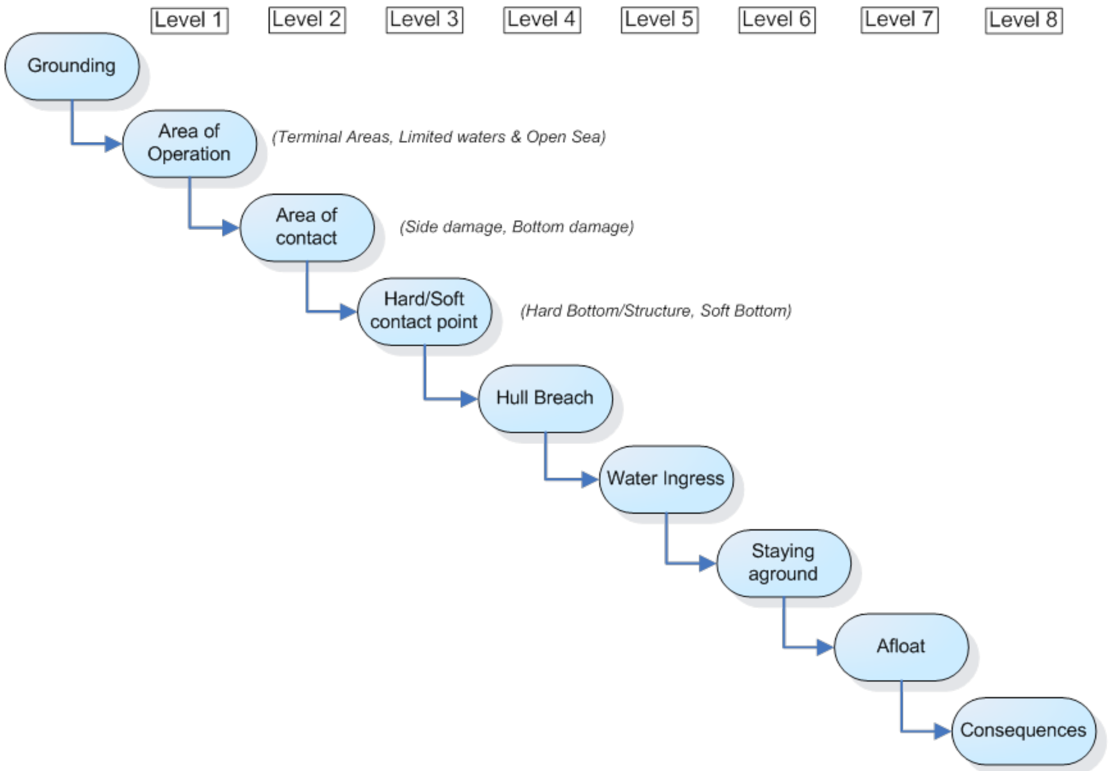


Fig. 10-2 High-level event sequence for Grounding Accidents to Cruise and ROPAX ships

Both high-level event sequences for fire and explosion developed in SAFEDOR showed slight differences as shown by the comparison in Fig. 10-3 (Cruise) and Fig. 10-4 (RoPax). In the event sequence for RoPax the origin of fire was considered along with extinguishing measures in the machinery, vehicle deck and accommodation area. In the risk model for Cruise the focus was put on the escalation, i.e. whether the fire can be extinguished in the compartment of origin or spread. Considering the particularities of RoPax and Cruise ships this distinction was regarded appropriate and ship category dependent risk models were developed.

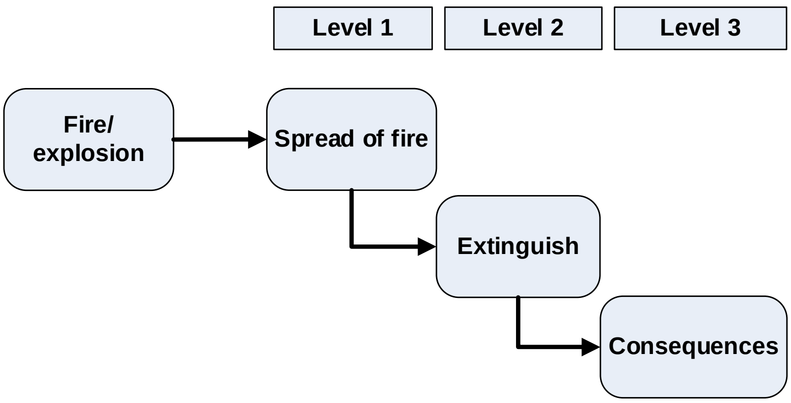


Fig. 10-3 High-level event sequence for fire / explosion on cruise ships (based on SAFEDOR FSA on Cruise)

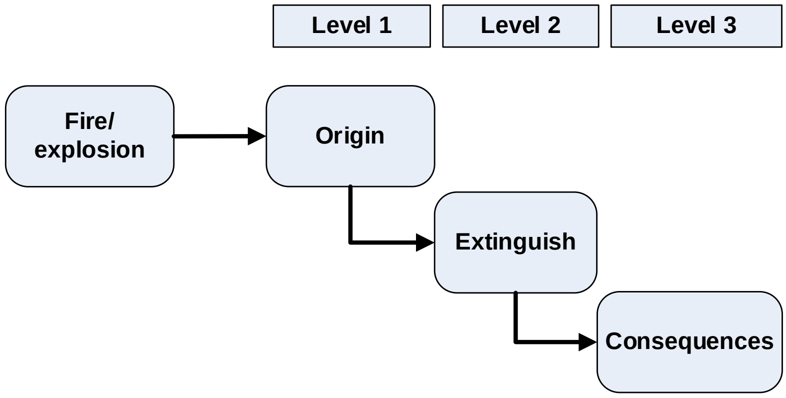


Fig. 10-4 High-level event sequence for fire / explosion on RoPax ships (based on SAFEDOR FSA on RoPax)

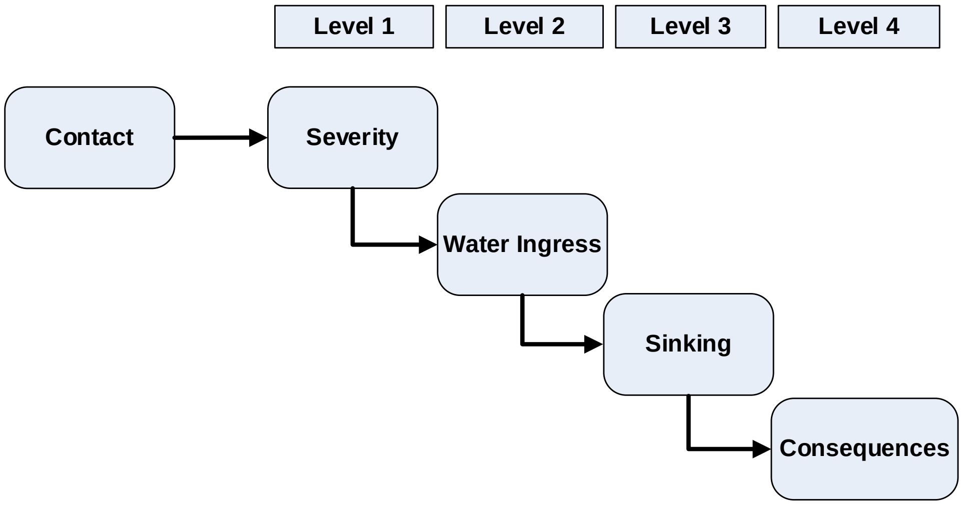


Fig. 10-5 High-level event sequence for contact / impact of RoPax ships (based on SAFEDOR FSA on RoPax)

Additionally, for RoPax an independent risk model relating to the flooding hazard was developed in the SAFEDOR FSA, which considers all risks relating to loss of water tightness relating to non-accidental failures, like doors left open or wave forces leading to non-accidental structural failure or opening of bow door (Herald of Free Enterprise and M/V Estonia type of accidents). Such casualties were typically assigned to the accident categories foundering and hull/machinery accidents in the IHS Fairplay casualty database. In particular for RoPax ships, water ingress to car deck has the potential of leading to rapid loss of stability and subsequently to capsizing, with high fatality rate for person on board. Since it contributes to the risk of RoPax ships, it was considered in the present study.

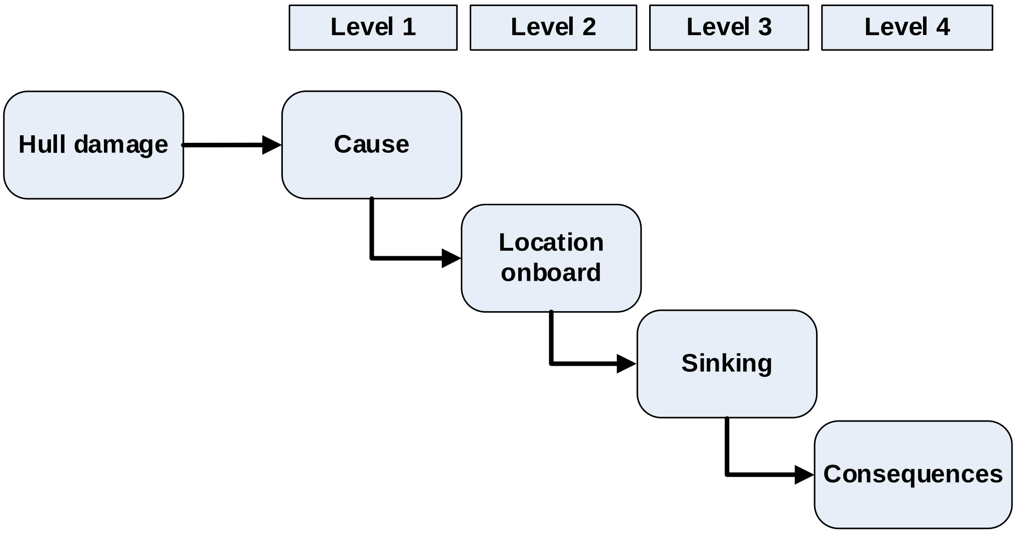


Fig. 10-6 High-level event sequence for hull damage of RoPax ships (based on flooding risk model SAFEDOR FSA on RoPax)

10.2 Quantitative Risk Model

10.2.1 Basic Information

In order to determine accident frequencies representative for pure passenger ships (Cruise and Passenger ships) as well as RoPax vessels, casualty reports are selected from the IHS Fairplay casualty database for the following ship types identified in (Table 10-1). Casualty reports are selected using the same filtering criteria specified for the GOALDS (2009- 2012) project:

- Accident categories collision (CN), contact (CT), grounding (GR) (also designated Wrecked/Stranded), fire & explosion (FX) and foundering (FD);
- Ship types: Cruise (representative for cruise and passenger ships) and Ro-Pax (representative for RoPax and RoPaxRail);
- GT ≥ 1000 – most ships below GT 1,000 operate on non-international voyages;
- ≥ 80 m length (L_{OA}) - most ships below 80 m in length operate on non-international voyages;
- Built ≥ 1982;
- Accidents in the period 1994-01-01 and 2012-12-31;
- IACS class at time of accident – to reduce the potential effect of under reporting;
- IACS class for determination of ship years;
- Froude No. ≤ 0.5 – to eliminate High Speed Craft (HSC) from the study.

The sample derived is regarded to be representative for ships built in accordance with current SOLAS regulations. Additional investigation showed that average accident frequencies for cruise ships as well as RoPax vessels not IACS classed were significantly lower than for IACS classed ships. For ships built between 1961 and 1982 and classed by IACS societies the average accident frequencies were higher for Cruise ships and RoPax for all accident categories. New navigational means were introduced on board ships in the 1990s even if not required by regulations in particular ECDIS is expected to have a significant effect on grounding accidents. In NAV 51/10 the effect of ECDIS is quantified to 66% risk reduction (without track control). ECDIS is required for ships passenger ships with or with more than 500 gross tonnes and constructed on or after 1. July 2012. It is known that ECDIS was already installed on new Cruise and RoPax starting in the 1990s. However, installation on already operating vessels was not required and therefore, the effect of ECDIS on grounding accident frequency cannot or only partly be considered by historical data for the period 1994 to 2012. Based on these investigations the consideration of ships complying with above listed criteria was regarded to be appropriate.

Deviating from the previous investigation in GOALDS, accidents of the category *contact* is considered for further review due to the fact that the accident of the *Costa Concordia* was assigned to this category[2]. These casualty reports were reviewed and re-assigned to accident categories if necessary in order to have a consistent consideration of accidents in the risk model. Additionally, a combined risk model was developed for grounding and contact risk. Furthermore and with the objective to determine the total risk of persons on board of ship types under consideration casualty reports of the accident categories fire & explosion, hull machinery and foundering were considered in order to update the related risk models considered for this investigation.

All casualty reports collected for collision, contact and grounding were carefully reviewed and formed the basis for the development of a database suitable for the risk analysis of the present investigation (see Annex E of this report).

Table 10-1 IHS Fairplay Statcode and ship type description for ship types considered in this investigation

Ship type	Level5Decode	Description	IHS StatCode
Ro-Pax	Passenger/Ro-Ro Ship (Vehicles)	A ro-ro cargo ship with accommodation for more than 12 passengers	A36A2PR
Ro-Pax-Rail	Passenger/Ro-Ro Ship (Vehicles/Rail)	A ro-ro cargo ship for the additional carriage of rail-vehicles and with accommodation for more than 12 passengers	A36A2PT
Cruise	Passenger/Cruise	A vessel certificated to carry more than 12 passengers, all of whom may be accommodated in cabins	A37A2PC
Pax	Passenger Ship	A vessel certificated to carry more than 12 passengers, some of whom may be accommodated in cabins	A37B2PS

10.2.2 Fleet at Risk

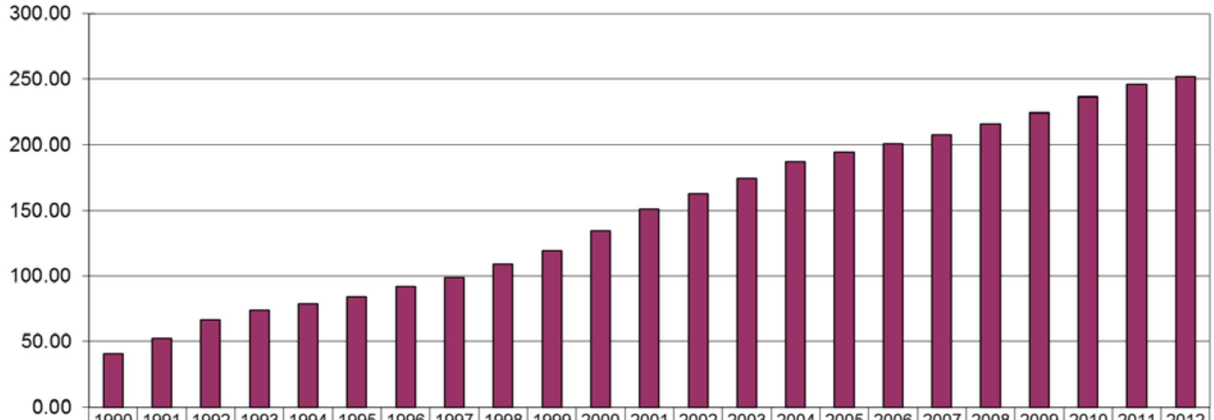
Some basic analyses of fleet data were performed in order to characterise the fleets of both ship categories under consideration and specify the sample used for the subsequent determination of accident frequencies. Such characteristics are the number of ships or the annual growth rate (indicating the introduction into world fleet of recent changes in regulations). It is mentioned that for later risk analysis two ship categories are used, one consisting of Cruise and passenger ships, the other consisting of RoPax and RoPaxRail, and

[2] As an alternative to grounding

relevant data is merged, i.e. ship years and number of accidents. The number of ships for the ship types passenger ship and RoPaxRail are small and consequently any risk calculation very uncertain. The definition of these two ship categories provided the advantages of considering these ship types in the risk analysis and achieving a sample with an acceptable uncertainty.

In the following the results are briefly summarised. More details can be found in Annex B of this report.

In total 266 cruise ships (≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC) were reported to be active between 1982 and 2012. Of these 258 vessels were classed by one of the IACS societies. Today cruise ship fleet comprises roughly 250 ships with a total passenger capacity of nearly 490,000. The development in fleet at risk in terms of ship years per year is shown in Fig. 10-7. The total number of ship years for 1994 to 2012 was 3,404.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ship years	41.09	52.67	66.59	74.08	78.84	84.16	91.83	99.08	109.0	119.5	134.3	150.9	162.7	174.5	187.0	194.3	200.5	207.6	215.9	224.5	236.8	246.2	251.7

Fig. 10-7 Number of ship years per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).

Focusing on the second decade of the time period analysis, namely 2000-2012, and categorising Cruise ship fleet by ship's nominal passenger capacity, the following can be observed (Fig. 10-8, Fig. 10-9 and Fig. 10-10):

- The larger part of cruise ship fleet is coming from ships having a passenger capacity of 1,500-2,500 persons.
- Cruise ships carrying 2,500-3,500 passengers are the second largest part of cruise operational ship fleet.
- Cruise ships with passenger capacity larger than 4,500 persons appeared first after 2009 thus the particular capacity provides the higher percentage of growth.

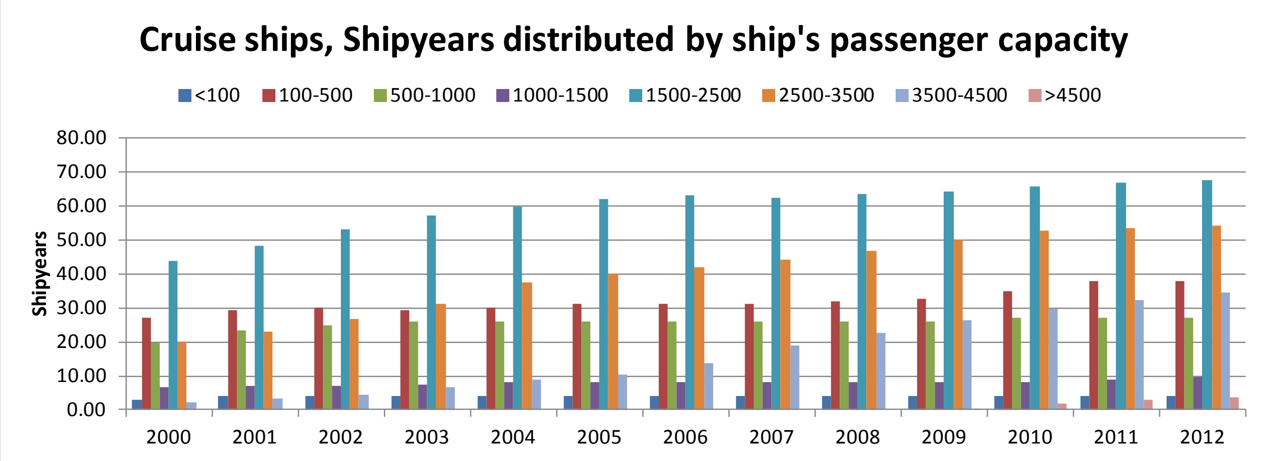


Fig. 10-8 Number of ship years per year for cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

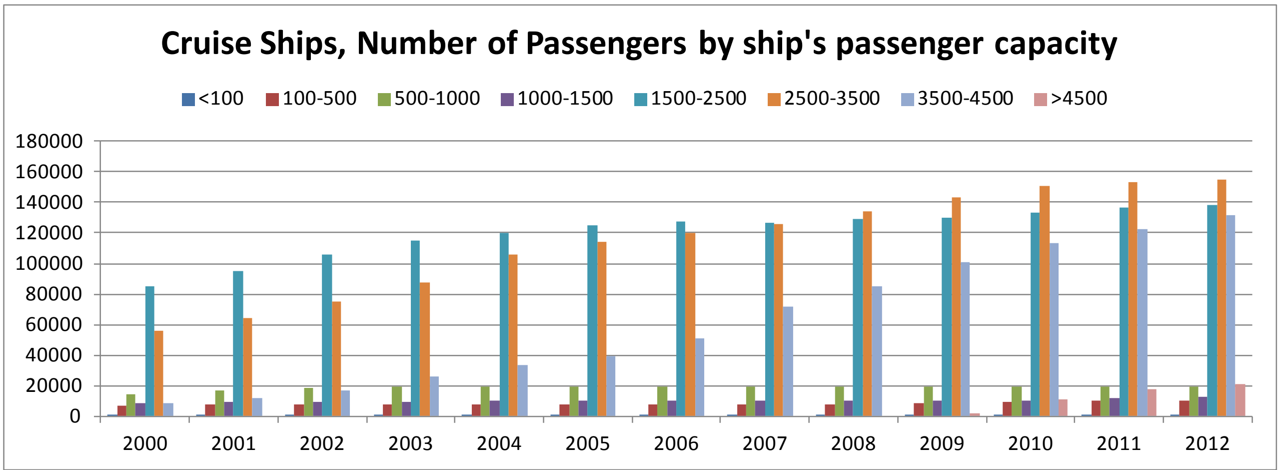


Fig. 10-9 Number of Passengers per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

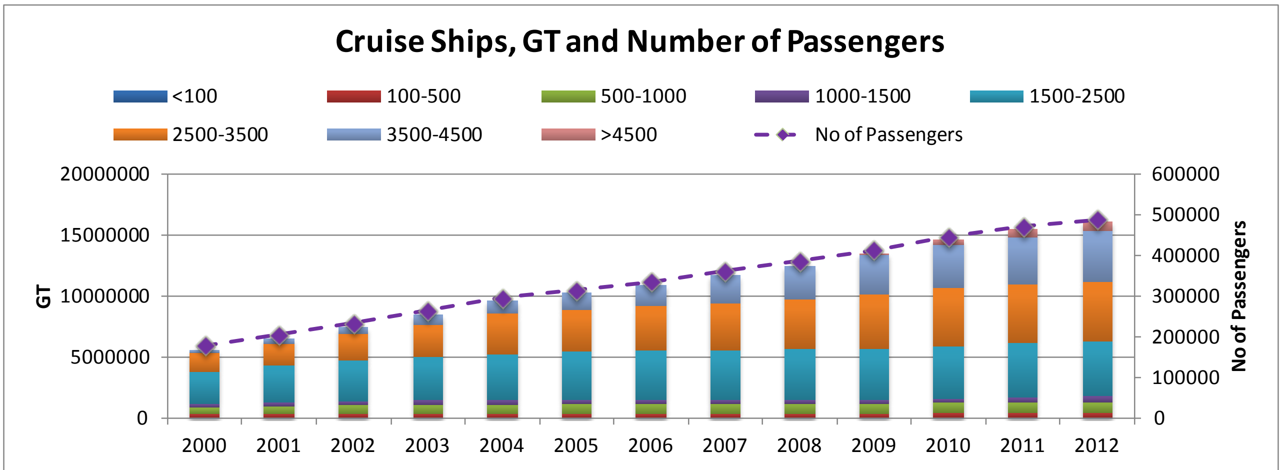
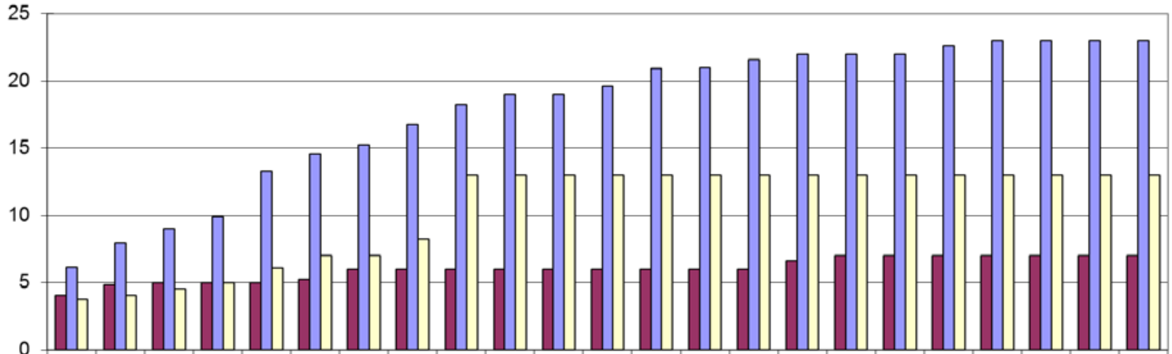


Fig. 10-10 GT and Number of Passengers per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

With 43 ships the fleet of pure passenger ships was significantly smaller than fleet of cruise ships. The majority of this small world fleet was classed by Non-IACS societies (23) or other organisations (13). With respect to maximum gross tonnage (< 14,000 gross tonnes) and passenger capacity (< 1,750 passengers) IACS passenger ships were smaller than IACS Cruise ships. Similar observations were made with respect to Non-IACS ships or ships without class. All ships were below 150 m of length.

For the period 1990 to 2012 the number of ship years per year are summarised in Fig. 10-11 considering subsets “IACS”, “Non-IACS” and “Empty”. The cumulative number of ship years for 1990 to 2012 was 139 ship years (“IACS” class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	4	5	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7
Non IACS	6	8	9	10	13	15	15	17	18	19	19	20	21	21	22	22	22	22	23	23	23	23	23
EMPTY	4	4	5	5	6	7	7	8	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13

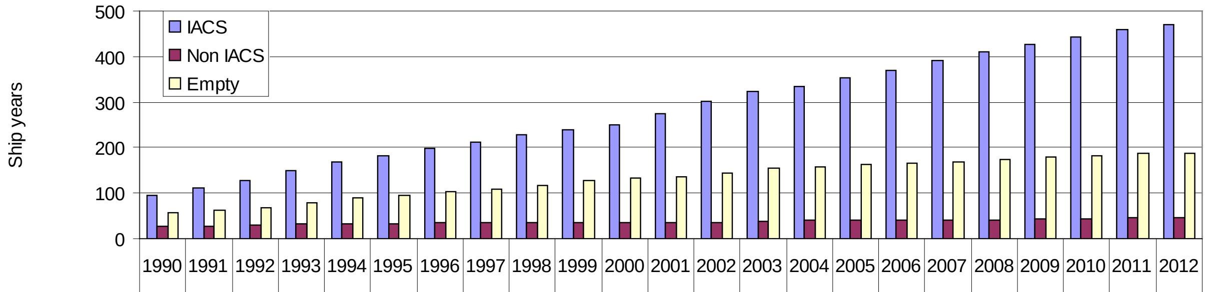
Fig. 10-11 Number of ship years versus year for Passenger ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).

The comparison between Cruise and passenger ships fleet showed that the latter will contribute only marginally to a merged category.

IHS-Fairplay ship register contained 735 RoPax vessels built after 1981, ≥ 1,000 GT and an L_{OA} ≥ 80 m of which 485 were currently classed by an IACS society, 48 for “Non-IACS” society and 202 for “other organisations”. The subset of Non-IACS ships contained mainly vessels smaller than or equal to 10,000 GT (77%), whereas for IACS ships 63% were between 10,000 and 40,000 gross tonnes. Accordingly, most of IACS ships had a length between 150 m and 200 m whereas for Non-IACS ships 80% were shorter than 150 m.

For IACS ships a general trend towards larger vessels was identified shown by the increase of average ships size in terms of gross tonnage. In 2012 the average ships size was ~20,000 GT, 30% higher than in 1990.

The number of ship years per year distributed over the three subsets considered (“IACS”, “Non-IACS” and “EMPTY”) is plotted in Fig. 10-12. IACS classed ships contributed more than 60% of all ship years with slightly increasing percentage towards the end of the observation period (~67% in 2012). The cumulative number of ship years between 1990 and 2012 for RoPax ships was 6,520 respectively 6,035 for ’94 to ’12 (“IACS” class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	94	112	129	150	168	182	198	211	228	238	249	275	302	322	334	353	371	392	411	426	443	459	471
Non IACS	27	28	30	32	33	34	34	34	34	34	34	35	36	37	40	41	41	41	42	44	44	47	47
Empty	58	64	68	80	88	95	103	109	118	127	133	137	145	154	159	163	167	168	174	180	183	187	189

Year

Fig. 10-12 Number of RoPax ship years for each subset for "IACS" and "Non-IACS" class ships.

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising RoPax fleet by ship's nominal passenger capacity, the following can be observed (Fig. 10-13, Fig. 10-14 and Fig. 10-15):

- The larger part of RoPax fleet is coming from ships having a passenger capacity of 500-1,000 persons and it is continuously increasing over the years.
- RoPax ships carrying 1,000-1,500 passengers is the second larger part of RoPax operational ship fleet.
- Growth rates vary up to 10% after year 2005 with respect to the ships up to 2,500 passengers.
- In annual base, the largest number of passengers is carried by RoPax ships with passenger capacity in the range of 1,500-2,500.

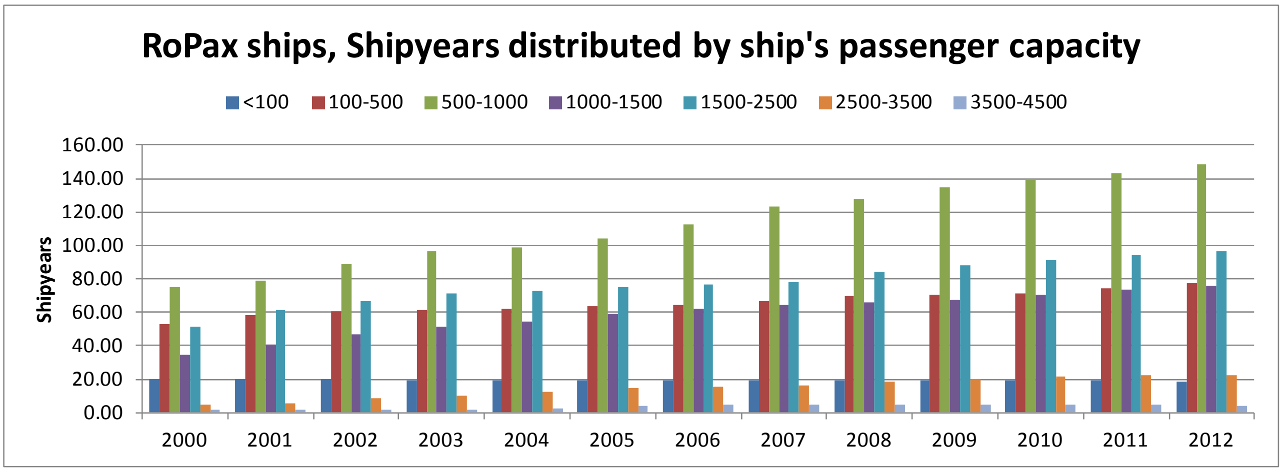


Fig. 10-13 Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

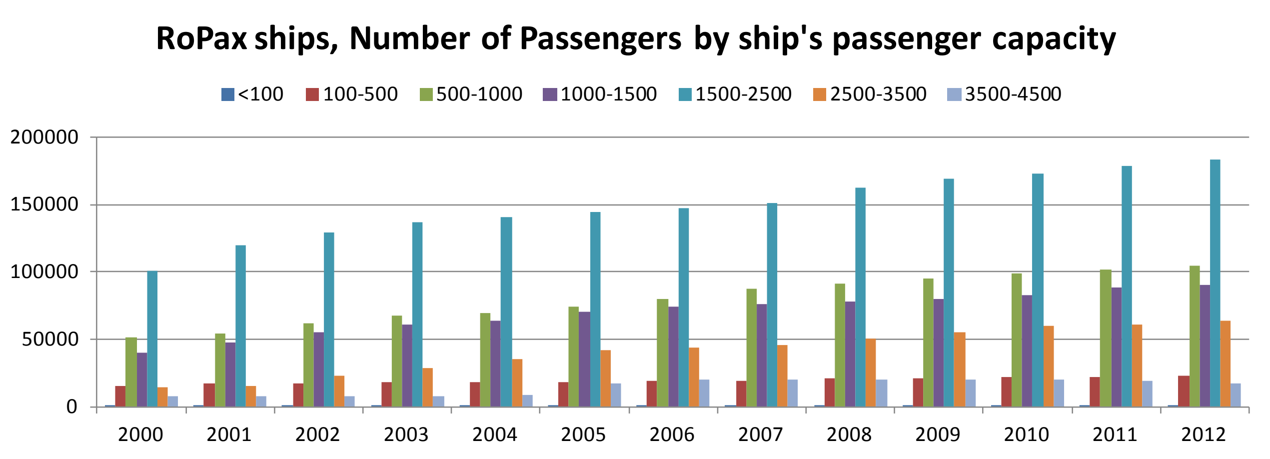


Fig. 10-14 Number of Passengers per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

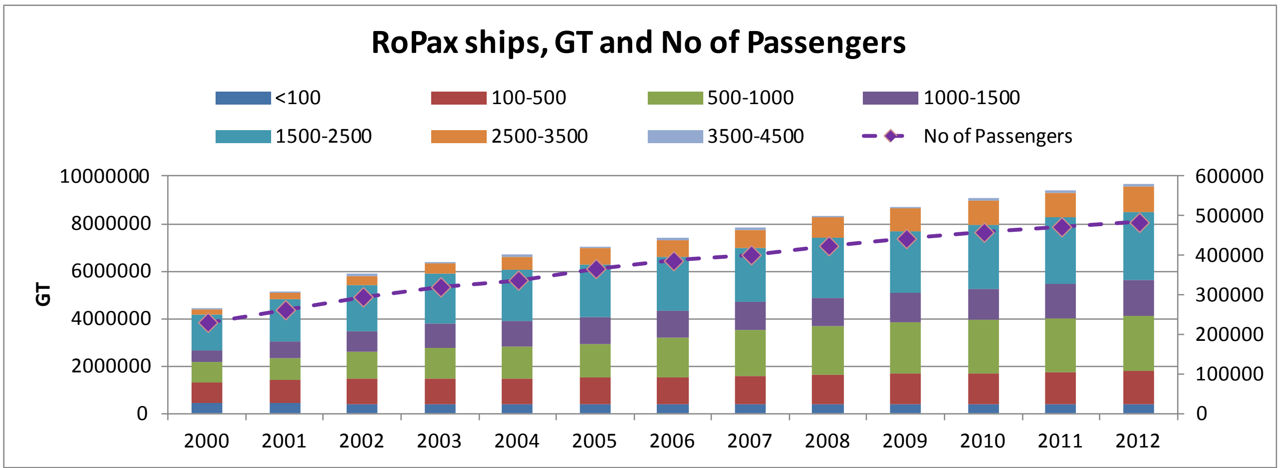
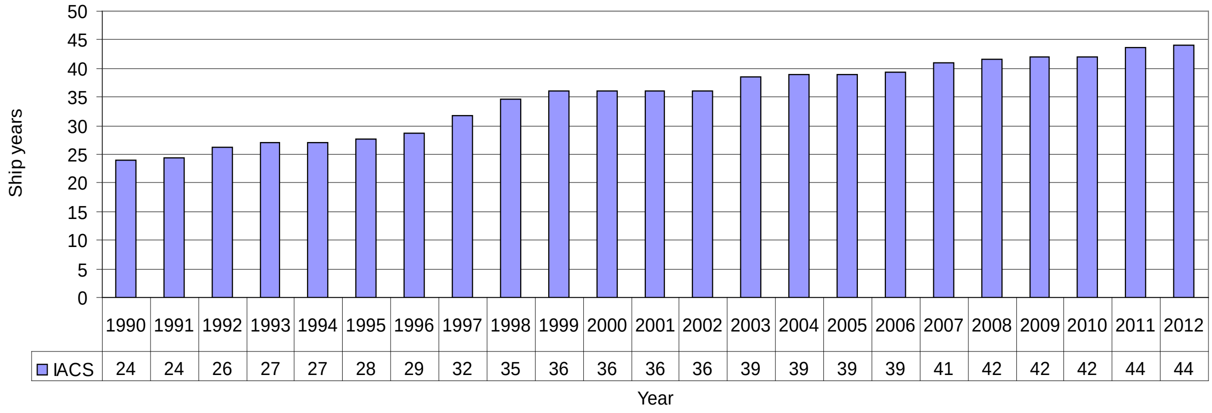


Fig. 10-15 GT and Number of Passengers per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

The world fleet of RoPaxRail ships was rather small with 47 vessels operating between 1990 and 2012. Compared to RoPax ships(IACS classed), large RoPaxRail vessels with more than 30,000 GT were very seldom, and like RoPax the majority of vessels (~70%) had a gross tonnage between 10,000 and 30,000 (RoPax 46%). 25% of RoPaxRail ships were smaller than 10,000 GT which was also close to the figure for RoPax ships (IACS: 27%). The average ship size of the fleet with respect to gross tonnage increased between 1990 and 2012 by about 25%, i.e. from 13,000 GT to ~16,000 tonnes.

Also, with respect to ship length the fleets of both ship types had large similarities and the typical ship had a length between 150 m and 200 m (RoPaxRail: ~60%; RoPax: ~47%). Finally, passenger capacity of both fleets showed similar characteristics and the vast majority of ships can transport between 200 and 1,500 passengers (RoPaxRail: ~80%; RoPax: ~75%).

The number of ship years per year for RoPaxRail ships over the period 1990 to 2012 is plotted in Fig. 10-16. In total 805 ship years were reported which was about 12% of the IACS RoPax fleet (704 for '94 to '12).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	24	24	26	27	27	28	29	32	35	36	36	36	36	39	39	39	39	41	42	42	42	44	44

Fig. 10-16 Number of ship years per year for IACS class RoPaxRail ships.

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising RoPaxRail ship fleet by ship's nominal passenger capacity, the following can be observed (Fig. 10-17, Fig. 10-18 and Fig. 10-19):

- The major part of RoPaxRail fleet is coming from ships having a passenger capacity of 100-500 persons.
- The fleet of RoPaxRail ships carrying 1000-1500 passengers is the second largest part of RoPaxRail operational ship fleet.
- In annual base, the largest number of passengers is carried by RoPaxRail ships having a passenger capacity in the range of 1,000-1,500.

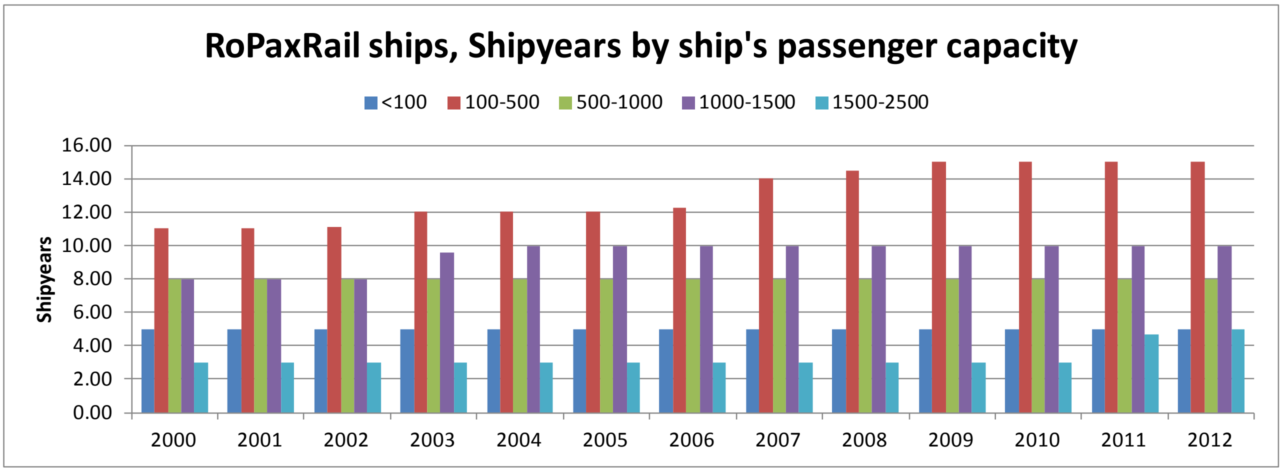


Fig. 10-17 Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

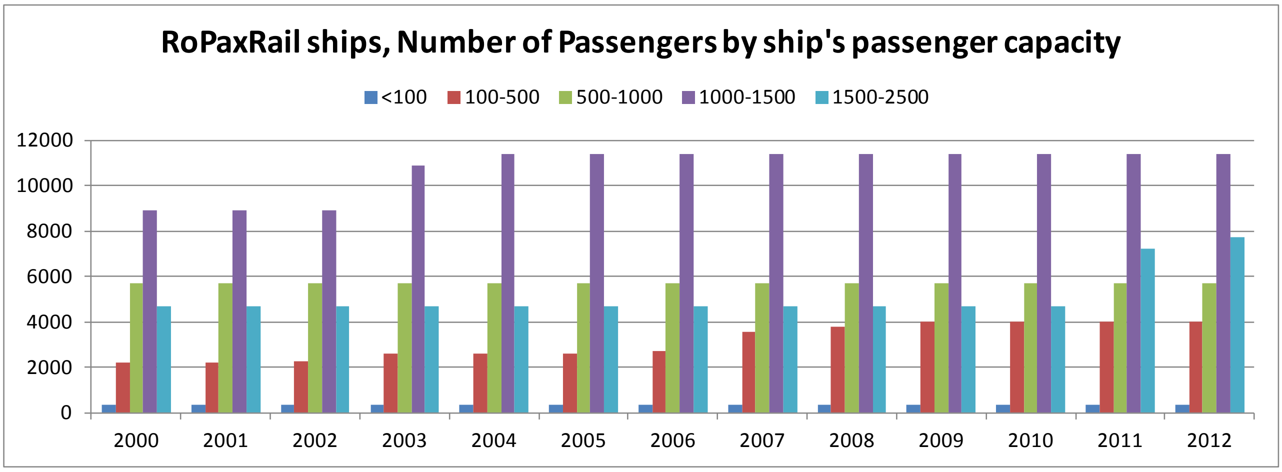


Fig. 10-18 Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

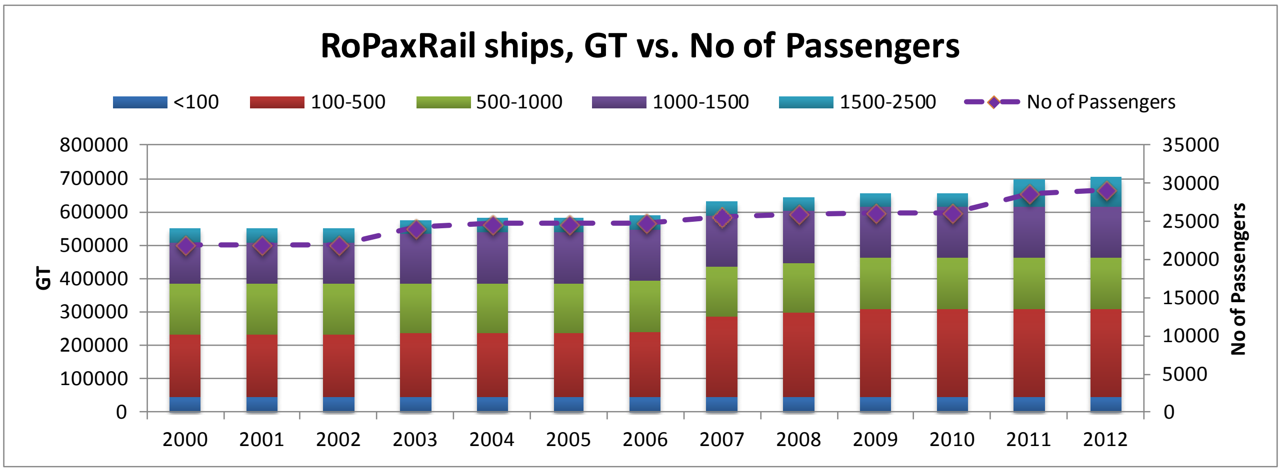


Fig. 10-19 Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

10.2.3 Casualties

Typically, in FSA risk model average initial accident frequency is used, calculated for a specific period. FSA guidelines do not specify this period. Therefore, for specifying the time period for which the average initial accident frequencies were calculated, the basic data was analysed using the information provided by IHS Fairplay. Because this was an initial investigation focused on specifying the period on which the sample is based IHS Fairplay raw data was used, i.e. without further analysis of the casualty reports. Main information collected in this investigation are summarised in APPENDIX C.

10.2.4 Accident Frequencies

As mentioned above, two representative ship categories are considered in the following quantitative risk analysis:

- Cruise considering cruise vessels and passenger ships;
- RoPax considering RoPax and RoPaxRail vessels.

With the basic data summarised in APPENDIX C frequencies were calculated for the initial event of the different accident categories collision (CN), contact (CT), grounding (GR) and fire/explosion (FX) and will be briefly summarised below (Fig. 10-20 and Fig. 10-21).

Cruise ship collisions were reported only after 1998. Therefore, annual accident frequencies were only calculated for 1998 to 2012 with maximum annual frequency in 2007. Grounding and contact accidents of cruise ships were reported over the whole period. For grounding maximum annual accident frequency was calculated for 1995 and for contact in 2008. Fire/Explosion accident frequency varied between 1994 and 2012, however, no particularities were observed like for collision.

The results for RoPax were similar to the development of accident frequencies for Cruise, with the contact) accidents exhibited the highest frequencies with a remarkable peak in year 2008.

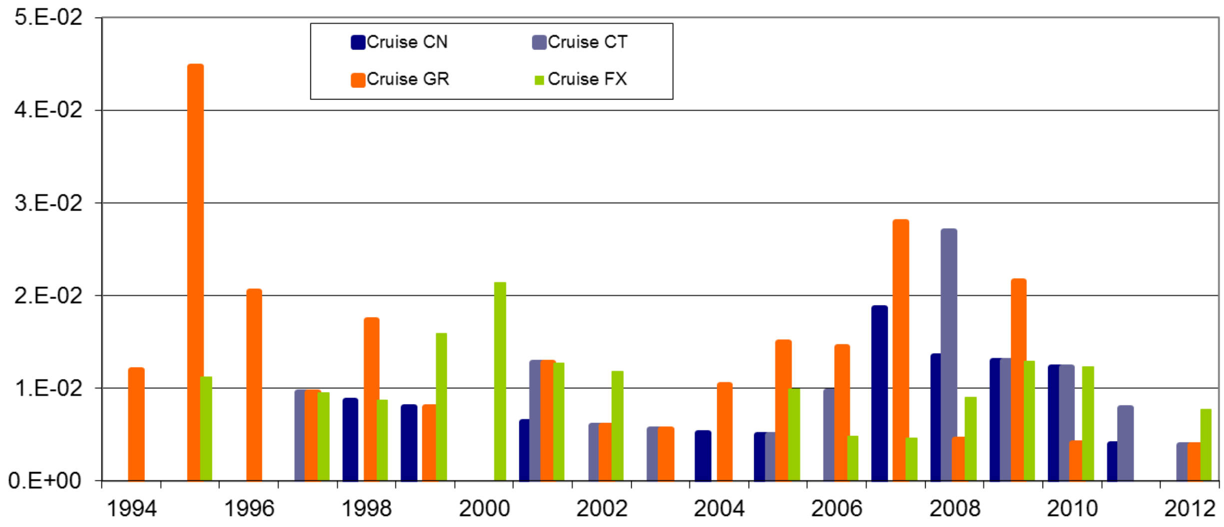


Fig. 10-20 Annual accident frequencies for ship type Cruise calculated for accident categories CN, CT, GR and FX considering only casualty reports complying with selection criteria.

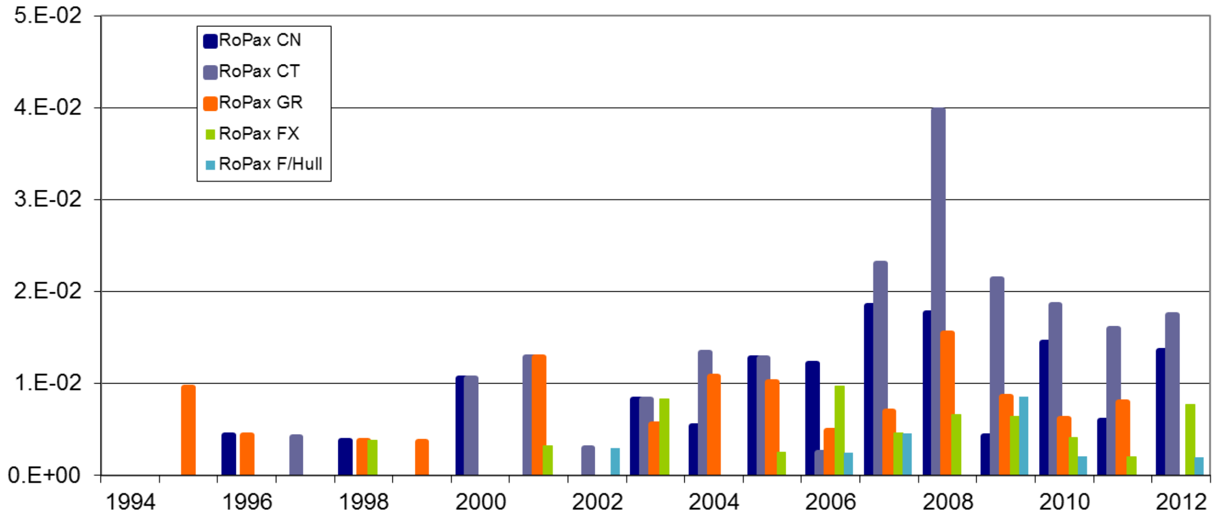


Fig. 10-21 Annual accident frequencies for ship type RoPax calculated for accident categories CN, CT, GR, FX and Foundering / Hull considering only casualty reports complying with selection criteria.

10.2.5 Quantitative Risk Model

For determining the risk for the two categories of passenger ships quantitative a risk model has been developed based on the results of previous risk analyses, i.e. in the FSAs on cruise and RoPax ships as well as that of the GOALDS project. Like in previous investigations the risk model consists of sub-models for each accident category (collision, contact, grounding, fire and explosion etc.) and total risk to person on board is calculated by superimposing the risks of the different accident categories. As mentioned in section 10.1 risk models for collision, contact and grounding were reviewed in detail based on a detailed analysis of casualty reports whereas for the remaining risk models the raw data from IHS Fairplay was used. In this context a new merged risk model covering grounding and contact accidents was developed.

In the following the risk models for the different accident categories are described distinguishing the two ship categories Cruise and RoPax as far as necessary.

Initial accident frequencies are determined considering the fleet at risk data and casualty reports for ships complying with the selection criteria summarised in section 10.2.1. Number of accidents and average accident frequencies are summarised in Table 10-2. It is mentioned that in some cases the figures will deviate from the discussion in previous section because for quantification of risk model only the reviewed reports were considered.

The comparison of the average accident frequencies of Cruise for both periods showed that for the period 2000 to 2012 the accident frequencies for collision and contact were higher than for 1994 to 2012. This is in contrast to grounding where accident frequency decreased by about 18%. For fire and explosion only small changes were observed (~2%).

Compared to the GOALDS project the average collision frequencies for both periods are slightly lower. This is mainly caused by the small number of accidents in 2011 and 2012 and, in parallel, further increasing fleet. For grounding the average accident frequency in the period 1994 to 2012 is slightly higher due to additional accidents identified for the period 1994 to 2000.

Similar to Cruise, the average accident frequency for collision and contact of RoPax is higher for the period 2000 to 2012 than for 1994 to 2012. In contrast to Cruise, this is also observed for the accident categories grounding, fire/explosion and hull damage.

In order to consider the development in the last years, initial accident frequencies for the period 2000 to 2012 are used.

Table 10-2 No of casualties and calculated accident frequencies for Cruise distinguishing the periods 1994 to 2012 and 2000 to 2012.

	Time Period 1994 - 2012		Time Period 2000 - 2012		GOALDS
	No of casualties[3]	Casualties/ship year[4]	No of casualties	Casualties/ship year [5]	1/ship year
Cruise					
Collision	19	5.78E-03	17	6.36E-03	6.99E-03
Contact	23	6.99E-03	22	8.23E-03	--
Grounding	30	9.12E-03	20	7.48E-03	1.07E-02
Fire/ Explosion	25	7.60E-03	21	7.86E-03	--
RoPax					
Collision	52	7.72E-03	50	9.38E-03	9.38E-03
Contact	87	1.29E-02	86	1.61E-02	
Grounding	31	4.60E-03	27	5.07E-03	
Fire/ Explosion	25	3.71E-03	24	4.50E-03	
Hull Damage	10[6]	1.48E-03	10	1.88E-03	

Collision

The collision risk model developed in GOALDS project has been updated with respect to:

- Merging the branches “en route” and “limited waters” because same probabilities are used;

[3] serious cases, IACS ships at the time of incident

[4] Calculated considering IACS classed ships and the selection criteria specified: Cruise 3,290 ship years, RoPax 6,738 ship years

[5] Calculated considering IACS classed ships and the selection criteria specified: Cruise 2,673 ship years, RoPax 5,328 ship years

[6] Details of these cases are summarised in Annex C of this report. These ten casualties are 7 hull damages with potential to sink and three founderings.

- In order to reduce the uncertainty in the risk model the dependent probabilities for the nodes of the ET “initiator”; “operational state” and “water ingress” are determined merging the information for Cruise and RoPax;
- Reducing the representative percentage of fatalities to 5% for fast sinking/capsizing in terminal areas[7].

The last item of this list is based on a re-evaluation of the possibility of capsizing in “terminal” area. Potential scenarios for capsizing in “terminal” area are discussed in particular with respect to water depth and ships’ main dimensions. For instance, the investigation of ship’s beam for “small[8]”, “medium” and “large” showed for the majority of ships that ship’s beam was larger than 20 m. It was concluded that this will have an influence on ship capsizing/sinking scenario and its consequences. For instance a ship with a beam of 20 m capsizing in water depth of 10 m cannot be fully flooded. The effect of limited water depth on capsizing was clearly shown in the accident of Herald of Free Enterprise that capsized outside the port of Zeebrugge in relatively shallow water. Due to shallow water the ships was only partly flooded which was expected to have a positive effect on the fatality rate.

Water depth in “terminal” area varies and no statistics for harbours called by Cruise and RoPax is available. However, for a lot of harbours water depth is below 20 m. With respect to the RoPax, project partners provided the information that typically the water depth in “terminal” areas is below 10 m. Taking further into account the SAR infrastructure in harbours the representative percentage of fatalities was set to 5%.

The updated collision risk model is shown in Fig. 10-22. In this figure the nodes containing ship category dependent values are highlighted. The remaining nodes were quantified on basis of the merged casualty reports.

Initial accident frequency for Cruise was calculated and was 6.36E-03 collisions per ship year with a 90% confidence interval of 4E-03 to 9.5E-03 collisions per ship year. The confidence interval was estimated using the approach by Engelhardt (1994) **10** . For RoPax the initial collision frequency was 9.38E-03 collisions per ship year with a 90% confidence interval of 7.3E-03 to 1.18E-02 collisions per ship year.

Dependent probability of ship being struck was estimated to about 50% based on 65 casualty reports (struck: 33; striking: 32) together for Cruise (18) and RoPax (47). 33 casualty reports provide information (Cruise: 8; RoPax: 25) for estimating the dependent probability for operational area, i.e. distinguishing between accidents in “limited waters/en route” and “terminal area”. About one third of all collisions took place in “limited waters/en route”.

7 Definition of Operational State:
En route: operation in Open Sea (≥ 12 nm from the coast, archipelagos).
Limited waters: operation in coastal waters (< 12 nm), restricted waters, rivers, canals, inland waters.
Terminal areas: operation in port, anchorage, port approach, at berth.

8 For this investigation ship size was related to passengers: small up to 800, large above 3000 and medium in between.

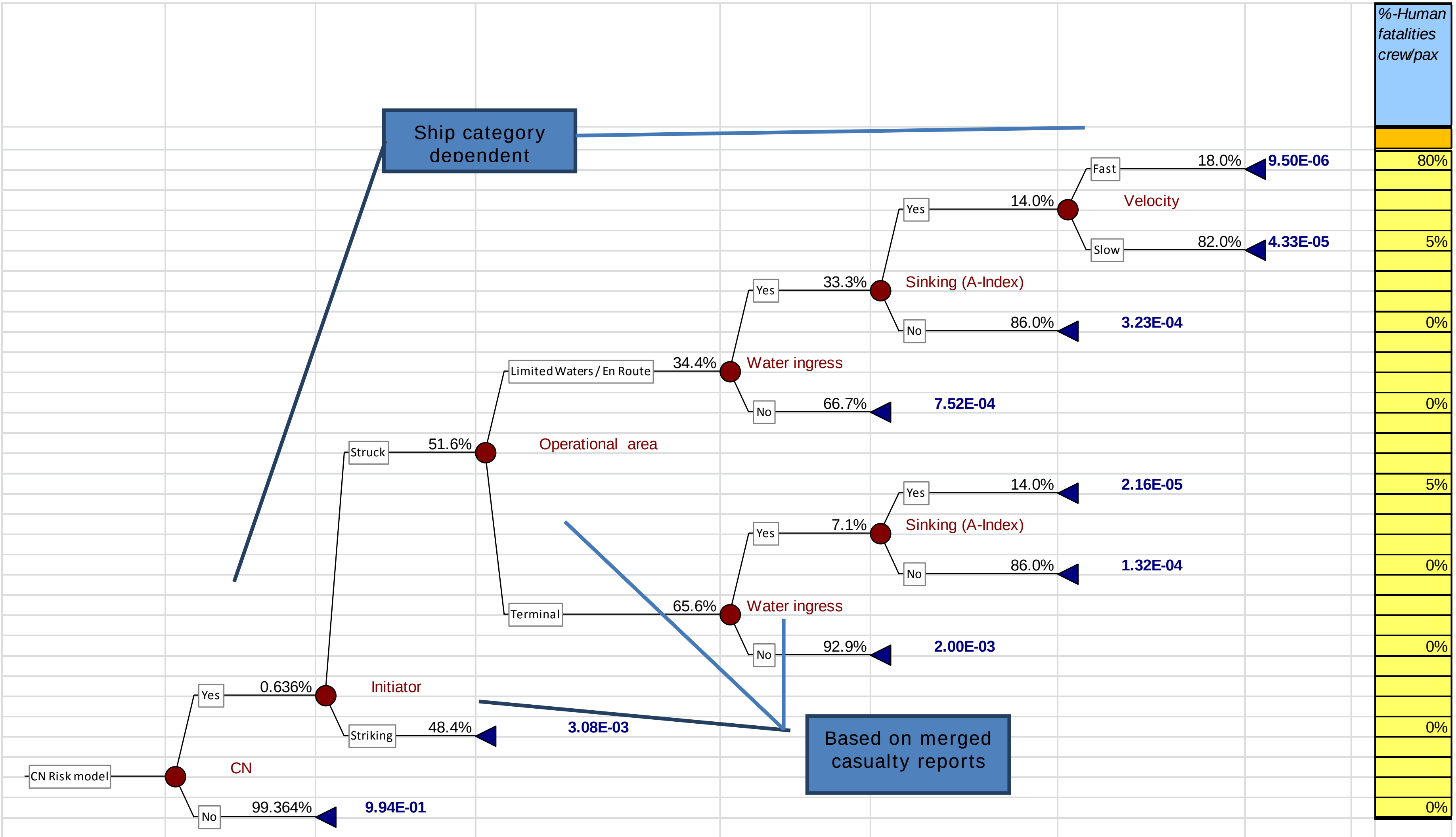


Fig. 10-22 Collision risk model for Cruise and RoPax ship

The probability of water ingress (breach of hull and subsequently water ingress) was estimated separately for both operational areas in order to consider the different operations, i.e. lower speed in terminal areas and higher “en route”. For terminal area the probability of hull breach was estimated to 7% (based on 14 reports) whereas for remaining areas this probability was 33% (based on 6 reports).

Probability of sinking was set equal to 1 minus Attained index calculated by means of SOLAS 2009 damage stability requirements.

The ship size was considered by the number of person on board as well as the probability of sinking reflected by the Attained index. Due to the limited information a more elaborated consideration of ship size was not possible, e.g. ship size dependent probability of water ingress.

Contact / Grounding

One objective of the present investigation is an improved consideration of raking damages. The investigations carried out show that raking damages can be caused by contact, e.g. contact to an iceberg, as well as grounding. Therefore, a combined risk model for contact and grounding was developed (Fig. 10-23 (Cruise) and Fig. 10-24 (RoPax)). In these models, the probability of sinking is estimated using the attained subdivision index A, calculated separately for bottom or side damages.

It should be reminded at this point that the probabilistic model for the side damage characteristics, which was used for the calculation of the corresponding A-index, is based on data from both grounding and contact accidents. This model is explained in the final report from Task 3 of this study. As a result, it is possible that the model developed herein, exhibiting a distribution of the potential damage length shifted towards shorter damages, could be in this respect non-conservative.

It should be noted that the simplification of using an “equivalent” damage, representing the envelope of the damaged region in case of multiple breaches used in the newly developed model for calculating A-Index for contact and grounding, is a conservative approximation. In addition, in case of grounding in terminal areas or in limited waters, if the ship does not remain aground and does not lose its propulsion and manoeuvring capability, the master usually has the option of voluntary beaching a ship that has sustained a major damage, in order to avoid sinking or capsizing. It might be argued therefore, that in this case the probability of avoiding a ship loss would be higher than the corresponding A-Index.

To some extent, it may be argued that the combined conservative impact of these two issues is expected to counteract the impact of using a probabilistic model that may predict smaller damage lengths, in comparison with a probabilistic model that would be based entirely on data from grounding accidents. Although it is of course not possible to quantify these counteracting contributions, it is expected that the results of damage stability calculations based on the proposed model can be used as an acceptable comparative measure of the survivability of passenger ships in case of a grounding accident. The proposed formulation, as well as the corresponding software tool, being based on the “direct approach”, is easily adaptable in case an improved sample of accidents, with sufficient quantitative data for the breach characteristics, will be available in the future. In such case, the simplification of the “equivalent” damage could be also replaced by a more advanced probabilistic model, allowing for multiple breaches.

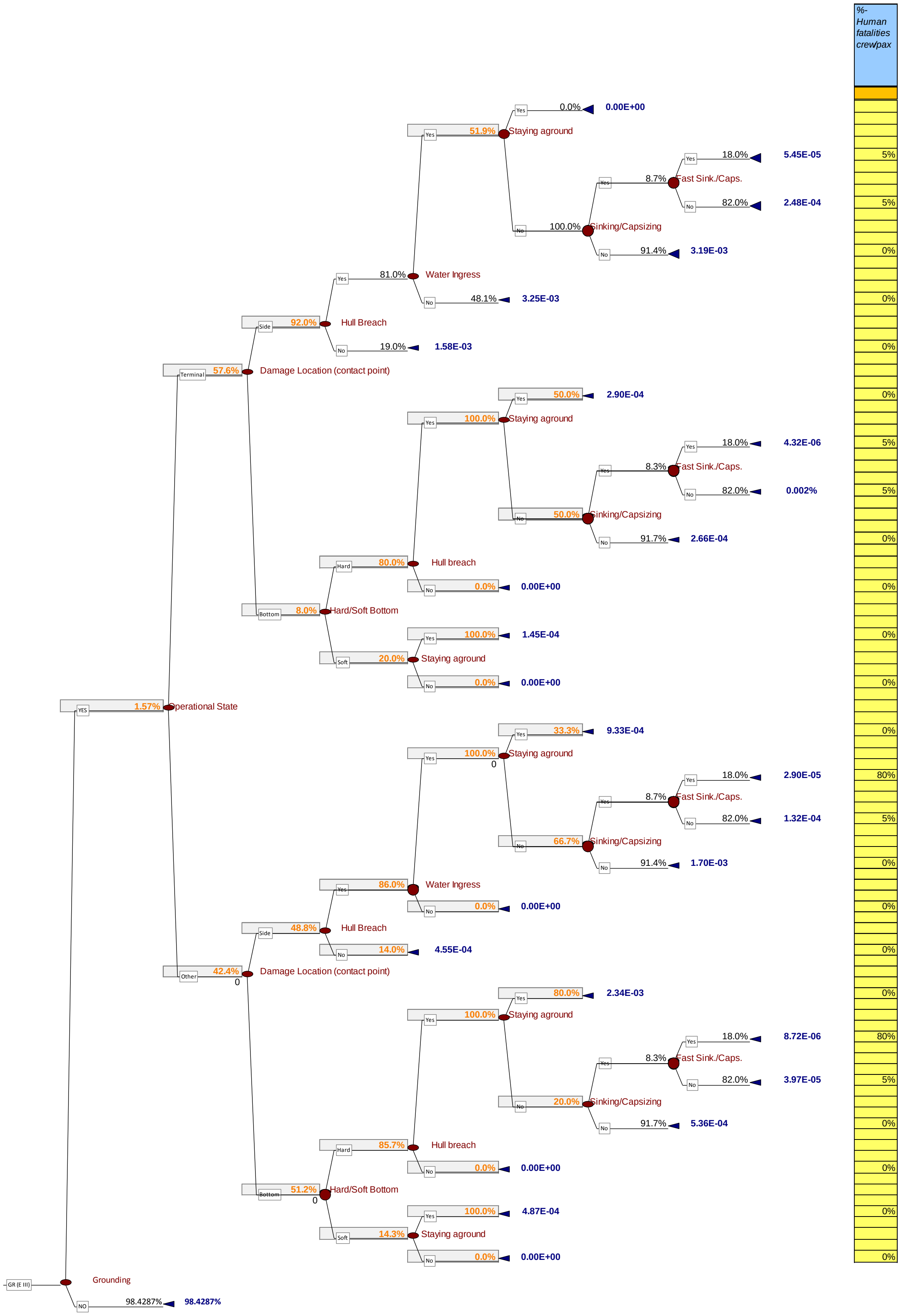


Fig. 10-23 Risk Model for grounding accidents of Cruise ships

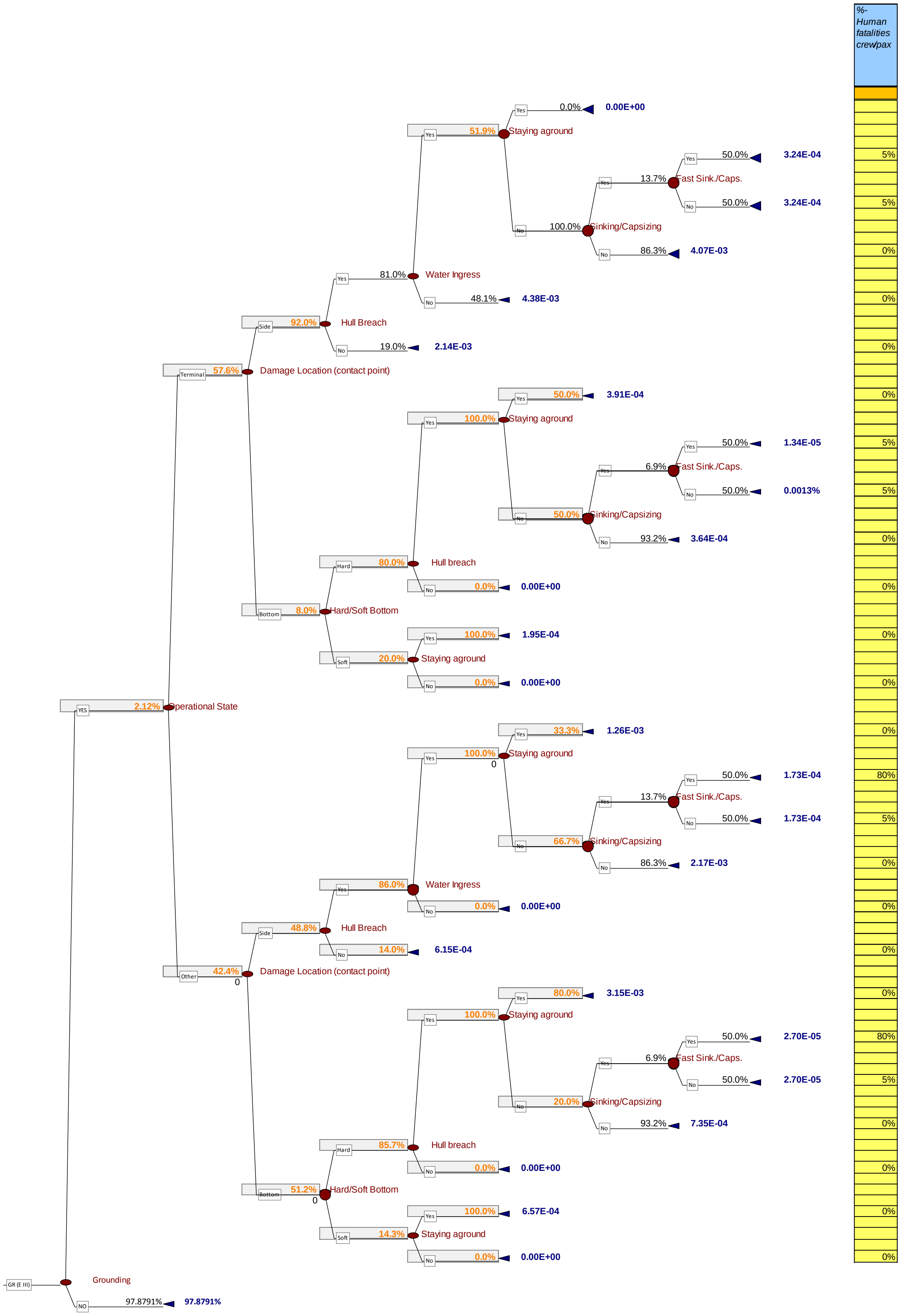


Fig. 10-24 Risk Model for grounding accidents of RoPax ships

The results with respect to casualties and frequencies (casualties per ship-year) are summarised in Table 10-3. The corresponding fleet at risk is equal to 2,673 ship-years for cruise and pure passenger ships and 5,328 ship-years for RoPax and RoPax Rail.

Table 10-3 Number of casualties and calculated accident frequencies for Cruise and RoPax ships (Groundings and Contacts)

	Cruise ships		RoPax ships	
	Casualties	Casualties/ship year	Casualties	Casualties/ship year
Groundings	20	7.48E-03	27	5.07E-03
Contacts	22	8.23E-03	86	1.61E-02
Total	42	1.57E-02	113	2.12E-02

As shown in the risk models, in case a grounding accident took place, there was a 57.6% probability that the accident took place in a terminal area and a 42.4% probability that the accident took place in limited waters or open sea respectively.

1. Accidents in terminal areas

1.1. *Side accidents*. Most accidents in terminal areas were of the side damage type (92% probability). For these accidents, the probability of a hull breach is 81%. The probability of water ingress in case of a hull breach is equal to 51.8% and the probability of staying aground of 0%. The probability of surviving is set equal to A_{GRS} (A-index for grounding accidents of type S00), in which case no consequences are assumed. In case the ship does not survive, the probability of fast sinking or capsizing is set equal to 18% for cruise ships and 50% for RoPax ships. A number of fatalities equal to 5% of POB was assumed in case of sinking/capsizing within terminal areas.

1.2. *Bottom accidents*. In case of bottom accidents in terminal areas, a 20% probability of striking against a soft bottom is estimated. In this case no breach is assumed, and no consequences are calculated. The corresponding probability of striking against a hard bottom or other hard obstacle is therefore equal to 80%. In this case, based on the available data, the probability of a hull breach is set equal to 100%. The probability of water ingress in case of sustaining a hull breach at the bottom is always 100%; therefore the corresponding node is omitted. The probability of staying aground is estimated equal to 50%, in which case no consequences are assumed. If the ship does not remain aground, the probability of surviving is set equal to A_{GRB} (A-index for grounding accidents of type B00), in which case no consequences are assumed. In case the ship does not survive, the probability of fast sinking or capsizing is set equal to 18% for cruise ships and 50% for RoPax ships. A number of fatalities equal to 5% of POB was assumed in case of sinking/capsizing within terminal areas.

2. Accidents in limited waters and open sea

2.1. *Side accidents*. The dependent probability of side damages for accidents in limited waters and open sea is estimated equal to 48.8%. The dependent probability of a hull breach in case of side accidents in limited waters or open sea is estimated equal to 86.4%. The probability of water ingress is set equal to 100%, based on the available data. The probability that the ship remains aground (with no consequences to human life) is estimated based on the available data to be equal to 33.3%. If the ship does not remain aground, the probability of surviving is set equal to A_{GRS} (A-index for grounding accidents of type S00), in which case no consequences are assumed. In case the ship does not survive, the probability of fast sinking or capsizing is set equal to 18% for cruise ships and 50% for RoPax ships. A number of fatalities equal to 5% (resp. 80%) of POB was assumed in case of slow (resp. fast) sinking/capsizing in limited waters or open sea.

2.2. *Bottom accidents*. Based on the available data the dependent probability of bottom damages for accidents in limited waters and open sea is set equal to 51.2%. The dependent probability of striking against a soft bottom in case of bottom accidents in limited waters or open sea is estimated equal to 14.3%. No consequences are assumed in this case. In case of striking against a hard bottom or other hard obstacle, the dependent probability of a hull breach is set equal to 100%. Since water ingress is an inevitable result of a hull breach in case of bottom damage, no such node is included in the risk model. The probability that the ship remains aground (with no consequences to human life) is set equal to 80%. If the ship does not remain aground, the probability of surviving is set equal to A_{GRB} (A-index for grounding accidents of type B00), in which case no consequences are assumed. In case the ship does not survive, the probability of fast sinking or capsizing is set equal to 18% for cruise ships and 50% for RoPax ships. A number of fatalities equal to 5% (resp. 80%) of POB was assumed in case slow (resp. fast) sinking/capsizing in limited waters or open sea.

Fire & Explosion

Risk of Fire & Explosion was calculated using the risk model of the SAFEDOR FSA on Cruise with updated initial accident frequency. The risk model as developed for the FSA on Cruise is shown in Fig. 10-25. Using the scenarios as given in the FSA the risk in terms of PLL for a large cruise ship (6,500 POB) was calculated to 2.3E-02 fatalities per ship year.

The consequences for person on board were estimated using the model developed in SAFEDOR FSA:

- 2 fatalities for fire in more than one compartment with medium to large person density and rapid extinguishing
- 2 fatalities for fire in more than one compartment with low to medium person density and slow extinguishing

- 5 fatalities for fire in more than one compartment with high person density and slow extinguishing
- 5 fatalities for fire outside compartments and fire could be contained in fire zone with low to medium person density
- 2.5% fatalities for fire outside compartments and fire could be contained in fire zone with high person density
- 0.5% fatalities for fire outside compartments and fire could not be contained in fire zone but restrained
- 7.5% fatalities for fire ending with total loss of vessel.

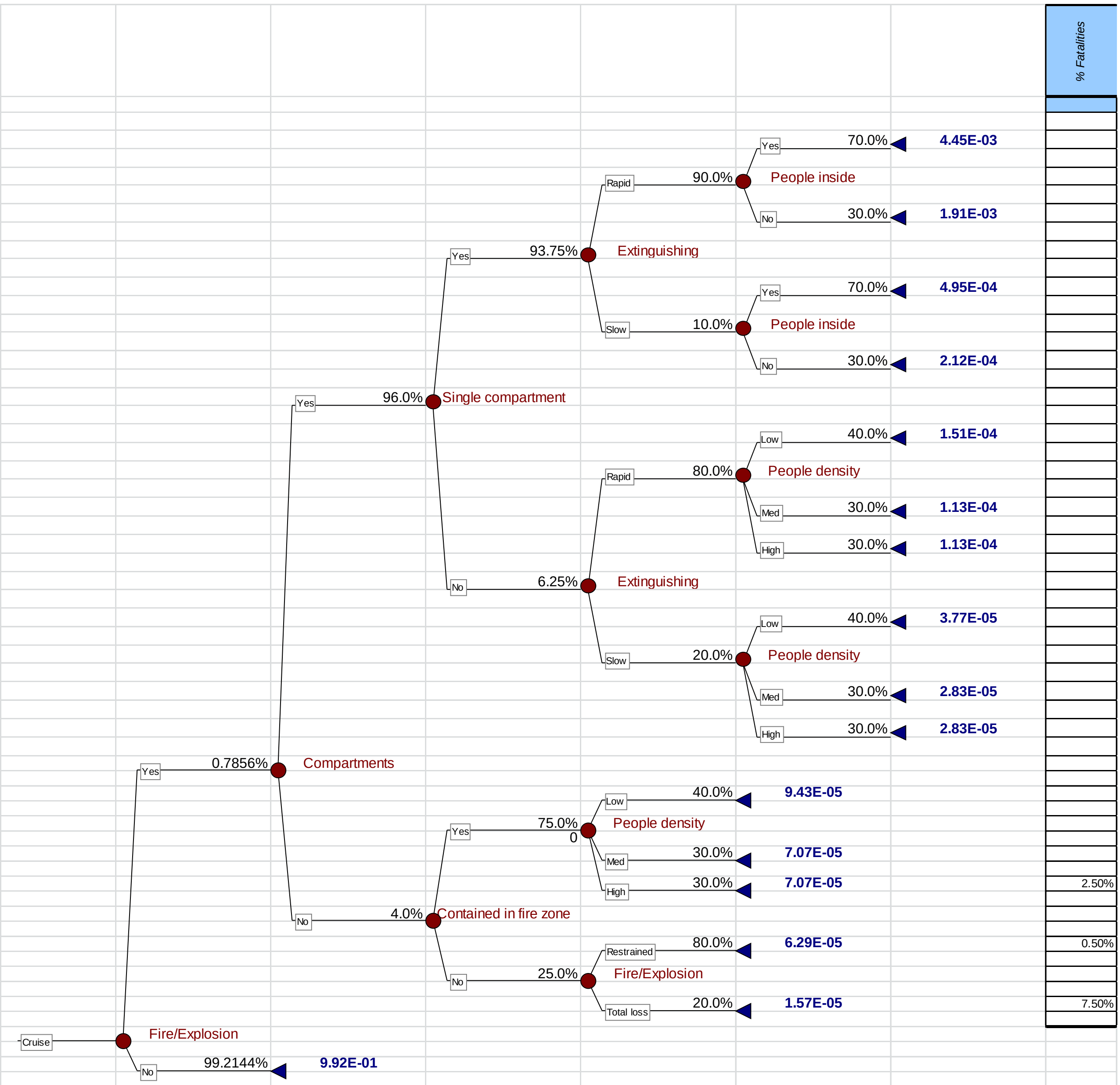


Fig. 10-25 Fire / explosion risk model for Cruise taken from SAFEDOR FSA

Risk of fire and explosion was calculated using the risk model of the SAFEDOR FSA on RoPax with updated initial accident frequency. The risk model as developed for the FSA is shown in

Fig. 10-26. The risk in terms of PLL was calculated to 6.5E-02 fatalities per ship year for a medium size RoPax vessel and updated initial accident frequency. In SAFEDOR FSA the consequences for persons on board were estimated as follows:

- 0.7% for fire in machinery – escalation – unsuccessful evacuation
- 75% for fire in machinery – escalation – fire uncontrolled
- 8% for fire on vehicle deck - escalation – unsuccessful evacuation
- 8% for fire in accommodation - escalation – unsuccessful evacuation

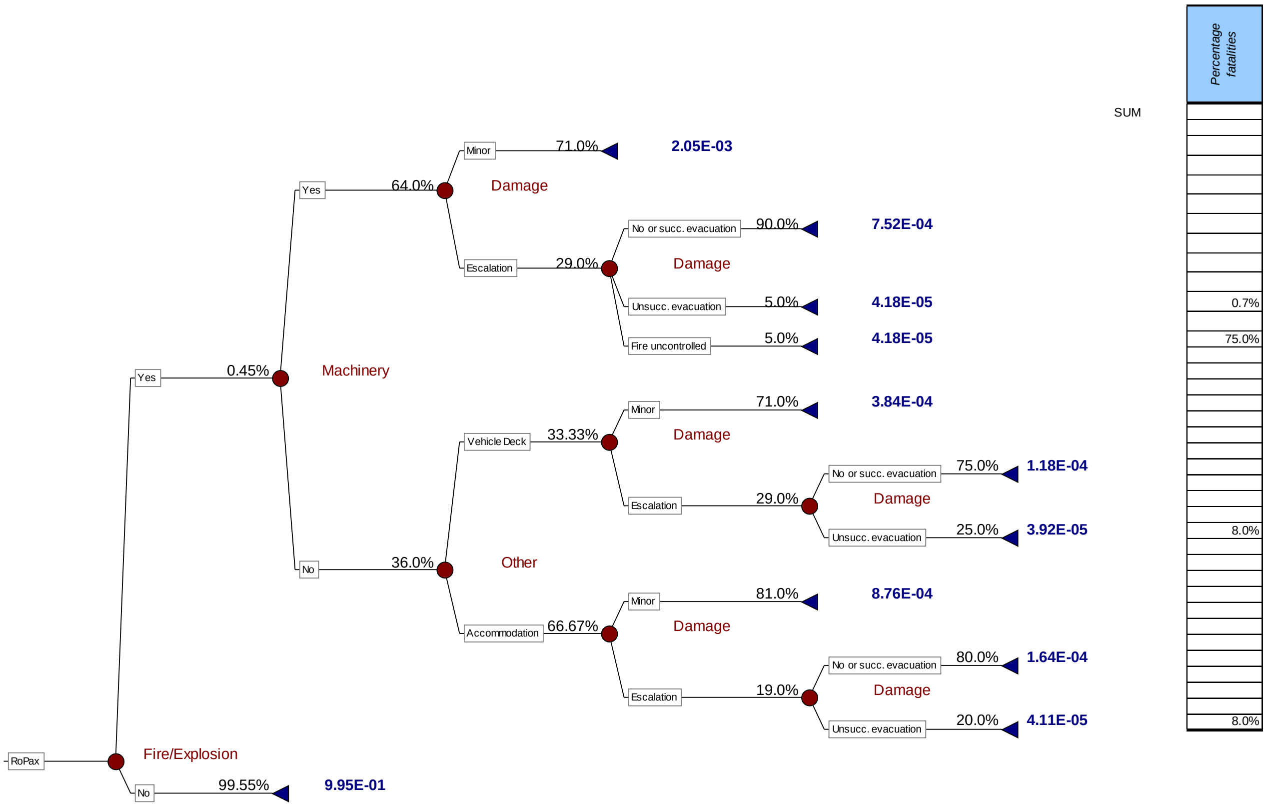


Fig. 10-26 Fire/Explosion risk model for RoPax (From SAFEDOR FSA on RoPax)

Hull Damage

The risk models developed for SAFEDOR FSA on RoPax addressed both consequences to loss of water tightness. Therefore, for this investigation both risk models were merged to a risk model flooding.

In general, it was not clearly explained if the risk model of the SAFEDOR FSA on RoPax already considered the impact of the so-called Stockholm Agreement on ship design, as well as the amendments to SOLAS and IACS Unified Requirements to bow doors and other external doors developed following the Estonia accident. All had contributed to reduced probability for water entering the Ro-Ro deck as well as increased probability for survival in case water enters the Ro-Ro deck. Based on first analyses with the SAFEDOR model it was concluded that this risk model did not adequately consider recent development in design of RoPax. The dependent probabilities used in the SAFEDOR FSA risk model were regarded as too high. For instance in 60% of cases where wave caused bow door damages and in 20% of open doors the ship sinks. Reducing these dependent probabilities to more realistic, but still conservative values, of 10% for both scenarios reduces the risk by about 34%. Further, consideration of SOLAS 2009 damage stability criterion in the scenario wave damage of hull lead to further decrease in the risk of flooding by about 20% to 25% for medium and large RoPax, whereas for small vessels the effect is negligible.

The risk model used for this investigation is shown in Fig. 10-27. The consequences in terms of assumed fatalities are unchanged:

- 12% fatalities for scenarios ending with slow sinking
- 66% fatalities for scenarios ending with fast sinking, and
- No fatalities for all other scenarios.

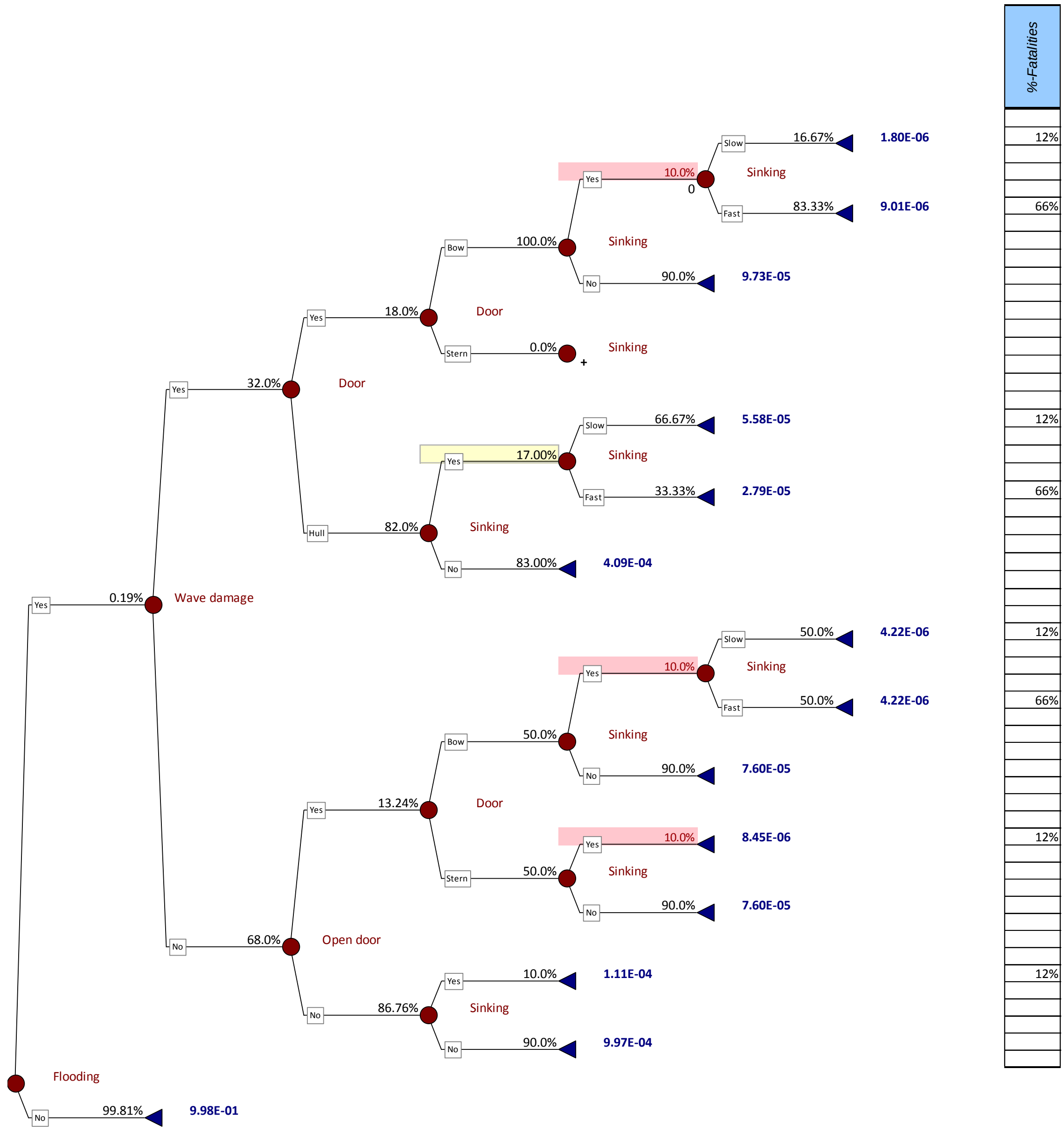


Fig. 10-27 Flooding risk model RoPax with updated probabilities and initial accident frequency

11 RISK EVALUATION

For two Cruise and three RoPax ships the risk has been calculated. The characteristic data for the reference ships are summarised in Table 11-1 considering length, gross tonnage, R-Index (SOLAS 2009) respectively A-Index for contact/grounding as well as nominal person on board. For risk calculation occupancy rates were considered as specified using information from project partners, CLIA as well as GOALDS project. Thereafter, the relative occupancy rate for Cruise ships was 90% applicable for passenger and crew. For occupancy rates on RoPax three different seasons were distinguished:

1. 100% occupancy for passenger for 12.5% of the year;
2. 75% occupancy for passenger for 25% of the year; and,
3. 50% occupancy for passenger for 62.5% of the year.

Crew was kept constant on the nominal number. These occupancy rates were applied constant on all ship sizes.

For collision risk the R-Index was used which, typically, is lower than the attained index for ships built (conservative because slightly higher risk is calculated). Hence, the risk of existing ships is lower than for ships just complying with SOLAS requirements.

In following subsequent sections the calculated risk is expressed in terms suggested in FSA Guidelines, i.e. PLL per ship year and FN diagram. Additionally, risk is calculated in terms used in other industries and transportation, i.e. billion passenger hours and billion passenger kilometres. The contribution of different accident categories to total risk is also provided. All risks are calculated using initial accident frequency for the period from 2000 to 2012. For evaluating the risk FN diagram with updated risk areas (intolerable – ALARP – negligible) are used.

Table 11-1 Characteristic data for ships used to calculate risk due to ship operation using the risk models explained in section 10.2

	Length (OA)	GT	$R_{SOLAS\ 2009}$	A^{9}_{bottom}	A_{side}	Passengers	Crew
	m	tonnes					
	Cruise						
Small	128	11,800	0.6978	0.8799	0.8312	316	162
Medium	269	92,000	0.8214	--	--	3000	1000
Large	315.67	153,400	0.8597	0.9171	0.9135	5135	1595
	RoPax						
Small	100.59	7,900	0.7214	0.9789	0.9171	600	25
Medium (Med)	185	43,000	0.778	0.9987	0.9165	1600	100
Large (Baltic)	251	60,000	0.8297	0.9707	0.9351	3060	220

11.1 Cruise

Using the risk models for the different accident categories the risk to person on board is calculated in terms of potential loss of life (PLL). Risk in terms of PLL is calculated using the number of person on board (POB) as given in Table 11-1 and considering an average occupancy rate of 90%[10]. The average occupancy rate was determined on basis of annual reports of two large cruise operators as well as on information provided by CLIA for Antarctic journeys, where it was assumed that the occupancy level is slightly lower than for other locations. Changing the occupancy rate will change the risk as well as the thresholds for the risk areas in FN diagram.

The results for the different accident categories as well as the total risk are summarised in Table 11-2 for the different reference ship sizes. Grounding/contact risk for medium size Cruise ship was not calculated because this ship size was not considered in design optimisation and, therefore, no Attained indices were determined. The main risk contributors were grounding/contact and collision (always about 90% of total risk).

[9] Calculated with new model developed in this project.
[10] Occupancy factor is applied to both, passenger and crew

Table 11-2 Risk for Cruise ships in terms of PLL based on average accident frequency 2000 to 2012

	Time Period 2000 - 2012				
	No of casualties	**Accident frequencies**	**Potential Loss of Lives**		
		Acc./Ship year^{-1}	Fatalities/ship year $^{-1}$		
Size category			Small	Medium	Large
Max POB[11]			484	4,000	6,730
Av. Passengers			284	2,700	4,622
Collision	17	6.36E-03	1.01E-02	3.92E-02	6.57E-02
Contact / **Grounding**	42	1.57E-02	4.70E-02		3.34E-01
Fire/Explosion	21	7.86E-03	2.7E-03	1.3E-02	2.1E-02
Total	--	2.99E-02	5.98E-02		4.2E-01

The FN diagrams for the two reference ship sizes are shown in Fig. 11-1 and Fig. 11-2. The risk areas in these figures (negligible, ALARP and intolerable risk) were determined using updated r-value (fatalities per billion $ turnover), an average turnover of 50,000 $ per passenger year and the average number of passengers. So the risk was calculated considering all persons on board, i.e. passenger and crew, whereas the thresholds relate to the societal benefit in terms of turnover (passengers: 284 and 4,622).

As shown Cruise ships were principally in the ALARP risk area, sometimes slightly in the region of intolerable risk.

The shape of the FN curve relates to the assumptions used when developing the risk models. The consequence in terms of fatalities assigned to a scenario in the risk model is always a value representative for the consequences of all similar scenarios. The group of similar scenarios will lead to different numbers of fatality. In order to keep the risk model manageable similar scenarios were merged and a representative number of fatalities assigned. For collision and contact/grounding the risk models considered two representative fatality rates (5% and 80%). Due to the fact that collision and contact/grounding were the major risk contributors the shape of FN curve was dominated by these accident categories. It should be noted that for the evaluation of risk control options by cost benefit assessment the risk in terms of PLL was used which is independent of the granularity of the consequences.

[11] POB: person on board considers passengers and crew; maximum POB nominal passenger capacity plus crew (see also Table 11-1)

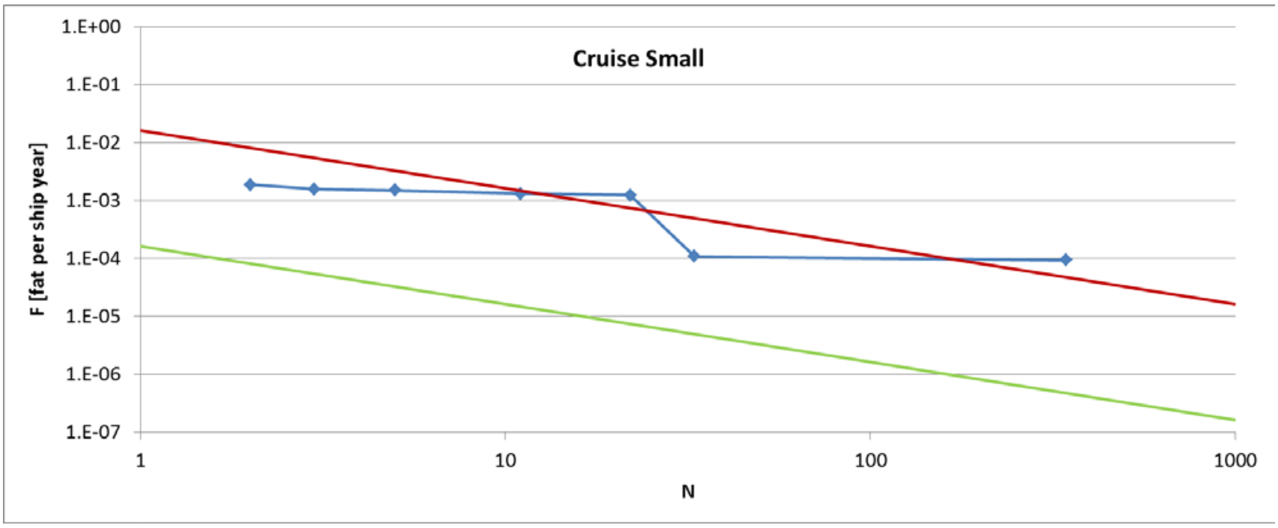


Fig. 11-1 FN diagram for "Small" Cruise (POB=484)

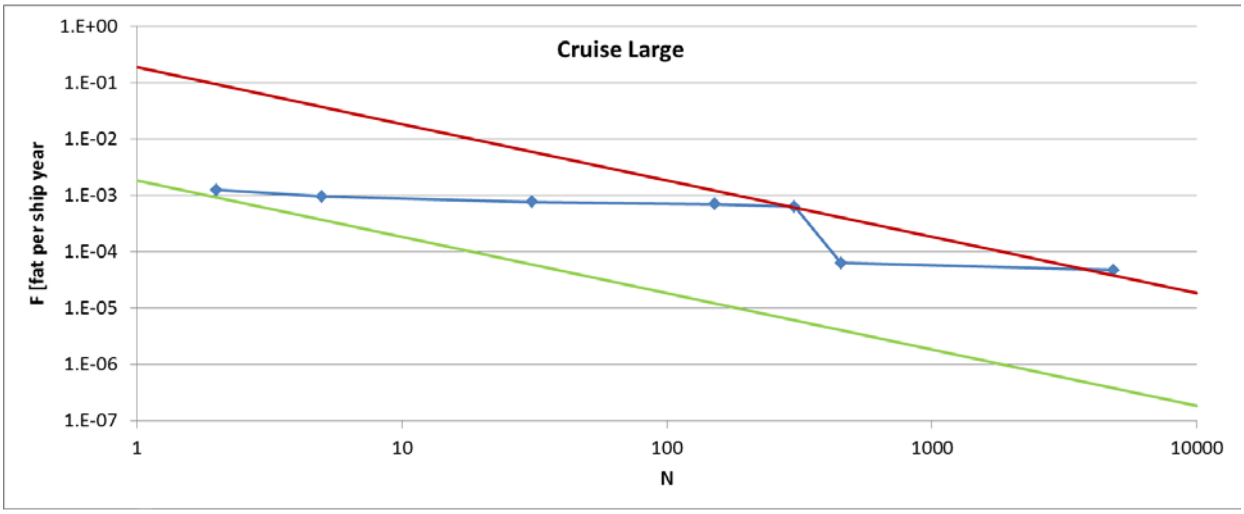


Fig. 11-2 FN diagram for "Large" Cruise (POB=6,730)

The individual risk (IR) for a person on board of a cruise vessel is calculated for different units, e.g. per hour, per journey (7 or 14 days) and results are summarised in Table 11-3 and Table 11-4. As mentioned above, the occupancy rate was assumed to be 90%. For calculating the individual risk of a person per hour on board of a cruise ship the PLL per ship year was divided by the number of operating hours per year. The calculation is based on the assumption that a cruise vessel typically operates 360 days per year and is at sea for 12 hours per day. Furthermore, more relevant for the cruise segment; the risk for two typical journeys (7 days and 14 days) are calculated. These data provided the information to calculating the individual risk for person with different exposure time. The results were made comparable to other transport means by calculating the risk in terms of fatalities per billion passenger hours and billion passenger kilometres.

Table 11-3 Journey dependent individual risk for "Small" Cruise

SMALL								
Max Passengers	316		7 days	14 days				
Crew	162	No Days operation per year	360	360	Speed	15	kn	
		At sea per day	12	12		27.8	km/h	
Occupancy	90%	No of days per trip	7	14				
POB	430	Hrs per trip	84	168	Annual Pax km	3.4E+07		
Pax on board	284	Hrs per year	4320	4320				
	PLL	Individual Risk						
	Fat per ship year					per 10^9 passenger hrs	per 10^9 passenger km	
CN	1.01E-02	per person hr	5.4E-09	5.4E-09		5.4E+00	2.0E-01	
		per journey	4.6E-07	9.1E-07				
GR/CT	4.70E-02	per person hr	2.4E-08	2.4E-08		2.4E+01	8.6E-01	
		per journey	2.1E-06	4.2E-06				
FX	3.04E-03	per person hr	1.6E-09	1.6E-09		1.6E+00	5.9E-02	
		per journey	1.4E-07	2.7E-07				
Total	6.01E-02	per person hr	3.2E-08	3.2E-08		3.1E+01	1.1E+00	
		per journey	2.7E-06	5.4E-06				

Table 11-4 Journey dependent individual risk for "Large" Cruise

Large								
Max POB	5135		7 days	14 days			
Crew	1595	No Days operation per year	360	360	Speed	15	kn
		Hrs. at sea per day	12	12		27.8	km/h
Occupancy	90%	No of days/journey	7	14			
POB	6057	Hrs per trip	84	168	Annual Pax km	5.5E+08	
		Hrs per year	4320	4320			
	PLL	Individual Risk					
	Fat per ship year					per 10^9 passenger hrs	per 10^9 passenger km
CN	6.57E-02	per person hr	2.5E-09	2.5E-09		2.5E+00	9.0E-02
		per journey	2.1E-07	4.2E-07			
GR	3.34E-01	per person hr	1.3E-08	1.3E-08		1.3E+01	4.6E-01
		per journey	1.1E-06	2.1E-06			
FX	2.14E-02	per person hr	8.2E-10	8.2E-10		8.2E-01	2.9E-02
		per journey	6.9E-08	1.4E-07			
Total	4.21E-01	per person hr	1.6E-08	1.6E-08		1.6E+01	5.8E-01
		per journey	1.4E-06	2.7E-06			

11.2 RoPax

The risk to persons on board is calculated with the risk models explained above for the different accident in terms of potential loss of life (PLL). Risk is calculated for ships complying with SOLAS 2009 requirements. Typically, Attained index is higher than SOLAS requirements and therefore the risk is lower. Occupancy rates as mentioned above have been applied. The results are summarised in Table 11-5 below.

As shown by these PLL values the main risk contributor is grounding/contact with about 45% of total risk. Collision contributes to about 25% of total risk and flooding about 20% which is lower than the results of SAFEDOR FSA, where a contribution of 50% was calculated.

The FN diagrams for the three representative ship sizes are plotted in Fig. 11-3, Fig. 11-4 and Fig. 11-5. Like for cruise ships, the thresholds for the risk regions negligible – ALARP – intolerable were calculated considering the average annual number of passengers per journey, i.e. 282 for small, 1,000 for medium and 1,912 passengers for large RoPax, and the average annual turnover per passenger (50,000 $). The risk was calculated considering all persons on board (passenger and crew considering occupancy rates).

As shown by these figures the societal risk for the three representative RoPax vessel was partly in the region of intolerable risk. One of the reasons for that is the update of the data for calculating the boundaries between risk regions, i.e. fatalities per billion $. This characteristic value decreased by a factor of eight since 1999. Fig. 11-6 shows this effect by plotting the FN curve for the Medium RoPax vessel in an FN diagram with the risk regions used in SAFEDOR. Based on the thresholds used in SAFEDOR project, medium RoPax ships are fully in risk region where ALARP process should be applied.

Additionally, it should be mentioned again the limited consideration of the Stockholm agreement in the Safedor project led to higher probability of sinking and, subsequently, higher risk.

Table 11-5 Risk for RoPax ships in terms of PLL based on average accident frequency 2000 to 2012

	Time Period 2000 - 2012				
	No of casualties	**Accident frequencies**	**Potential Loss of Lives**		
		Ship year $^{-1}$	Fatalities/ship year $^{-1}$		
			Small	Medium	Large
Max. POB			625	1,700	3,280
Av. Number passenger			375	1,000	1,912
Collision	50	9.38E-03	2.76E-02	6.05E-02	8.96E-02
Contact / Grounding	113	2.12E-02	4.66E-02	8.28E-02	4.35E-01
Fire / Explosion	24	4.50E-03	1.26E-02	5.52E-02	8.21E-02
Flooding	10	1.88E-03	2.19E-02	7.75E-02	1.05E-01
Total	--	3.70E-02	1.09E-01	2.76E-01	7.12E-01

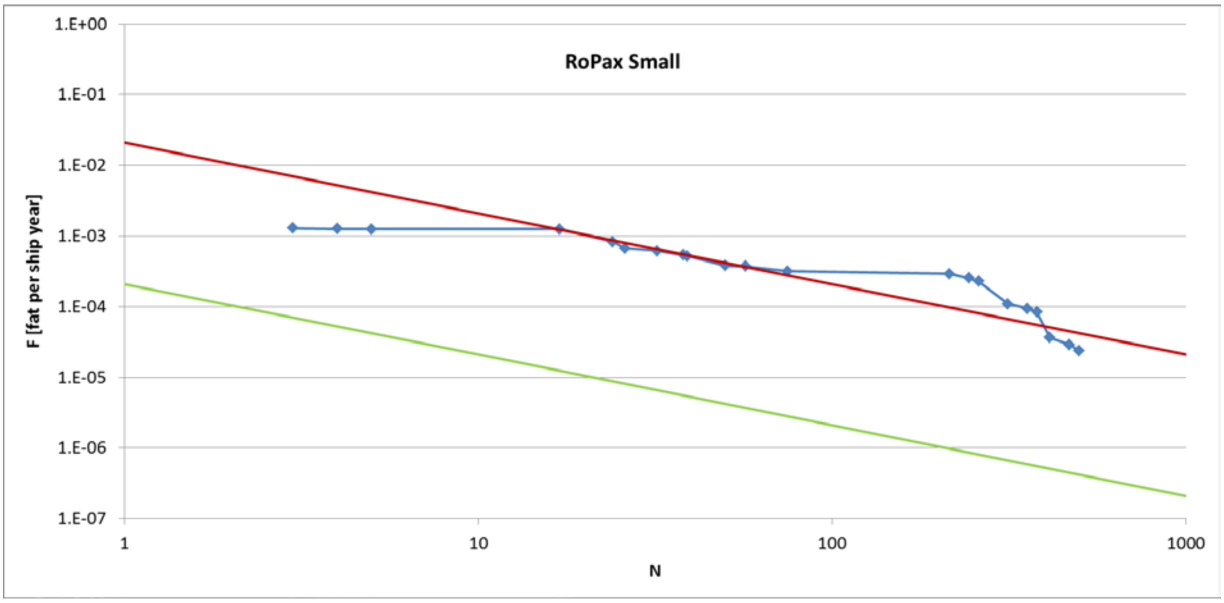


Fig. 11-3 FN diagram for "Small" RoPax considering seasonal passenger numbers and on R-Index

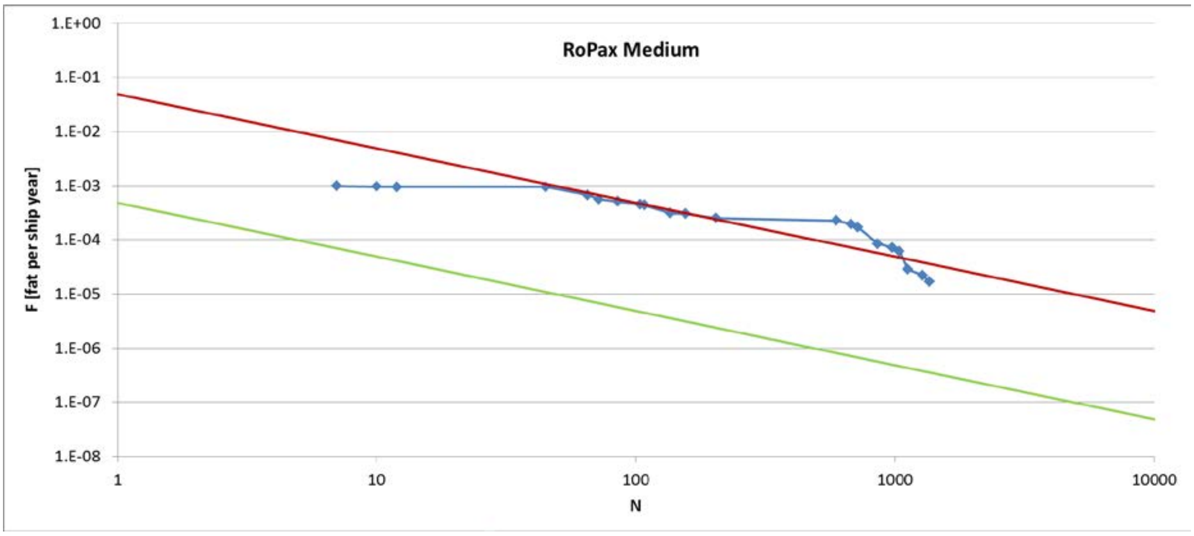


Fig. 11-4 FN diagram for "Medium" RoPax considering seasonal passenger numbers and on R-Index

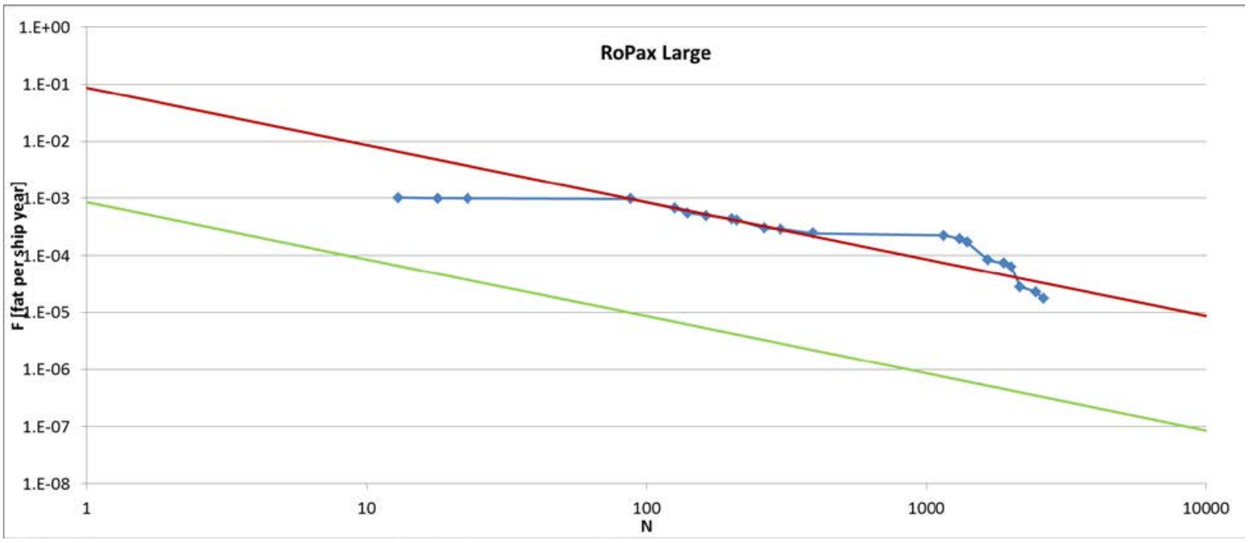


Fig. 11-5 FN diagram for "Large" RoPax considering seasonal passenger numbers

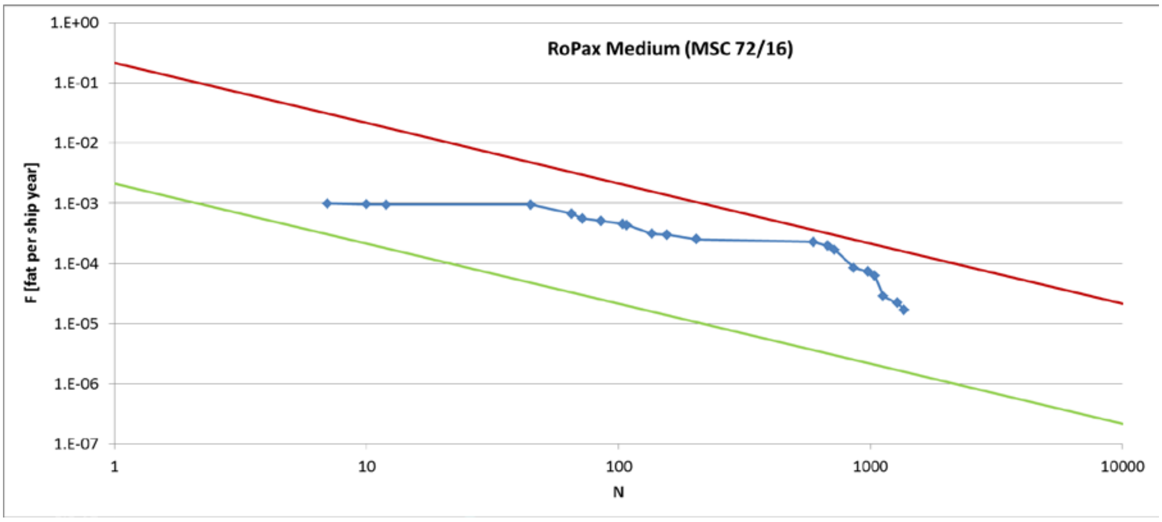


Fig. 11-6 FN diagram for "Medium" RoPax considering seasonal passenger numbers and previous threshold values for fatalities

Individual risk is calculated for passengers on the three reference RoPax vessels in terms of fatalities per hour and trip. For this calculation two representative journeys are used for Medium and Large RoPax, one between Dover and Calais and the other between Kiel and Oslo. For Small RoPax only the journey between Dover and Calais is considered. The results are summarised in Table 11-6,

Table 11-8 and Table 11-10.

Additionally, for one of the trips the risk in terms of fatalities per billion passenger hours and fatalities per billion passenger kilometres has been calculated, results are summarised in Table 11-7, Table 11-9 and Table 11-11.

Table 11-6: Journey dependent individual risk for "Small" RoPax

SMALL			
Pax	600		Calais-Dover
Crew	25	No Days operation per year	360
Total	625	At sea per trip (hrs)	1.5
Load	%-year	No of trips per day	10
100%	12.5%	Hrs per day	15
75%	25.0%	Hrs per year	5400
50%	62.5%		
POB	400		
	PLL		
	per ship year	Individual Risk	
CN	2.76E-02	per hr	1.3E-08
		per journey	1.9E-08
GR/CT	4.66E-02	per hr	2.2E-08
		per journey	3.2E-08
FX	1.53E-02	per hr	6.4E-09
		per journey	1.3E-07
FL	2.60E-02	per hr	1.1E-08
		per journey	2.2E-07
Total	1.16E-01	per hr	4.8E-08
		per journey	9.7E-07

Table 11-7 Individual risk in terms of fatalities per 10^9 person hours and 10^9 person kilometres for "Small" RoPax (Calais-Dover)

SMALL				
Pax	600			
Crew	25	Speed	18	kn
Total	625		33.3	km/h
		Annual Pax km	9.6E+07	
POB	400			
	PLL			
	Fat per ship year	per person hr	per 10^9 passenger hrs	per 10^9 passenger km
CN	2.76E-02	9.6E-09	9.6E+00	2.9E-01
GR/CT	4.66E-02	1.6E-08	1.6E+01	4.9E-01
FX	1.53E-02	6.4E-09	6.4E+00	1.9E-01
FL	2.60E-02	1.1E-08	1.1E+01	3.3E-01
Total	1.16E-01	4.8E-08	4.8E+01	1.4E+00

Table 11-8 Journey dependent individual risk for "Medium" RoPax

Medium (Med)				
Pax	1600		Kiel - Oslo	Calais-Dover
Crew	100	No Days operation per year	360	360
Total	1700	At sea per trip (hrs)	20	1.5
Load	%-year	No of trips per day	1	10
100%	12.5%	Hrs per day	20	15
75%	25.0%	Hrs per year	7200	5400
50%	62.5%			
POB	1100			
	PLL			
	per ship year	Individual Risk		
CN	6.05E-02	per hr	7.6E-09	1.0E-08
		per journey	1.5E-07	1.5E-08
GR/CT	8.28E-02	per hr	1.0E-08	1.4E-08
		per journey	2.1E-07	2.1E-08
FX	4.19E-02	per hr	5.3E-09	7.1E-09
		per journey	1.1E-07	1.1E-08
FL	6.20E-02	per hr	7.8E-09	1.0E-08
		per journey	1.6E-07	1.6E-08
Total	2.47E-01	per hr	3.1E-08	4.2E-08
		per journey	6.2E-07	6.2E-08

Table 11-9 Individual risk in terms of fatalities per 10^9 person hours and 10^9 person kilometres for "Medium" RoPax (Kiel-Oslo)

Medium (Med)				
Pax	1600			
Crew	100	Speed	18	kn
Total	1700		33.3	km/h
		Annual Pax km	2.6E+08	
POB	1100			
	PLL			
	Fat per ship year	per person hr	per 10^9 passenger hrs	per 10^9 passenger km
CN	6.05E-02	7.6E-09	7.6E+00	2.3E-01
GR/CT	8.28E-02	1.0E-08	1.0E+01	3.1E-01
FX	FX	4.19E-02	5.3E-09	5.3E+00
FL	FL	6.20E-02	7.8E-09	7.8E+00
Total	Total	2.47E-01	3.1E-08	3.1E+01

Table 11-10 Journey dependent individual risk for "Large" RoPax

Large (Baltic)				
Pax	3060		Kiel - Oslo	Calais-Dover
Crew	220	No Days operation per year	360	360
Total	3280	At sea per trip (hrs)	20	1.5
Load	%-year	No of trips per day	1	10
100%	12.5%	Hrs per day	20	15
75%	25.0%	Hrs per year	7200	5400
50%	62.5%			
POB	2133			
	PLL			
	per ship year	Individual Risk		
CN	8.96E-02	per hr	5.8E-09	7.8E-09
		per journey	1.2E-07	1.2E-08
GR/CT	2.03E-01	per hr	1.3E-08	1.8E-08
		per journey	2.6E-07	2.6E-08
FX	8.12E-02	per hr	5.3E-09	7.1E-09
		per journey	1.1E-07	1.1E-08
FL	1.04E-01	per hr	6.8E-09	9.0E-09
		per journey	1.4E-07	1.4E-08
Total	4.78E-01	per hr	3.1E-08	4.2E-08
		per journey	6.2E-07	6.2E-08

Table 11-11 Individual risk in terms of fatalities per 10^9 person hours and 10^9 person kilometres for "Large" RoPax (Kiel-Oslo)

Large (Baltic)				
Pax	3060			
Crew	220	Speed	18	kn
Total	3280		33.3	km/h
		Annual Pax km	5.1E+08	
POB	2133			
	PLL			
	Fat per ship year	per person hr	per 10^9 passenger hrs	per 10^9 passenger km
CN	8.96E-02	5.8E-09	5.8E+00	1.8E-01
GR/CT	2.03E-01	1.3E-08	1.3E+01	4.0E-01
FX	8.12E-02	5.3E-09	5.3E+00	1.6E-01
FL	1.04E-01	6.8E-09	6.8E+00	2.0E-01
Total	4.78E-01	3.1E-08	3.1E+01	9.3E-01

11.3 Comparison to Other Transport Modes

In this section the results of the risk analysis are compared to other transport modes using risk dimensions typically applied in these areas of transport. It is mentioned that the risk for the reference ships is calculated based on the assumption of SOLAS 2009 compliant ship, i.e. based on R-Index and not on A-Index. Details with respect to the reference values for other transport modes can be found in Part 1, Appendix B of this report.

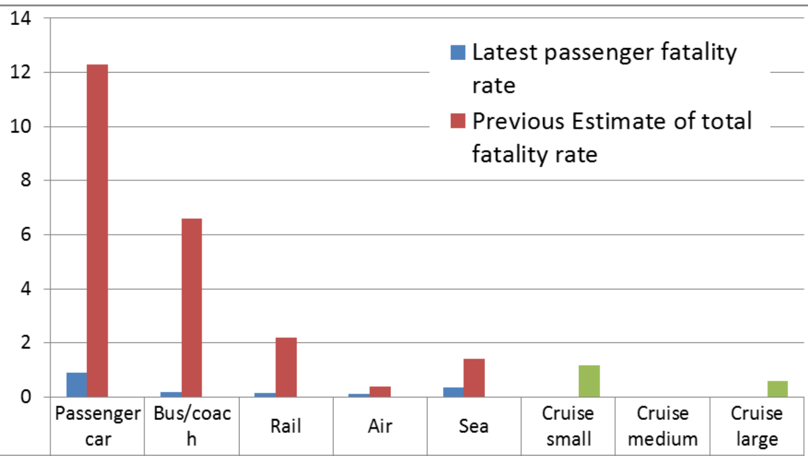
Fig. 11-7 shows the comparison between the risks calculated for the two Cruise ship sizes, “small” and “large”, and other transport modes: passenger car, bus/coach, rail and air. Risk is shown in terms of fatalities per billion passenger kilometres. For the transport modes passenger car, bus/coach, rail and air two values are given, one for the Previous Estimate of total fatality rate based on EU data up to 2001 combined with a trend adjustment to 2007 and the other for the “Latest passenger fatality rate” from EU. “Latest passenger fatality rate” can be regarded as a lower bound because of effects like under-reporting and, respectively, “Previous Estimate of total fatality rate” as an upper bound. As shown, risk based on “Latest passenger fatality rate” is significantly lower than “Previous Estimate of total fatality rate”, e.g. for passenger car the ratio between “Previous Estimate of total fatality rate” and “Latest passenger fatality rate” is about twelve. Also the variation between different transport modes is high. For instance, following “Previous Estimate of total fatality rate” the risk of car passengers is about thirty times higher than for air transport. However, following “Latest passenger fatality rate” the risk ratio between car passenger and air transport is nine. Fig. 11-7 shows that the risk of cruise ship is in the range for sea transport set by “Latest passenger fatality rate” and “Previous Estimate of total fatality rate”.

Also it should be mentioned in this context that the results of this investigation and “sea” were determined on basis of different information or samples. For “sea” historical data was used including personal and major accidents. Furthermore, “sea” combines data on cruise, RoPax and small passenger ships in EU waters only. For this investigation the risk model was developed considering only serious accidents.

Fig. 11.11 shows the same risk comparison in terms of billion passenger hours. Firstly, it was observed that changing the measurement unit had a significant effect on the relation between different transport modes. For instance, air traffic had the lowest risk in terms of fatalities per billion kilometres was overtaken by sea and rail when using billion passenger hours. Again, the risk of Cruise ships agreed well with the data for sea transport.

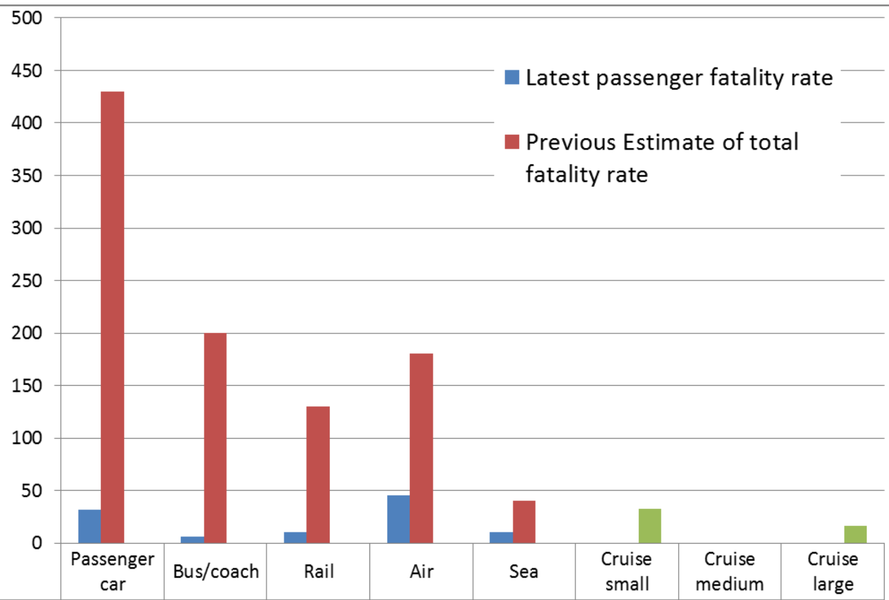
Generally, this comparison showed that the risk for Cruise ships was in the expected range (compared to “sea”) and in similar range compared to other modes of transport.

Fig. 11-9 shows the comparison between different transport modes for ship category RoPax in terms of fatalities per billion passenger kilometres. Like for Cruise ships, the risk provided by “Previous Estimate of total fatality rate” are significantly higher than the risk calculated in this investigation for the three RoPax sizes small, medium and large. In contrast, the risk determined by “Latest passenger fatality rate” is lower.



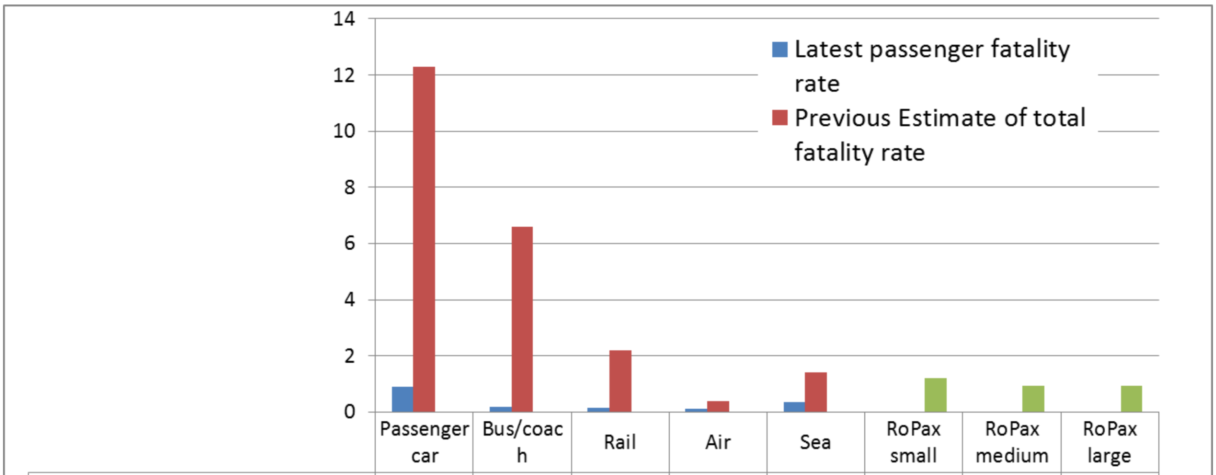
	Passenger car	Bus/coach	Rail	Air	Sea	Cruise small	Cruise medium	Cruise large
Latest passenger fatality rate	0.9	0.2	0.16	0.1	0.34			
Previous Estimate of total fatality rate	12.3	6.6	2.2	0.4	1.4			
EMSA III						1.16		0.58

Fig. 11-7 Comparison between different transport modes and Cruise ships of this investigation in terms of fatalities per billion passenger kilometres



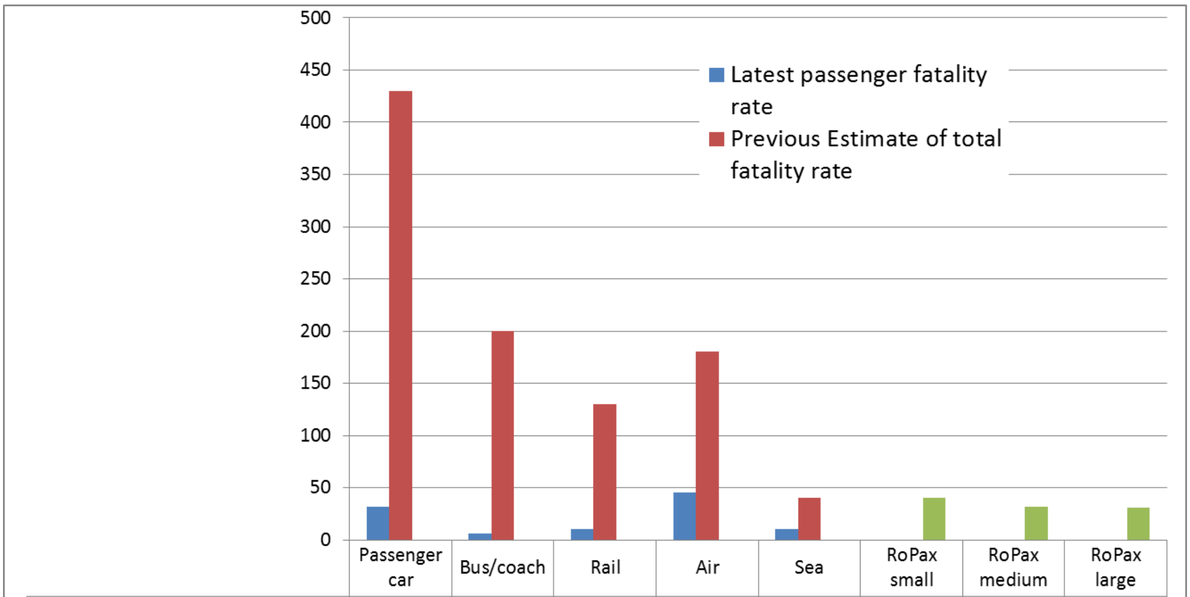
	Passenger car	Bus/coach	Rail	Air	Sea	Cruise small	Cruise medium	Cruise large
Latest passenger fatality rate	32	6	10	45	10			
Previous Estimate of total fatality rate	430	200	130	180	40			
EMSA III						32.34		16.09

Fig. 11-8 Comparison between different transport modes and Cruise ships of this investigation in terms of fatalities per billion passenger hours



	Passenger car	Bus/coach	Rail	Air	Sea	RoPax small	RoPax medium	RoPax large
Latest passenger fatality rate	0.9	0.2	0.16	0.1	0.34			
Previous Estimate of total fatality rate	12.3	6.6	2.2	0.4	1.4			
EMSA III						1.20	0.94	0.93

Fig. 11-9 Comparison between different transport modes and RoPax ships of this investigation in terms of fatalities per billion passenger kilometres



	Passenger car	Bus/coach	Rail	Air	Sea	RoPax small	RoPax medium	RoPax large
Latest passenger fatality rate	32	6	10	45	10			
Previous Estimate of total fatality rate	430	200	130	180	40			
EMSA III						40.11	31.21	31.14

Fig. 11-10 Comparison between different transport modes and RoPax ships of this investigation in terms of fatalities per billion passenger hours

Again, this comparison between the risk for cruise and RoPax vessel and other transport modes showed that the evaluation greatly depends on the metric used. An evaluation of the risk in terms of *fatalities per billion kilometres* is beneficial for all transport means with a *high velocity,* with inferior performance of sea transport. When evaluating the risk in terms of passenger hours, however, then comparative data are more uniform among all modes of transport. Following the Formal Safety Assessment guidelines it is recommended to evaluate the risk of ships in terms of *fatalities per ship year*. As shown by the FN diagrams the risk for

RoPax vessel is partly in the area of intolerable risk, when considering the updated threshold values, whereas the risk for cruise ships is in tolerable risk area.

11.4 Concluding Risk Evaluation

The risk for cruise ships has been calculated using updated and new developed risk models, and considering updated initial accident frequencies (based on historical data for the period from 2000 to 2012). Risk models were updated based on information provided by most recent casualty reports of IHS Fairplay database.

Evaluating the results for RoPax ships by means of societal risk with the updated threshold values for intolerable risk show that the FN curve partly lies in the area of intolerable risk.

One reason for this significant change in the FN evaluation, compared to the SAFEDOR FSA, is the use of *updated boundaries for the risk areas*. As explained in section 8.3.4 of this report and in Appendix A of part 1 the relation between risk and turnover in the reference air industry has been significantly changed within the last 15 years leading to lower boundaries for the risk acceptance areas. The results for RoPax ships in terms of PLL show that the main risk contributor is grounding-contact.

As mentioned above, the risk evaluation on the basis of the FN diagram should be used as a benchmark indicating that additional risk control options should be analysed, rather than as a strict assessment criterion. This conclusion is also supported by a similar comparison to other modes of transport like above for Cruise shown in Fig. 11-9 and Fig. 11-10:

- Risk of transport by sea for RoPax in terms of fatalities per 10^9 passenger kilometres
    - is slightly above values for “Previous Estimate of total fatality rate” for sea transport, but significantly higher than “Latest passenger fatality rate” results for all means of transport
    - is significantly lower than “Previous Estimate of total fatality rate” for passenger car and bus/coach
    - is lower than “Previous Estimate of total fatality rate” for rail
    - is higher than “Previous Estimate of total fatality rate” for air transport
- Risk of transport by sea for RoPax in terms of fatalities per 10^9 passenger hours
    - is roughly the same as “Previous Estimate of total fatality rate” for sea transport
    - is about four to six times higher than “Latest passenger fatality rate” values for sea transport
    - is significantly lower than “Previous Estimate of total fatality rate” for all other means of transport
    - is about the same compared to “Latest passenger fatality rate” values for passenger car and air transport but higher than for bus/coach.

11.5 Sensitivity Analysis

Risk models were developed for two ship types, Cruise and RoPax, and the following accident categories:

- Collision;
- Grounding/contact;

For these risk models a sensitivity analysis has been carried out and is summarised below. Risk model are linear models establishing a relation between initial accident frequencies and consequences in term of human fatalities. The results of these sensitivity investigations in conjunction with the uncertainty intervals given in section 13 provide the information for evaluating the soundness of the recommendations.

11.5.1 Collision

Collision risk model is shown in Fig. 10-22. Sensitivity analysis was carried out by variation of single parameters in the risk model and calculation of the change in the risk to person on board.

Assuming five more collision means an increase in initial accident frequency of 29% for Cruise and 10% for RoPax. Due the linearity of the risk model risk would increase respectively by 29% (Cruise) and 10% (RoPax).

Increasing the number of struck ships by five would change the relation between struck and striking slightly, i.e. 55% struck instead of 51%, and the risk would increase in the same way by 7%.

Increasing the number of collision in limited waters by five (50% more accidents in this area) would increase the risk for Cruise by about 22% and for RoPax about 24%. In the same way it was observed that five more accidents in terminal area (+36%) decrease the risk by about 11%, respectively, about 12% for RoPax.

Currently, the dependent probability of water ingress in terminal area is 7%. One additional accident in terminal area with water ingress would yield a dependent probability of 13% and an increase of risk by 8% for Cruise and 4% for RoPax.

A dependent probability for fast sinking of 50% for Cruise that affect only the scenarios of collisions “en route” and “limited waters” would increase the risk by 117%. A reduction of the fatality rate for fast sinking from 80% to 50% (-38%) would led to a risk reduction for Cruise by 27%, respectively 34% for RoPax.

The investigation demonstrated that the collision risk model was highly sensitive with respect to the probability of fast sinking and fatality rate for fast sinking.

The impact of the model sensitivity on the cost-benefit assessment is demonstrated in the following by the example of selected parameters and design variants for each ship type and size category.

Fig. 11-11 shows a comparison for small and large cruise ships and the sensitivity of the cost threshold with respect a variation in the number of accidents, i.e. initial accident frequency. For these results number of accidents were increased, respectively decreased by ten accidents and in cost thresholds calculated. The sensitivity in the result is plotted in terms of error bars over the “mean” value for the original value. The change in the number of collision accidents is equal to a relative change in initial accident frequency of ±59%.

The respective results for RoPax ships are plotted in Fig. 11-12. For RoPax the variation in number of accidents is equivalent to ±20% of initial accident frequency.

Changing the number of accidents in the calculation of the dependent probability struck/striking by ±10 (keeping the total number of accident constant), i.e. probability of being struck varying between 68% and 35% lead to the results summarised in Fig. 11-13 and Fig. 11-14.

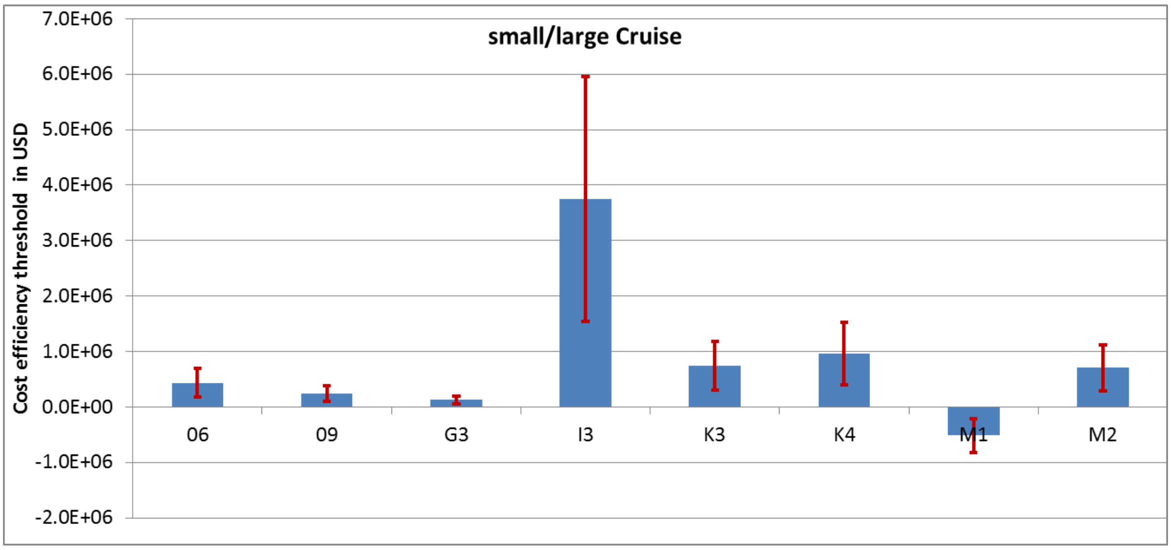


Fig. 11-11 Sensitivity wrt to initial accident frequency. Cost thresholds for cruise sample ship #2 (06, 09) and #1 (G3, I3, K3, K4, M1 and M2[12]) calculated using VPF of 4 million USD.

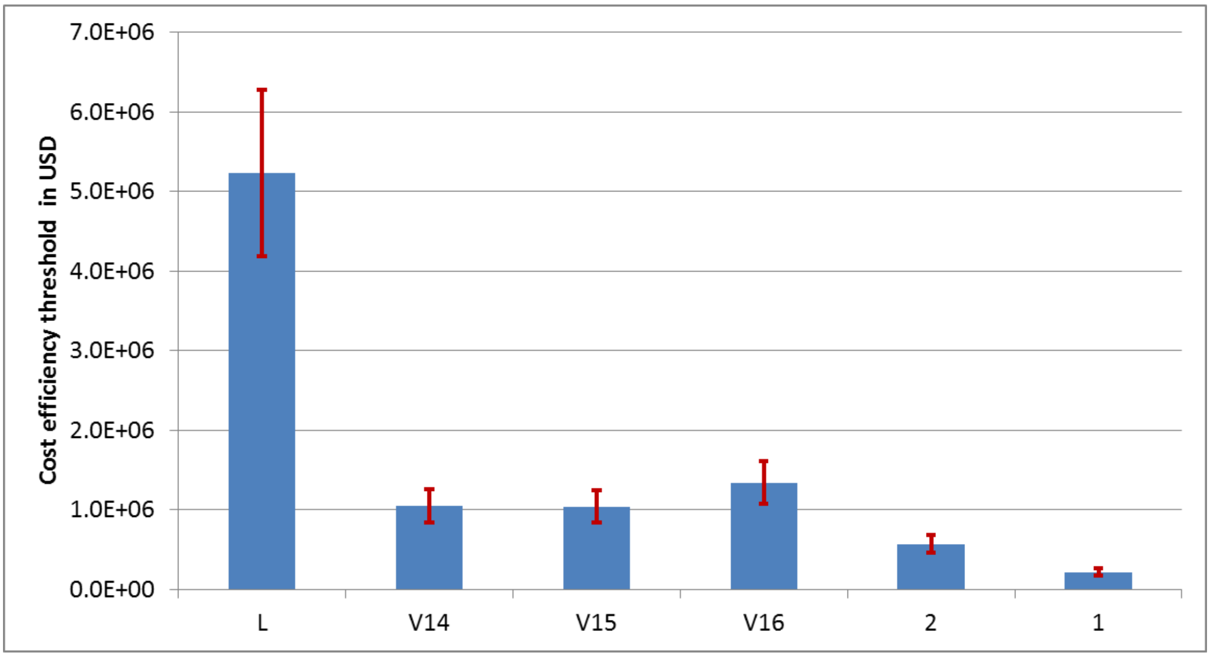


Fig. 11-12 Sensitivity wrt initial accident frequency. Cost threshold for RoPax sample ship ship #3 (L), #4 (V14, V15, V16[13]), #5 (2) and #6(1) calculated using VPF of 4 million USD.

[12] RCO nos K4, M1 and M2 are described in DNVGL report No. 2015-0168» Evaluation of risk from raking damages due to grounding, final report»

[13] RCO nos V15 and V16 are described in DNVGL Report No. 2015-0168 "Evaluation of risk from raking damages due to grounding, final report".

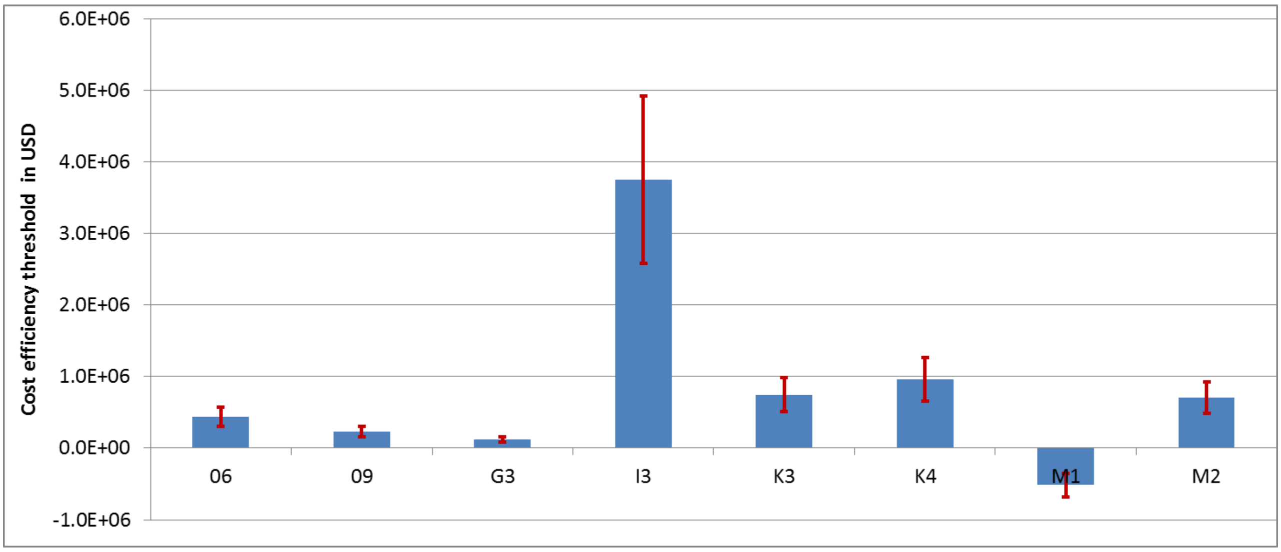


Fig. 11-13 Sensitivity wrt struck/striking. Cost threshold for Cruise sample ships #2(06, 09) and #1 (G3, I3, K3, K4, M1 and M2) calculated using VPF of 4 million USD.

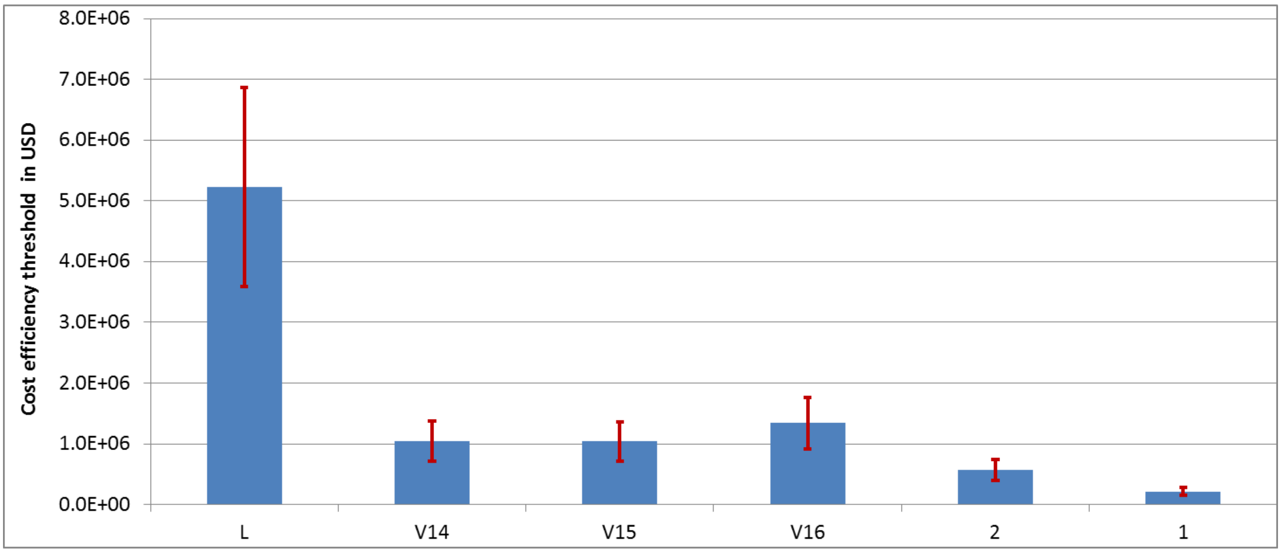


Fig. 11-14 Sensitivity wrt struck/striking. Cost threshold for RoPax sample ship #3(L), #5(V14, V15, V16), #5(2) and #6(1) calculated using VPF of 4 million USD.

Similar to the analysis above the sensitivity with respect to the operational area was determined by changing the subdivision of the number of casualties onto the two categories (terminal – other waters) by ±10 (corresponding to ±48% change in dependent probability). The results were summarised in Fig. 11-15 and Fig. 11-16.

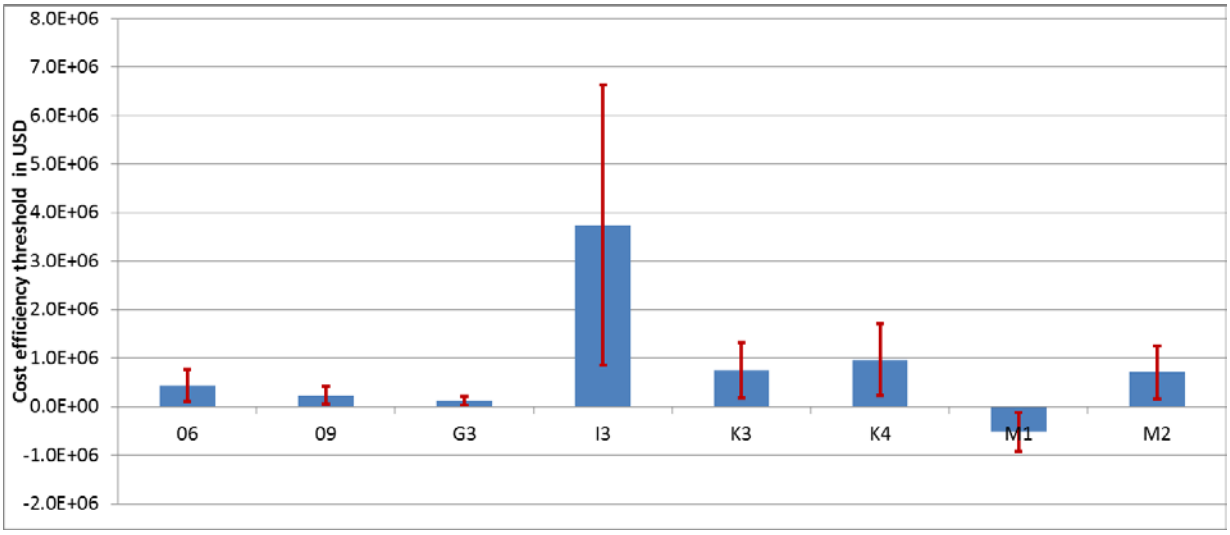


Fig. 11-15 Sensitivity wrt operational area. Cost threshold for Cruise sample ships #2(06, 09) and #1 (G3, I3, K3, K4, M1 and M2) calculated using VPF of 4 million USD

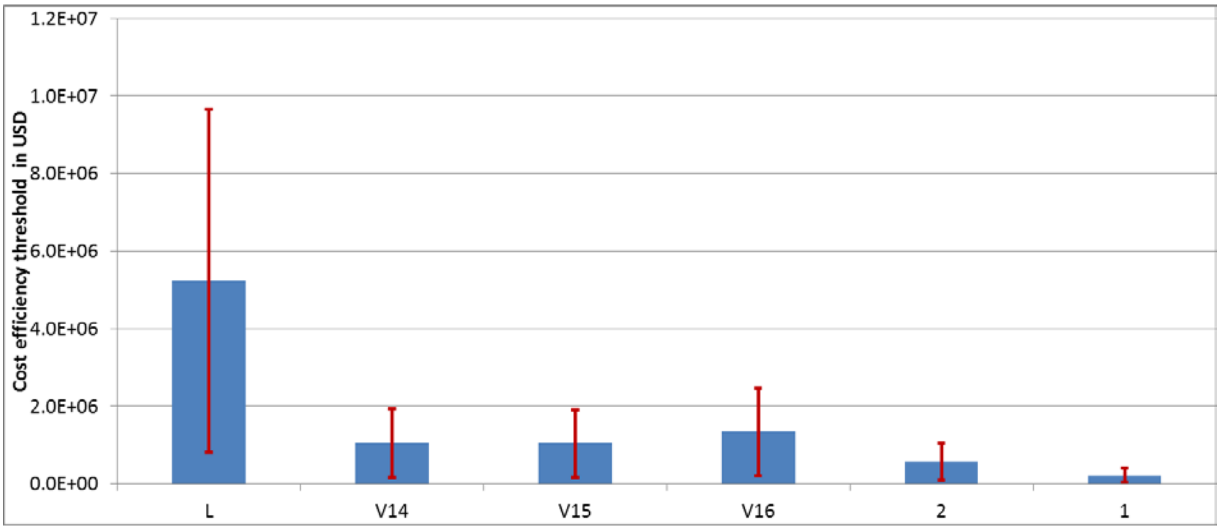


Fig. 11-16 Sensitivity wrt operational area. Cost threshold for RoPax sample ship #3(L), #5(V14, V15, V16), #5(2) and #6(1) calculated using VPF of 4 million USD

Finally, the influence of the assumptions made for the sinking velocity were investigated by changing the probability of fast sinking by ±10%, i.e. between 8% and 28% for Cruise.

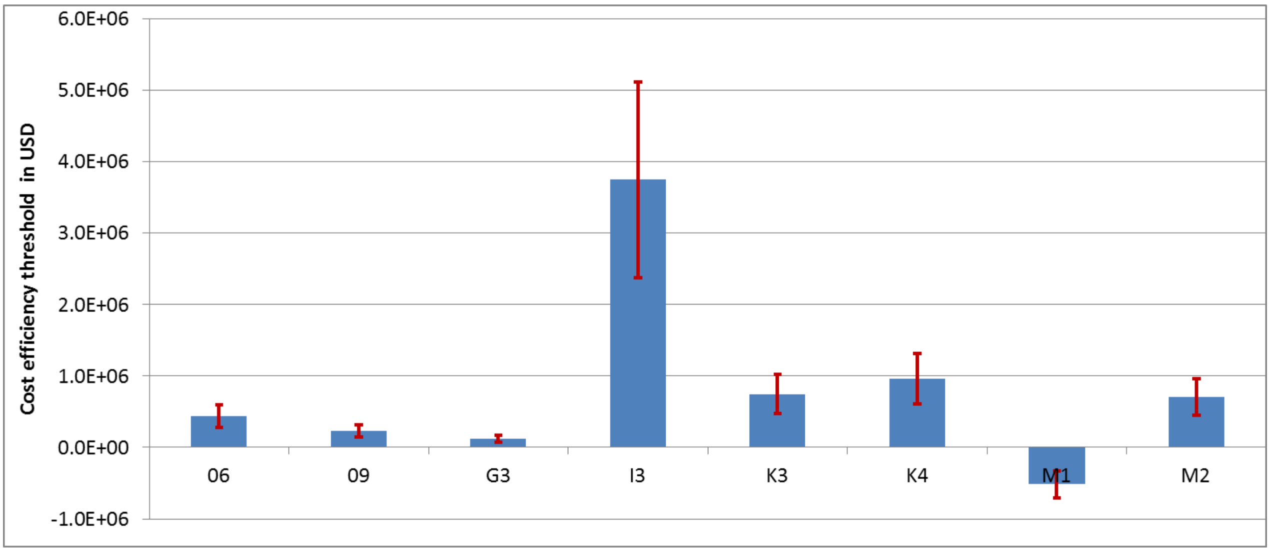


Fig. 11-17 Sensitivity wrt fast/slow sinking. Cost threshold for Cruise sample ships #2(06, 09) and #1 (G3, I3, K3, K4, M1 and M2) calculated using VPF of 4 million USD

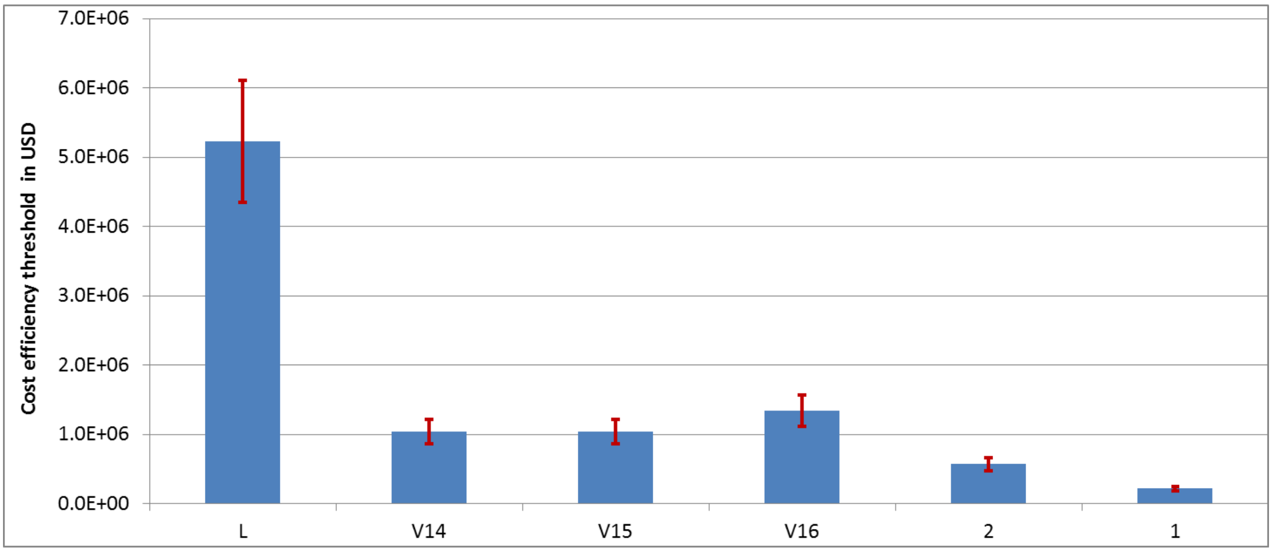


Fig. 11-18 Sensitivity wrt fast/slow sinking. Cost threshold for RoPax sample ship #3(L), #5(V14, V15, V16), #5(2) and #6(1) calculated using VPF of 4 million USD

11.5.2 Grounding/Contact

Grounding/contact risk models for Cruise and RoPax vessels are shown in Fig. 10-23 and Fig. 10-24. A sensitivity analysis has been carried out using the same approach as for collision risk model.

Assuming fire more grounding/contact means an increase in initial accident frequency of 12% for Cruise ships and, respectively, 4% for RoPax. Due to the linearity of the risk model risk increases in the same way.

A change in the dependent probabilities for "operational state", e.g. by five more accidents in terminal area (+4%), would increase the dependent probability of an accident in terminal area to 59% and subsequently reduce the risk for Cruise by 1% and for RoPax by less than 2%. In contrast, assuming these five additional accidents occurring in “limited waters” (+6%) would increase the risk for Cruise ships by 1.5%, respectively, RoPax 2%.

Regarding only accidents in “terminal area” the risk model distinguishes side and bottom damages. Investigation showed that the risk model showed no sensitivity with respect to an increased number of accidents with side damage or bottom damage. This is because accidents in terminal area had only a small contribution to overall risk. The same was observed for probability of water ingress in terminal area.

Higher sensitivity was observed for accidents in “limited waters”. For instance an increase of the dependent probability of “side damage” from 49% to 54% would led to an increase in grounding/contact risk by 4% for Cruise and 7% for RoPax. Reducing the probability of hull breach in case of side damage led to a reduction of risk by 6% for Cruise and 8% for RoPax. If the probability of staying aground after side damage was increased from 33% to 40% (one accident more) a risk reduction was observed of 5% for Cruise ships and 7% for RoPax.

For bottom damages, a reduction of the probability of grounding/contact on hard sea bed from 86% to 81% led to a risk reduction of 0.9% for Cruise ships and 0.6% for RoPax ships. Higher sensitivity was observed for the parameter “staying aground”. A reduction of the probability for staying aground from 80% to 70%, five accidents less, led to a risk reduction of 8% for Cruise ships and 6% for RoPax ships.

Similar to collision risk model a higher sensitivity with respect to fatality rates was observed. For instance reducing the average fatality rate for fast sinking from 80% to 50% reduced the risk for Cruise vessel by 21%, respectively 29% for RoPax.

Similar to the sensitivity investigation for collision summarised above the influence on the thresholds used for cost benefit assessment of the parameter initial accident frequency as well as the dependent probabilities operational area and fast/slow sinking was analysed.

The effect of following parameter variation were investigated

- Initial accident frequency: ±10 accidents for each ship type under consideration equivalent to a change in the initial accident frequency ±24% for Cruise and ±9% for RoPax. The results on cost thresholds for CAF of four million USD were summarised in Fig. 11-19 and Fig. 11-20.
- Dependent probability for operational area: ±10 accidents for each of the categories (terminal – other waters) with constant total number of casualty reports. Results summarised in Fig. 11-21 and Fig. 11-22.
- Fast/slow sinking: variation in dependent probability fast sinking by ±10% (sum of both probabilities = 100%). Results summarised in Fig. 11-23 and Fig. 11-24.

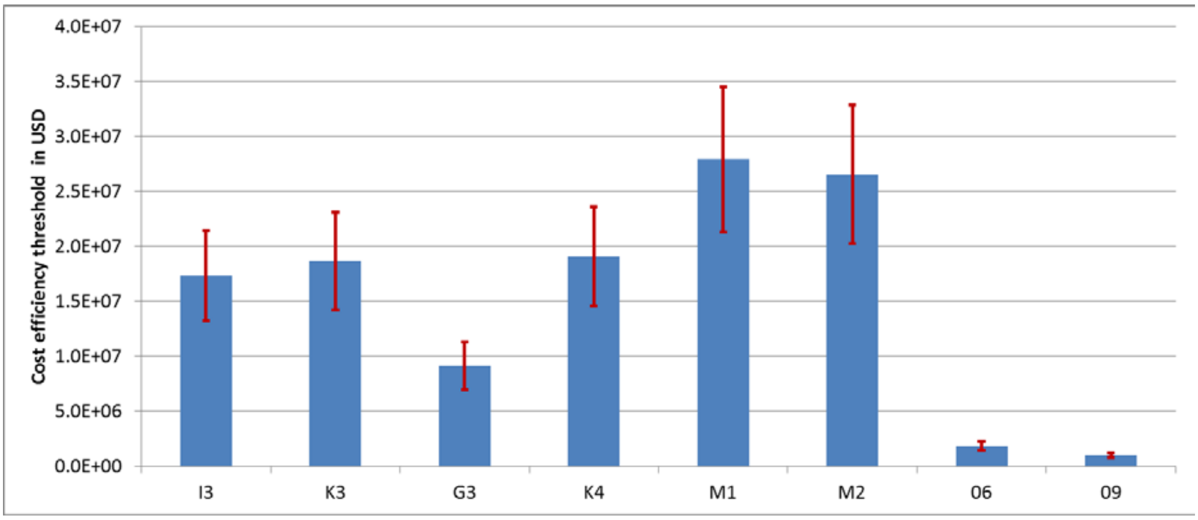


Fig. 11-19 Sensitivity wrt initial accident frequency. Cost thresholds for cruise sample ship #1 (G3, I3, K3, K4, M1 and M2) and #2 (06, 09) calculated using VPF of 4 million USD

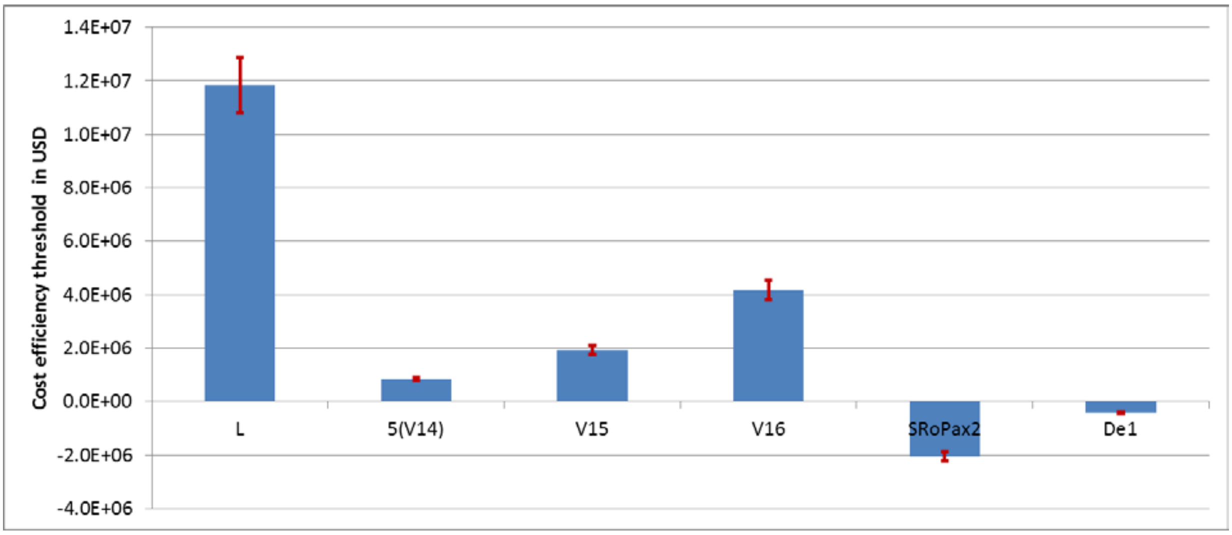


Fig. 11-20 Sensitivity wrt initial accident frequency. Cost thresholds for RoPax sample ship #3 (L), #4 (V14, V15, V16), #5(SroPax2) and #6 (De1) calculated using VPF of 4 million USD

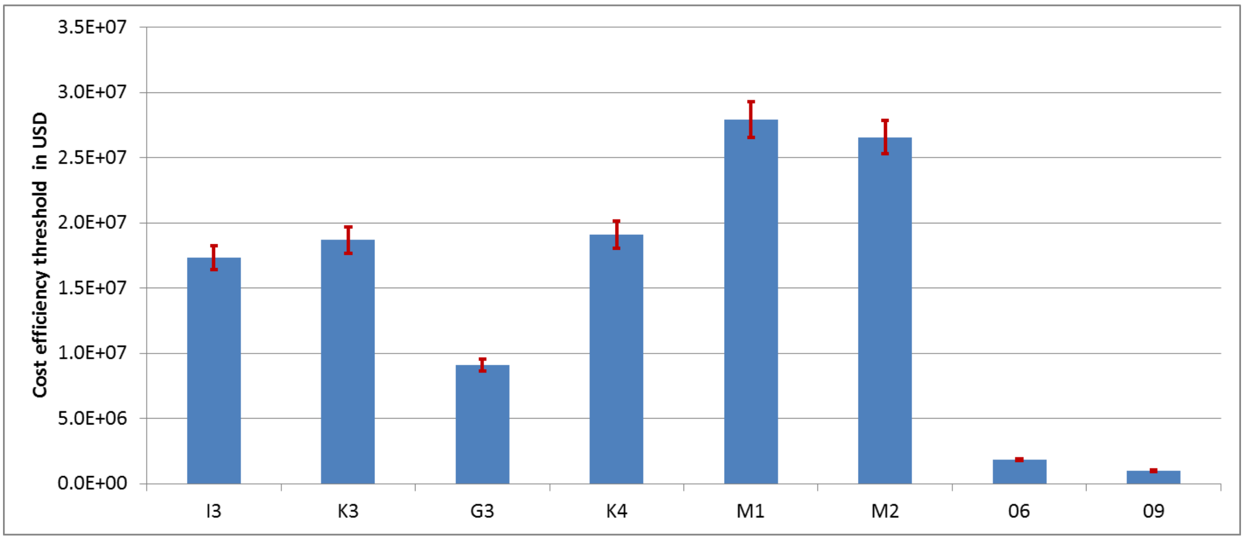


Fig. 11-21 Sensitivity wrt operational area. Cost thresholds for cruise sample ship #1 (G3, I3, K3, K4, M1 and M2) and #2 (06, 09) calculated using VPF of 4 million USD

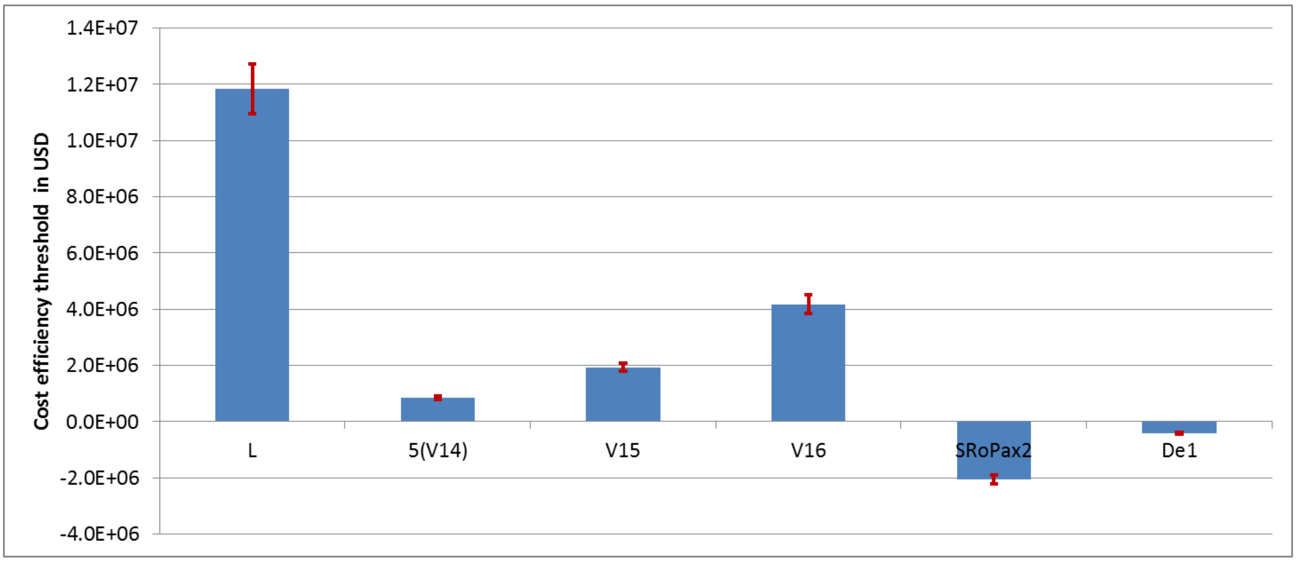


Fig. 11-22 Sensitivity wrt operational area. Cost thresholds for RoPax sample ship #3 (L), #4 (V14, V15, V16), #5(SroPax2) and #6 (De1) calculated using VPF of 4 million USD

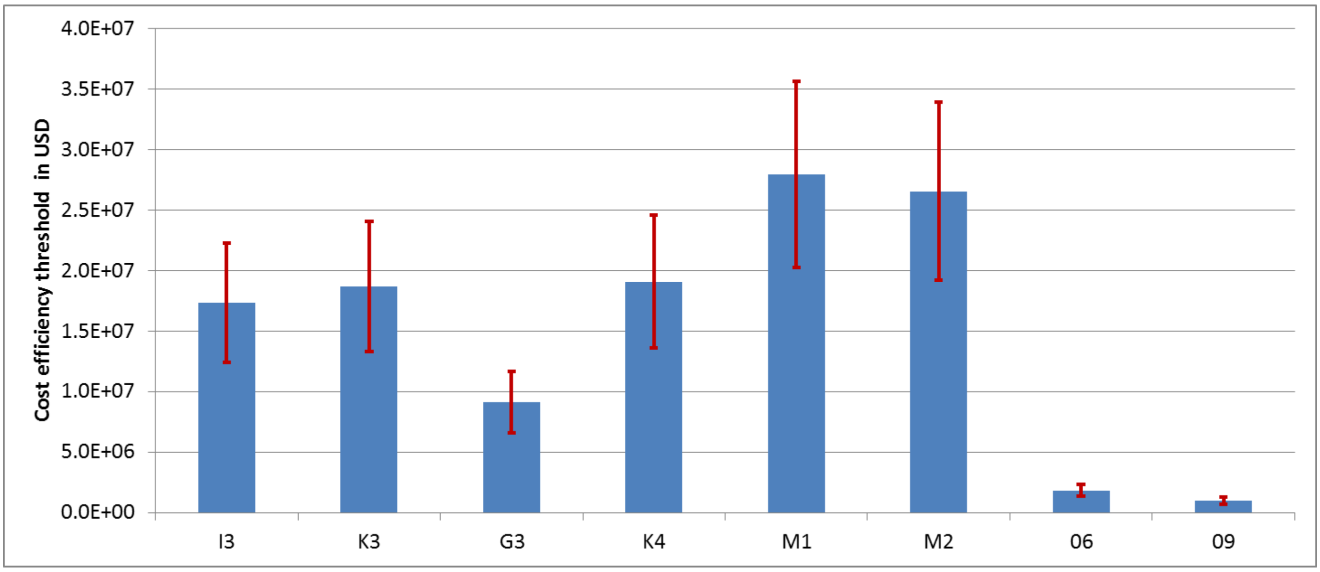


Fig. 11-23 Sensitivity wrt fast/slow sinking. Cost thresholds for cruise sample ship #1 (G3, I3, K3, K4, M1 and M2) and #2 (06, 09) calculated using VPF of 4 million USD

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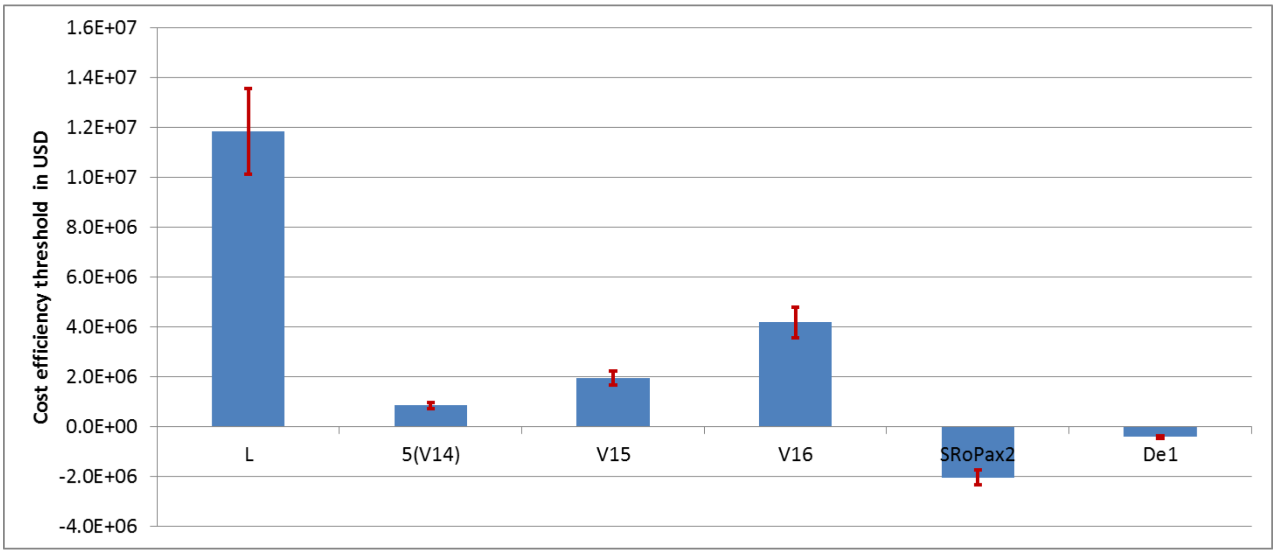

Fig. 11-24 Sensitivity wrt fast/slow sinking. Cost thresholds for RoPax sample ship #3 (L), #4 (V14, V15, V16), #5(SroPax2) and #6 (De1) calculated using VPF of 4 million USD

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12 NEW PASSENGER SHIP DESIGNS

New designs of 6 passenger ships have been developed to form the basis for the optimization and benchmark for the subdivision index, as well as for grounding and the effect of open water tight doors.

All designs comply with the current statutory rules and regulations, e.g. SOLAS2009 including SRtP where applicable. The design of the RoPax vessels use the revised formulation for the s-factor to consider water on deck as agreed at SLF55 and approved by SDC1.

The designs have been selected in close cooperation between the designers and ship operators in such a way that the world fleet will be well represented.

Table 12-1 Overview of sample ships

No	Yard	Type	Length bp	Breadth	Draught	Gross Tonnage	Number of Persons
1	MW	Large cruise	294.64 m	40.80 m	8.75 m	153400	6730
2	FC	Small cruise	113.70 m	20.00 m	5.30 m	11800	478
3	STX-FIN	RoPax Baltic	232.00 m	29.00 m	7.20 m	60000	3280
4	STX-FRA	RoPax Mediterranen	172.40 m	31.00 m	6.60 m	43000	1700
5	KEH	RoPax ferry	95.50 m	20.20 m	4.90 m	7900	625
6	KEH	Double end	96.80 m	17.60 m	4.30 m	5040	610

Fig. 12-1 shows the current distribution of ro-ro passenger and cruise ships. The ships that were used in the GOALDS project are indicated in the figure as well as the selected designs in this project. It can be seen that the selection of sample ships covers the whole range of the world fleet with regard to ship size and number of persons on board. Based on the feedback from the EU member states a small double ender RoPax ferry has been added to the original set off ships to cover in a better way the fleet of passenger ship operating in the EU.

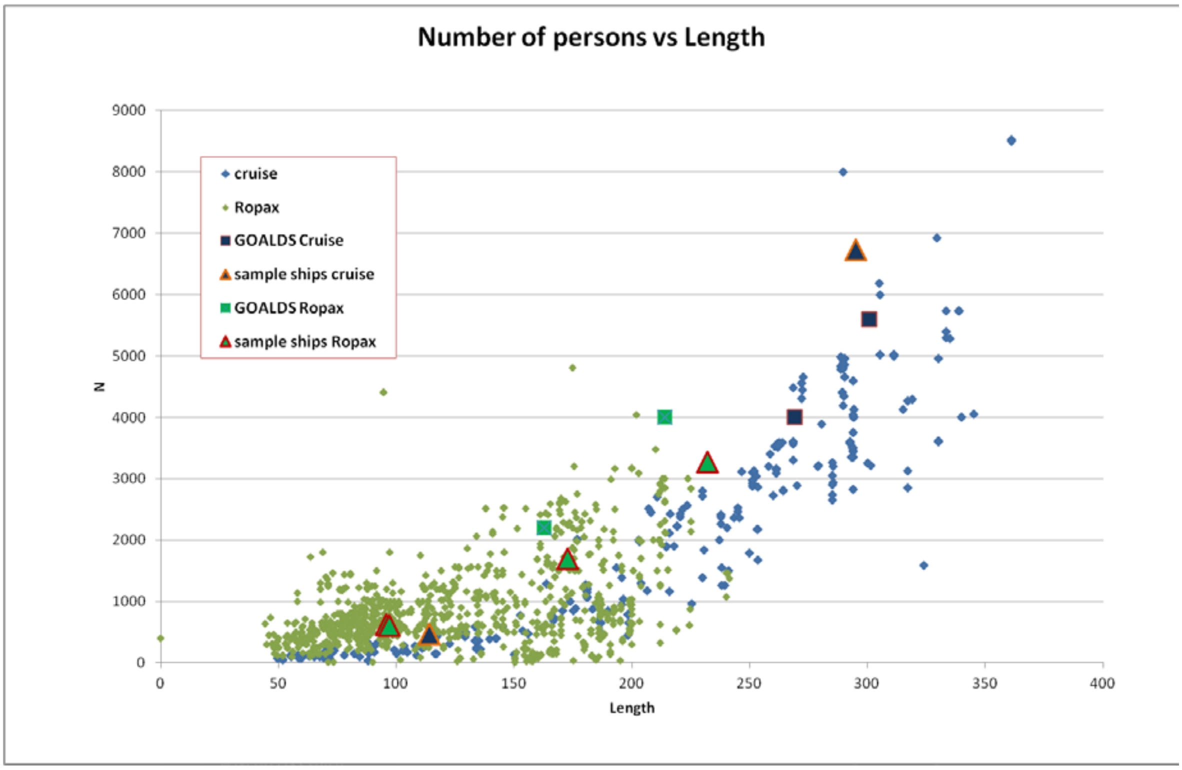


Fig. 12-1 Distribution of world fleet RoPax and Cruise

Also with regard to the covered range of required subdivision index the sample of ships to be investigated closes the gaps left by the GOALDS study.

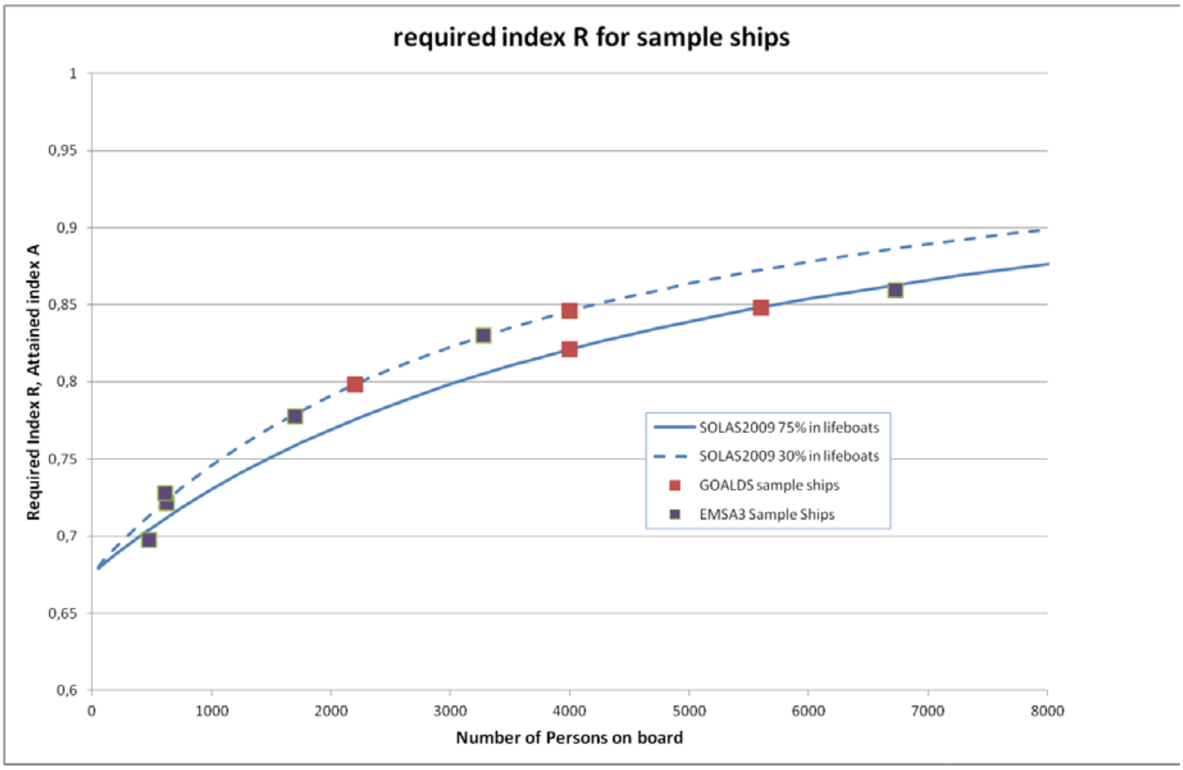


Fig. 12-2 Required index for passenger ships

The ro-ro passenger ships (RoPax) represent typical designs for specific routes and their functional requirements, including one route in the Baltic Sea and one in the Mediterranean. Also for the cruise ships specific functional requirement have been agreed with the operators to reflect realistic designs.

The functional requirements of the designs are completed by operational profiles to form a business model for each ship. This business model will be kept constant during the optimization process to allow a fair and realistic comparison of the design options.

The detailed design is worked out by design teams consisting of a shipyard/designer and an operator for each ship. In the following pages each basic design is described more in detail.

12.1 Ship #1 Large Cruise Ship

12.1.1 Business Model

As the basis for the design of this ship a business model has been agreed with the operator to define the basic parameters which need to be fulfilled. These parameters and the business model will be kept unchanged throughout the design process and also during further design studies during a later stage of this project.

The vessel is designed as a worldwide operating cruise vessel for itineraries between 7 and 14 days.

Following main parameters are to be kept to maintain the business model of this vessel:

1. 2050 guest staterooms whereof approximately 78% have sea view and approximately 70% are balcony cabins. The required percentage of cabins for disabled persons according CLIA guidelines
2. 5100 passengers
3. 1580 crew berths where of approximately 50 in single cabins (officers) and the remaining in double cabins
4. Public rooms on lower decks
    a. Main theatre with approximately 1000 seats
    b. One two-deck level main dining room with adjacent main galley
    c. 12000 m² of other public spaces, like small restaurants, casino, shops, bars etc
5. Public rooms on upper decks
    a. Large lido restaurant with integrated galley
    b. Observation lounge in the front
    c. 4700 m² of other public spaces like spa area, night club, kids area etc
    d. Open pool area with 2 pools in centre and one pool aft
    e. Covered pool area with sliding roof
6. Two public staircases connecting with in total 14 lifts connecting all passenger decks including tender area
7. Two tender areas with access to tender platforms
8. Crew mess and recreation areas
9. Medical centre according CLIA guidelines
10. Provision rooms for 3 weeks
11. Storage rooms and workshops according to ship size
12. Laundry of suitable size
13. 11 crew lifts connecting all passenger decks and service corridor

14. Separate crew stair cases and corridors to connect all crew spaces and cabins without crossing passenger areas
15. Longitudinal service corridor without any watertight door to connect stores, provision areas, workshops, laundry area and crew lifts to allow suitable transport of goods
16. Restrictions of main dimensions
    a. Length over all < 330.0 m
    b. Maximum draught < 9.0m
    c. Maximum air draught on design draught <61.0m (Bridge of Americas)
17. Tank capacities
    a. Heavy Fuel Oil 3900 m^3
    b. Gas oil 700 m^3
    c. Potable water 4000 m^3
    d. Heeling water 1400 m^3
    e. Waste water 3200 m^3
18. Deadweight 11500t at design draught
19. Stability requirements to be complied with including 1500 t growth margin
20. Service speed with 100% pod power and 15% sea-margin 22 knots
21. Sufficient power of the transverse thrusters to sustain 16,7 m/s wind in worst condition
22. Operational profile: as an average 360 days per year in service, whereof
    a. 17% in port
    b. 17% low speed (12 knots)
    c. 30% medium speed (18 knots)
    d. 36% high speed (21 knots)

12.1.2 General Description of the Ship

This sample ship is a state-of-the-art design of a Post Panama sized modern cruise ship with size of 153000 GT. It is designed for worldwide cruises with capacity of more than 6700 persons onboard. The design of the vessel complies with all relevant international rules and regulations which are in force at the beginning of 2014.

Life saving appliances are provided for 6730 persons onboard for long international voyage. The vessel is a mono hull design with seven main vertical zones and watertight subdivision below the bulkhead deck including partial bulkheads on the bulkhead deck.

Most of the passenger cabins are in the superstructure, but there are more cabins located in the hull. Passenger public spaces are located on three decks in the hull. Further public spaces and sun decks are located on the top of the vessel.

The vessel has a diesel-electric type propulsion plant located in two watertight compartments. Two electric pod-propulsion motors and the corresponding equipment are located in separate watertight compartments.

The ship has following main characteristics:

Length over all	~318 m
Length between perpendiculars	294.60 m
Subdivision length	315.67 m
Breadth	40.80 m
Subdivision draught	8.75 m
Height of bulkhead deck	11.80 m
Number of passengers	5135
Number of crew	1595
Gross tonnage	153400 GT
Deadweight	11500 t
No of cabins	2050
GT/Stateroom	74.8
GT/Lower Bed	37.4
Service speed	22 knots
Trial speed	23 knots
Installed propulsion power	38000 kW
Installed power of main engines	76800 kW

12.1.3 Regulations

The design complies with all relevant IMO rules and regulations applicable for ships with keel laid after 1 January 2014, which includes following codes:

1. SOLAS1974 as amended, including probabilistic damage stability and "Safe Return to Port" (SOLAS2009)
2. Intact Stability Code (IS Code 2008)
3. Load line Convention
4. MARPOL, including fuel oil tank protection
5. MLC2006

12.1.4 General Arrangement

The following Fig. 12-4 and Fig. 12-5, show the General Arrangement plan

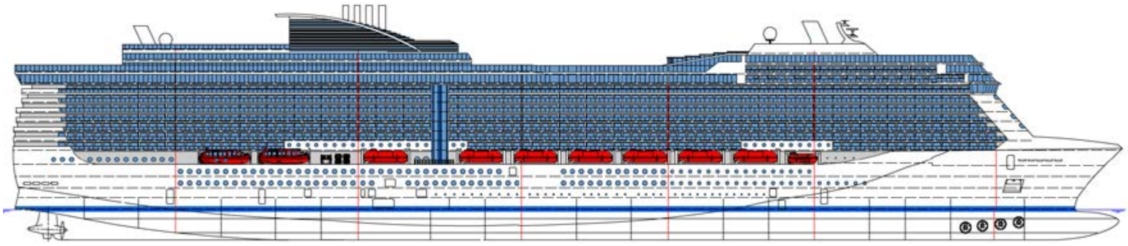


Fig. 12-3 Profile – Large Cruise vessel

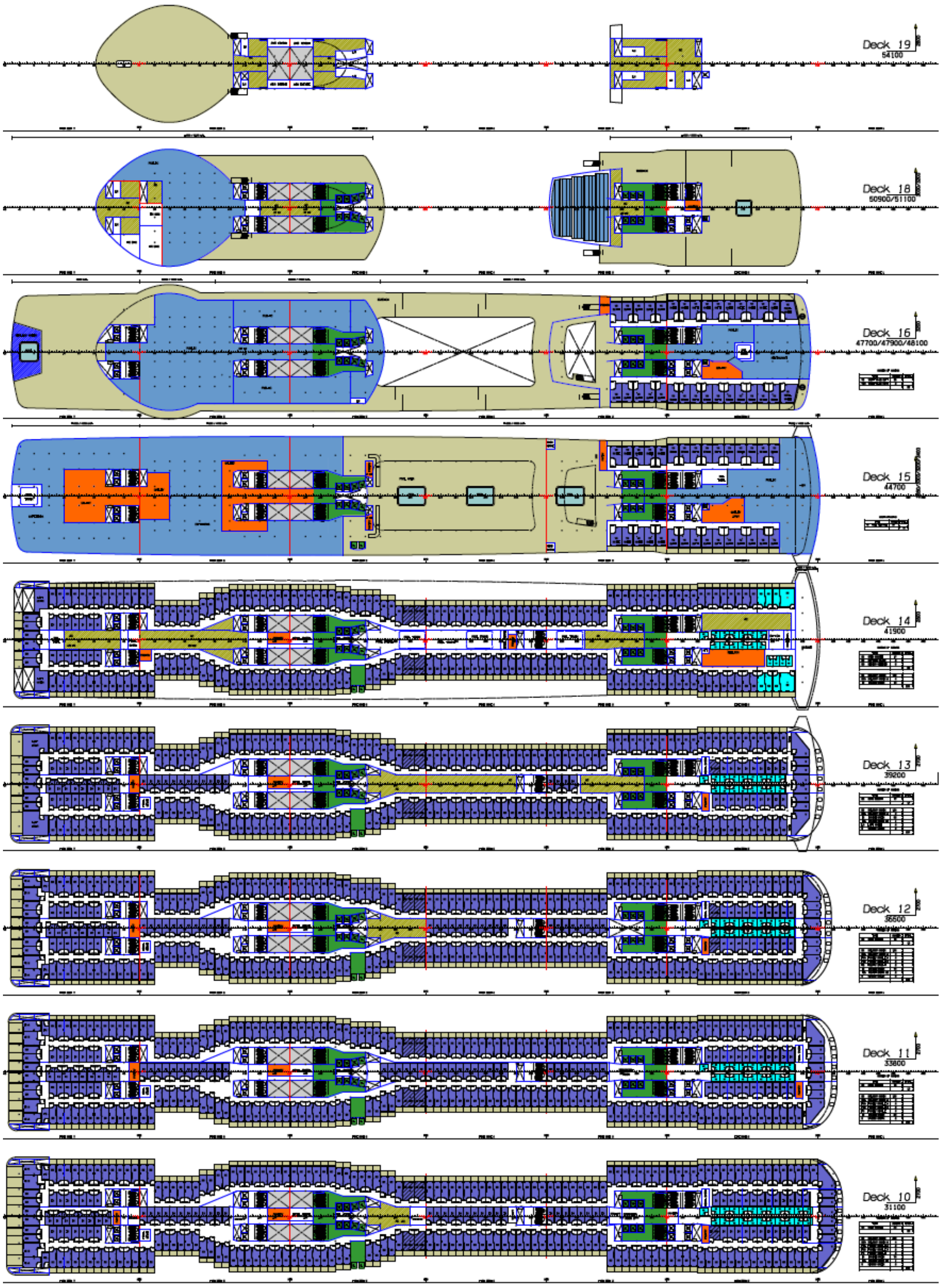


Fig. 12-4 Deck 10 – 19 – Large Cruise Vessel

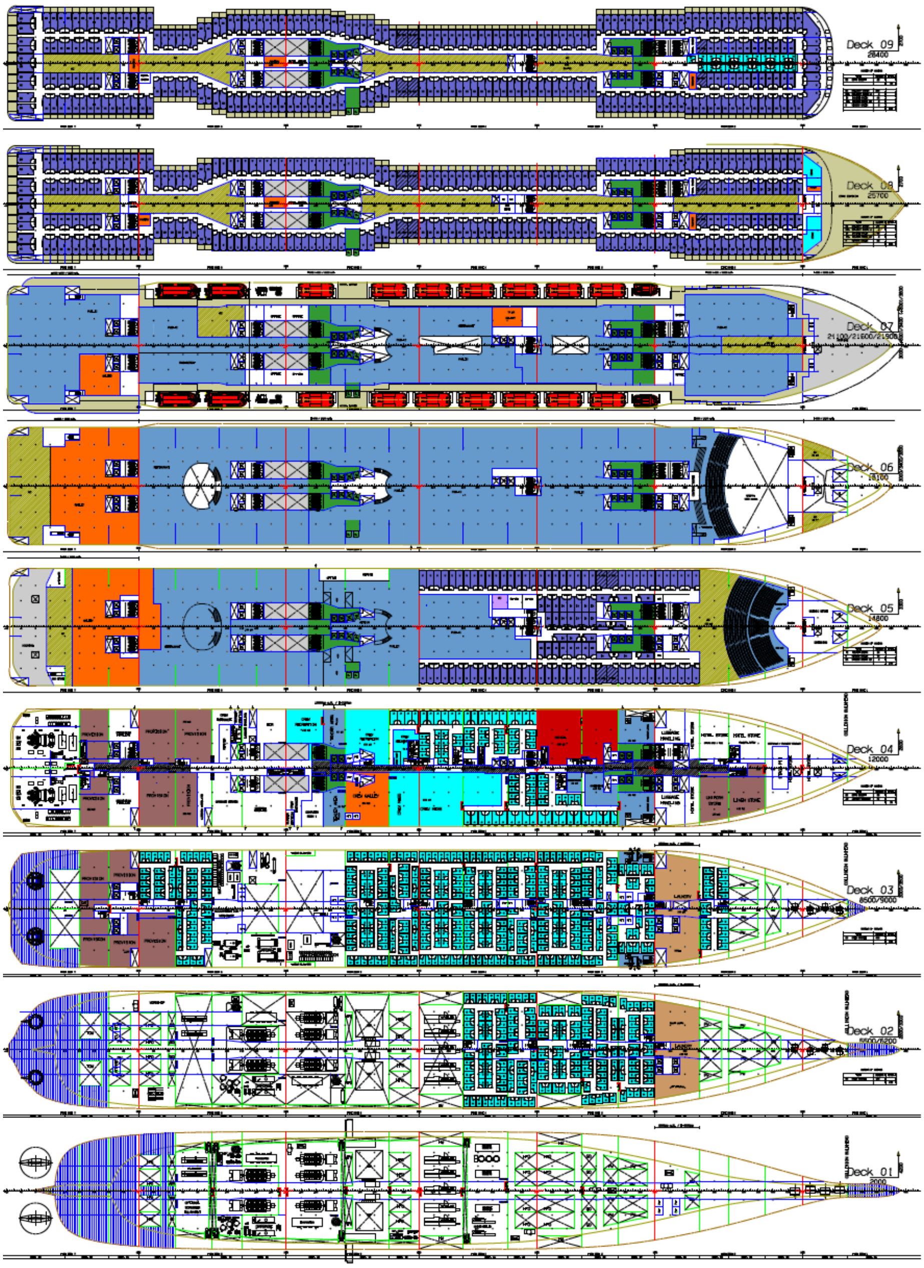


Fig. 12-5 Decks 01 – 09 – Large Cruise Vessel

12.1.5 Hullform

The ship has a conventional modern hull form of a twin screw vessel with bulbous bow, slender skeg and transom stern.

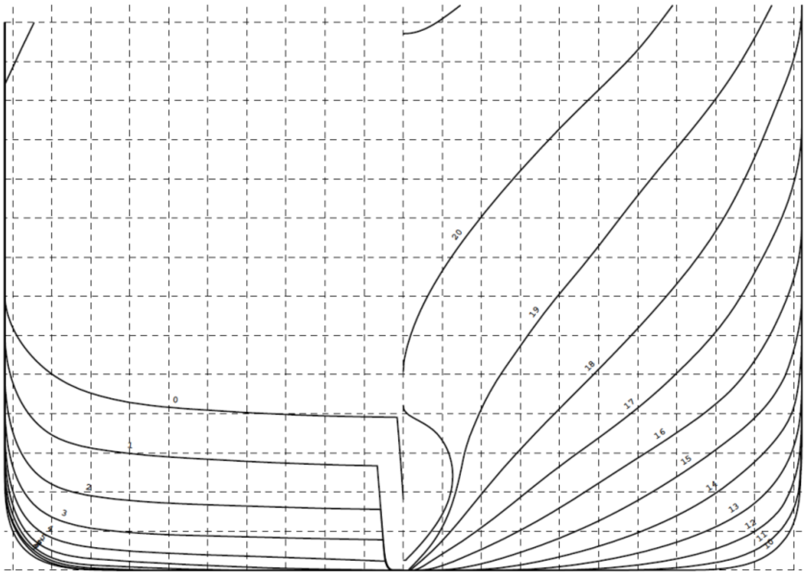


Fig. 12-6 Body plan – Large Cruise Vessel

12.1.6 Engine configuration

The engine configuration is based on a diesel-electric concept with 5 power stations each consisting of a medium speed diesel engine with generator and two podded propulsors.
The engine plant is designed to deliver the full load (propulsion and hotel load) with four main engines running on maximum 95% MCR, while the fifth engine is installed as a back-up engine for redundancy purposes only. The hotel load required in port should be covered by one engine only.
The anticipated hotel load is 12500 kW under tropical conditions.

All five main engines are equipped with scrubbers to be able to burn heavy fuel with higher sulphur contents also within SECAs.

12.1.7 Tankplan and capacities

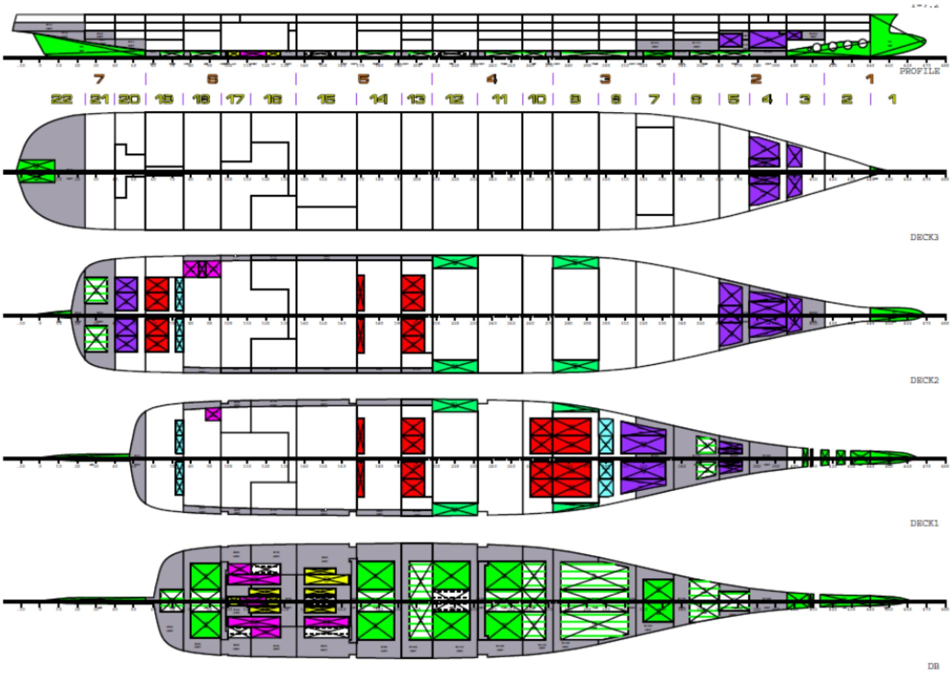


Fig. 12-7 Tank plan – Large Cruise Vessel

The capacities achieved for the various purposes are shown in **Table 12-2**:

Table 12-2 Tank capacities– Large Cruise Vessel

Description	RHO	Volume	Requirement	DELTA	Weight
POTABLE WATER	1.000 t/m³	4101.35 m³	4000.00 m³	101.35 m³	4101.35 t
HEELING WATER	1.000 t/m³	1455.87 m³	1400.00 m³	55.87 m³	1455.87 t
BALLAST WATER	1.025 t/m³	3520.70 m³	3400.00 m³	120.70 m³	3608.72 t
TECHNICAL WATER	1.000 t/m³	504.17 m³	500.00 m³	4.17 m³	504.17 t
HEAVY FUEL OIL	0.980 t/m³	3917.72 m³	3900.00 m³	17.72 m³	3839.37 t
LUBRICATING OIL	0.900 t/m³	290.23 m³	275.00 m³	15.23 m³	261.21 t
GAS OIL	0.880 t/m³	732.87 m³	700.00 m³	32.87 m³	644.93 t
SPECIAL TANKS	1.000 t/m³	731.05 m³	500.00 m³	231.05 m³	731.05 t
GREY WATER	1.000 t/m³	854.50 m³	0.00 m³	854.50 m³	854.50 t
TREATED WASTE WATER	1.000 t/m³	2457.60 m³	0.00 m³	2457.60 m³	2457.60 t

12.1.8 Subdivision

Following subdivision is used for damage calculations:

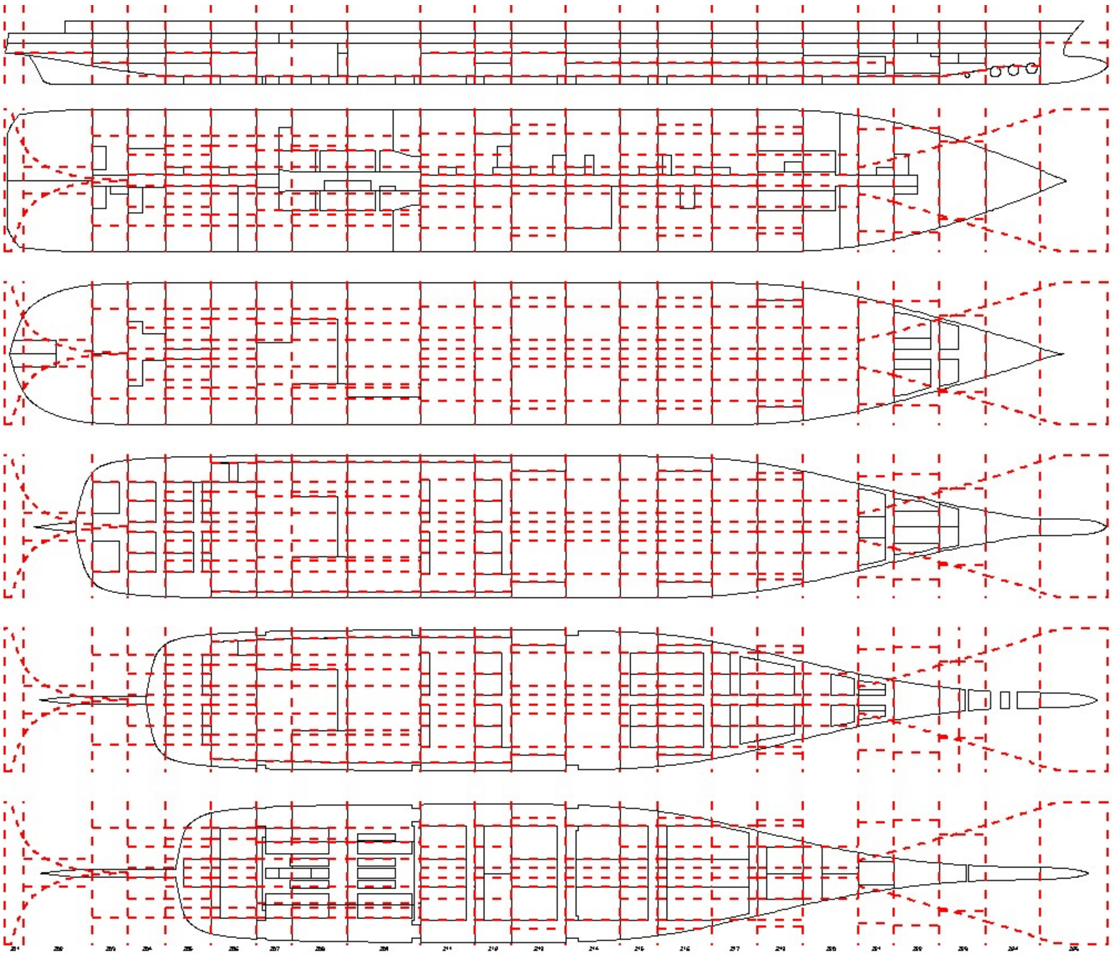


Fig. 12-8 Subdivision used for calculations - – Large Cruise Vessel

12.1.9 Hydrodynamics

12.1.9.1 Speed power performance

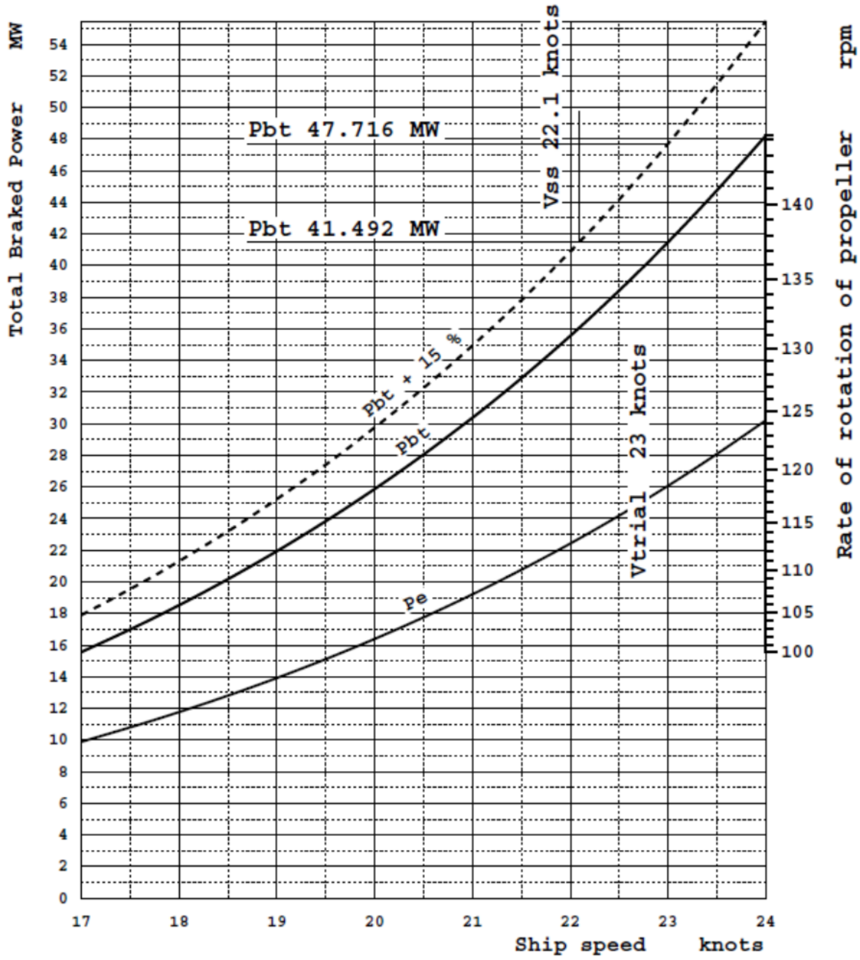


Fig. 12-9: Speed power performance- – Large Cruise Vessel

12.1.9.2 Manoeuvrability

The ship is equipped with 3 bow thrusters of 3500 kW each to maintain manoeuvrability at the required wind speed in the worst direction.

Under the given wind speed the ship will be able to keep its position without the help of tugs.

12.1.10 Intact stability

12.1.10.1 Loading conditions

Table 12-3 shows an overview of the loading conditions designed for further examination of the sample ship, while further details are given in Table 12-4:

Table 12-3 Description of the designed loading conditions– Large Cruise Vessel

NAME	Description
LD20	100% Consumables max. Draught
LD23	50% Consumables
LD25	10% Consumables
LD33	20% HFO, 100% PW, 20%GW
LD35	100% HFO, 20% PW, 100%GW

Table 12-4 Loading condition details– Large Cruise Vessel

NAME	Dead Weight	Ballast water	Trim	HEEL	GM	Bending moments	Shear Forces
LD20	14878.20 t	0.00 t	-0.05 m	0.20 °	3.30 m	75.58 %	91.74 %
LD23	9360.65 t	601.42 t	-0.11 m	0.27 °	2.87 m	65.72 %	96.04 %
LD25	7918.54 t	1370.74 t	-0.08 m	0.30 °	2.82 m	52.22 %	96.76 %
LD33	10531.70 t	601.42 t	-0.21 m	0.25 °	2.84 m	68.55 %	96.15 %
LD35	13098.40 t	963.58 t	0.17 m	0.21 °	3.26 m	76.90 %	92.41 %

As requested by the business model 1500 t of future growth have been assumed and added to the loading conditions. This growth margin enables the ship to compensate any likely weight increase during the life time. Table 12-5 shows the appropriate loading conditions and the achieved floating positions.

Table 12-5 Loading conditions details with 1500t of future growth

NAME	Dead Weight	Ballast water	Trim	HEEL	GM	Bending moments	Shear Forces
LD200	14954.00 t	0.00 t	0.06 m	0.22 °	3.14 m	78.52 %	91.18 %
LD230	11356.30 t	1097.10 t	-0.19 m	0.26 °	2.93 m	92.78 %	95.01 %
LD250	9676.95 t	1593.37 t	-0.01 m	0.29 °	2.86 m	96.91 %	95.56 %
LD330	12031.70 t	601.42 t	-0.20 m	0.25 °	2.83 m	41.58 %	94.59 %
LD350	14785.50 t	1150.63 t	0.02 m	0.21 °	3.24 m	95.99 %	91.51 %

12.1.10.2 GM Limiting curve

Fig. 12-10 shows the summary of the GM requirements together with the actual loading conditions.

There are various limits shown which all need to be complied with, in particular there is the limit of the intact stability criteria as defined by the IS code 2008, and 3 limits for compliance with the damage stability requirements.

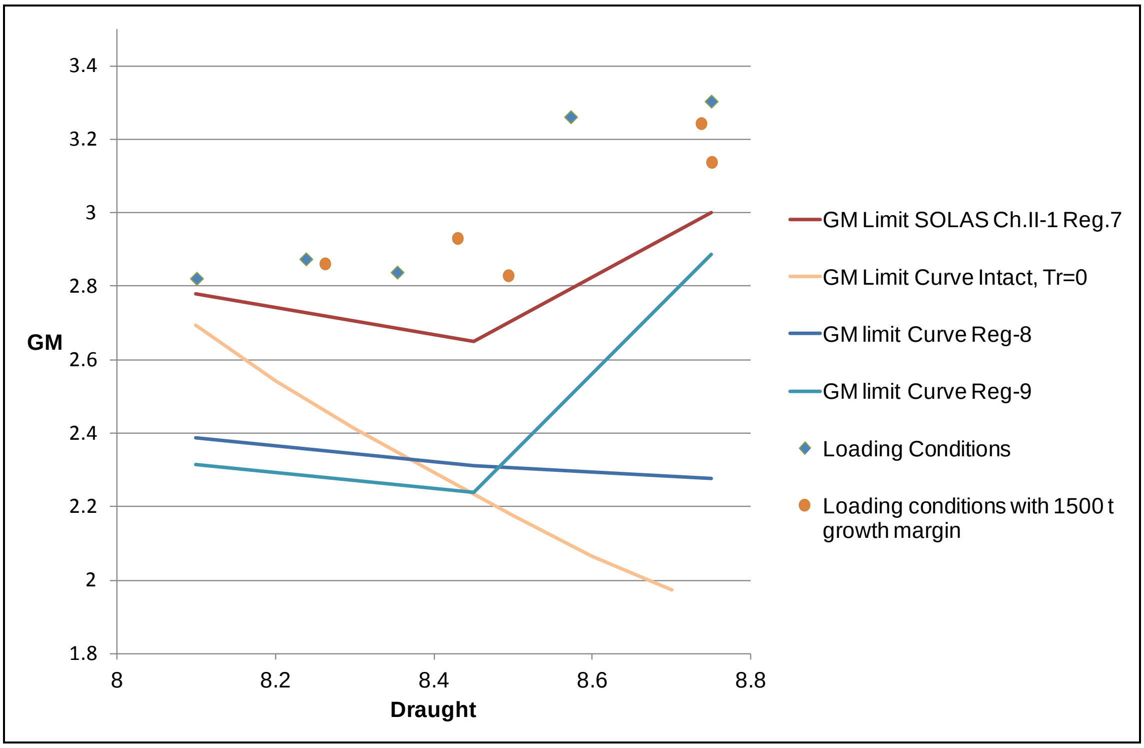


Fig. 12-10 GM Limiting curves

12.1.11 Results of damage stability calculation

12.1.11.1 Attained index A vs R

The following tables show the result of the damage stability calculations according SOLAS II-1.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.511 m
Breadth at the load line	40.800 m
Breadth at the bulkhead deck	40.800 m
Number of persons N1	5422
Number of persons N2	1308

Required subdivision index R = 0.85969

Attained subdivision index A = 0.86255

Table 12-6 Attained index for each initial condition

INIT	DAMTAB	Draught	GM	A/R	A	A*WCOEF	WCOEF
DL	DAMP	8,1	2,78143	1,00383	0,862984	0,0862984	0,1
DL	DAMS	8,1	2,78143	1,01383	0,871582	0,0871582	0,1
DP	DAMP	8,45	2,65466	0,991154	0,85209	0,170418	0,2
DP	DAMS	8,45	2,65466	0,9968	0,856943	0,171389	0,2
DS	DAMP	8,75	3,00165	1,0054	0,864341	0,172868	0,2
DS	DAMS	8,75	3,00165	1,01483	0,872447	0,174489	0,2

Table 12-7 Index according to number of zones.

DAMAGES	W*P*V*S	W*P*V
1-ZONE DAMAGES	0.29997	0.29997
2-ZONE DAMAGES	0.38202	0.38281
3-ZONE DAMAGES	0.16165	0.18965
4-ZONE DAMAGES	0.01798	0.07463
5-ZONE DAMAGES	0.00091	0.01965
A-INDEX TOTAL	0.86255	0.96671

12.1.11.2 SOLAS Reg.II-1/8 and 9.8 results

Although the compliance with the required subdivision index R is for this ship more stringent the damage requirements according regulation 8 need to be complied with.

Table 12-8 shows the GM limits to achieve s>0.9 for all damage cases according regulation 8.3.

Table 12-8 GM limits for s>0.9 acc. Reg. 8.3

Draught	MINGM
8.10 m	2.388 m
8.45 m	2.311 m
8.75 m	2.275 m

Regulation 9 requires a continuous double bottom throughout the ship. However in the compartments 15, 16 and 18 this requirement cannot be met. Therefore calculations for bottom damages according regulation 9.8 have been made showing that all cases of bottom damage will be survived with s=1, see Table 12-9.

Table 12-9 GM limits for S=1 acc. Reg. 9.8

Draught	MINGM
8.10 m	2.314 m
8.45 m	2.238 m
8.75 m	2.887 m

The corresponding GM limiting curves are shown in Fig. 12-10.

12.2 Ship #2 Small Cruise Ship

12.2.1 Business Model

As the basis for the design of this ship a business model has been agreed with the operator to define the basic parameters which need to be fulfilled. These parameters and the business model will be kept unchanged throughout the design process and also during further design studies during a later stage of this project.

The vessel is designed as a worldwide operating cruise vessel for itineraries of a range 9-21 days.

The cruise ship is oriented for cruises in arctic and antarctic regions. Passengers experience is focused on observation and exploration.

The ship is “destination oriented”:

- Main public areas located on upper decks for enhanced observation
- experience
- Unique restaurant for full day service
- Large scenic observation lounges
- No theatre, no casino, no pool

Following main parameters are to be kept to maintain the business model of this vessel:

1. Number of persons on board: 478 (316 passengers and 162 crew)
2. Pax Accomodation as follow:
    a. 158 Total pax cabins
    b. 316 Total pax lower berths
    c. Outside cabin ratio 100%
    d. 3 Suites
    e. 4 Window cabins
    f. 151 Balcony cabins
    g. Balcony cabins ratio (97%)
3. Crew accommodation as follow:
    a. 84 Total crew cabins
    b. 162 Total crew berths
    c. 2 Captain Class cabins (single)
    d. 2 Senior Officer cabins (single)
    e. 12 Officer cabins (single/double)
    f. 68 Crew cabins (double/triple/quadruple)
4. Space utilization details for public and service spaces :
    a. One Pax Restaurant with 320 seats and abt.650m^2 with integrated galley
    b. Abt.1400 m^2 of other internal public spaces
    c. Abt. 1250 m^2 of outside public spaces
    d. One exploration bar
    e. One Explorer Lounge
    f. One SPA Area
    g. One Gym
    h. One embarkation area to RIBS
    i. One public area with:
    j. Expedition area
    k. Conference room
    l. Shop & internet Bar
    m. Hospital

n. Abt. 30m^2 for pantry
o. One laundry of abt.140m^2
p. One refrigerated garbage store
q. Abt. 320m^2 for provisions
r. Abt. 320m^2 for technical spaces

5. 3 pax lifts connecting all passenger decks
6. 3 service lifts (all connecting passenger decks e 1 of them connecting laundry also)
7. Longitudinal service corridor without any watertight door to connect provision embarkation area, provision stores, and laundry area
8. Tank capacities
   a. Marine Gas Oil 550 m^3
   b. Lube Oil 30 m^3
   c. Potable water 310 m^3
   d. Heeling water 180 m^3
   e. Ballast/Waste wat. 630 m^3
   f. Technical water 80 m^3
9. Deadweight 1240t at design draught
10. One bow thruster and one aft thruster (1200 KW each) with controllable pitch propeller type
11. Fresh water production system capable to produce 240t/day
12. Waste water treatment system capable to treat 114m3/day of black water and 119m3/day of gray water
13. Four Diesel generators of 2575KW each
14. Propulsion system with 2x3500KW electric motors and shaft lines
15. Trial speed of 17knots at T=5.10m, calm water, and propulsion motors each developing 2850KW at the motor output flange
16. Operational profile: as an average 360 days per year in service, whereof 36% in port and 64% in navigation.

12.2.2 General Description of the Ship

This sample ship is a design of a small cruise ship designed for exploration cruises worldwide with capacity of 478 persons onboard. The design of the vessel complies with all relevant international rules and regulations which are in force at the beginning of 2014.

Life saving appliances are provided for 478 persons onboard for long international voyage. The vessel is a mono hull design with three main vertical zones and watertight subdivision below the bulkhead deck including partial bulkheads on the bulkhead deck.

Passenger cabins are located in three decks, crew cabins are located in five decks.

The vessel has a diesel-electric type propulsion plant located in two watertight compartments. Two electric motors, connected to shaft line, are separated by a longitudinal watertight bulkhead.

The ship has following main characteristics:

Length over all	~128 m
Length between perpendiculars	113.7 m
Subdivision length	125.8 m
Breadth	20.0 m
Subdivision draught	5.3 m
Height of bulkhead deck	7.23 m
Number of passengers	316
Number of crew	162
Gross tonnage	11800 GT
Deadweight	1240 t
No of pax cabins	159
GT/Stateroom	74.8
GT/Lower Bed	38.7
Service speed	16 knots
Trial speed	17 knots
Installed propulsion power	7000 kW
Installed power of main engines	10300 kW

12.2.3 Regulations

The design complies with all relevant IMO rules and regulations applicable for ships with keel laying after 1 January 2014, which includes following codes:

1. SOLAS1974 as amended, including probabilistic damage stability and “Safe Return to Port” (SOLAS2009)
2. Intact Stability Code (IS Code 2008)
3. ICE rules (Ice Class 1C)
4. Load line Convention
5. MARPOL, including fuel oil tank protection

12.2.4 General Arrangement

The following figures show the General Arrangement plan:

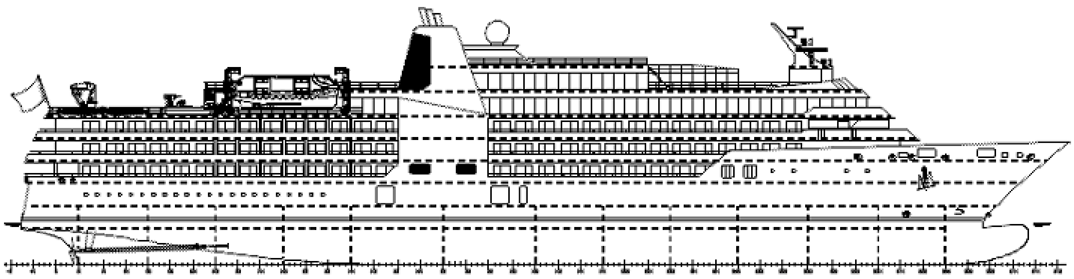


Fig. 12-11 Profile view – Small Cruise Vessel

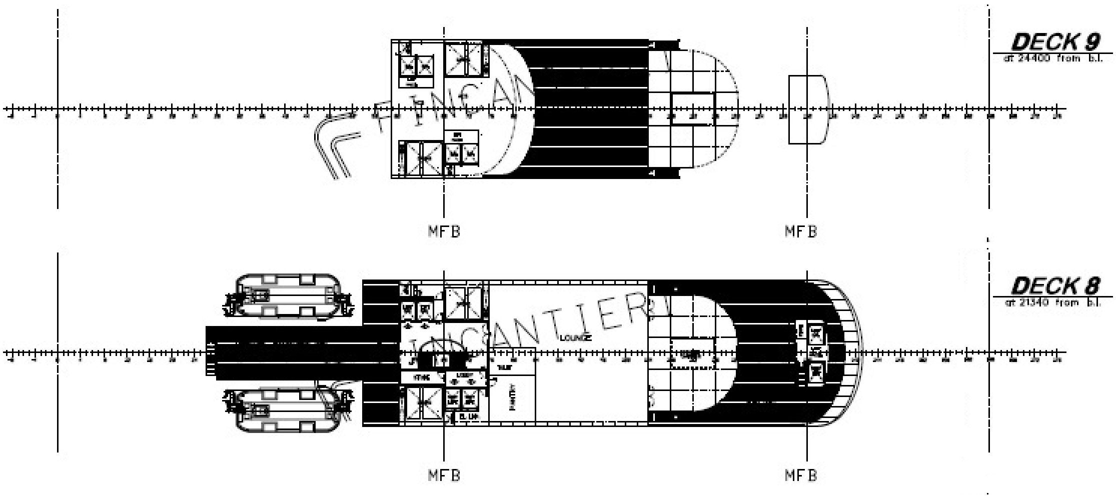


Fig. 12-12 Deck 8 – 9 – Small Cruise Vessel

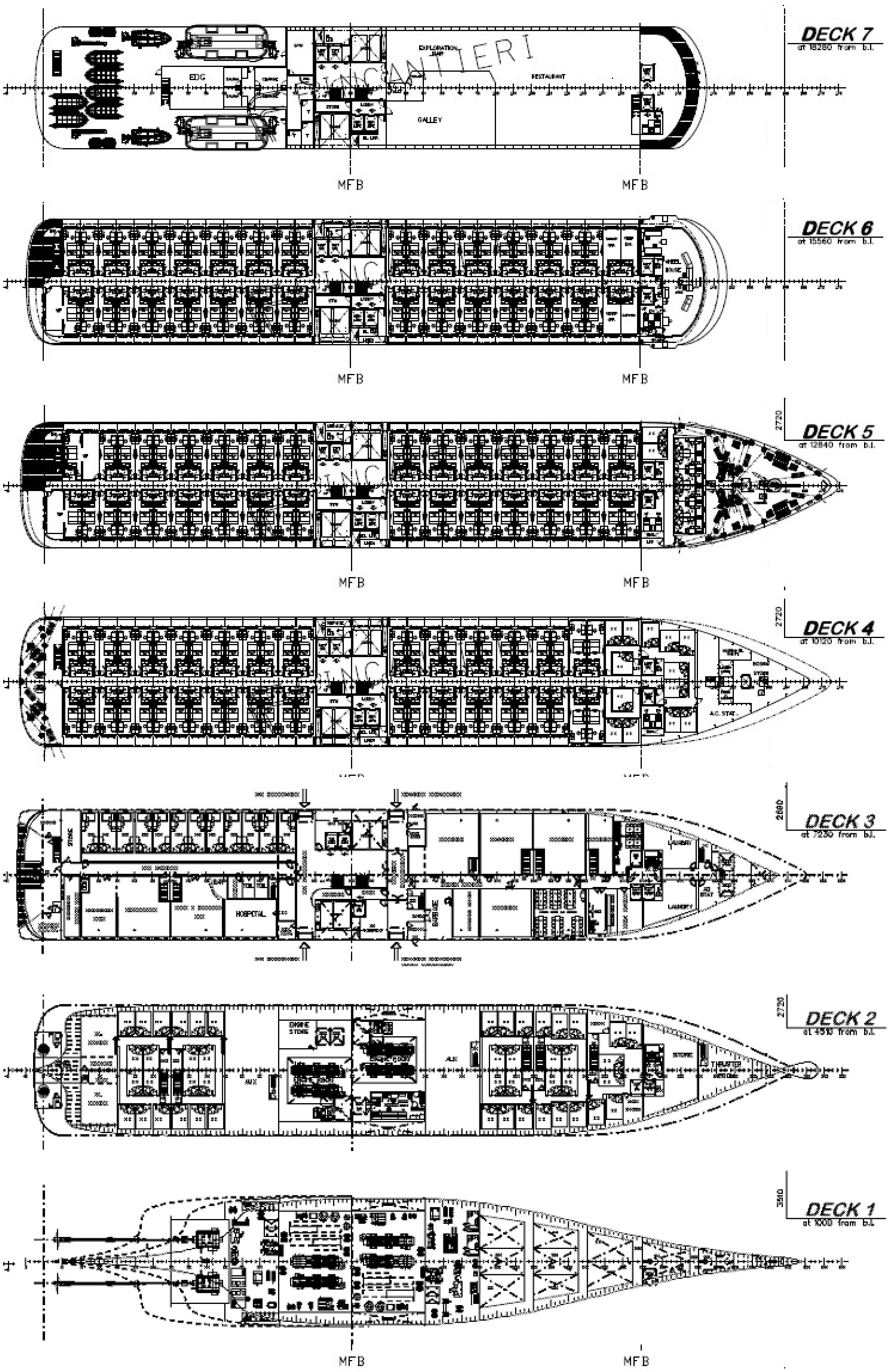


Fig. 12-13 Decks 1 – 7 – Small Cruise Vessel

12.2.5 Hullform

The ship has a conventional modern hull form of a twin screw vessel with bulbous bow and slender skeg and transom stern.

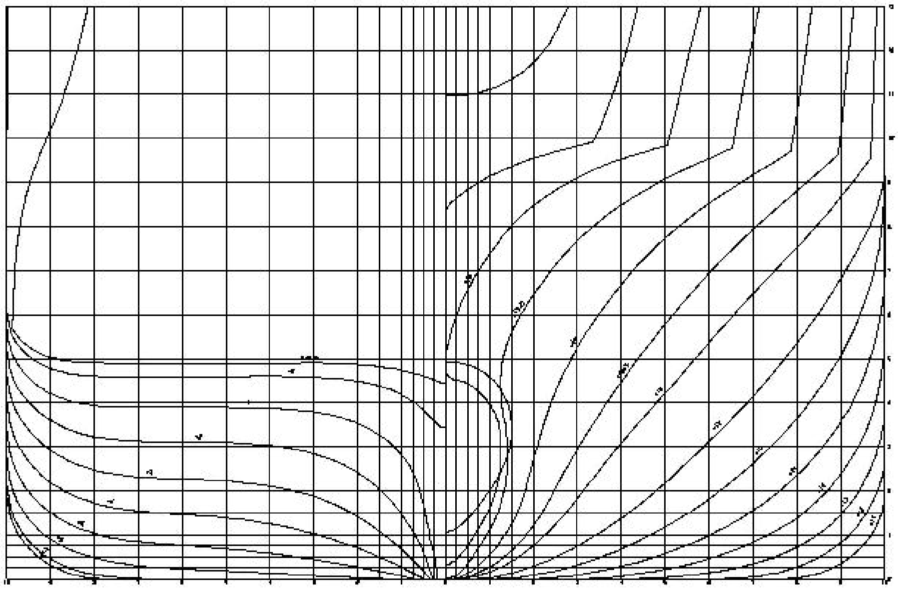


Fig. 12-14 Bodyplan – Small Cruise Vessel

12.2.6 Engine configuration

The engine configuration is based on a diesel-electric concept with 4 GEN-SETS.
The engine plant is designed to deliver the full load (propulsion at service speed and hotel load) with three main engines running on maximum 90% MCR and without sea margin. The hotel load required in port should be covered by one engine only.

With four engines running at 85% of MCR the ship is able to reach the maximum speed (17 knots) with a sea margin of 15%.

The anticipated hotel load is 2000 kW in port and 2800Kw in navigation under tropical conditions.

Scrubbers are not necessary because of using MGO only. The usage of MGO only is an owner requirement due to the fact that the local rules of a small island in the Antarctic region do not allow the presence of HFO on board.

12.2.7 Tankplan

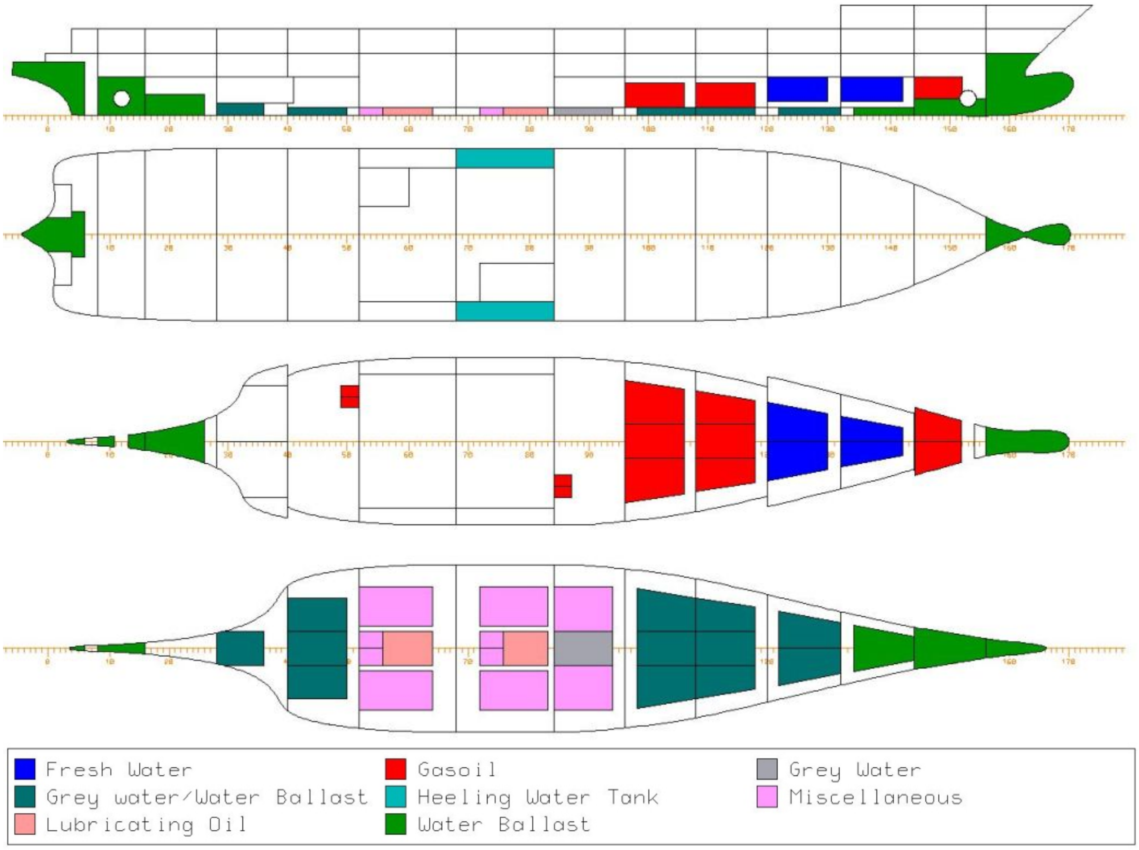


Fig. 12-15 Tankplan – Small Cruise Vessel

The following capacities are achieved for the various purposes:

Table 12-10 Tank capacities – Small Cruise Vessel

Description	RHO t/m^3	Volume m^3	Requirement m^3	Delta m^3	Weight t
Marin Gas Oil	0.880	584	550	34	514
Potable Water	1.000	315	310	5	315
Lube Oil	0.900	43	30	13	39
Heeling Water	1.000	182	180	2	182
Ballast/Grey water	1.025/1.000	707	630	77	725/707
Technical water	1.000	107	80	27.3	107
Miscellaneous tanks	1.000	129	100	28.7	129

12.2.8 Subdivision

Following subdivision is used for damage calculations:

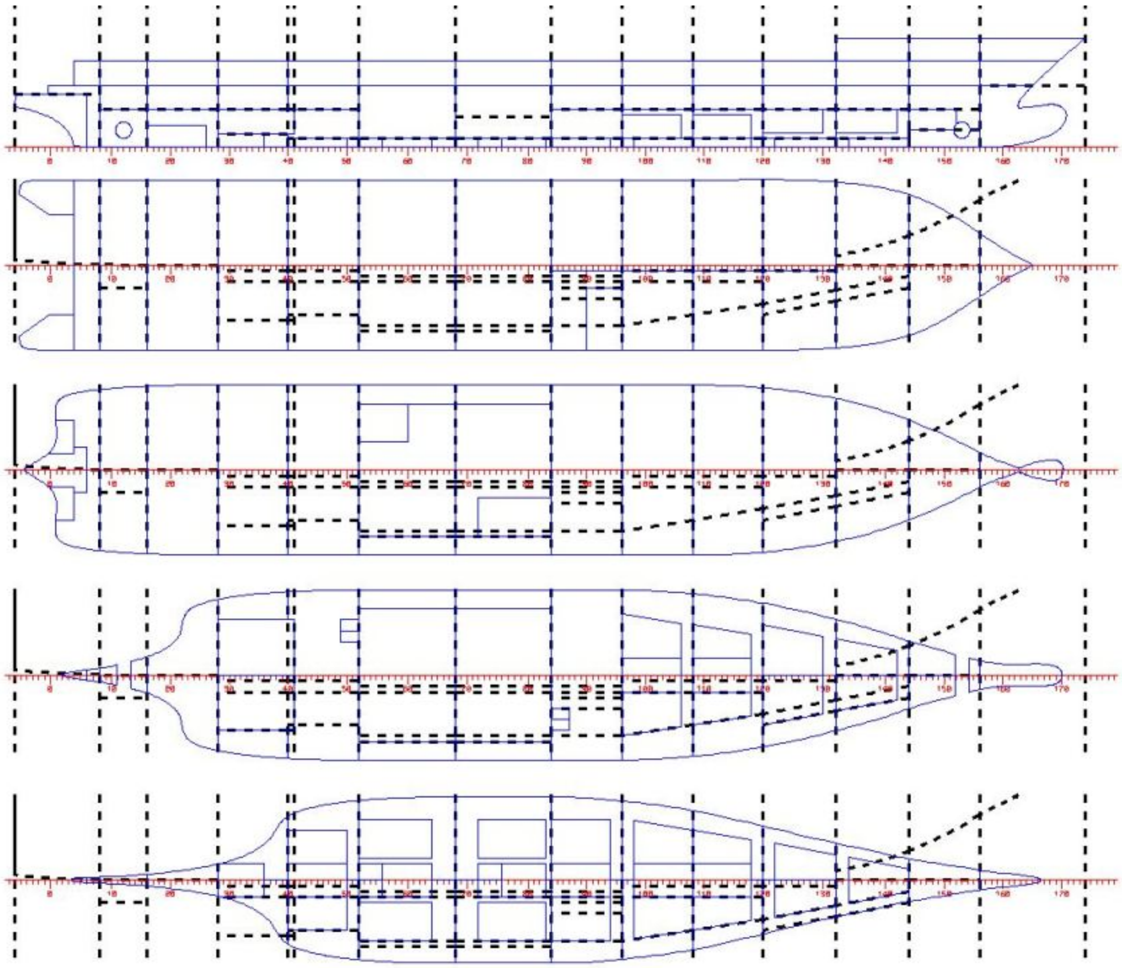


Fig. 12-16 Subdivision used for calculations – Small Cruise Vessel

12.2.9 Hydrodynamics

12.2.9.1 Speed power performance

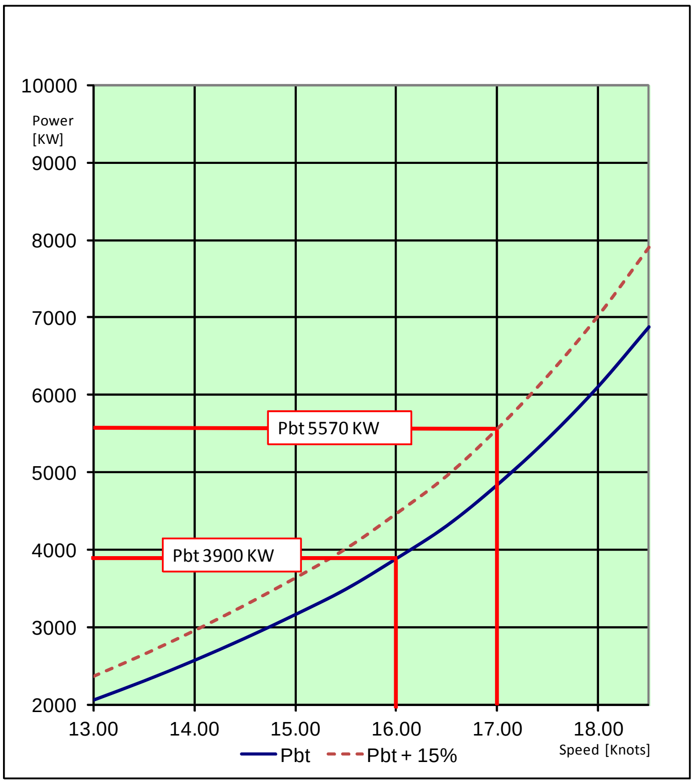


Fig. 12-17 Speed power performance – Small Cruise Vessel

12.2.9.2 Manoeuvrability

The ship is equipped with 1 bow thruster and 1 stern thruster of 1200 kW each to maintain manoeuvrability at the required wind speed in the worst direction.

Under the given wind speed the ship will be able to keep its position without the help of tugs.

12.2.10 Intact stability

12.2.10.1 Loading conditions

Table 12-11 and Table 12-12 show the loading conditions designed for further examination of the sample ship:

Table 12-11 Description of the designed loading conditions – Small Cruise Vessel

NAME	Description
LD01	Contractual deadweight
LD02	10% Consumables
LD03	100% Consumables max. Draught
LD04	ICE Condition

Table 12-12 Loading condition details – Small Cruise Vessel

NAME	Dead Weight	Ballast water	T	Trim	HEEL	GM
LD01	1240 t	81.1 t	5.09 m	0.04 m	0.0 °	1.38 m
LD02	903 t	201.9 t	4.92 m	0.11 m	0.0 °	1.32 m
LD03	1670.3 t	391.8 t	5.30 m	-0.21 m	0.0 °	1.57 m
LD04	1503.8 t	113.9 t	5.19 m	0.26 m	0.0°	1.38 m

12.2.10.2 GM Limiting curve

The following diagram, Fig. 12-18 shows the summary of the GM requirements together with the actual loading conditions.

There are various limits shown which all need to be complied with, in particular there is the limit of the intact stability criteria as defined by the IS code 2008, and 2 limits for compliance with the damage stability requirements.

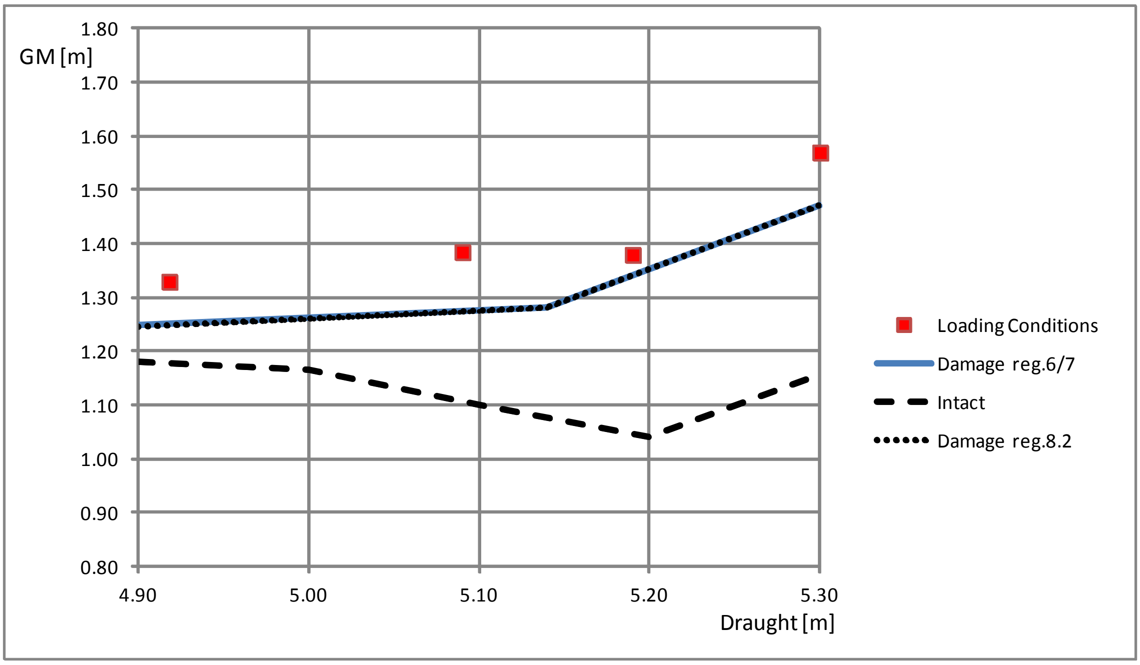


Fig. 12-18 GM Limiting curve – Small Cruise Vessel

12.2.11 Results of damage stability calculation

Attained index vs R

Table 12-13 and Table 12-14 show the result of the damage stability calculations according SOLAS II-1.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.798 m
Breadth at the load line	20.000 m
Breadth at the bulkhead deck	20.000 m
Number of persons N1	478
Number of persons N2	0

Required subdivision index R = 0.69781

Attained subdivision index A = 0.72023

Table 12-13 Attained index for each initial condition – Small Cruise Vessel

INIT	Draught	GM	A/R	A	A*WCOEF	WCOEF
DL	4.900	1.250	1.04	0.72777	0.14555	0.2
DP	5.140	1.280	1.03	0.72127	0.28851	0.4
DS	5.300	1.470	1.03	0.71625	0.28650	0.4

Table 12-14 Index according to number of zones.

DAMAGES	W*P*V*S	W*P*V
1-ZONE DAMAGES	0.36601	0.36601
2-ZONE DAMAGES	0.31606	0.38807
3-ZONE DAMAGES	0.03817	0.14676
4-ZONE DAMAGES	0.00000	0.05364
A-INDEX TOTAL	0.72023	0.95448

12.2.11.1 SOLAS Reg. 8 and 9 results

The following table shows the GM limits to achieve s>0.9 for all damage cases according regulation 8.2-3

Table 12-15 GM limits for s>0.9 acc. Reg. 8.3

Draught	MINGM
4.90 m	1.246 m
5.14 m	1.280 m
5.30 m	1.470 m

Based on this data the reg.8.2-3 is more stringent as with same value of GM for the initial conditions the reg.7 has some margin.

The vessel complies with reg.9 as a continuous double bottom with a height of 1m (B/20) or more has been placed along the ship.

12.3 Ship #3 Baltic cruise ferry

12.3.1 Business Model

The vessel is intended to operate on a short international voyage in Baltic Sea as a passenger ship with 3280 seagoing persons on board.

Following main parameters are to be kept to maintain the business model of this vessel:

1. 720 passenger staterooms.
2. 3060 passengers
3. 220 crew berths where all cabins are outdoor type. 68 double person crew cabin and 82 single crew/officer cabins.
4. 1200 trailer lane meters on deck 3
5. 1350 car lane meters on deck 5
6. Public rooms on decks 5,6,7,8,9
7. Two public staircases and four passenger lifts connecting all passenger decks
8. Crew mess and lounge on deck 10
9. Storage rooms and workshops according ship size
10. Two service lifts
11. Tank capacities
    a. Liquefied natural gas 800 m^3
    b. Gas oil 1200 m^3
    c. Potable water 1600 m^3
    d. Heeling water 800 m^3
    e. Grey water 1200 m^3
12. Deadweight 5450 tonnes in water having a density of 1,005 ton/m^3
13. The speed of the vessel with an output power maximum 85 % of MCR of the main engines and 15 % sea margin shall be 24.0 knots.
14. Two bow and two stern thrusters

12.3.2 General Description of the Ship

The vessel shall be a modern RoPax ferry for operation on the Baltic Sea with size of 60000 GT. The vessel is rated for a maximum of 3280 persons onboard and able to carry trucks, cars, and road trailers on short international voyages. This consists of 220 crewmembers and 3060 passengers.

The vessel is mono hull design with bulbous bow and a transom stern. The ship has six main fire zones and watertight subdivision below the watertight bulkhead deck.

The ship has diesel-mechanical propulsion with medium speed dual fuel engines driving two CP propellers. Two medium-speed diesel engines are connected via a reduction gearbox for both shaft lines. These equipment’s located in separate watertight compartments for each shaft line.

The ship has following main characteristics:

Length over all	~251 m
Length between perpendiculars	232 m
Subdivision length	250,96 m
Breadth	29,00 m
Subdivision draught	7,20 m
Height of bulkhead deck	10,10 m
Number of passengers	3060
Number of crew	220
Gross tonnage	60000 GT
Deadweight	5450 t
No of pass cabins	720
No of crew cabins	150
Trailer lane meters on deck 3	1200
Car lane meters on deck 5	1350
Installed power of main engines	54 960 kW

12.3.3 Regulations

The design complies with all relevant IMO rules and regulations applicable for ships with keel laying after 1 January 2014, which includes the following:

1. SOLAS 1974 as amended and as applied for short international voyages, including probabilistic damage stability and Safe return to Port. In the context of Safe return to Port-safety concept the operation area is the Baltic Sea with max. 12 hours operation.
2. Damage stability requirements of EC Directive 2003/25/EC(“Water on Deck) with 4 metres wave height
3. Intact Stability Code (IS CODE 2008)
4. International Convention on Load Lines, 1966 (LL 1966) as amended
5. International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL 1973) as amended including Annex IV(without certification), V and VI
6. ILO, Marine Labour Convention 2006

12.3.4 General Arrangement

Fig. 12-19 shows the General Arrangement plan.

In the bigger RoPax ships there are possibilities to utilize spaces forward of machinery spaces and below the bulkhead deck to different purposes. Typically there is located big room (lower hold) inside the B/5 limits for either for cargo or stores. The choice between these two different uses of this available space is typically made subject to the operation profile of the ship.

The sample ship 3 is chosen to be overnight passenger RoPax operating in the Baltic Sea with a high passenger capacity. The high passenger capacity implies s that there is a bigger need of spaces for stores and provision in the ship compared to a ship that is dedicated more to transport cargo. Environmental requirements to operation in the operation area will be tightened during the coming years and these raised also demands for the machinery solution of the ship. The environmental issues can be tackled either by the choosing of more green fuel such as LNG or clean the exhaust gas by scrubbers.

To fulfil these different demands the available space below the bulkhead deck is chosen to utilize for LNG tanks and stores instead of long lower hold for the cargo in this case. The advantage of long hold for storage purposes is that the area can be operated without open the water tight doors. The machinery using LNG as bunker fuel is an advanced solution. By this solution the ship will fulfil all coming environmental requirements and at same time machinery maintenance demands become lower for different components due the cleaner fuel.

The Baltic overnight ferries typically have very short time in port and it is not practical to operate long lower hold as the loading of this space is quite slow. For these reasons it is already quite a common practise in the Baltic area that there are no lower holds for the cargo in this kind of ship.

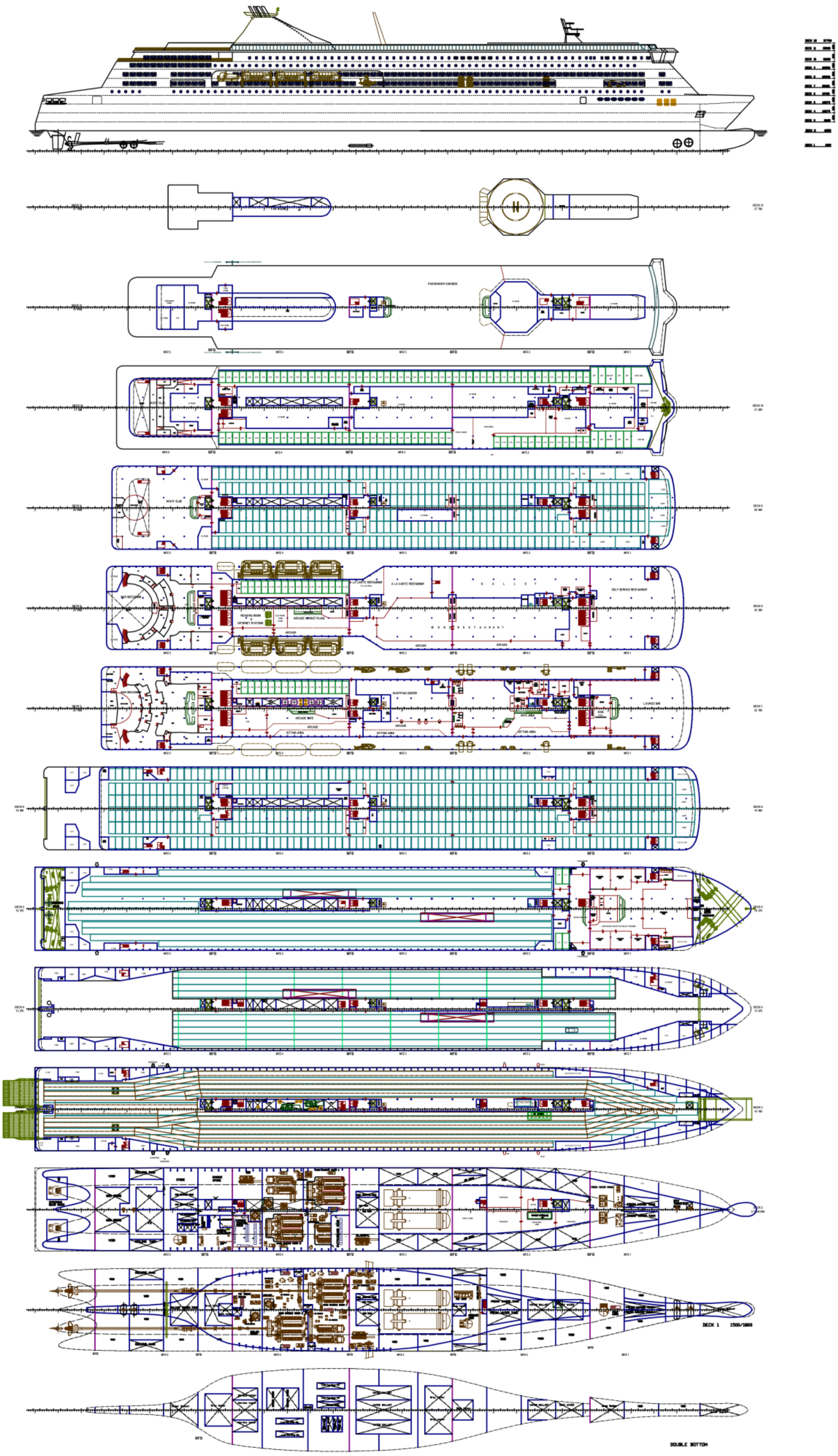


Fig. 12-19 General Arrangement – Baltic RoPax

12.3.5 Hullform

The ship has modern hull form with bulbous bow and transom stern as shown in Fig. 12-20.

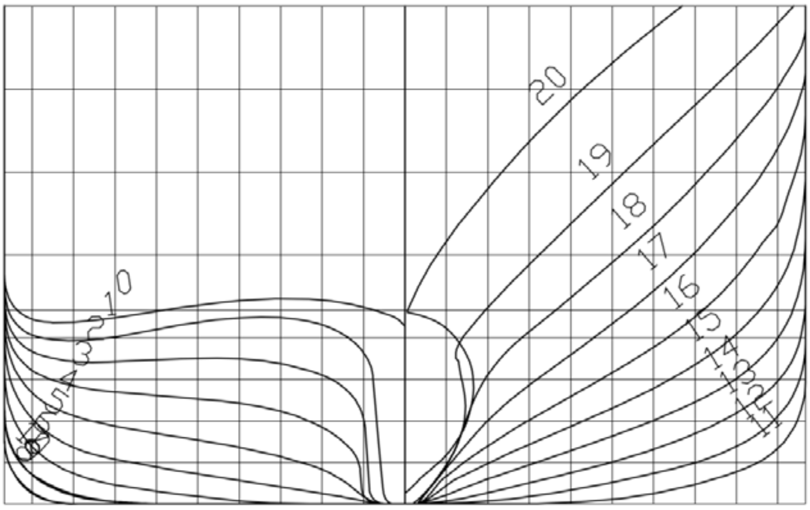


Fig. 12-20 Body plan – Baltic RoPax

12.3.6 Engine Configuration

The ship has diesel mechanical propulsion. Each CP-propeller is driven by two medium-speed dual fuel engines via a reduction gearbox. The engines and reduction gear box for each shaft line are located different watertight compartments. Four auxiliary dual fuel engines each driving a generator for to supply power for the ships network. These auxiliary engines are also divided into two different watertight compartments.

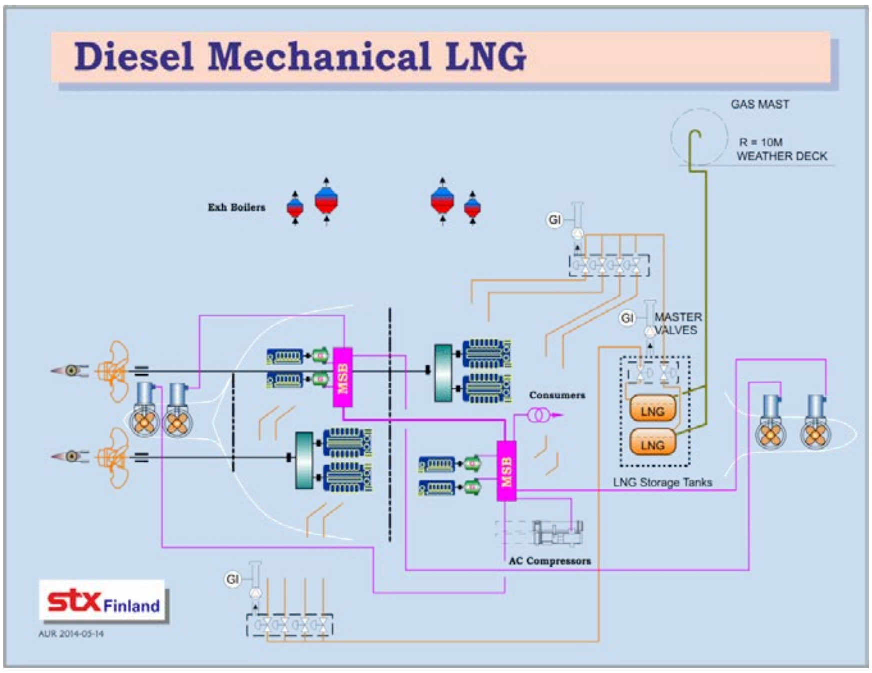


Fig. 12-21 Machinery lay out

12.3.7 Tank Plan

The following figure shows the tank arrangement of the sample ship.

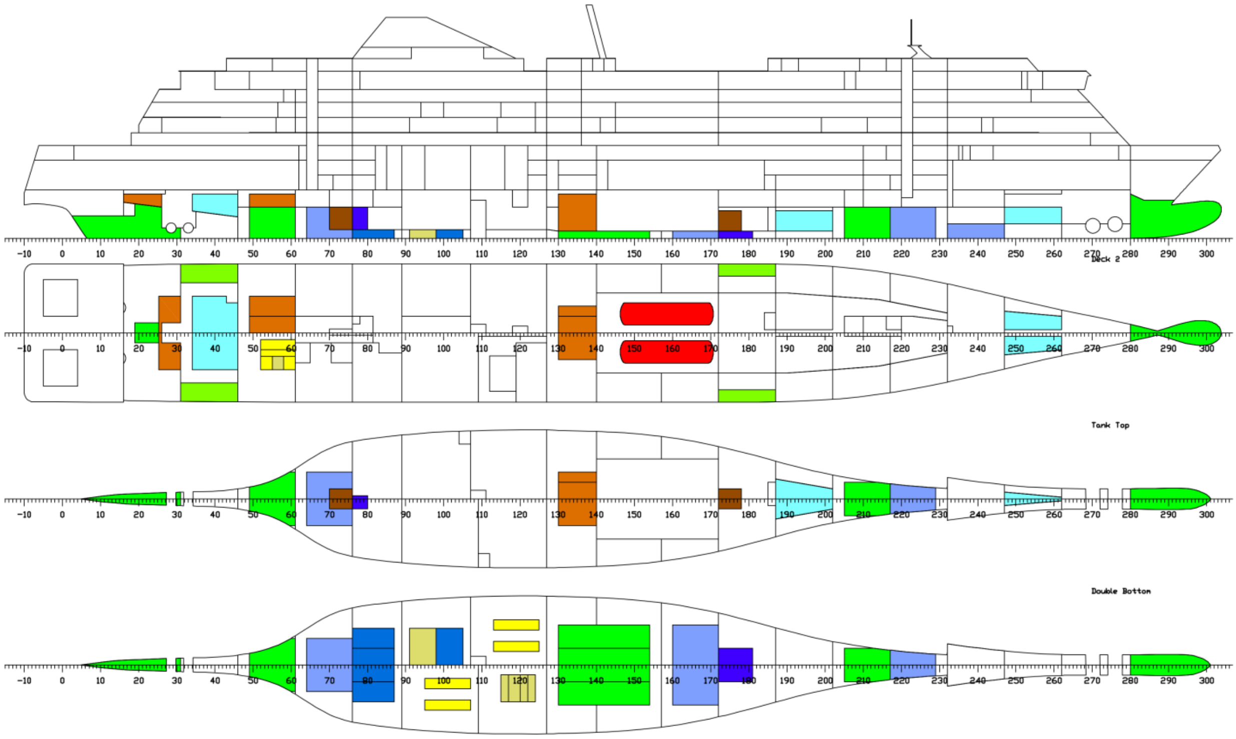


Fig. 12-22 Tank plan – Baltic RoPax

The following capacities are achieved for the various purposes with this layout:

Table 12-16 Tank capacities – Baltic RoPax

Purpose	Description	Rho	VNET
PW	Potable Water	1,000 t/m^3	1650 m^3
HWB	Heeling Water	1,000 t/m^3	890 m^3
WB	Ballast Water	1,005 t/m^3	2080 m^3
SW	Technical Water	1,000 t/m^3	290 m^3
LO	Lubrication Oil	0,900 t/m^3	175 m^3
GO	Gas Oil	0,860 t/m^3	1290 m^3
LNG	Liquefied Natural Gas	0,470 t/m^3	830 m^3
MIS	Miscellaneous	Varies	150 m^3
GW	Grey Water	1,000 t/m^3	1270 m^3
BLW	Black Water	1,000 t/m^3	175 m^3

12.3.8 Subdivision

The vessel has been divided into 19 watertight compartments below the bulkhead deck, i.e. the car deck. The car deck (deck 3) has been assumed as horizontal subdivision preventing progressive flooding upwards to reach above deck 3. Thus watertight car deck has been utilized in the attained index in damage cases, when damage will extend only up to bulkhead deck. Above the bulkhead deck the aft and fore corners (P+S) has been divided into a few separate partial watertight compartments to increase the residual stability after damage.

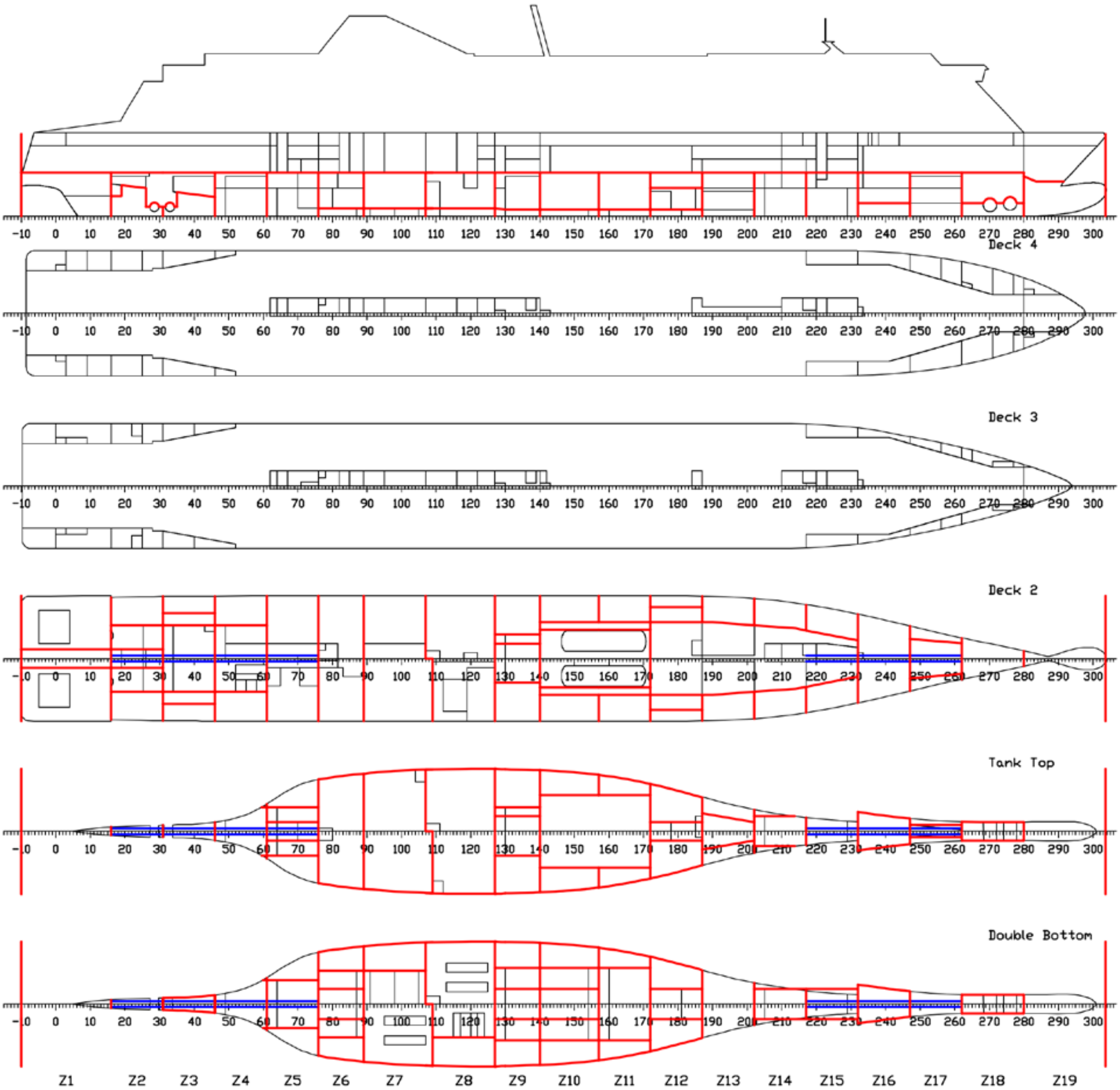


Fig. 12-23 Subdivision – Baltic RoPax

12.3.9 Hydrodynamics

12.3.9.1 Speed Power Performance

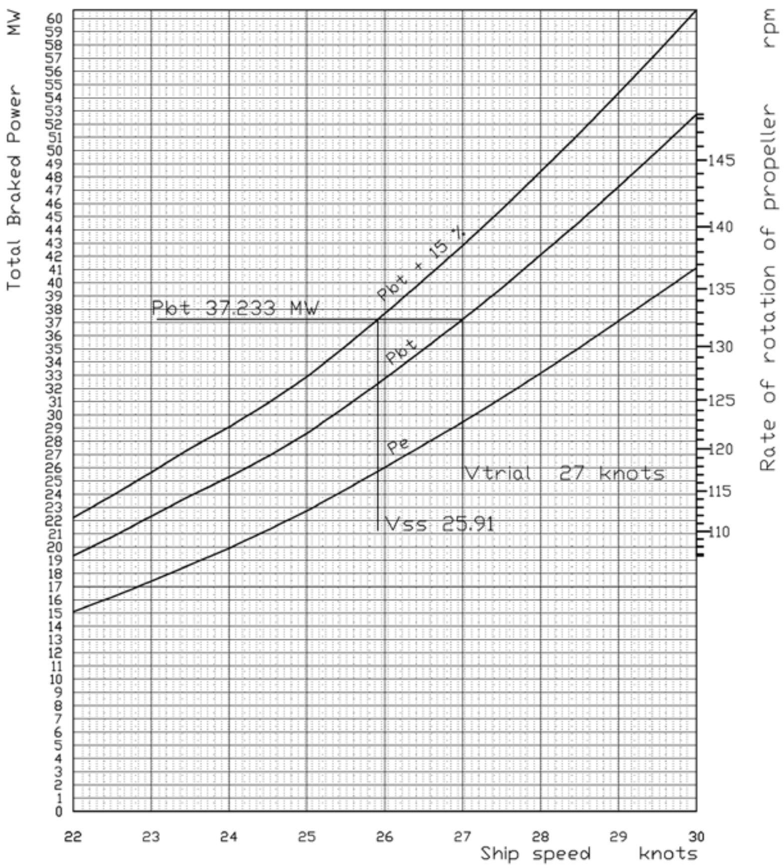


Fig. 12-24 Speed-Power performance – Baltic RoPax

12.3.10 Intact Stability

12.3.10.1 Loading Conditions

The design deadweight of the vessel is 5450 tonnes when it is loaded at a design moulded draught of 7,00 meters in water having a density of 1.005 ton/m3.

Design Deadweight of the vessel shall be assumed to be as follows:

Trailers	2150 t
Cars	350 t

Passengers and crew	300 t
LNG	350 t
MGO	250 t
Lubrication oil	100 t
Fresh water	750 t
Technical water	150 t
Heeling water	400 t
Ballast water	50 t
Grey water	50 t
Provision and stores	350 t
Miscellaneous	200 t
Total deadweight	5450 t

The following loading conditions are studied:

L1 – Trailers+cars specified DWT=5450 t
L2 - Trailers+cars specified, Arrival
L3 - Departure, passengers no cargo 100% bunkers
L4 - Arrival, passengers, no cargo, 10% bunkers
L5 - As L1 + Ice load
L6 - As L2 + Ice load
L7 - As L3 + Ice load
L8 - As L4 + Ice load
L9 – 50% Cargo/bunkers/stores

Table 12-17 Loading condition details – Baltic RoPax

NAME	DWT	WB	Draught	Trim	GM
L1	5450	50.00	7.00	-0.02	2.76
L2	4018	175.00	6.75	-0.03	2.58
L3	2900	50.00	6.55	0.04	2.77
L4	1775.51	432.51	6.35	-0.01	2.73
L5	5720.7	50.00	7.04	0.01	2.66
L6	4664.42	555.72	6.86	-0.01	2.56
L7	3448.21	327.51	6.65	0.00	2.67
L8	2499.42	885.72	6.48	0.01	2.69
L9	3298	50.00	6.62	-0.02	2.65

12.3.10.2 GM Limiting Curve

The following diagram, Fig. 12-25, shows the summary of the GM requirements with actual loading conditions. There are shown limit curves of the intact and damage stability.

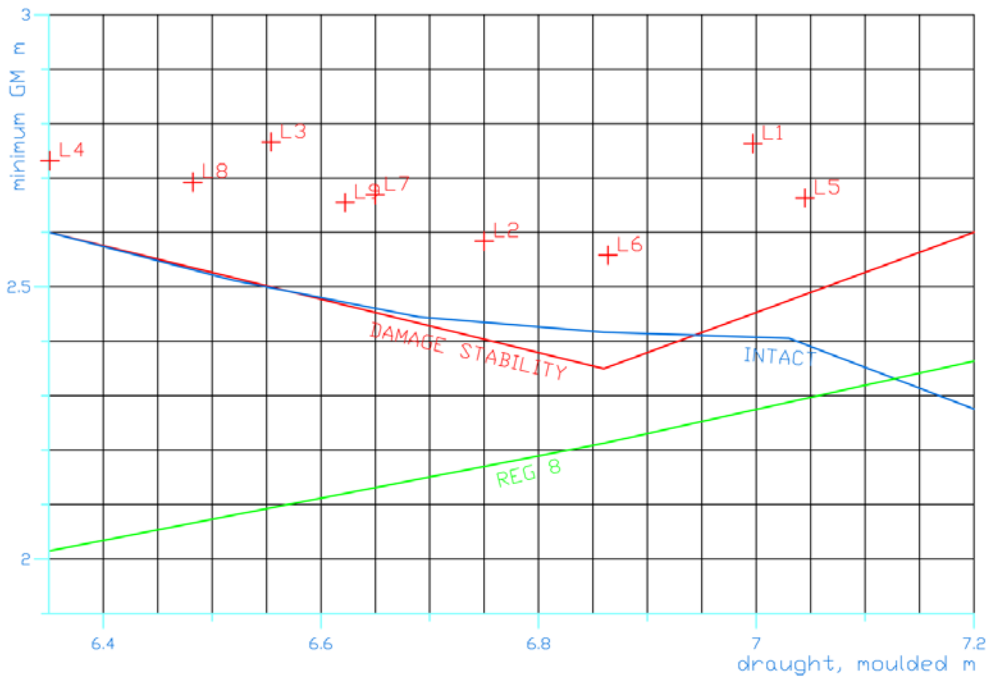


Fig. 12-25 GM Limiting curves – Baltic RoPax

12.3.11 Damage Stability

12.3.11.1 Attained Index vs Required Index

Damage stability calculations according SOLAS2009 (MSC.216(82)) have been carried out.

Required index according to regulation 6:

$$R = 1 - \frac{5000}{Ls + 2{,}5N + 15225}$$

where:

Ls = Subdivision length
N = N1 + 2* N2
N1 = persons in lifeboats
N2 = persons in excess of N1

For the sample ship 3 the required index has been calculated with following parameters:

Subdivision Length	250.96 m
Number of persons N1	984
Number of persons N2	2296

Required subdivision index for the ship 3: R= 0.830

The attained index has been calculated according the SOLAS 2009 and explanatory notes MSC.1/Circ. 1226 and the results are summarised in Table 12-18.

Table 12-18 Summary of attained index A calculations

INIT	Draught	GM	A/R	A	A*WCOEF	WCOEF
DL	6.35	2.60	1.106	0.91806	0.09181	0.1
DL	6.35	2.60	1.1082	0.91982	0.09198	0.1
DP	6.86	2.35	1.0163	0.84350	0.1687	0.2
DP	6.86	2.35	1.0241	0.85002	01700.	0.2
DS	7.20	2.60	1.0118	0.83983	0.16797	0.2
DS	7.20	2.60	1.0167	0.84382	0.16876	0.2

Attained subdivision index port side A =0.85694

Attained subdivision index starboard side A =0.86150

Attained subdivision index for the ship 3: A=0.85922

12.3.11.2 SOLAS Reg. II-1/8 and 9.8 Results

In addition to fulfil the required subdivision index the passenger ships have special requirements that have to be met. Regulation 8 includes special requirements concerning ships stability and regulation 9 includes requirements concerning double bottom.

According to regulation 8 the passenger ship is to be capable of withstanding damages along the side shell. It is required that t "si" shall not be less than 0.9 for the defined damages for the three loading conditions used in the index calculation. Assumed extent of minor damage shall be as follows:

Longitudinal extent 0.03Ls or 3.0 m = 7.53 m
Transverse extent 0.1B or 0.75 m = 2.90 m
Vertical extent up to ds + 12.5 m = 19.70 m

Table 12-19 shows the GM limits to achieve si>0.9 for all damage cases.

Table 12-19 Minimum GM values according to Reg. 8.3

Draught	MINGM	GM in index calculation
6.35m	2.015m	2.60m
6.86m	2.213m	2.35m
7.20m	2.364m	2.60m

The sample ship 3 fulfils Regulation 9 concerning the height and extent of the double bottom and therefore it is not required to analyse double bottom damages as presented for unusual bottom arrangements according to Regulation 9.8.

12.4 Ship #4 Mediterranean RoPax

12.4.1 Purpose and General Standard of the Vessel

The Vessel is designed to operate on short international voyages with 1700 (1600 passengers and 100 crew) seagoing persons. The vessel is built for transporting cars, road trailers and other light roro cargo.

The Vessel and its systems are designed for world-wide traffic, and tailored for a year round service in Mediterranean Area.

12.4.2 General Description

The Vessel is designed as a roro passenger ship with a bulbous bow, transom stern, two semi-balanced rudders and two propellers. The Vessel's main cargo deck is designed for easy and fast cargo handling. Loading and unloading takes place via stern and bow. Three decks 3, 5 and 7 are arranged for carriage of roro vehicles and considered as special category spaces arranged in two horizontal fire zones.

The Vessel's hull beneath Deck 3 is divided by transversal and longitudinal watertight bulkheads into compartments with house tanks, main propulsion machinery, electric plant, air condition cooling plant, provision stores, sanitary arrangements, bow thruster room and steering gear room.

Emergency helicopter landing area is arranged on Deck 13.

Accommodation is to be situated in the superstructure. Public spaces are to be situated on Decks 8 and 9. Passenger cabins are located at Decks 10 and 11, and crew quarters on Decks 11 and 12. The wheelhouse is located on Deck 11.

Assembly stations are located inside on decks 8 & 9.

Heeling tank pairs are fitted for compensation of list due to asymmetric load and wind.
Manoeuvring is to be aided by two bow thrusters and a stern thruster.

12.4.3 Main Dimensions and free heights

Length overall	185.00 m
Length between perpendiculars abt.	172.40 m
Breadth moulded max.	31.00 m
Depth moulded to the Main Deck abt	9.60 m
Depth moulded to the Upper Deck	15.45 m
Design draught moulded	6.60 m
Scantling draught moulded	6.70 m
Gross Registered Tonnage	43 000 UMS

Free Heights:

Main trailer Deck 3	5.00 m
Upper trailer Deck 5	4.80 m
Upper car deck 7	3.00 m
Passenger public spaces, generally	2.50 m
Passenger accommodation excl. toilet units	2.10 m
Crew areas, and galleys generally	2.10 m
Crew accommodation excl. toilet units	2.10 m

12.4.4 Typical turnaround time / operating profile:

Main sailing times: around 6 hrs. One longer trip per week
Main sailing trips: abt 90 miles
Channelling: 0,25 to 0,75 hrs
Stay in ports: 1,5 to 3 hrs.

Actually this operating profile could also apply to RoPax operating in West Atlantic area.Profile may vary a lot in the Mediterranean operations (variable distances between ports) and there is no specific architectural feature dedicated to Mediterranean operation.

This ship is designed for a polyvalent use with more freight in winter and more pax in summer with some additional pedestrian passengers, who are sailing during the day. The number of berth available fits to the average number of passengers on boards of 62.5% of the passenger capacity, which has been used in the risk model to calculate the potential loss of life.

12.4.5 Deadweight and Capacities

Example distribution of the deadweight at the design draught with homogenous trailer cargo:

Trailers deck 3 & 5	4500 t	at +2 m/deck
Cars, Upper Car Deck	350 t	at +0.7 m/deck
Passengers with luggage	170 t	
Crew with effects	11 t	
Heavy fuel oil	600 t	
Diesel oil	80 t	
Lubricating oil	55 t	
Heeling water for 4000 t.m	350 t	
Potable Fresh Water	300 t	
Technical fresh water	50 t	
Sprinkler water	50 t	
Miscellaneous stores	150 t	
Provision and shop stores	80 t	
Sludge	5 t	
Sewage	5 t	
TOTAL	6755 t	

Fuel capacity corresponds to operating for 7 days.

Capacity of tanks:

Heavy fuel oil storage	600 m^3
Heavy fuel oil daily & settling	4 x 60 m^3
Diesel oil	200 m^3
Potable water	400 m^3
Technical fresh water	60 m^3
Grey Water	150 m^3
Black water	30 m^3
Lubricating oil storage	100 m^3
Dirty oil	30 m^3
Bilge water	90 m^3
Sludge	40 m^3
Cooling water drain	18 m^3
Heeling Water	700 m^3
Sprinkler water tank	50 m^3
Ballast water abt.	2500 m^3

Cargo capacity:

Cars on Upper Deck, 1100 lane meters/231 cars (slot size 4.75 x 2.40 m)

Trailer lanes on Main Deck 3	1200 m
Trailer lanes on Lower Deck 1	1200 m
Total	2400 m

Width of trailer lanes on generally 3.1 m, may be reduced by up to 30 cm in way of walkways, local bulkheads and pillars shown in the General Arrangement.

Passengers and crew Cabins:

Total number of pax cabins:	333
Beds+Pullmans :	994
Total number of crew cabins:	100

12.4.6 Regulations

The Vessel is designed to fulfil the following international regulations:

- IMO, International convention of Safety of Life at Sea SOLAS-1974 as amended and including probabilistic damage stability and Safe return to port

- Intact stability Code (IS Code 2008)

- IMO, LL - 1966, International Convention on Load Lines,

- IMO, MARPOL-1973/78 International Convention for the Prevention of Pollution from Ships. Annexes I, III, IV, V and VI

⇨ Future regulation 7-2.3 of SOLAS II.1 with TGZmax 0.20m and TRange 20deg for each damage case that involves a ro-ro space.

12.4.7 Speed

The Vessel's trial speed and service speed is 22.0 knots at the moulded draught corresponding to the design deadweight with 15 % sea margin on power.

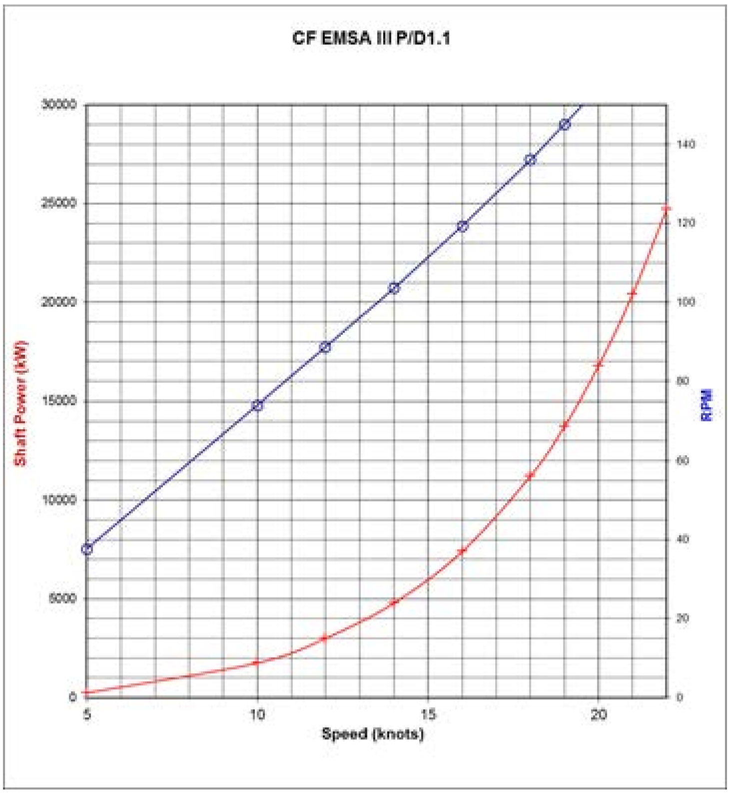


Fig. 12-26 Mediterranean RoPax – Speed/Power curve

12.4.8 Stability and Trim

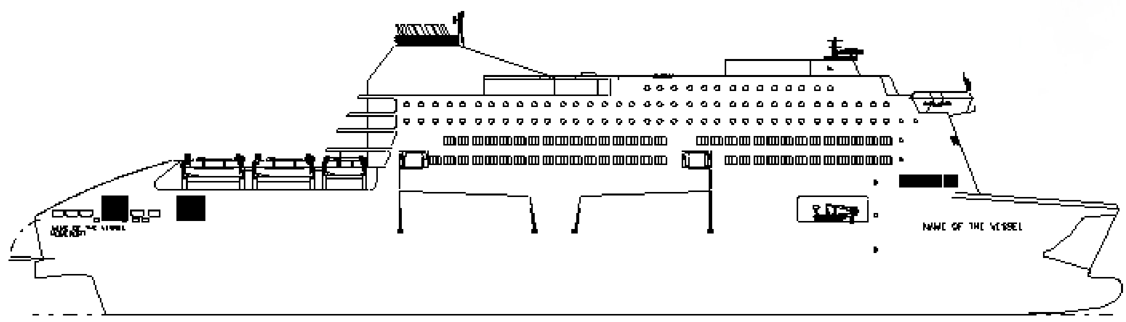
The vessel is designed to sail on about even keel (trim of less than 0.2 m by bow and 0.4 m by stern) when loaded with homogeneous and the design stowage plan cargo according to deadweight distribution given here above for the design draught.

Trim adjustment +/- 1 m at draught corresponding to 50% design deadweight by filling fwd / aft ballast to be checked.

12.4.9 GENERAL ARRANGEMENT

The general arrangement is shown on following figures.

External View



Longitudinal Section

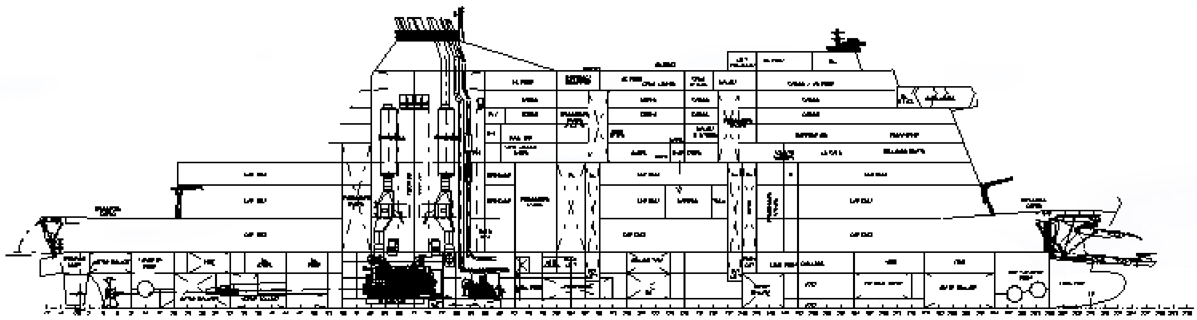


Fig. 12-27 External view and longitudinal section – Mediterranean RoPax

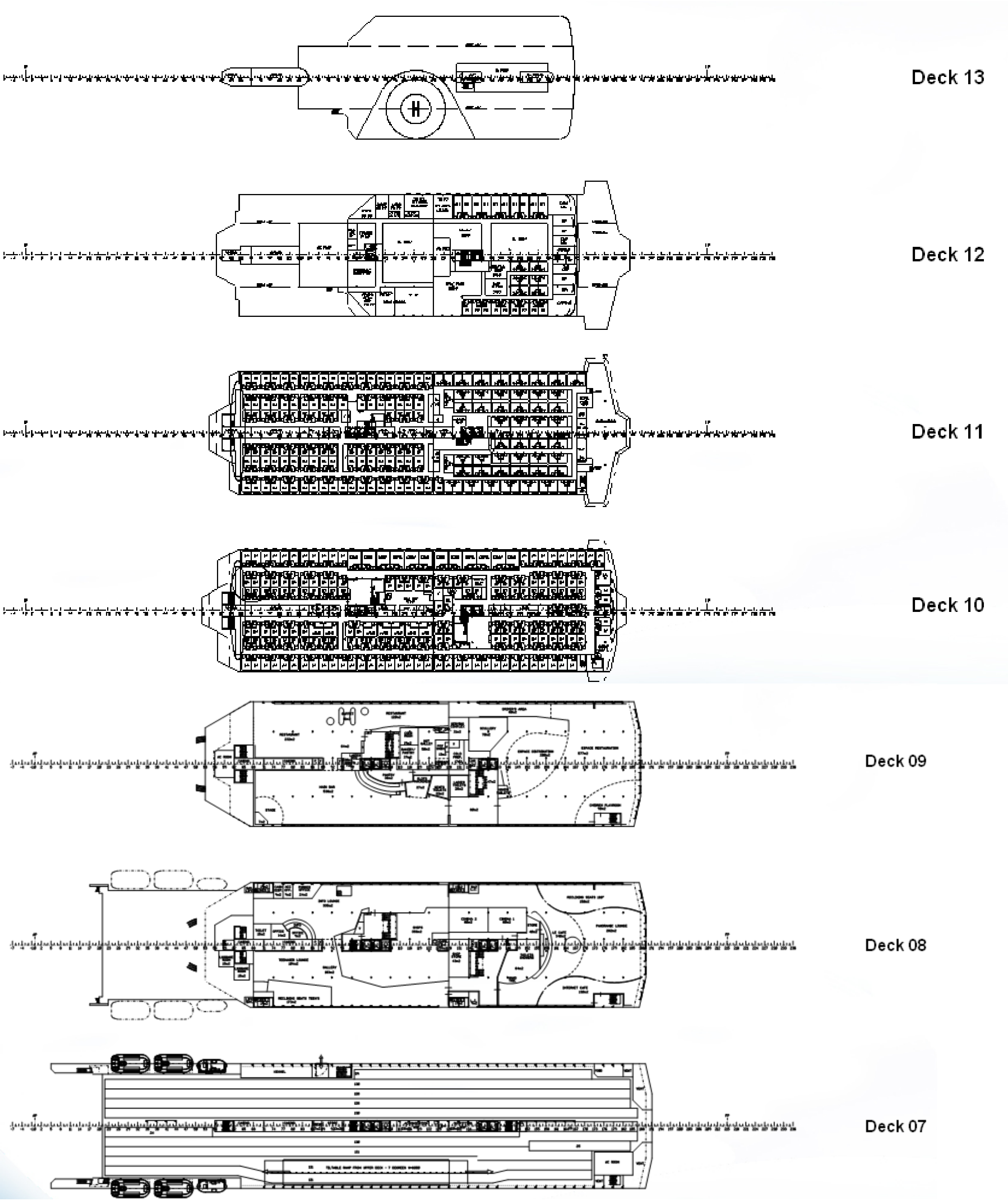


Fig. 12-28 Decks 07 to 13– Mediterranean RoPax

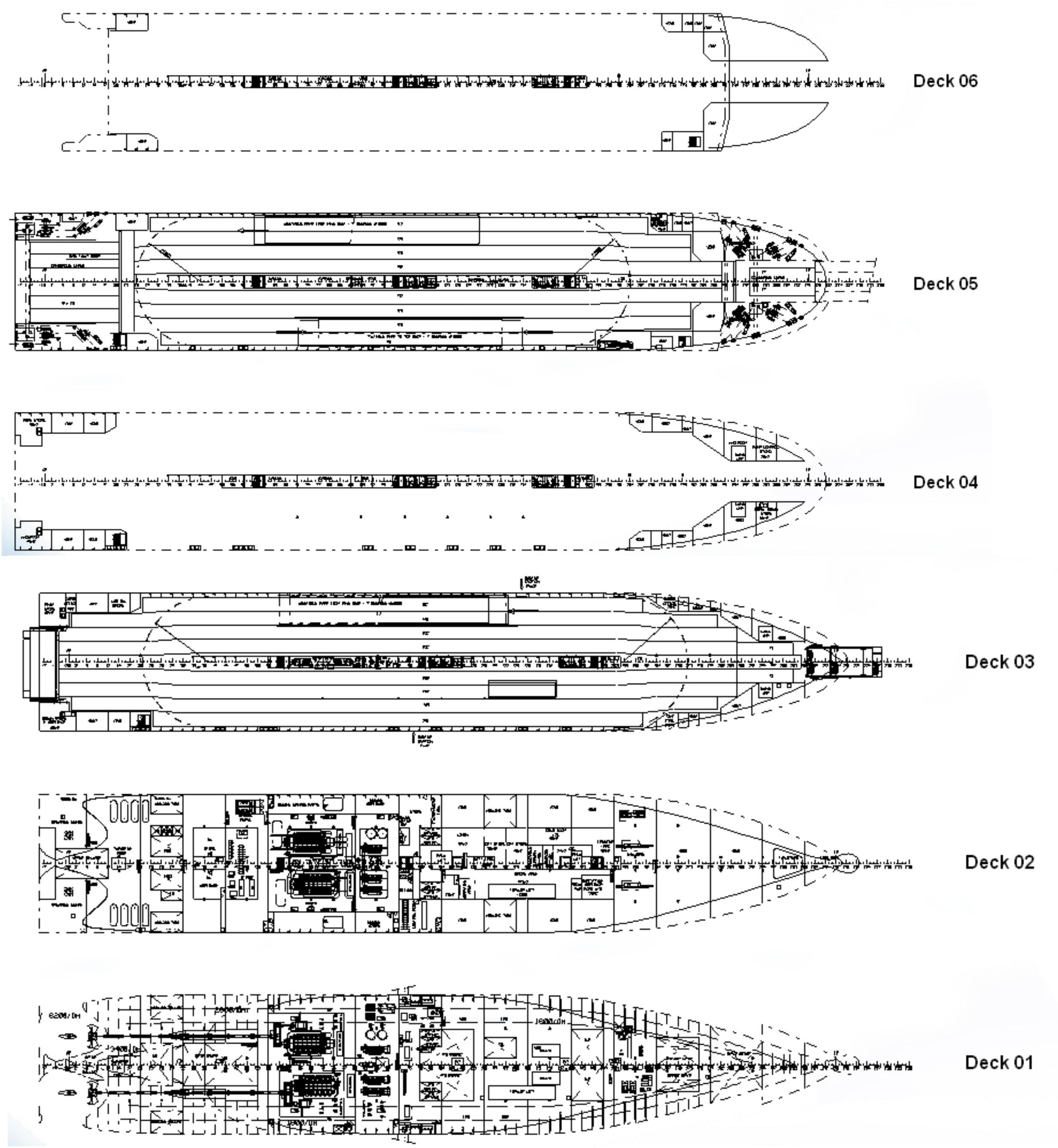


Fig. 12-29 Decks 01 to 06– Mediterranean RoPax

12.4.10 MACHINERY

The ship is designed according to the Diesel mechanical propulsion concept.

The propulsion plant consists of two shaft lines with controllable pitch propeller. Each shaft line is driven by two medium speed Diesel engines via a reducing gear box.

The electrical power is produced by two medium speed diesel generators and two shaft generators.

The heat is produced by two oil fired boilers and four exhaust gas economizers (one on each propulsion Diesel engine exhaust gas system).

The equipment and the fuel oil systems are designed to operate with Heavy Fuel Oil 380 cST at 50°C, (RMH35 according to ISO 8217) and Marine Gas Oil (DMA according to ISO 8217).

Propulsion Plant

The propulsion plant consists of:

4 main diesel engines rated to obtain the defined speed. For guidance 4 x MAN 6L 48/60 at 500 RPM rated at 6900 kW each or equivalent is considered.
2 reducing gear boxes
2 thrust bearings (thrust bearing can be integrated into the reducing gear box)
2 shaft lines
2 controllable pitch propellers

Diesel Generators

Two diesel generators, medium speed, four stroke, non-reversible are provided. For guidance MAN 7L 27/38 or equivalent, rated at about 2200 kW each at 750 RPM are considered.

Two shaft generators.

12.4.11 Capacity plans

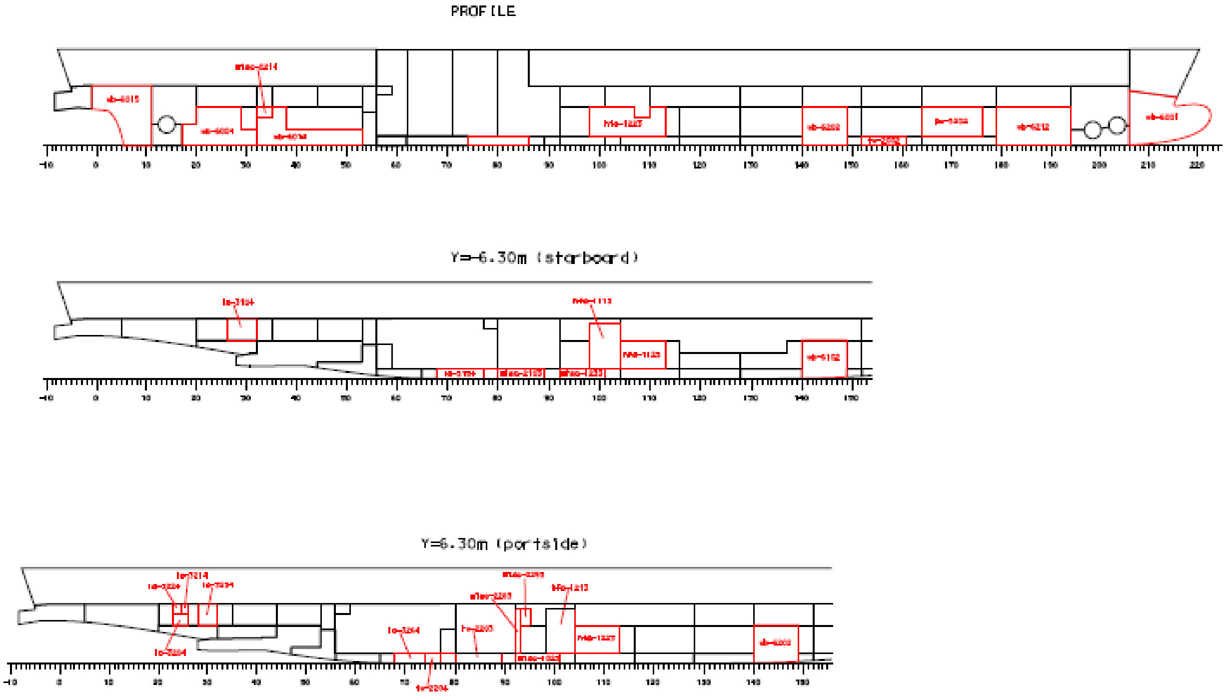


Fig. 12-30 Tank Plan - profile

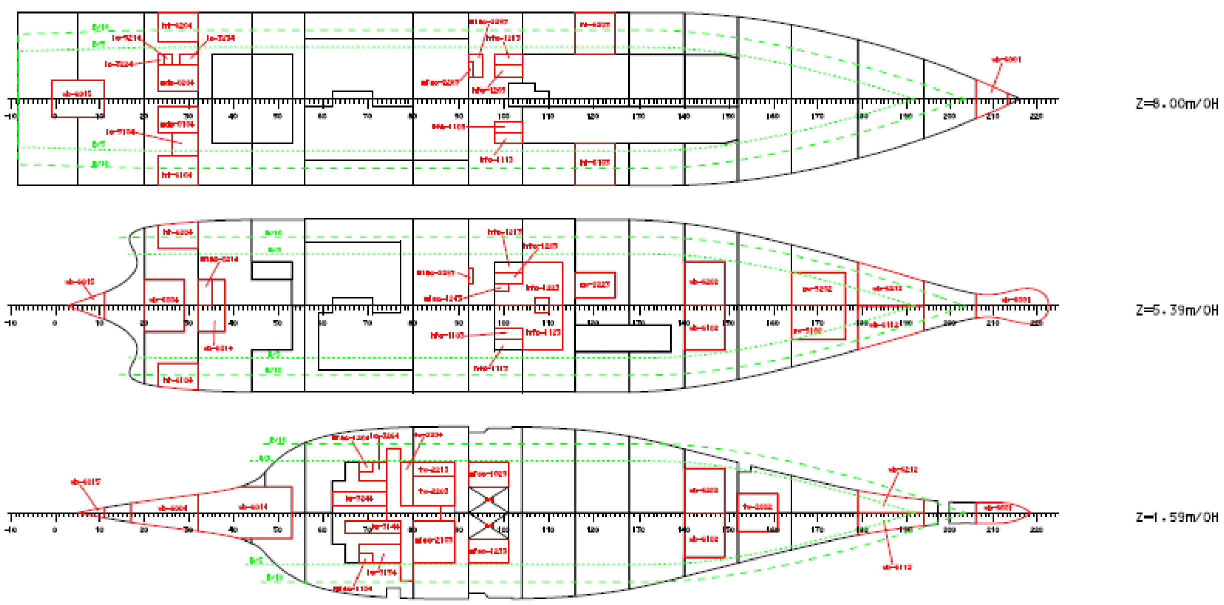


Fig. 12-31 Tank plan– Mediterranean RoPax

12.4.12 LOADING CONDITIONS

Table 12-20 Loading conditions– Mediterranean RoPax

Description	Draft (m)	Trim (m)	GM(corrected) (m)	KG(corrected) (m)
Design DW=6755 t	6.600	-0.007	3.52	14.99
Max Load FB	6.700	0.000	3.61	14.82
Cars and trailers 10 % consumables	6.519	0.001	3.48	15.06
Cars and trailers, 50 % consumables	6.558	0.001	3.48	15.06
No cars and trailers 10 % consumables	5.800	0.000	4.29	14.22

12.4.13 Intact stability

Intact stability is including in the minimum required GM curves shown in Fig. 12-33.

It is seen that the damage stability limit curve is more restrictive than the intact stability one.

12.4.14 Damage stability – (New SOLAS Reg.II-1/7-2.3)

In the context of this EMSA3 study, the calculation has been performed according to the new regulation 7-2.3 of SOLAS II.1 with TGZmax 0.20m and TRange 20deg for each damage case that involves a Ro-Ro space.

Deterministic side damage acc. to SOLAS Reg.II-1/8.2.2

S port = 0. 93745
S starboard = 0. 93745

12.4.14.1 Probabilistic requirements according to SOLAS 2009

Total persons on board used for R calculation : 1700
Total persons in lifeboats used for R calculation : 568
Subdivision length 184.997 m
Breadth at the load line 31.000 m
Breadth at the bulkhead deck 31.000 m

Required subdivision index R = 0.778

Draft / GM : 6.7 / 3.4 6.34 / 3 5.8 / 4.1

Attained subdivision index A = 0.83982

Margin on the index = 0.061

It is to be noted that this initial reserve is a relatively high but it may be useful for a real project to take account for progressive flooding at a later design stage. Any addition of a gas tank of significant size, would also lead to lose some index.

This also reflects the fact that our sample ship is carrying a relatively small number of persons compared to its size. It corresponds to a polyvalent use with more freight in winter and more passengers in summer with some additional pedestrian passengers, who are sailing during the day.

The figure below (Fig. 12-32) shows that there is some loss of attained index in the fore part for 3 zones damages.

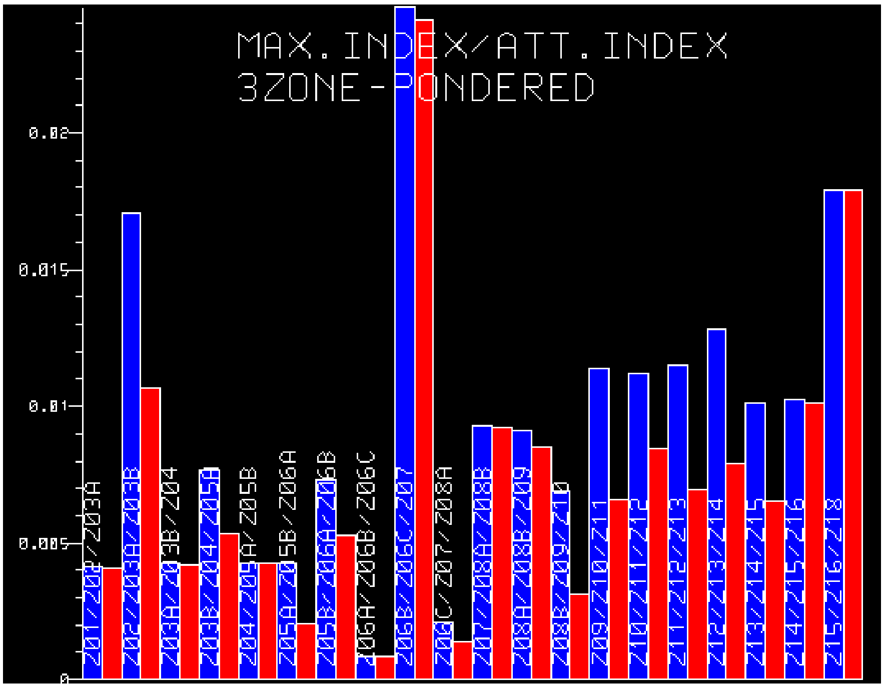


Fig. 12-32 3-Zone damages max index vs attained index

For the continuation of this study and in particular the optimization of attained index, this value of A = 0.840 will be the reference, which will be taken into account for all comparisons. This version used as basis is called “V0”.

12.4.15 GM limiting curves

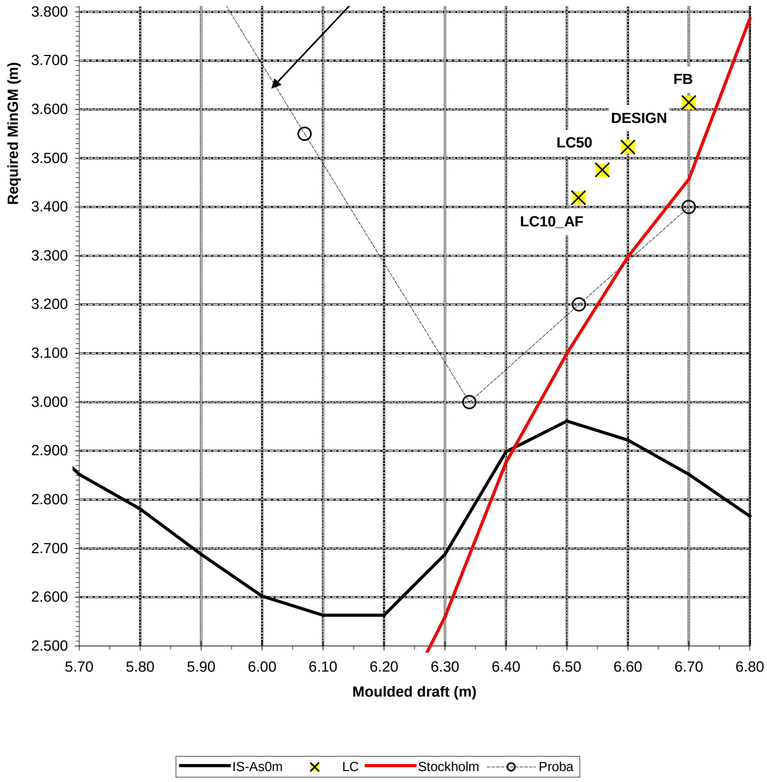


Fig. 12-33 GM limit diagram

12.5 Ship #5 Small ropax

12.5.1 INTRODUCTION

This section describes the basic information about the sample ship number 5, a small RoPax. Small passenger ships have been less researched in previous projects concerned with stability and there is a growing concern that any increase in the R index may unduly penalise small ships.

In selecting a candidate type of small ship, we are presented with a choice between a passenger ship and a RoPax ship. From a technical point of view, it would seem that a RoPax vessel with a large undivided special category space carrying vehicles ought to have a lower survivability compared to a similar passenger ship, and therefore a RoPax vessel would be more suitable for analysing the potential for raising the R index. In addition, the new formulation for the s value from SLF 55 would further lower the A index, potentially making it more difficult to meet an increased R index.

This is of course a qualitative judgement based on experience, and it would not be possible to completely rule out the possibility of a similar passenger ship having inherent design features which would lead to a lower A index compared to a similar RoPax vessel. It may be that a small sensitivity or parametric study would need to be conducted to deal with this issue.

At the first EMSA coordination meeting, it was decided that the small RoPax vessel ought to have a length of around 100 m and have sufficient passengers to trigger the 2 compartment standard for minor damages.

12.5.2 Business Model

The business model for this vessel had to be derived by analysing similar vessel types and their associated routes since there was no clear route or business model among the RoPax operators in the research consortium.

A search was carried out on the Shippax Database for RoPax vessels between 70 and 100 m, built in the last 5 years. Significant numbers of these vessels were double ended RoPax vessels and were discarded. The relevant ones are tabulated below. It should be noted that all the vessels found serve domestic routes do not by default fall under SOLAS, however some operators do choose to build their vessel to comply with SOLAS. Some of the routes would in all likelihood receive some kind of subsidy, and so the commercial case for these vessels is somewhat difficult to evaluate. The Fogo ferry is a KNUD E. HANSEN A/S design that is currently being constructed.

Table 12-21 Overview- some small RoPax ferries in operation

Name	LOA (m)	LBP (m)	B (m)	T (m)	D (m)	L/B	SPEED (knots)	MCR (kW)	GT	DWT (tonnes)	LM (m)	CARS	PAX
Finlaggan	89.90	81.80	16.90	3.50	5.50	4.84	16.50	8000	5626	780	135	85	550
Atlantida	96.94	86.50	18.00	4.60	7.00	4.81	16.40	10604	6820	800		140	750
Landegode	96.00	89.98	17.40	4.20	5.50	5.17	17.00	5200	5695	650	324	120	390
Pasio per Formentera	101.00	86.60	17.00	4.30	6.00	5.09	20.00	9002	6146	850	304	150	800
Fogo	80.90	71.00	17.20	4.00	6.50	4.13	14.00	5100	4437	905	190		200

The route details of the various vessels are shown in the table below:

Table 12-22 Route details of some small RoPax Ferries

Name	Voyage	Turnaround
Finlaggan	1h55m-2h20m	25m-55m
Atlantida	45m-4h	30m-17h15m
Landegode	3h15m	2h-6h15m
Pasio per Formentera	3h30m	16h
Fogo	45m	15m-1h15m

It should be noted that the Atlantida was never put into its intended service, and so the voyage and turnaround times are estimated from the timetable of the replacement vessel. Similarly, the details for the Fogo vessel are estimated from the schedule of the current vessel.

For the vessels above with relatively short turnaround times, they all cease operations at night and so have a longer layover after the final voyage

As can be seen above, there is a significant variation in voyage length and turnaround time among the sample vessels investigated. One trend is that the vessels with the longer layover times tend to have a larger passenger capacity, perhaps balancing passenger numbers against the number of daily voyages.

Based on the above, and taking into account the wishes of the operator, the business case is stated as follows:

- Vessel to be for short international voyages of up to around 4 hours in length
- Deadweight and lane metres are prioritised for commercial revenue purposes
- 600 day passengers accommodated in public spaces only, no cabins

12.5.3 General Description

The sample ship is a small RoPax ferry designed for short international voyages of around 4 hours in duration, with a short turnaround time, and multiple trips per day, as befits a revenue earning route based on carrying trailers.

The main vehicle deck is of sufficient clear height for trailers and has around 400 trailer lane metres of 3.0 m width. The vehicle deck is fitted with 4 sections of hoistable car decks on the port side for increased flexibility. Bow and stern doors are fitted for drive through operation, though only single tier loading is supported.

Accommodation for 600 passengers is arranged on 2 decks in public spaces, no cabins are provided due to the short voyage duration. Lifeboats arranged for at least 30% of total number of persons onboard as per SOLAS requirements for short international voyages.

Propulsion is provided by a diesel mechanical system consisting of 2 main engines driving 2 controllable pitch propellers via a gearbox. 2 PTOs are provided as well as 2 auxiliary engines for the electrical load.

Main characteristics as follows:

Length over all	100.596 m
Length between perpendiculars	95.50 m
Subdivision Length	98.526 m
Breadth	20.20 m
Subdivision Draught	4.90 m
Height of Bulkhead Deck	7.10 m
Number of Passengers	600
Number of Crew	25
Gross Tonnage	7900 approx
Deadweight	1487 tonnes
Trailer Lane Metres	400 approx
Service Speed	18 knots
Installed power main engines	2 x 3600 kW
Installed power auxiliary engines	2 x 632 kW

12.5.4 Regulations

The design complies with all relevant IMO rules and regulations for ships at the time of writing, in particular:

- SOLAS 1974 as amended, including probabilistic damage stability (SOLAS 2009)
- Intact Stability Code (IS Code 2008)
- Load Line Convention

It is assumed that the vessel is not operating in a SECA area, so scrubbers or LNG fuel are not part of the design. Scrubbers would certainly affect the stability of the design, however switching to LNG or MGO would have less impact, but it is beyond the scope of this project to investigate these options. It is considered that this vessel design allows it to operate both outside and within a SECA given that switching tank designations between HFO and MGO or low sulphur HFO would have no effect on the subdivision aspects of the design. LNG fuel is not part of this design. Whilst scrubbers would certainly affect the stability of the design, it has been considered beyond the scope of this project to investigate such options. The assessment of this design assumes it is not operating in a SECA.

Ballast water treatment is not explicitly considered here, but there should be sufficient space in the vessel to include this if required.

12.5.5 General arrangement

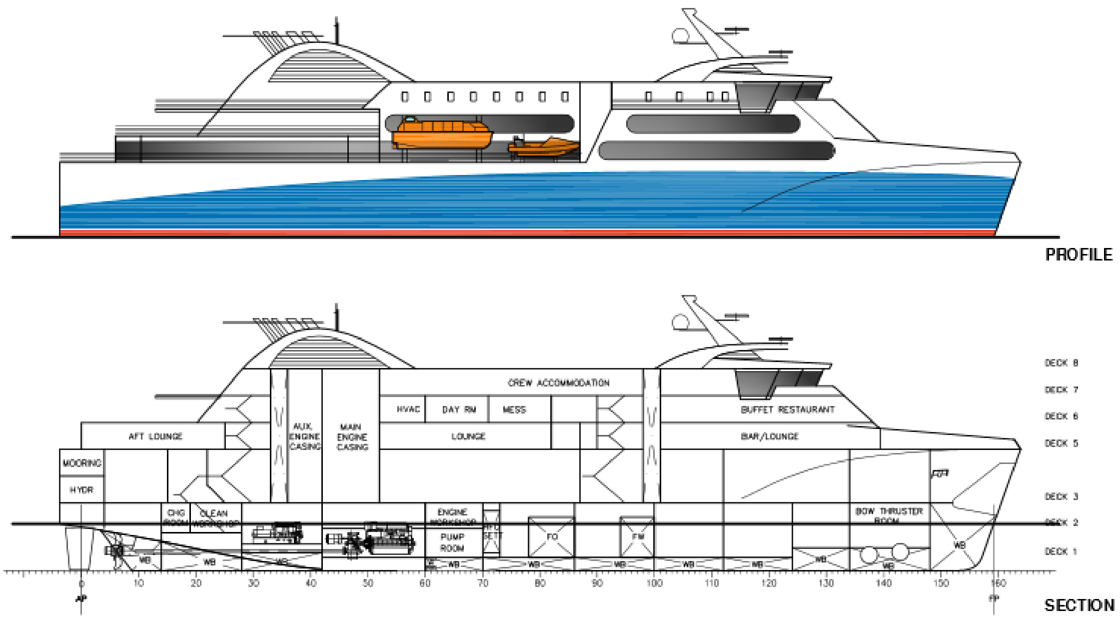


Fig. 12-34 Profile – Small RoPax

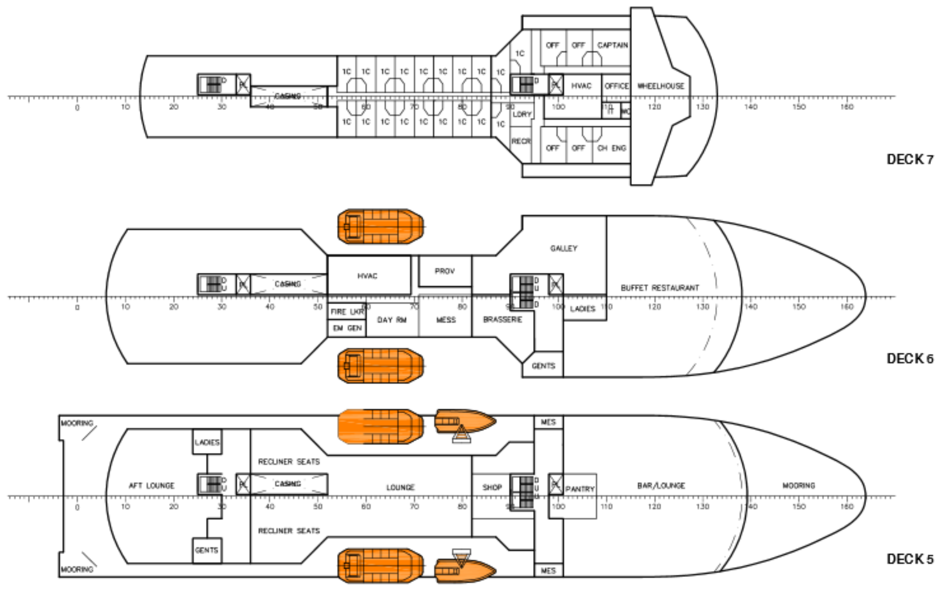


Fig. 12-35 General arrangement deck 5 – deck 7 – Small RoPax

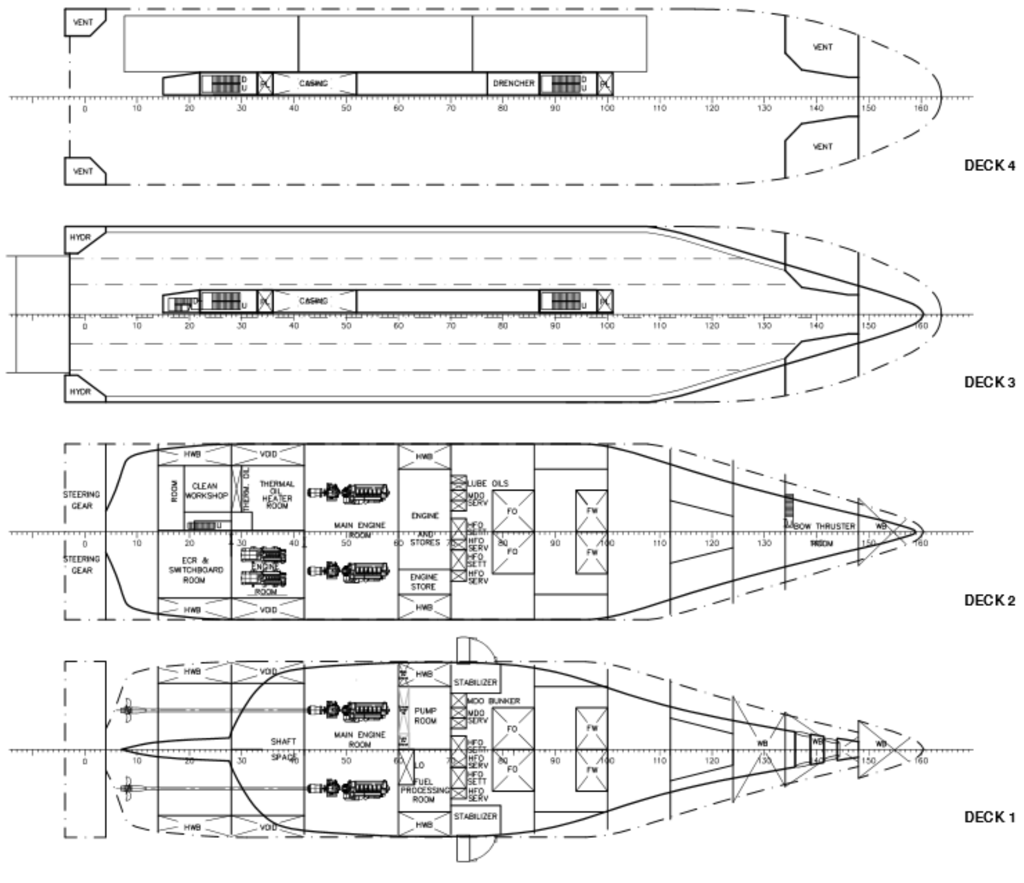


Fig. 12-36 General arrangement deck 1 - 4 – Small RoPax

12.5.6 Hullform

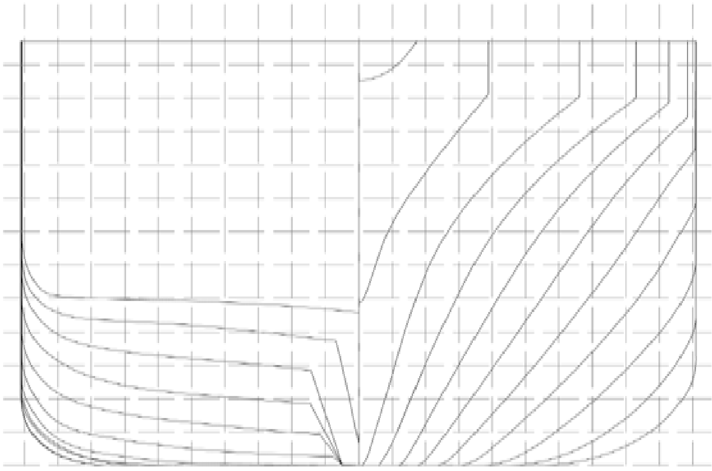


Fig. 12-37 Lines plan – Small RoPax

12.5.7 Engine configuration

The engine configuration utilises a diesel mechanical arrangement with 2 prime movers of 3600 kW each driving 2 controllable pitch propellers via a gearbox. Service speed of 18 knots is achieved at 90% MCR with 15% sea margin. Hotel load of approximately 600 kW served by 2 auxiliary engines of 632 kW each. PTO (600 kW each) on each engine to power the bow thrusters.

Engines assumed to run on HFO.

12.5.8 Tankplan

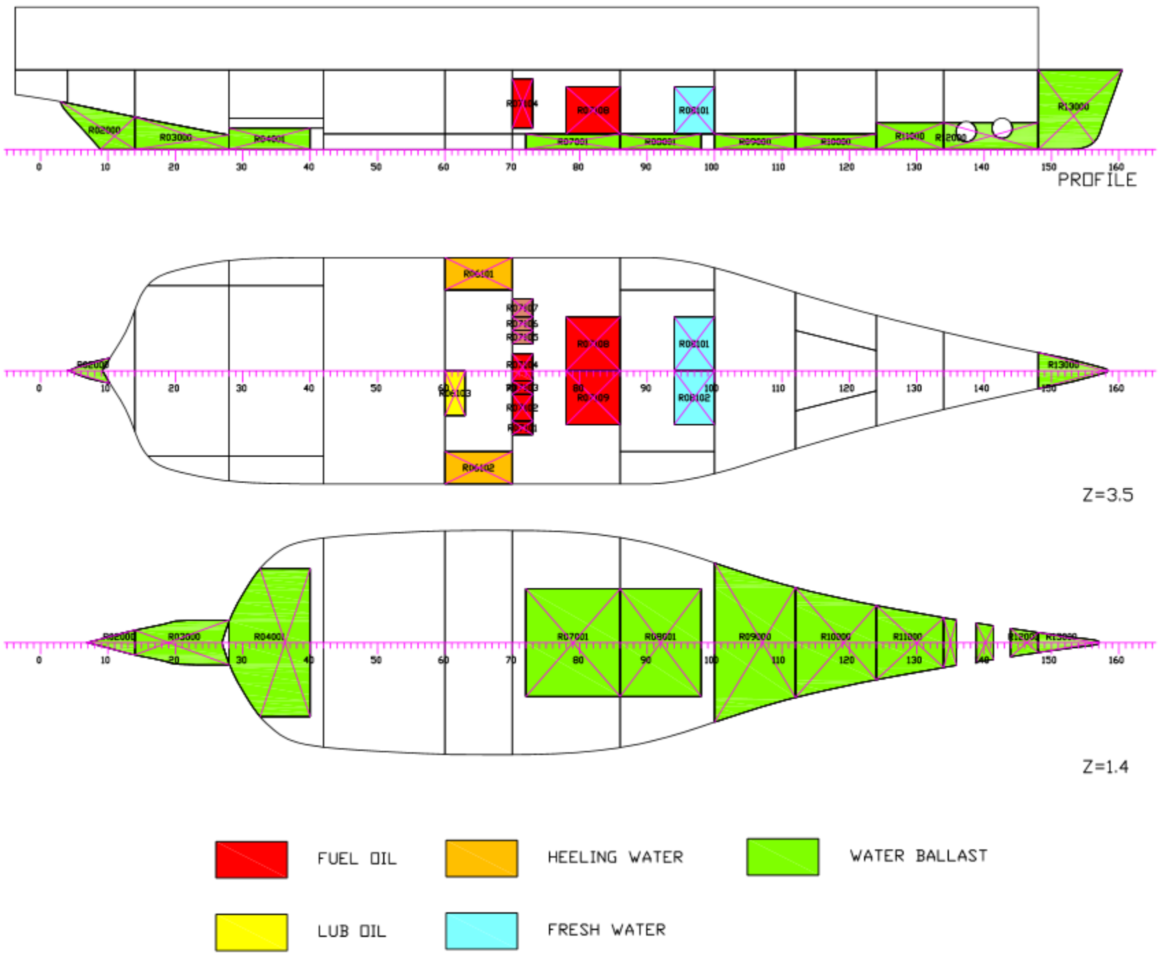


Fig. 12-38 Tank Plan – Small RoPax

The following capacities are achieved for the various purposes:

Table 12-23 Tank capacities – Small RoPax

Description	RHO tonnes/m^3	Volume m^3	Weight tonnes
Heavy Fuel Oil	0.99	246	243
Diesel Oil	0.86	31	27
Lub Oil	0.90	21	19
Heeling Water	1.025	195	200
Fresh Water	1.00	140	140
Water Ballast	1.025	750	952

12.5.9 Subdivision

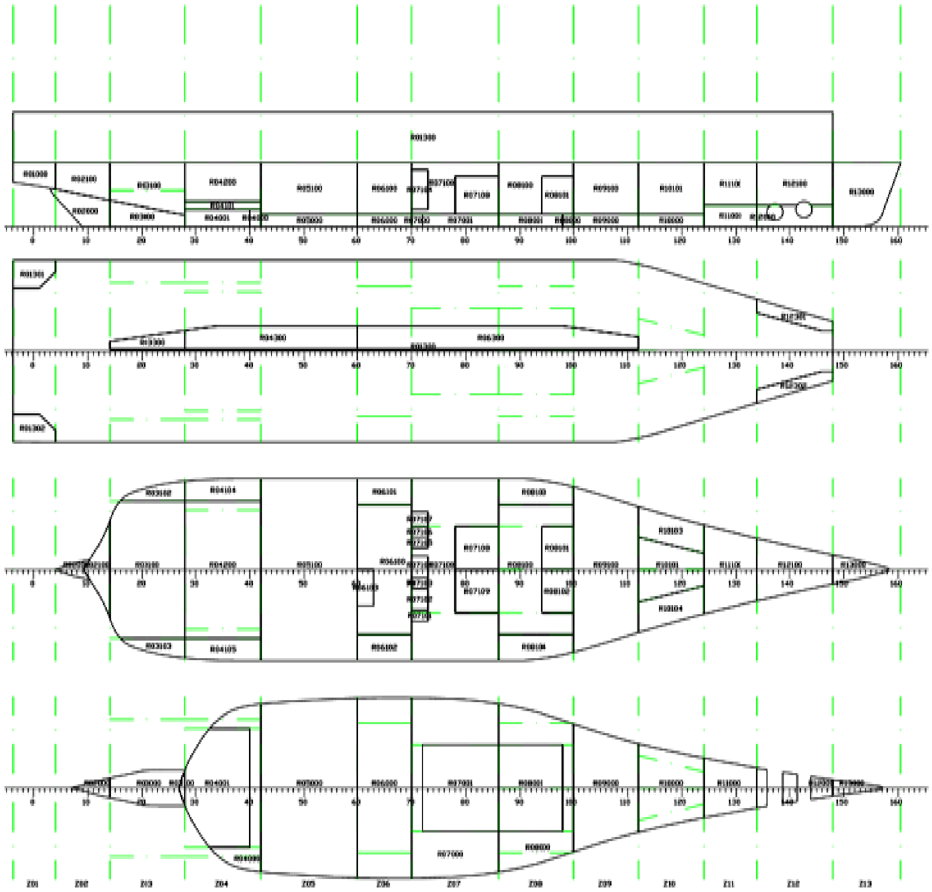


Fig. 12-39 Subdivision – Small RoPax

12.5.10 Hydrodynamics

12.5.10.1 Speed power performance

Necessary delivered power (Pd) at 18 knot = 5910 kW

Necessary installed power (Pi*) at 16 knot = 6840 kW

Pi* is based on following efficiencies / coefficients:

Seamargin:	15 %	MCR:	90 %
Shaft eff.:	98 %	Gear Eff.:	98 %

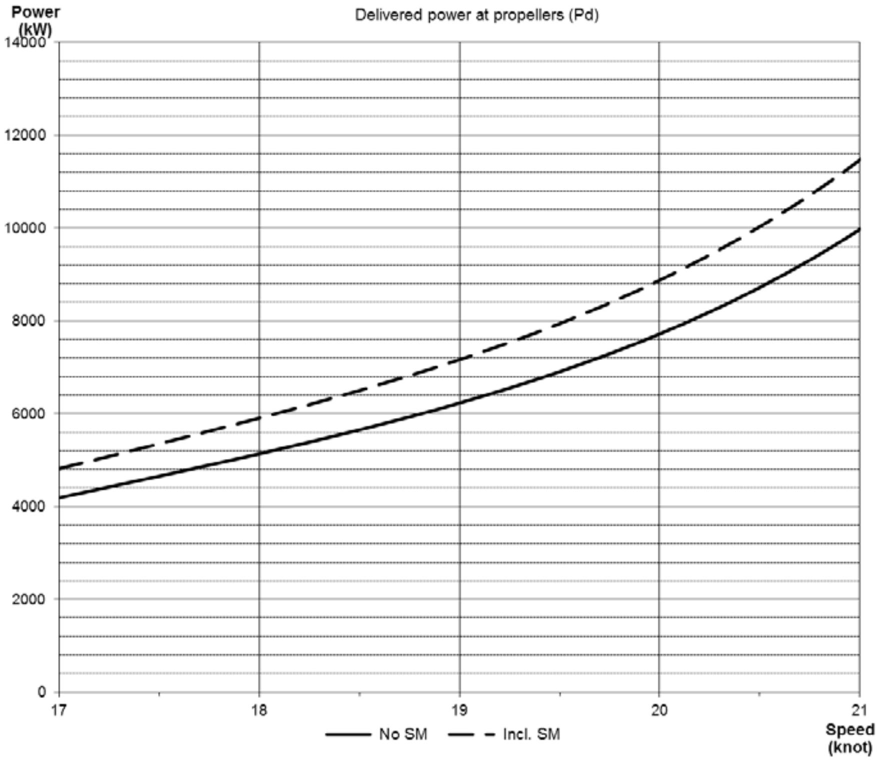


Fig. 12-40 Speed/Effect diagram – Small RoPax

12.5.10.2 Manoeuvrability

The vessel is equipped with 2 bow thrusters of 600 kW each and 2 high lift rudders.

12.5.11 Intact Stability

12.5.11.1 Loading Conditions

The following table (Table 12-24) details the loading conditions considered for this design.

Table 12-24 Loading conditions – Small RoPax

ID		Draught mld (m)	Trim (m) (+ve by bow)	GMf (m)
Con02	Design Departure	4.877	0.007	2.102
Con03	Design Arrival	4.746	0.096	1.977
Con04	Full Passengers No Cargo Departure	4.372	0.119	2.404
Con05	Full Passengers No Cargo Arrival	4.206	-0.055	2.370
Con06	Ballast Arrival	4.202	0.086	2.496

Homogenous cargo is assumed at 2 tonnes per lane metre for a total of 800 tonnes of cargo.

12.5.11.2 GM Limiting Curve

GM limit curves have been generated to the requirements of the 2008 Intact Stability Code and SOLAS 2009. The following diagram (Fig. 12-41) illustrates the GM limit curves with the loading conditions described above plotted to show compliance with both the intact and damage stability requirements.

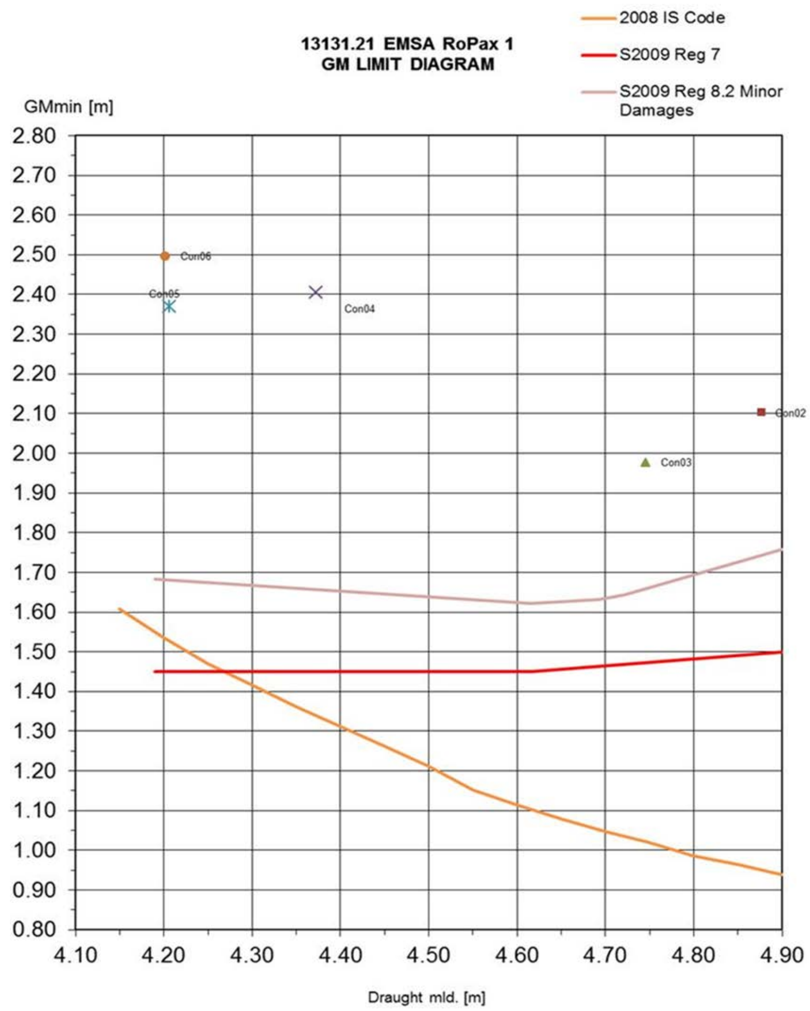


Fig. 12-41 GM Limit Diagram – Small RoPax

12.5.12 Results of Damage Stability Calculation

Damage stability has been assessed to the requirements of SOLAS 2009 Chapter II-1. This has included the calculation of the attained index in accordance with Regulation 7 and the assessment of damage cases required by Regulation 8.

12.5.12.1 Attained index vs R

The following table shows the results of the calculations carried out to derive the Attained index. The damage assessment has included port and starboard damages with the values below showing the combined results.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length:	98.528 m
Breadth at the load line:	20.219 m
Breadth at the bulkhead deck:	20.200 m
Number of persons N1:	200
Number of persons N2:	425

Required subdivision index R = 0.72143
Attained subdivision index A = 0.774042
Attained subdivision index AWOD[14] = 0.72252

Table 12-25 Attained index – Small RoPax

INIT	T m	GM m	A/R	A	A*WCOEF	WCOEF
DP	4.190	1.450	1.08	0.77818	0.15564	0.200
DP	4.616	1.450	1.04	0.75221	0.30088	0.400
DS	4.900	1.500	0.98	0.70974	0.28389	0.400

12.5.12.2 SOLAS Reg. II-1/8 and 9.8 Results

It was found that the assessment of damage in accordance with Regulation 8 derived more onerous limiting GM values than those necessary to achieve the Required index alone. The initial GM values listed in the calculation of the Attained index above were those derived from the requirements of Regulation 8.2. The full range of limiting GMs derived from Regulation 8.2 is shown in the table below:

Table 12-26 Limiting GM based on SOLAS Reg.II-1/8.2

Draught (m)	Minimum GM (m)
4.190	1.694
4.616	1.622
4.693	1.631
4.722	1.644

Using these GM values, the attained index A is 0.81552 and AWOD is 0.79473. The summarised results are shown below in Table 12-27.

Table 12-27 Attained index using GM required according to SOLAS Reg.II-1/8.2

INIT	T m	GM m	A/R	A	A*WCOEF	WCOEF
DP	4.190	1.694	1.21	0.87443	0.17489	0.200
DP	4.616	1.622	1.13	0.81590	0.32636	0.400
DS	4.900	1.758	1.09	0.78569	0.31428	0.400

[14] AWOD denotes use of the formulations for s agreed at SLF55 for cases when ro-ro deck is open to sea

Given the double bottom arrangement of the design it was not considered necessary to assess any damage stability cases to meet the requirements of Regulation 9.

12.6 Ship #6 RoPax double end ferry

12.6.1 Introduction

This section describes the basic information about a double ended RoPax. Small passenger ships have been less researched in previous projects concerned with stability and there is a growing concern that any increase in the R index may unduly penalise small ships.

12.6.2 Business Model

The business model for this vessel is based on the route between Helsingør in Denmark and Helsingborg in Sweden. The voyage is considered a short international voyage therefore SOLAS applies. Currently 2 different classes of double ended roro passenger ferry operate on the route which consists of an 18 minute crossing and 12 minute turnaround time.

	Aurora af Helsingborg	Mercandia IV
LBP (m)	106.36	90.00
Breadth (m)	27.60	15.00
Draught (m)	5.50	3.60
GT	10918	4511
DWT (tonnes)	2300	1257
Passengers	1250	400
Lane Metres (lm)	535	290
Service Speed (knots)	14.00	12.00
Installed Power (kW)	9760	2750
Built	1992	1989

The Mercandia IV has 2 vehicle decks, although only the main deck has sufficient height for trailers. The design of Mercandia IV is unique in that there is no engine room, but it has 10 Cummins diesel engines at the side of the upper vehicle deck driving a diesel electric system. This unconventional arrangement will not be replicated in the new design.

The Aurora af Helsingborg was originally designed as a train ferry, and is also fitted with a platform deck for cars on one side of the vessel.

Given that the breadth of the Aurora af Helsinborg is derived from its original purpose as a train ferry (L/B ratio of 3.85), and that the general form of double enders in the EC (particularly in Norway and Croatia) have a L/B ratio around 5.5 to 6, it was decided that the Mercandia IV would be more representative as a basis vessel for this analysis.

12.6.3 General Description of the ship

The sample ship is a small double ended RoPax ferry designed for short international voyages of around 15 to 18 minutes in duration, with a short turnaround time, and multiple trips per day, as befits a revenue earning route based on carrying trailers.

The main vehicle deck is of sufficient clear height for trailers and has around 280 trailer lane metres of 3.0m width. A second vehicle deck, with a reduced clear height, suitable for cars and caravans, with around 320 lane metres is fitted above the main deck. Bow and stern doors are fitted for drive through operation, and double tier loading is supported. The main vehicle deck is fully enclosed, while the upper deck is open at both ends. There are no ramps between vehicle decks.

Accommodation for 600 passengers is arranged in public spaces primarily located on one deck and there are no passenger cabin provided due to the short voyage duration. Crew cabins and mess facilities are located on a separate deck.

Although the vessel operates on a short international voyage, due to the sheltered nature of the route and the short distance, the administration normally exempts vessels from the requirement to carry lifeboats, and consequently the vessel is fitted with MESs and liferafts only. From a damage stability point of view, this raises the R index compared with a vessel fitted with lifeboats meaning that such vessels are required to have a higher survivability standard than comparable vessels that carry lifeboats.

Propulsion is provided by a diesel electrical arrangement consisting of 4 main generator sets and 4 directional propellers driven by electrical motors. There is one additional smaller auxiliary generator set. The machinery arrangement is only an indicative solution; there are certainly other possible combinations that would work. We have also not considered LNG or batteries in this analysis

Main characteristics as follows:

Length over all	102.22 m
Length between perpendiculars	96.80 m
Subdivision Length	102.219 m
Breadth	17.60 m
Subdivision Draught	4.3 m
Height of Bulkhead Deck	5.70 m
Number of Passengers	600
Number of Crew	10
Gross Tonnage	5040 approx
Deadweight	1580 tonnes
Trailer Lane Metres	278 approx
Car Lane Metres	322 approx
Service Speed	16 knots
Installed power main engines	5840 kW
Installed power auxiliary engines	500 kW

Regulations:

The design complies with all relevant IMO rules and regulations for ships at the time of writing, in particular:

- SOLAS 1974 as amended, including probabilistic damage stability (SOLAS 2009)
- Intact Stability Code (IS Code 2008)
- Load Line Convention
- The intended area of operation is within the Baltic Sea Sulphur Oxide (SOx) Emission Control Area (SECA). MDO operation is assumed as is the case with the current tonnage in service on the route.

12.6.4 General arrangement

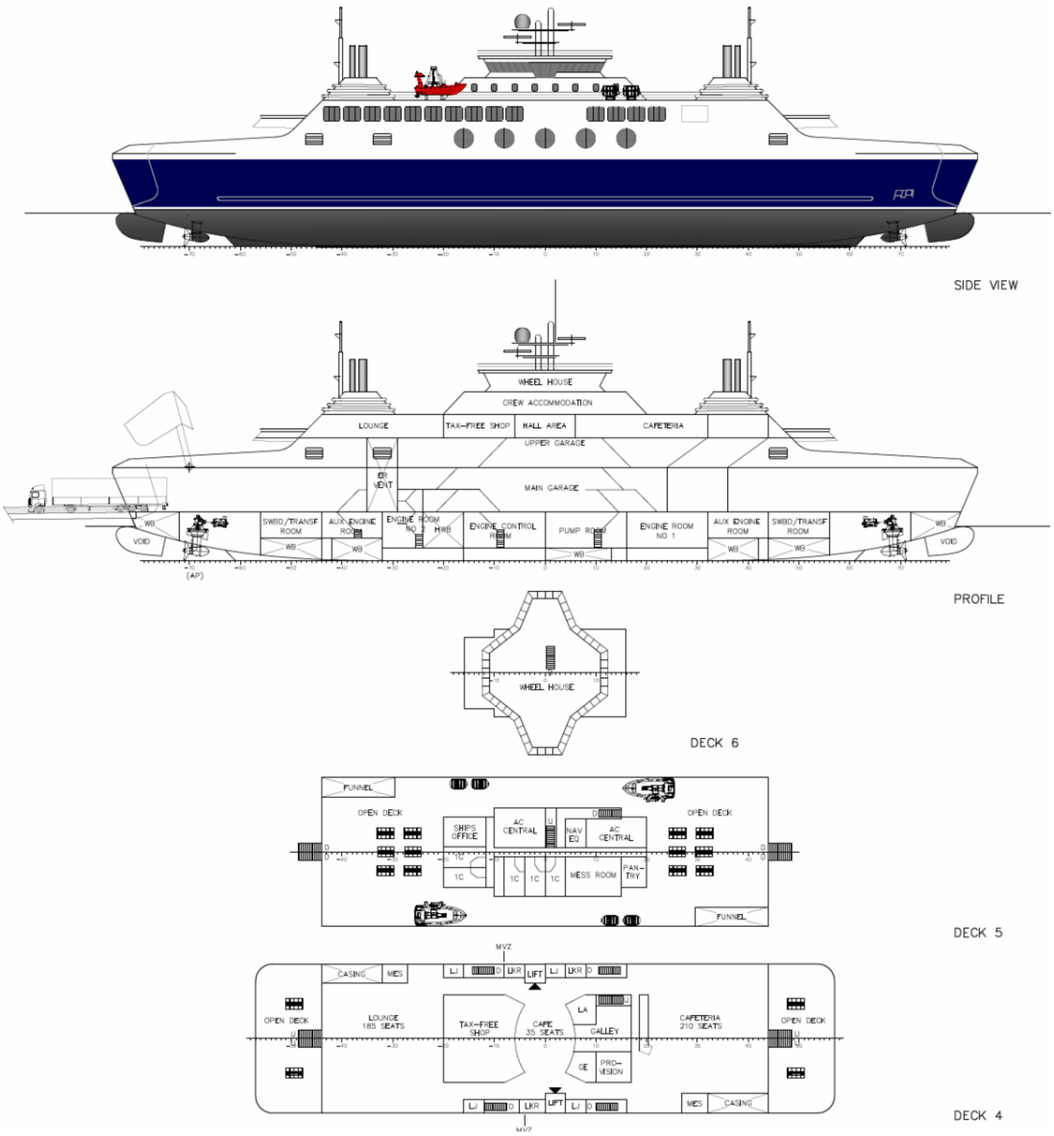


Fig. 12-42 Profile and deck 4 & 5- Double end Ferry

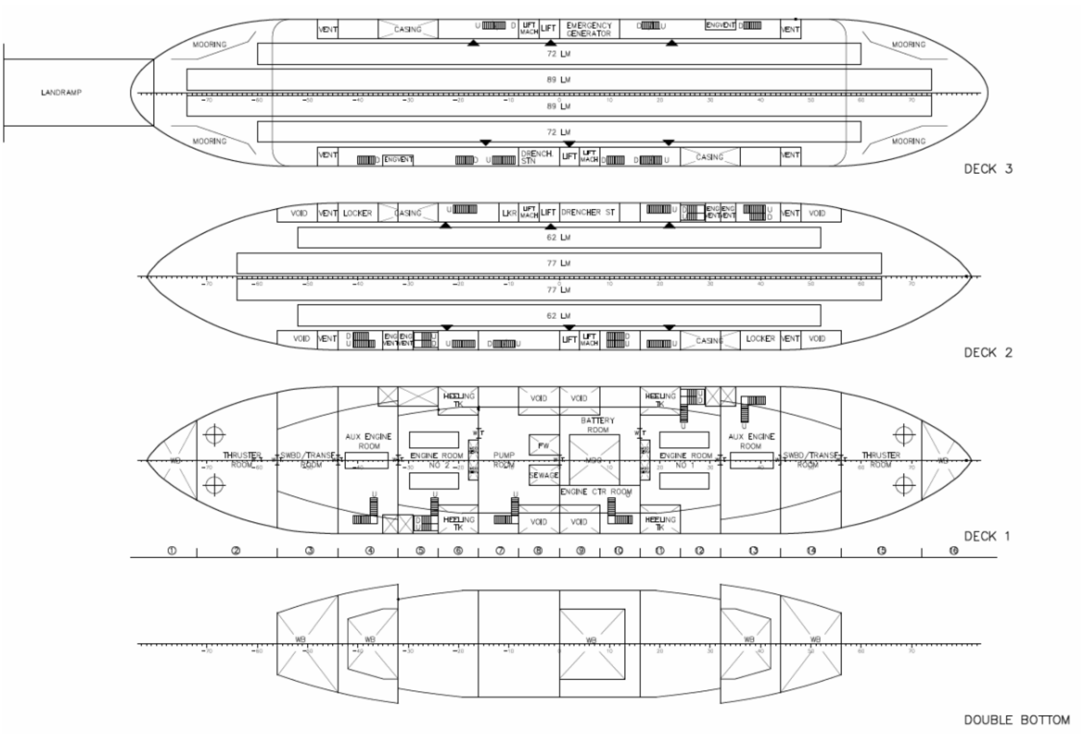


Fig. 12-43 General arrangement double bottom - deck 3- Double end Ferry

12.6.5 Hullform

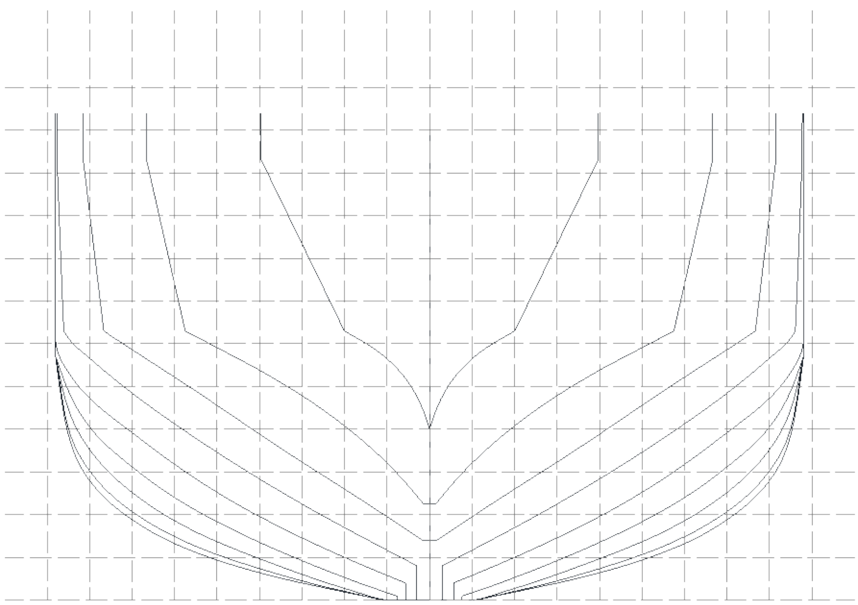


Fig. 12-44 Lines Plan- Double end Ferry

12.6.6 Engine configuration

The engine configuration utilises a diesel electric arrangement with four medium speed diesel generator sets each producing 1460kW. A secondary 500kW diesel generator can be used to provide additional power and cater for harbour loads. Propulsion is by way of four electric motors of around 1170 kW each driving 4 directional propellers. Service speed of 16 knots is achieved at 90% MCR with 15 % sea margin.

The engines are assumed to run on MDO.

12.6.7 Tankplan

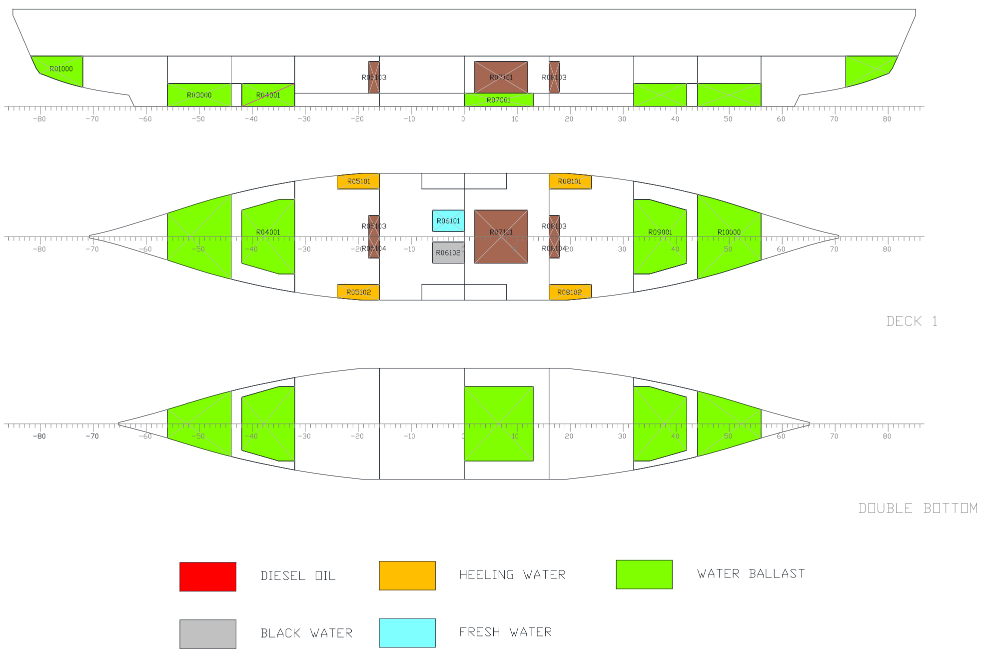


Fig. 12-45 Tank Plan- Double end Ferry

The following capacities are achieved for the various purposes:

Table 12-28 Tank capacities- Double end Ferry

Description	RHO tonnes/m³	Volume m³	Weight tonnes
Diesel Oil	0.86	168	145
Lub Oil	0.90	11	10
Heeling Water	1.025	215	220
Fresh Water	1.00	30	30
Water Ballast	1.025	631	647

12.6.8 Subdivision

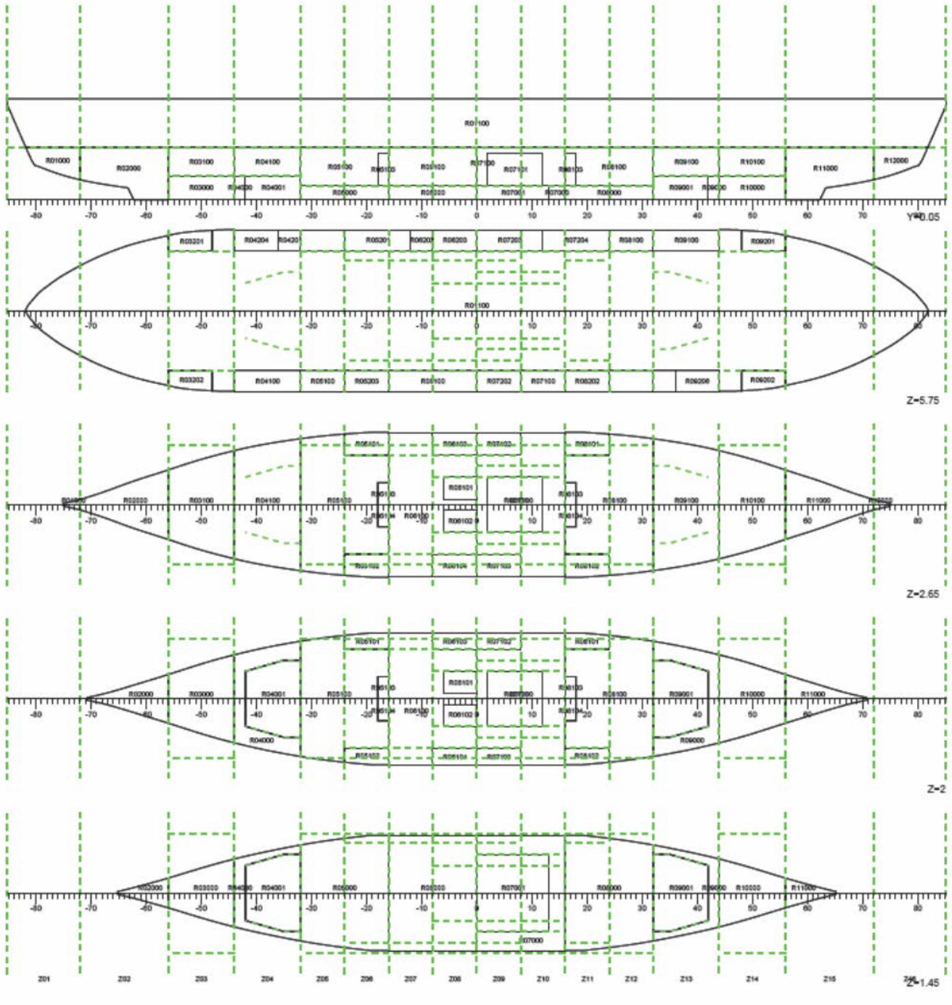


Fig. 12-46 Subdivision- Double end Ferry

12.6.9 Hydrodynamics

12.6.9.1 Speed power performance

Necessary delivered power (Pd) at 16 knot = 3390 kW (no seamargin)

Necessary installed power (Pi*) at 16 knot = 4660 kW

Pi* is based on following efficiencies / coefficients:

Seamargin:	15 %	MCR:	90 %
Shaft eff.:	95 %	Gear Eff.:	98 %
El.motor loss	0 %	Conv. Loss:	0 %

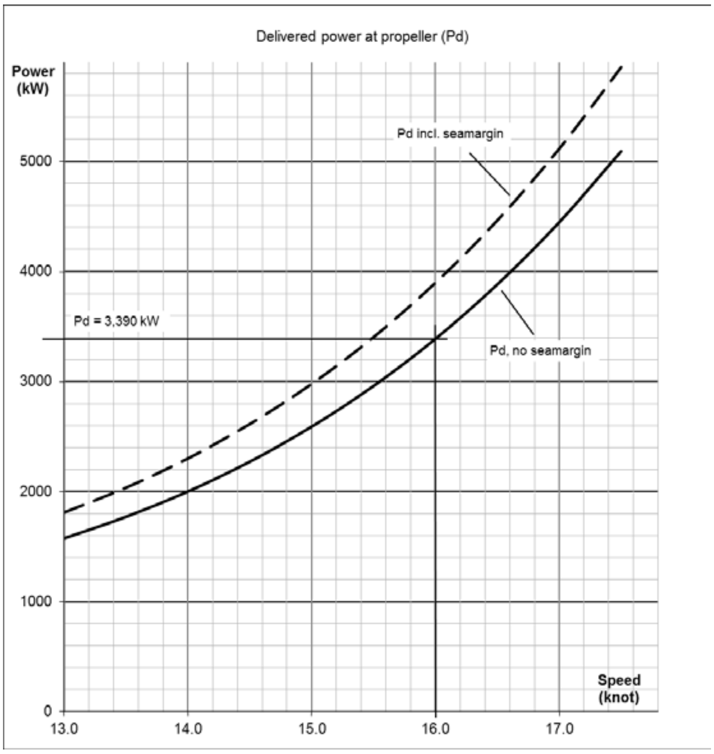


Fig. 12-47 Power/Speed diagram- Double end Ferry

12.6.9.2 Manoeuvrability

The vessel is fitted with four directional propellers which can be used for manoeuvring there are no additional rudders or tunnel thrusters fitted.

12.6.10 Intact Stability

12.6.10.1 Loading Conditions

The following table details the loading conditions considered for this design.

Table 12-29 Loading conditions- Double end Ferry

ID	Description	Draught mld (m)	Trim (m) (+ve by bow)	GMf (m)
Con01	Design Load Departure	3.99	0.03	2.008
Con01	Design Load Arrival	4.01	0.01	1.902
Con03	Ballast Arrival	3.39	0.02	3.128
Con04	Scantling Draught Departure	4.30	0.03	2.220
Con05	Full Pax No Cargo Departure	3.54	0.08	2.465
Con06	Full Pax No Cargo Departure	3.44	0.01	2.355

The design condition assumes a total load of 715 tonnes of trucks and cars along with 600 passengers.

12.6.10.2 GM Limiting Curve

GM limit curves have been generated to the requirements of the 2008 Intact Stability Code and SOLAS 2009. The following diagram illustrates the GM limit curves with the loading conditions described above plotted to show compliance with both the intact and damage stability requirements.

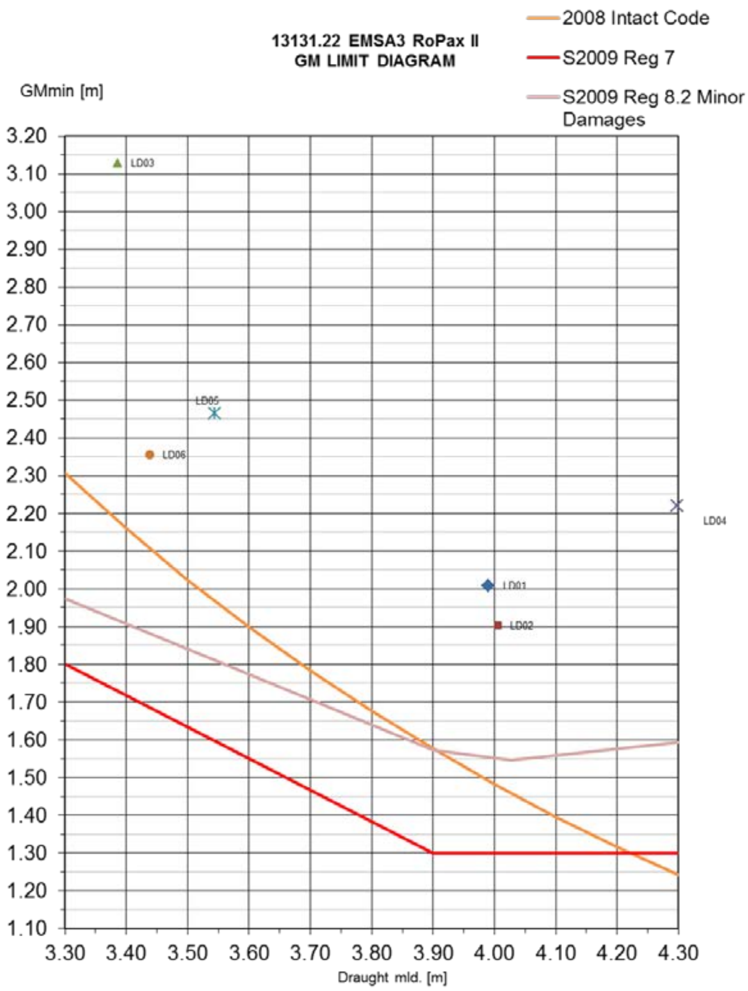


Fig. 12-48 GM limit diagram- Double end Ferry

12.6.11 Results of Damage Stability Calculation

Damage stability has been assessed to the requirements of SOLAS 2009 Chapter II-1. This has included the calculation of the attained index in accordance with Regulation 7 and the assessment of damage cases required by Regulation 8.

12.6.11.1 Attained index vs R

The following table shows the results of the calculations carried out to derive the Attained index. The damage assessment has included port and starboard damages with the values below showing the combined results.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	102.219 m
Breadth at the load line	17.189 m
Breadth at the bulkhead	17.188 m
deck	0
Number of persons N1	610
Number of persons N2	

Required subdivision index R = 0.72792
Attained subdivision index A = 0.76478
Attained subdivision index A_{WOD}[15] = 0.74911

Table 12-30 Summary of index calculations- Double end Ferry

INIT	T (m)	GM (m)	A/R	A	A*WCOEF	WCOEF
DP	3.300	1.800	1.18	0.85830	0.17166	0.200
DP	3.900	1.300	1.04	0.75471	0.30188	0.400
DS	4.300	1.300	1.00	0.72810	0.29124	0.400

12.6.11.2 Reg 8 and 9.8 Results

It was found that the assessment of damage in accordance with Regulation 8 derived more onerous limiting GM values than those necessary to achieve the Required Index alone. The initial GM values listed in the calculation of the Attained Index above were those derived from the requirements of Regulation 8.2. The full range of limiting GMs derived from Regulation 8.2 is as follows (Table 12-31):

Table 12-31 Limiting GM according to SOLAS Reg.II-1/8.2

Draught (m)	Minimum GM (m)
3.300	1.974
3.900	1.573
4.027	1.545
4.300	1.593

Using these GM values, the attained index A is 0.85227 and A_{WOD} is 0.841231. The summarised results are shown in Table 12-32 below

[15] AWOD denotes use of the formulations for s agreed at SLF55 for cases when ro-ro deck is open to sea

Table 12-32 Summary of index calculation based on limiting GM according to Reg.8.2

INIT	T (m)	GM (m)	A/R	A	A*WCOEF	WCOEF
DP	3.300	1.974	1.25	0.90741	0.18148	0.200
DP	3.900	1.573	1.18	0.85810	0.34324	0.400
DS	4.300	1.593	1.12	0.81887	0.32755	0.400

Given the double bottom arrangement of the design it was not considered necessary to assess any damage stability cases to meet the requirements of Regulation 9.

13 RISK CONTROL OPTIONS AND COST BENEFIT ASSESSMENTS ON SAMPLE SHIPS

13.1 General assumptions applied in the Cost Benefit Assessments

The basic assumption for cost benefit assessment is to transfer all costs and potential income into a Net Present Value. For this an assumed lifetime of 30 years and 5 % depreciation rate has been accounted for.

For each design the assumptions regarding the costs related to the design modifications are given. However in those cases where the design modification involved additional fuel consumptions the following assumptions have been made with respect to the development of the fuel oil price.

The basic data for trend developments have been taken from EIA energy outlook **11** in which development trends as shown in Fig. 13-1 are predicted.

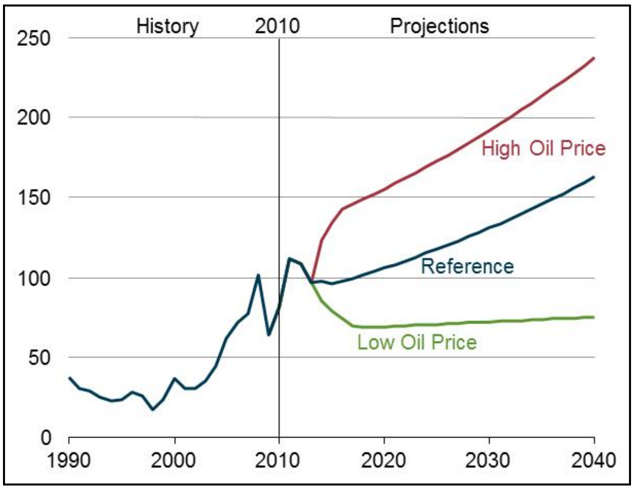


Fig. 13-1 Projected fuel oil price

The current prices for HFO and MGO; 600 USD/t and 900 USD/t, have been obtained using the average reported prices for 2013 and 2014(until now) in Rotterdam using Clarkson Intelligence as a source.

The price of LSHFO is obtained based on a 20/80 distribution of the HFO and MGO price. This is the distribution that is required in order to obtain a content of 0.5 % sulphur.

Price of LNG is taken as 94.1% of the MGO cost. This is a standard assumption used in analysis based on the LNG supplier’s standard way of pricing where it is referred to that the cost of the LNG should correspond to 80% of the use of MGO.

For each sample ship a fuel mix taking into account operating area and new requirements has been developed.

13.1.1 Calculation of Cost Thresholds

Identification of risk control options focus on structural design modification with potential of increasing damage stability, i.e. Attained index calculated in accordance with SOLAS 2009. The cost-benefit assessment calculation is based on CAF thresholds of 4 mill. USD and 8 mill. USD and risk reduction related to increased Attained Index. These cost thresholds in terms of NPV and related to the change in A provided by the design change are calculated based on the collision risk model. Due to the fact that initial accident frequencies as well as dependent probabilities in the risk models are uncertain, distributions were estimated and cost thresholds calculated by Monte Carlo simulation.

13.2 Ship #1 Large Cruise Ship

13.2.1 General Approach

The applied approach for defining design variations with higher attained index is twofold. One way is to perform a systematic variation of breadth and freeboard as this may have significant impact on the damage stability results, while maintaining the inner subdivision generally constant. This way may have significant impact on the life cycle costs, as the annual fuel consumption may change significantly.

The second approach considers this possibly negative effect and is modifying the watertight subdivision and location or function of rooms to achieve an optimized design within the boundary of the hull dimensions.

The following table shows an overview of the applied design variations, which will be described in the following sections one by one in more detail.

Table 13-1 Design variations – Large cruise

Version	Description
G2	Reference design
H4	Breadth increased by 1.0m
I3	Breadth increased by 1.0m Freeboard increased by 0.8m
J1	Breadth increased by 0.6m Freeboard increased by 0.2m
K1	change internal subdivision
K2	change internal subdivision as K1 part of bulkhead deck watertight
K3	change internal subdivision as K1 Freeboard increased by 0.4m
L1	change internal subdivision as K1 Breadth increased by 0.2m

13.2.2 Design Variations

13.2.2.1 Version H4

This version uses the most obvious risk control option with regard to stability and increases the breadth of the hull by 1.0m. The superstructure above the boat deck will be kept constant; the interior areas within the hull will be increased due to the changed shape.

The following figure illustrates the principle of modification

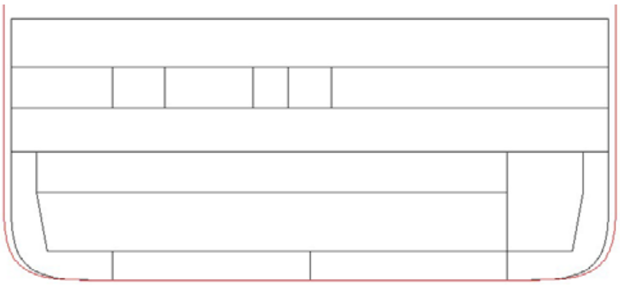


Fig. 13-2 Principle of modification

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas.

Table 13-2 Design changes – weight and areas

Version	G2	H4	change
Steelweight	29821 t	30301 t	481 t
GT	153400 GT	154671 GT	1271 GT
Interior	17200 t	17338 t	138 t
Lightweight	60253 t	60872 t	618 t
Public	34595 m2	34915 m2	320 m2
Cabin	75496 m2	75929 m2	433 m2

Due the wider hull form the deck spaces used for cabins and public rooms, as well as for some technical spaces are increased. These additional areas require additional efforts for outfitting and interior work, however the increased spaces do not result in additional revenue. The changes are too small to fit additional cabins, and also the gained space in public rooms generate additional income as there are no additional guests on board to spend money.

The increase of the hull caused an increase of propulsion power to maintain the required trial speed and as a consequence the installed power of the diesel generators had to be increased. The main engine plant has been changed from 3x12V and 2x14V engines to 2x12V and 3x14V engines.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-3 Loading conditions – design modification H4

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	14735 t	0 t	3822 t	4082 t	8.75 m	-0.08 m	4.37 m
LD23	50% Consumables	9336 t	632 t	1958 t	1435 t	8.26 m	-0.10 m	4.00 m
LD25	10% Consumables	7689 t	1421 t	411 t	433 t	8.10 m	-0.04 m	3.94 m
LD30	Contractual Deadweight	11724 t	0 t	2900 t	3100 t	8.45 m	0.26 m	3.87 m
LD33	20% HFO, 100% PW, 20%GW	10519 t	632 t	768 t	4072 t	8.37 m	-0.20 m	3.96 m
LD35	100% HFO, 20% PW, 100%GW	13060 t	994 t	3823 t	761 t	8.58 m	0.16 m	4.35 m
LD200	100% Consumables max. Draught	14836 t	0 t	3822 t	4082 t	8.75 m	0.05 m	4.21 m
LD230	50% Consumables	11332 t	1129 t	1958 t	1435 t	8.45 m	-0.18 m	4.04 m
LD250	10% Consumables	9647 t	1618 t	411 t	433 t	8.28 m	-0.02 m	3.99 m
LD330	20% HFO, 100% PW, 20%GW	12019 t	632 t	768 t	4072 t	8.51 m	-0.20 m	3.94 m
LD350	100% HFO, 20% PW, 100%GW	14761 t	1195 t	3823 t	761 t	8.75 m	0.01 m	4.32 m

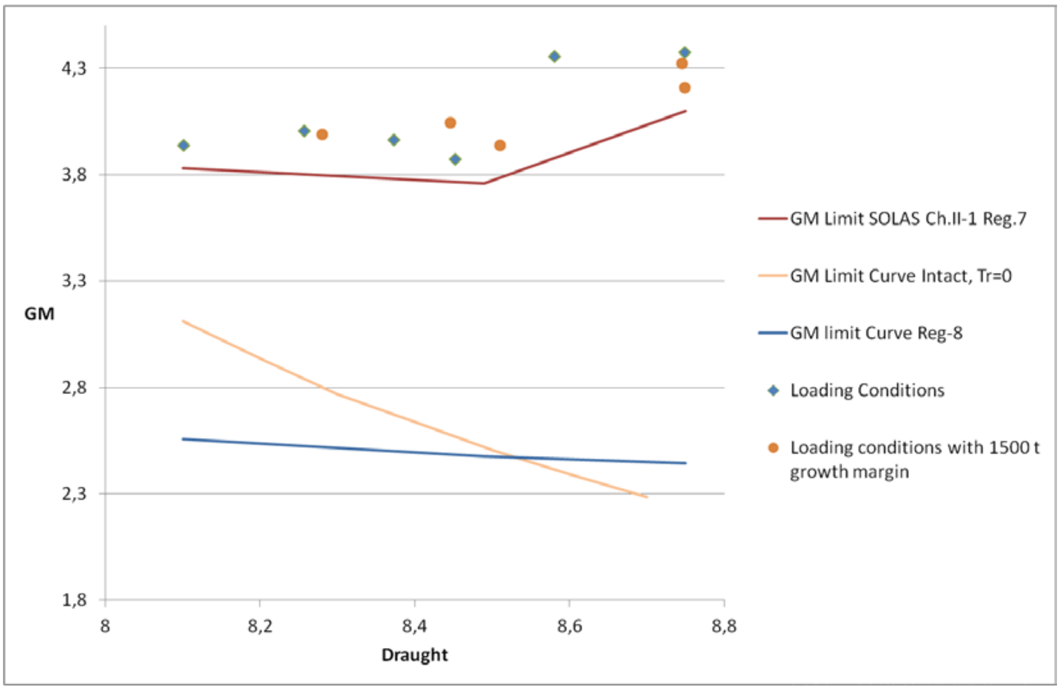


Fig. 13-3 GM Limiting curves – design modification H4

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.542 m
Breadth at the load line	41.800 m
Breadth at the bulkhead deck	41.800 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.90872

13.2.2.2 Version I3

In this version the breadth of the hull is increased by 1.0m and simultaneously the freeboard is increased by 0.8m. Due to the new height of the bulkhead deck, all other decks are shifted parallel except for the tank top, which stays at the minimum double bottom height of 2m above baseline. The width of the superstructure above the boat deck will be kept constant; the interior areas within the hull will be increased due to the changed shape.

The following figure illustrates the principle of modification:

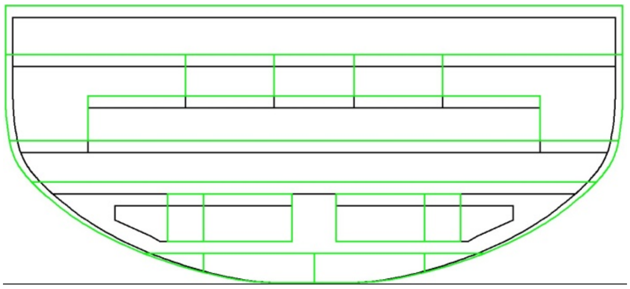


Fig. 13-4 Change in arrangement – design modification I3

Due to the increased deck height the available space for consumable tanks between tank top and crew decks is increased as well. The tank geometry is modified by shifting the longitudinal boundaries inwards while maintaining the required tank capacities.

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas.

Table 13-4 Design changes – weight and areas – design modification I3

Version	G2	I3	change
Steelweight	29821 t	30809 t	988 t
GT	153400 GT	158127 GT	4727 GT
Interior	17200 t	17358 t	158 t
Lightweight	60253 t	61400 t	1147 t
Public	34595 m2	34940 m2	344 m2
Cabin	75496 m2	76023 m2	527 m2
tech spaces	7333 m2	7538 m2	206 m2

Due the wider hull form the deck spaces used for cabins and public rooms, as well as for some technical spaces are increased. These additional areas require additional efforts for outfitting and interior work, however the increased spaces do not result in additional revenue. The changes are too small to fit additional cabins, and also the gained space in public rooms generate additional income as there are no additional guests on board to spend money.

The increase of the hull caused an increase of propulsion power to maintain the required trial speed and as a consequence the installed power of the diesel generators had to be increased. The main engine plant has been changed from 3x12V and 2x14V engines to 2x12V and 3x14V engines.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-5 Loading conditions – design modifications I3

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	14819 t	0 t	4214 t	3986 t	8.74 m	-0.04 m	3.91 m
LD23	50% Consumables	9636 t	641 t	2172 t	1437 t	8.27 m	-0.16 m	3.57 m
LD25	10% Consumables	8330 t	1864 t	411 t	433 t	8.15 m	-0.19 m	3.56 m
LD30	Contractual Deadweight	11730 t	0 t	2900 t	3100 t	8.44 m	0.15 m	3.46 m
LD33	20% HFO, 100% PW, 20%GW	10475 t	641 t	779 t	3982 t	8.34 m	-0.04 m	3.53 m
LD35	100% HFO, 20% PW, 100%GW	13542 t	1004 t	4214 t	761 t	8.61 m	0.12 m	3.93 m
LD200	100% Consumables max. Draught	15005 t	0 t	4214 t	3986 t	8.74 m	0.22 m	3.77 m
LD230	50% Consumables	11580 t	1085 t	2172 t	1437 t	8.45 m	-0.22 m	3.61 m
LD250	10% Consumables	10095 t	2084 t	411 t	433 t	8.31 m	-0.12 m	3.59 m
LD330	20% HFO, 100% PW, 20%GW	11975 t	641 t	779 t	3982 t	8.48 m	-0.04 m	3.51 m
LD350	100% HFO, 20% PW, 100%GW	14896 t	858 t	4214 t	761 t	8.73 m	0.23 m	3.92 m

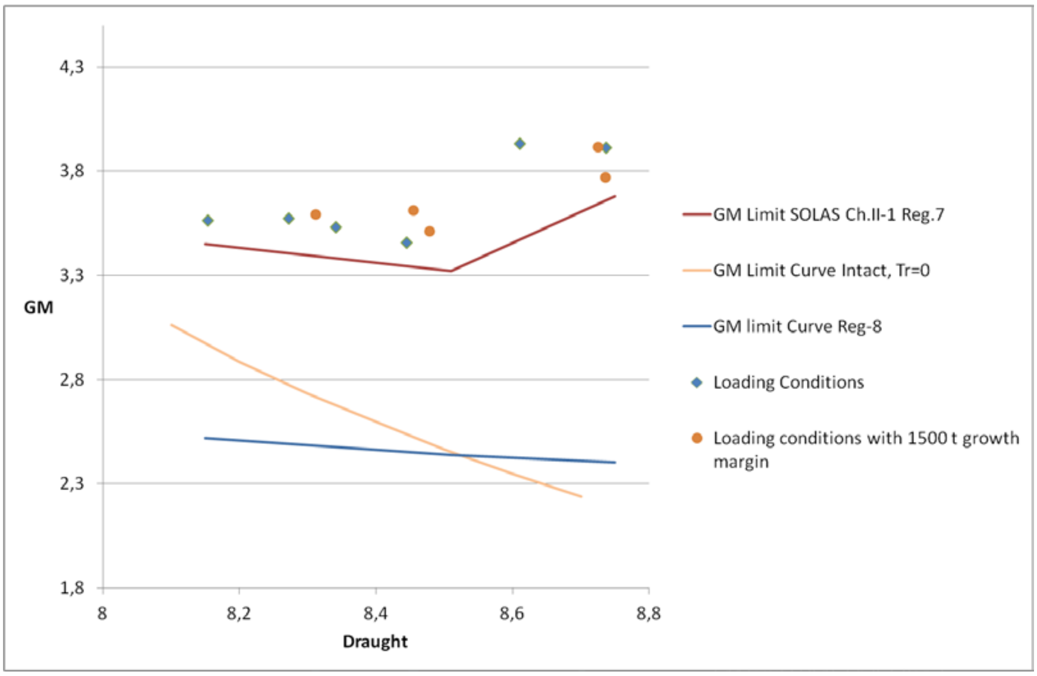


Fig. 13-5 GM Limiting curves – design modification I3

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.542 m
Breadth at the load line	41.800 m
Breadth at the bulkhead deck	41.800 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.92877

13.2.2.3 Version J1

In this version a more moderate change of breadth and freeboard has been applied; the breadth of the hull is increased by 1.0m and simultaneously the freeboard is increased by 0.8m. Due to the new height of the bulkhead deck, all other decks are shifted parallel except for the tank top, which stays at the minimum double bottom height of 2m above baseline. The width of the superstructure above the boat deck will be kept constant; the interior areas within the hull will be increased due to the changed shape.

The following figure illustrates the principle of modification:

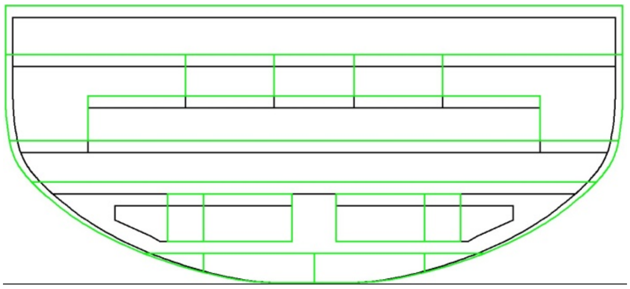


Fig. 13-6 Design modification version J1

Due to the increased deck height the available space for consumable tanks between tank top and crew decks is increased as well. The tank geometry is modified by shifting the longitudinal boundaries inwards while maintaining the required tank capacities.

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas.

Table 13-6 Design Changes version J1 – Weight and areas

Version	G2	J1	change
Steelweight	29821 t	30307 t	486 t
GT	153400 GT	155221 GT	1821 GT
Interior	17200 t	17289 t	89 t
Lightweight	60253 t	60652 t	398 t
Public	34595 m2	34800 m2	205 m2
Cabin	75496 m2	75812 m2	317 m2
tech spaces	7333 m2	7393 m2	60 m2

Due the wider hull form the deck spaces used for cabins and public rooms, as well as for some technical spaces are increased. These additional areas require additional efforts for outfitting and interior work, however the increased spaces do not result in additional revenue. The changes are too small to fit additional cabins, and also the gained space in public rooms generate additional income as there are no additional guests on board to spend money.
The increase of the hull caused an increase of propulsion power to maintain the required trial speed and as a consequence the installed power of the diesel generators had to be increased. The main engine plant has been changed from 3x12V and 2x14V engines to 2x12V and 3x14V engines.
With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-7 Loading conditions – design J1

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	15020 t	0 t	4002 t	4308 t	8.75 m	-0.02 m	3.97 m
LD23	50% Consumables	9252 t	0 t	2049 t	1486 t	8.19 m	0.52 m	3.55 m
LD25	10% Consumables	8150 t	1609 t	411 t	433 t	8.11 m	0.15 m	3.62 m
LD30	Contractual Deadweight	11738 t	0 t	2900 t	3100 t	8.44 m	0.12 m	3.40 m
LD33	20% HFO, 100% PW, 20%GW	10700 t	606 t	821 t	4308 t	8.35 m	-0.01 m	3.53 m
LD35	100% HFO, 20% PW, 100%GW	13859 t	968 t	4003 t	784 t	8.64 m	0.05 m	3.98 m
LD200	100% Consumables max. Draught	14900 t	0 t	4002 t	4308 t	8.74 m	-0.11 m	3.75 m
LD230	50% Consumables	10752 t	0 t	2049 t	1486 t	8.33 m	0.52 m	3.54 m
LD250	10% Consumables	9650 t	1609 t	411 t	433 t	8.25 m	0.15 m	3.60 m
LD330	20% HFO, 100% PW, 20%GW	12200 t	606 t	821 t	4308 t	8.49 m	-0.01 m	3.51 m
LD350	100% HFO, 20% PW, 100%GW	15083 t	692 t	4003 t	784 t	8.74 m	0.16 m	3.94 m

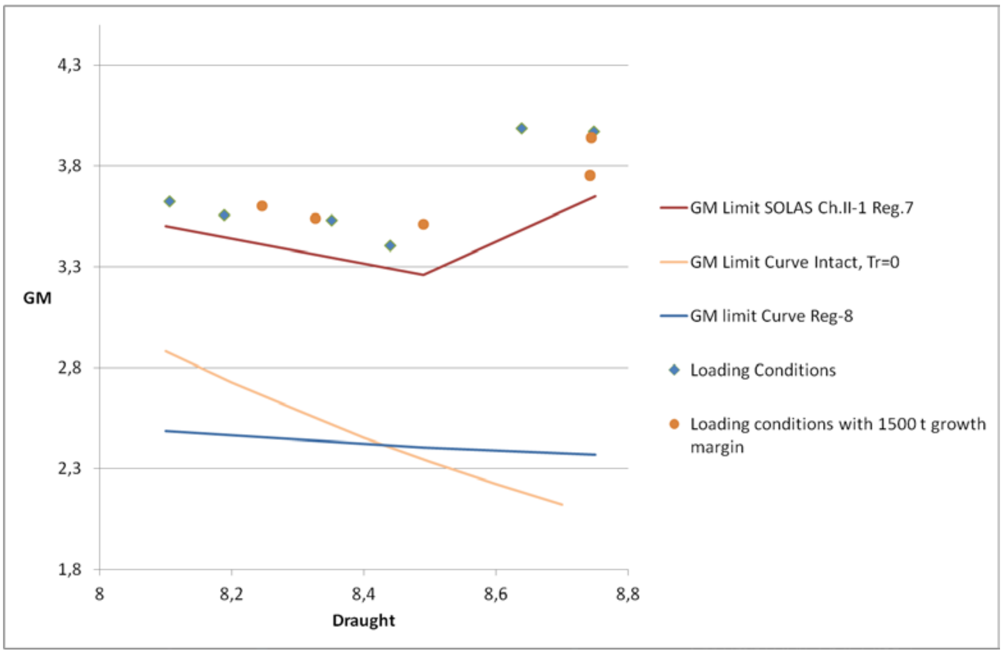


Fig. 13-7 GM Limiting Curves – design J1

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.542 m
Breadth at the load line	41.400 m
Breadth at the bulkhead deck	41.400 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.90055

13.2.2.4 Version K1

Due the significant influence of the increased breadth on the annual fuel consumption a different approach has been applied for this design. Although the internal watertight subdivision is assumed to be optimized some aspects have been identified, which may have significant influence on the attained index with reasonable changes of costs and operability. Following changes have been applied:

- Relocation of heeling tanks one deck upwards
- Relocation of main switchboard rooms to centre line
- Shift of bulkhead at frame 378 to frame 382 to recover space for loss of crew cabins due to shift of heeling tanks
- Lengthening of potable water tanks forward of frame 404 to compensate the loss of potable water capacity due to the shift of bulkhead frame 378.

The following figures illustrate the principle of modification:

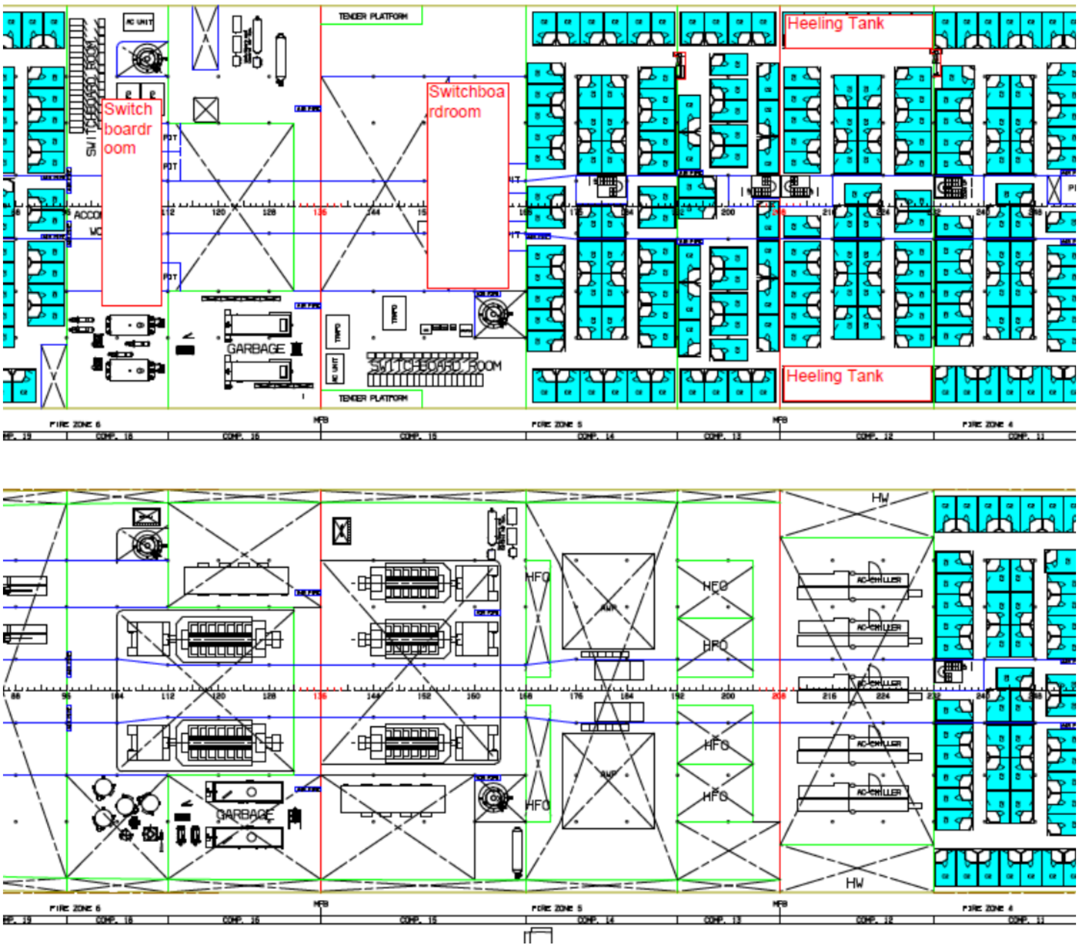


Fig. 13-8 Design change version K1

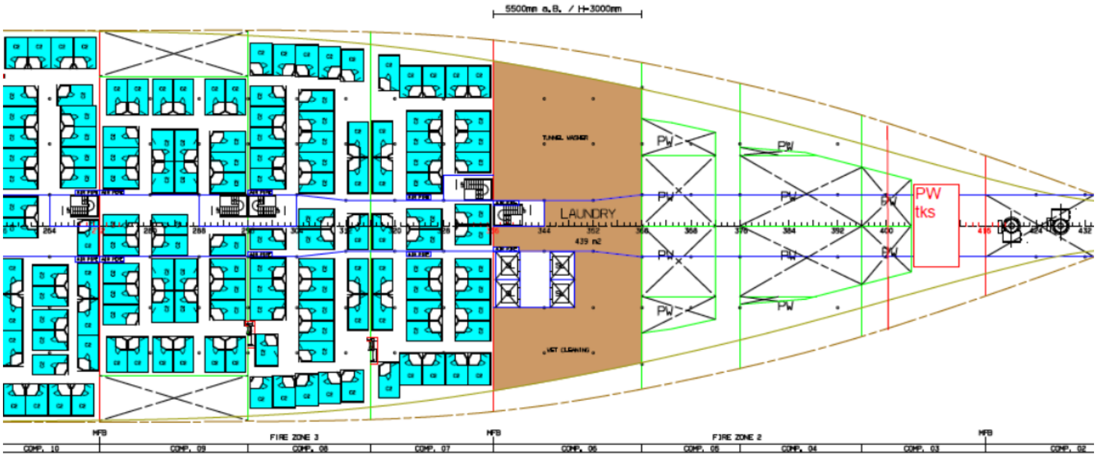


Fig. 13-9 Design change version K1

These changes lead only to small adjustment of the steel weight and outfitting areas. In addition the routing of pipes and ducts close to the centre line in way of the main switchboard rooms will become more complex due to the blocked passage way, which implies some additional building and design costs. No change in the engine plant has been made. With these changes the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-8 Loading conditions – design version K1

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	14621 t	0 t	3822 t	4259 t	8.75 m	-0.27 m	3.22 m
LD23	50% Consumables	9525 t	634 t	1958 t	1587 t	8.27 m	-0.27 m	2.85 m
LD25	10% Consumables	8787 t	1401 t	411 t	433 t	8.19 m	-0.09 m	2.93 m
LD30	Contractual Deadweight	11727 t	0 t	2900 t	3097 t	8.45 m	0.22 m	2.73 m
LD33	20% HFO, 100% PW, 20%GW	10744 t	634 t	768 t	4253 t	8.40 m	-0.39 m	2.83 m
LD35	100% HFO, 20% PW, 100%GW	13026 t	997 t	3823 t	647 t	8.58 m	0.17 m	3.23 m
LD200	100% Consumables max. Draught	14737 t	0 t	3822 t	4259 t	8.75 m	-0.09 m	3.06 m
LD230	50% Consumables	11521 t	1130 t	1958 t	1587 t	8.47 m	-0.34 m	2.90 m
LD250	10% Consumables	9698 t	1634 t	411 t	433 t	8.28 m	-0.05 m	2.84 m
LD330	20% HFO, 100% PW, 20%GW	12244 t	634 t	768 t	4253 t	8.54 m	-0.38 m	2.81 m
LD350	100% HFO, 20% PW, 100%GW	14713 t	1184 t	3823 t	647 t	8.74 m	0.02 m	3.21 m

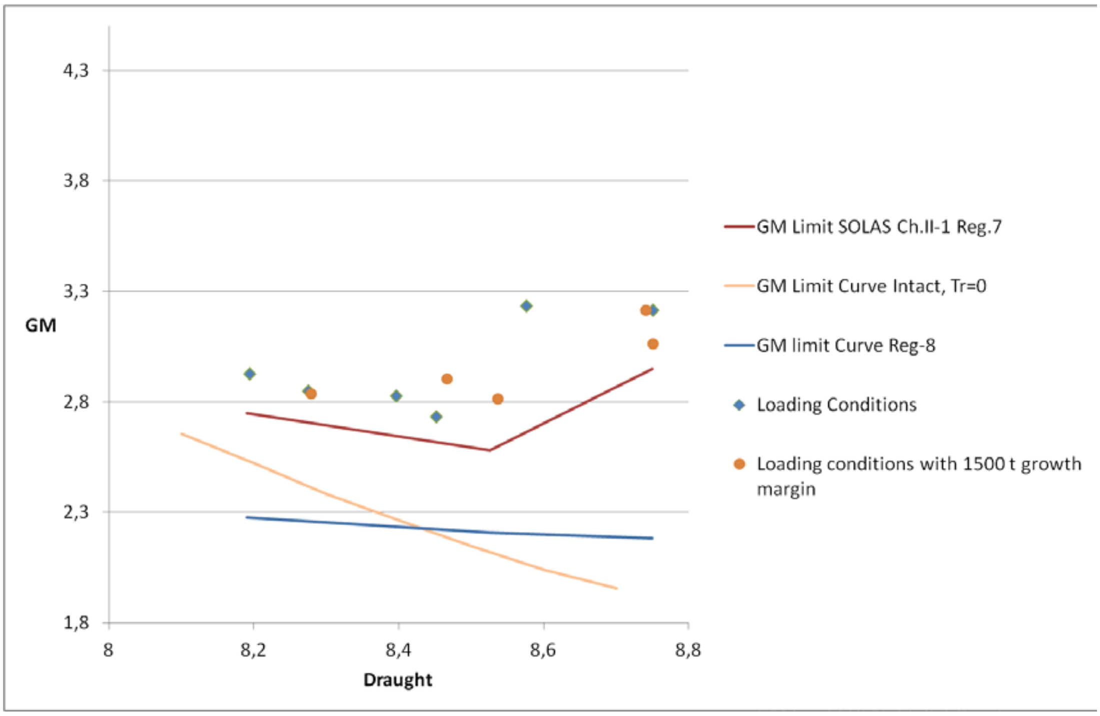


Fig. 13-10 GM Limiting curves K1

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.467 m
Breadth at the load line	40.800 m
Breadth at the bulkhead deck	40.800 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.87191

13.2.2.5 Version K2

This version is a further development of version K1. In addition to the changes to the internal subdivision, a part of the bulkhead deck has been made watertight, resulting in a relocation of staircases one deck upward.

Following changes have been applied:

- Relocation of heeling tanks one deck upwards
- Relocation of main switchboard rooms to centre line
- Shift of bulkhead at frame 378 to frame 382 to recover space for loss of crew cabins due to shift of heeling tanks
- Lengthening of potable water tanks forward of frame 404 to compensate the loss of potable water capacity due to the shift of bulkhead frame 378.

The following figures illustrates the principle of modification following the watertight deck

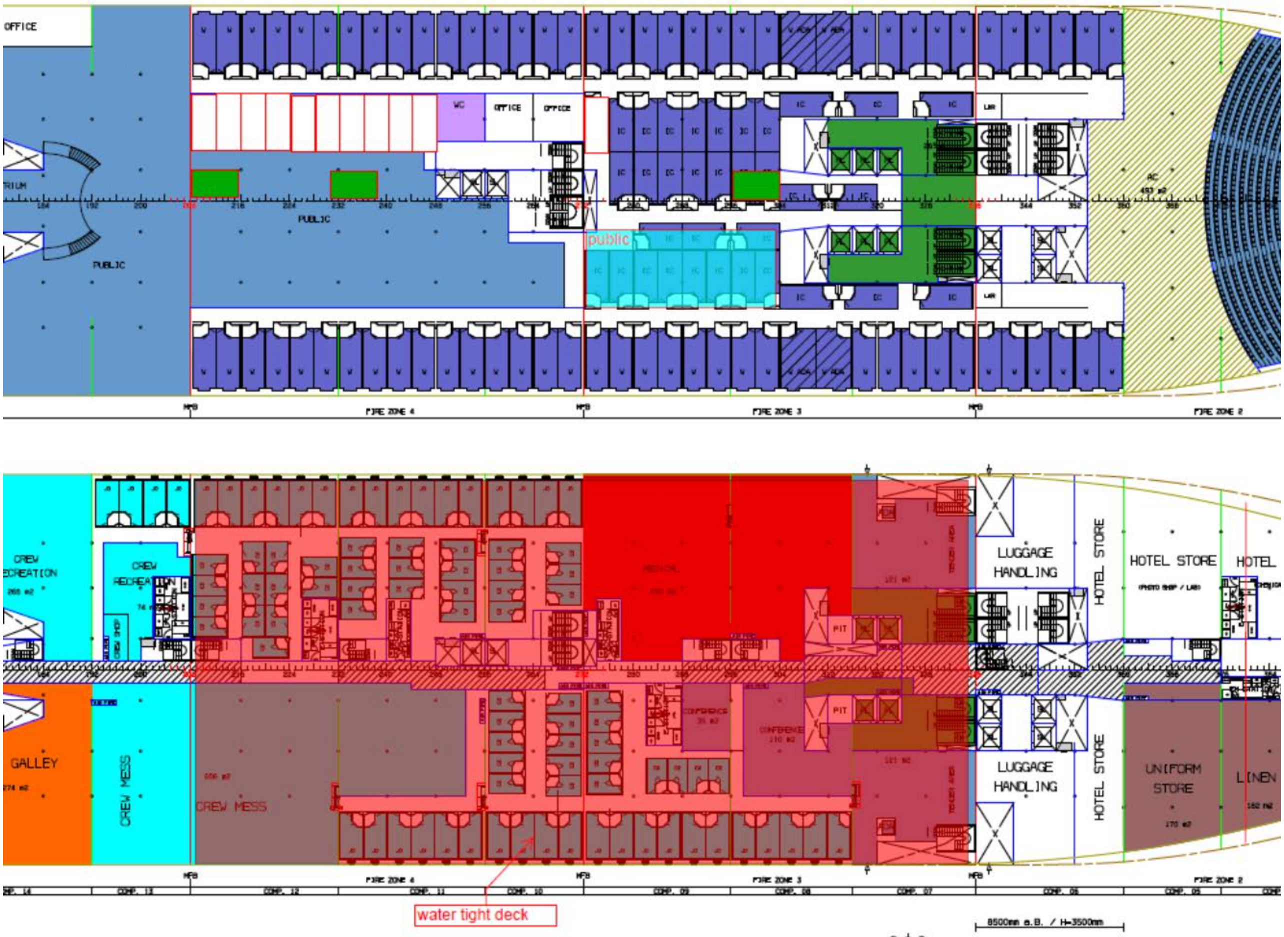


Fig. 13-11 Design Changes version K2

The remaining part of the bulkhead deck cannot be made watertight, due to the lifts serving the decks below.

In this layout a number of cabins (in total 3 inside cabins) on the deck above the bulkhead deck are lost due to the required space for staircases and corridors.

These changes lead only to small adjustment of the steel weight and outfitting areas. As in the version K1 the routing of pipes and ducts close to the centre line in way of the main switchboard rooms will become more complex due to the blocked passage way, which implies some additional building and design costs. No change in the engine plant has been made.

With these changes the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-9 Loading Conditions K2

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	14569 t	0 t	3822 t	4259 t	8.75 m	-0.28 m	3.21 m
LD23	50% Consumables	9525 t	634 t	1958 t	1587 t	8.28 m	-0.27 m	2.85 m
LD25	10% Consumables	7779 t	1401 t	411 t	433 t	8.10 m	-0.09 m	2.78 m
LD30	Contractual Deadweight	11727 t	0 t	2900 t	3097 t	8.45 m	0.22 m	2.73 m
LD33	20% HFO, 100% PW, 20%GW	10744 t	634 t	768 t	4253 t	8.40 m	-0.39 m	2.83 m
LD35	100% HFO, 20% PW, 100%GW	13026 t	997 t	3823 t	647 t	8.58 m	0.17 m	3.23 m
LD200	100% Consumables max. Draught	14657 t	0 t	3822 t	4259 t	8.75 m	-0.12 m	3.09 m
LD230	50% Consumables	11521 t	1130 t	1958 t	1587 t	8.47 m	-0.34 m	2.90 m
LD250	10% Consumables	9698 t	1634 t	411 t	433 t	8.28 m	-0.06 m	2.84 m
LD330	20% HFO, 100% PW, 20%GW	12244 t	634 t	768 t	4253 t	8.54 m	-0.38 m	2.81 m
LD350	100% HFO, 20% PW, 100%GW	14713 t	1184 t	3823 t	647 t	8.74 m	0.02 m	3.21 m

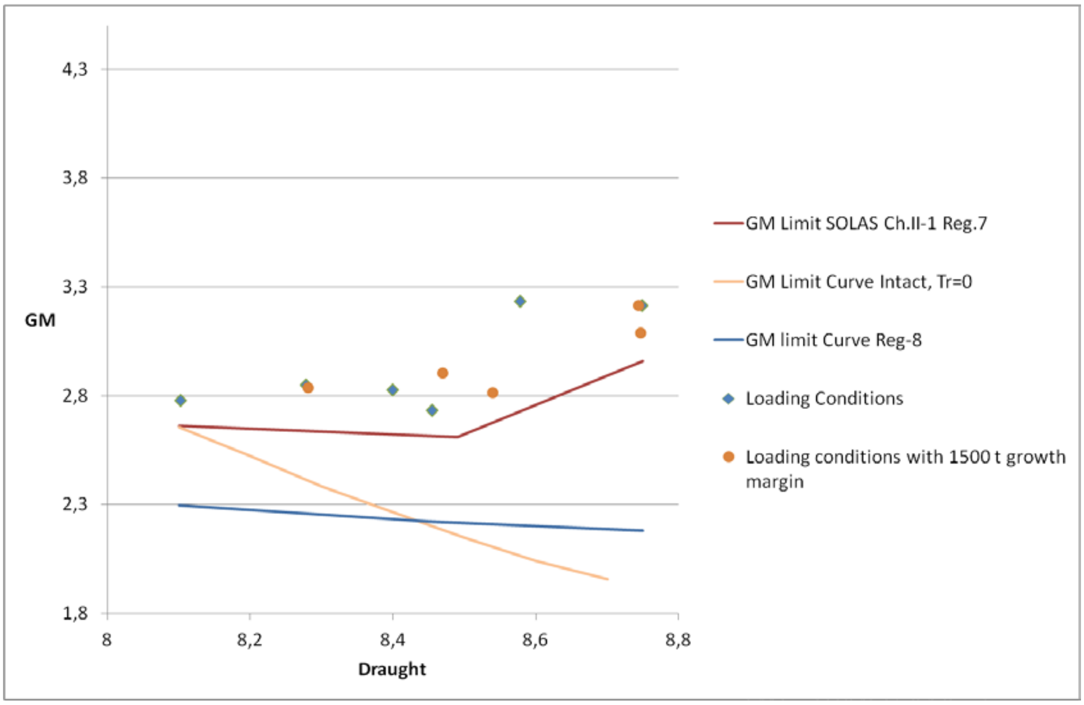


Fig. 13-12 GM Limiting curve – version K2

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.467 m
Breadth at the load line	40.800 m
Breadth at the bulkhead deck	40.800 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.87770

13.2.2.6 Version K3

This version is based on alternative K1, but the height of the bulkhead deck and thus the freeboard has been raised by 400mm.
Following changes have been applied:

- Raise of deck 4 from 11.8m to 12.2m
- Relocation of heeling tanks one deck upwards
- Relocation of main switchboard rooms to centre line
- Shift of bulkhead at frame 378 to frame 382 to recover space for loss of crew cabins due to shift of heeling tanks
- Lengthening of potable water tanks forward of frame 404 to compensate the loss of potable water capacity due to the shift of bulkhead frame 378.

The following figures illustrate the principle of modification:

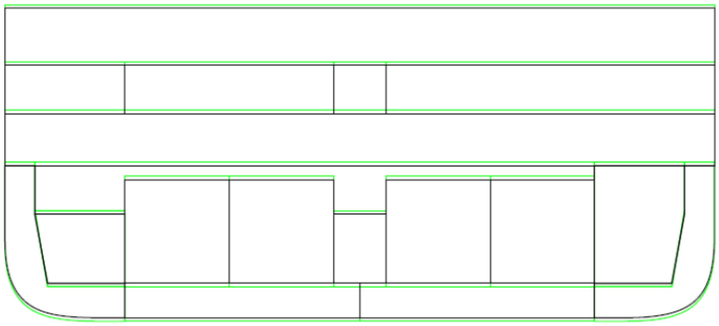


Fig. 13-13 Principle of modification – version K3

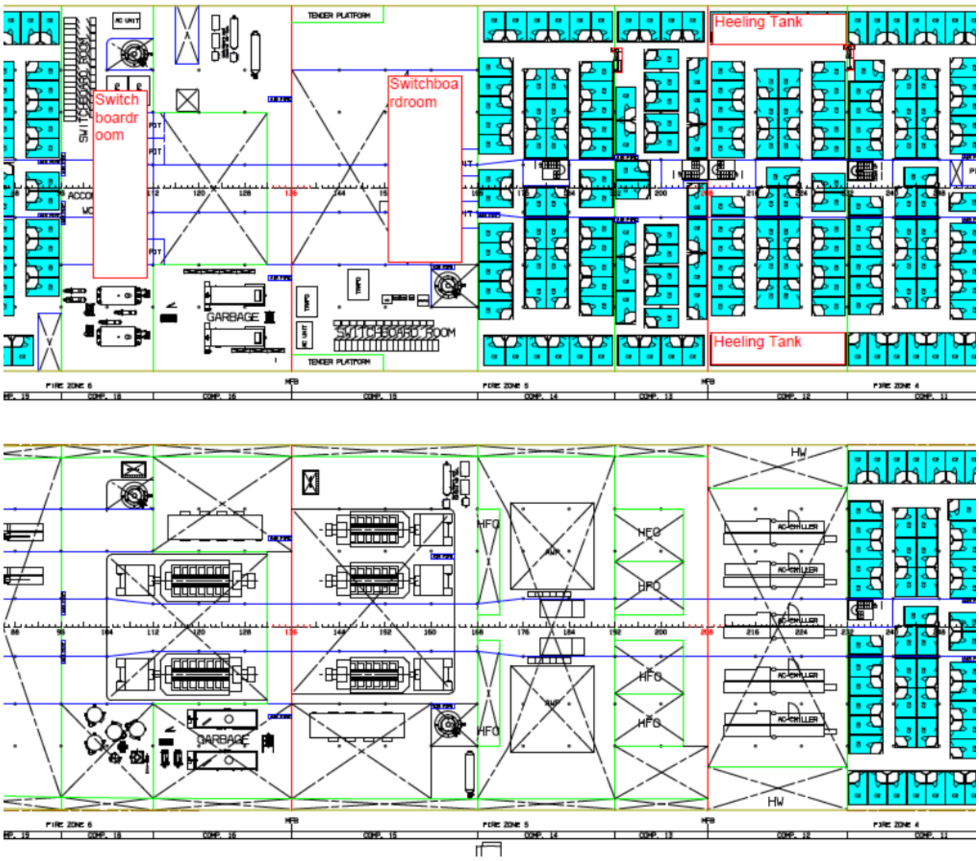


Fig. 13-14 Design modification – arrangement – K3

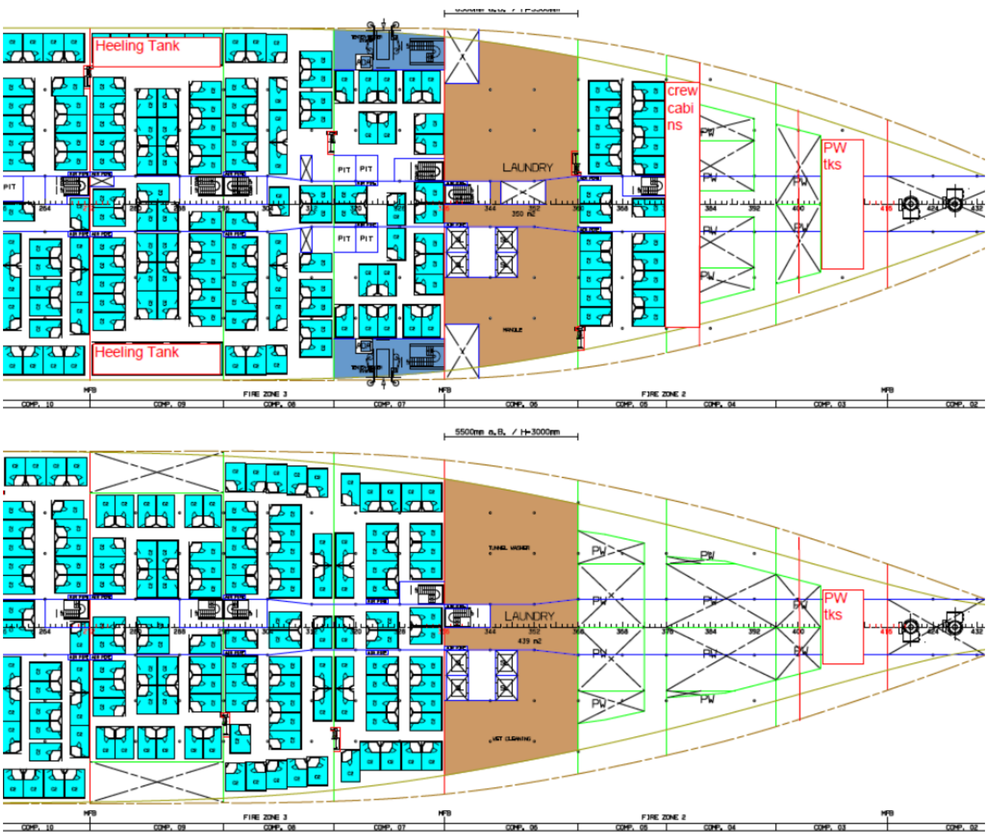


Fig. 13-15 Design modification – arrangement – K3

These changes lead only to small adjustment of the steel weight and outfitting areas. In addition the routing of pipes and ducts close to the centre line in way of the main switchboard rooms will become more complex due to the blocked passage way, which implies some additional building and design costs. No change in the engine plant has been made.

With these changes the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-10 Loading Conditions – design version K3

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	14483 t	0 t	3821 t	4164 t	8.75 m	-0.25 m	3.04 m
LD23	50% Consumables	9691 t	634 t	1975 t	1677 t	8.30 m	-0.31 m	2.68 m
LD25	10% Consumables	7846 t	1421 t	411 t	433 t	8.12 m	-0.13 m	2.60 m
LD30	Contractual Deadweight	11906 t	0 t	3093 t	3094 t	8.48 m	0.25 m	2.60 m
LD33	20% HFO, 100% PW, 20%GW	10877 t	634 t	792 t	4359 t	8.42 m	-0.37 m	2.65 m
LD35	100% HFO, 20% PW, 100%GW	13134 t	997 t	3919 t	672 t	8.59 m	0.21 m	3.06 m
LD200	100% Consumables max. Draught	14711 t	0 t	3821 t	3964 t	8.75 m	0.05 m	2.86 m
LD230	50% Consumables	11687 t	1130 t	1975 t	1677 t	8.49 m	-0.38 m	2.74 m
LD250	10% Consumables	9696 t	1655 t	411 t	433 t	8.29 m	-0.07 m	2.66 m
LD330	20% HFO, 100% PW, 20%GW	12377 t	634 t	792 t	4359 t	8.56 m	-0.36 m	2.65 m
LD350	100% HFO, 20% PW, 100%GW	14564 t	926 t	3919 t	672 t	8.73 m	0.16 m	3.01 m

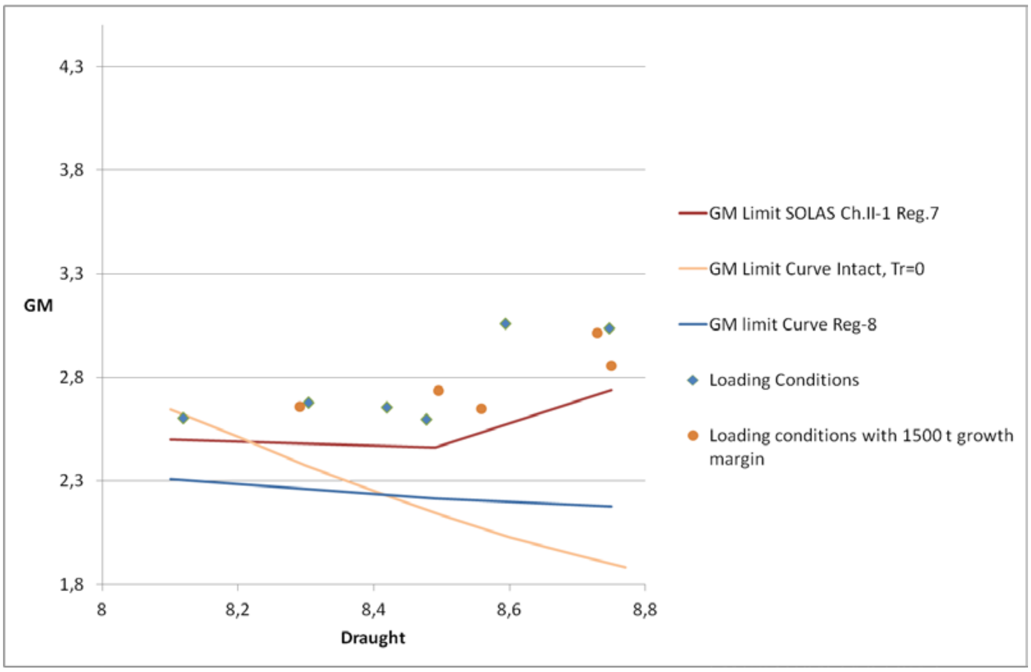


Fig. 13-16 Limiting GM curves – version K3

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.467 m
Breadth at the load line	40.800 m
Breadth at the bulkhead deck	40.800 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.87538

13.2.2.7 Version L1

This version is based on alternative K1, but the breadth of the vessel has slightly been increased to avoid excessive fuel costs.
Following changes have been applied:

- Increase of breadth from 40.8m to 41.0m
- Relocation of heeling tanks one deck upwards
- Relocation of main switchboard rooms to centre line
- Shift of bulkhead at frame 378 to frame 382 to recover space for loss of crew cabins due to shift of heeling tanks
- Lengthening of potable water tanks forward of frame 404 to compensate the loss of potable water capacity due to the shift of bulkhead frame 378.

The following figures illustrate the principle of modification:

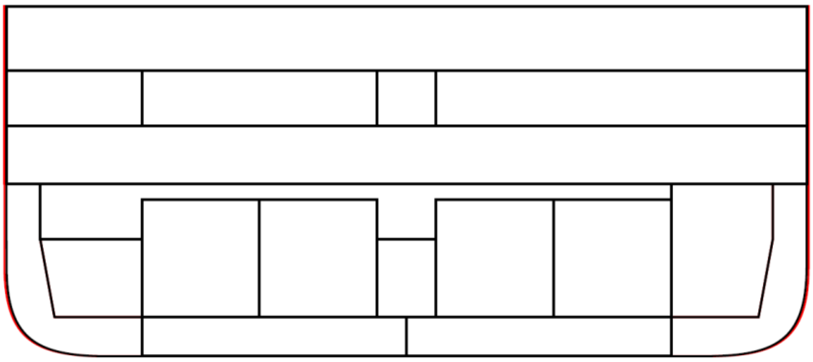


Fig. 13-17 Principles of modifications – design version L1

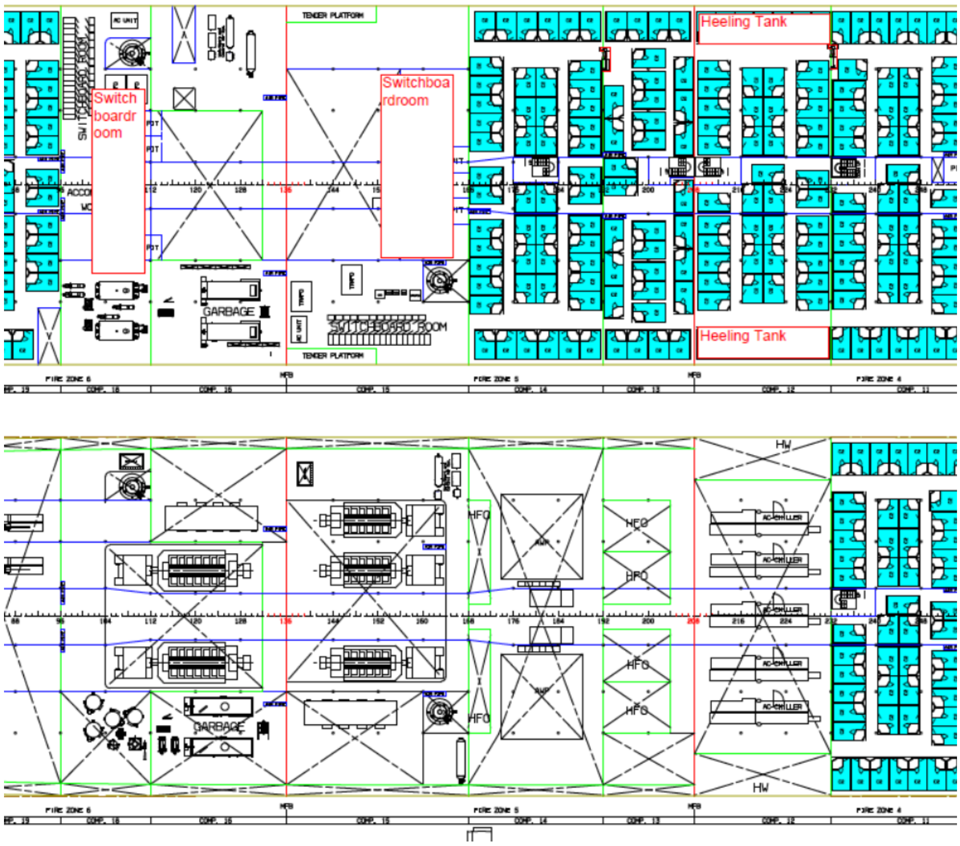


Fig. 13-18 Changes in arrangement – design version L1

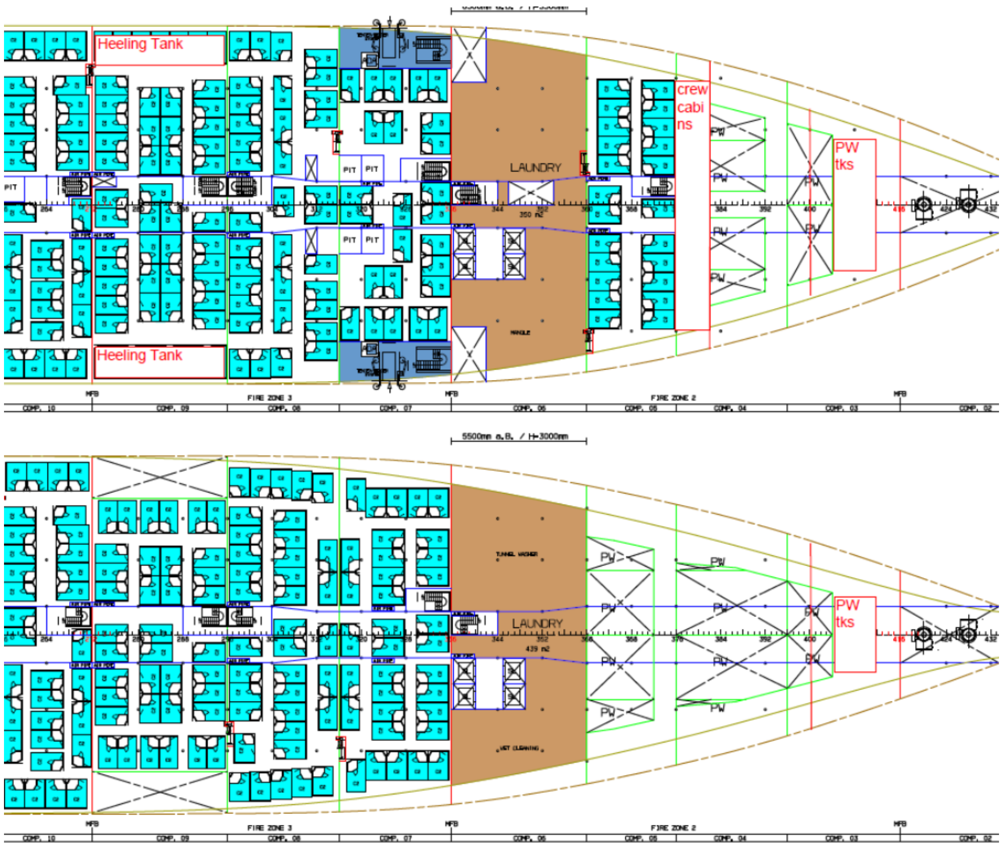


Fig. 13-19 Changes in arrangement – design version L1

These changes lead only to small adjustment of the steel weight and outfitting areas. In addition the routing of pipes and ducts close to the centre line in way of the main switchboard rooms will become more complex due to the blocked passage way, which implies some additional building and design costs. No change in the engine plant has been made.

With these changes the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-11Loading conditions – design version L1

NAME	TEXT	DW	BW	HFO	PW	T	TR	GM
LD20	100% Consumables max. Draught	14741 t	0 t	3822 t	4259 t	8.75 m	-0.21 m	3.36 m
LD23	50% Consumables	9547 t	637 t	1958 t	1587 t	8.27 m	-0.28 m	2.99 m
LD25	10% Consumables	7800 t	1406 t	411 t	433 t	8.10 m	-0.09 m	2.92 m
LD30	Contractual Deadweight	11727 t	0 t	2900 t	3097 t	8.44 m	0.22 m	2.87 m
LD33	20% HFO, 100% PW, 20%GW	10764 t	637 t	768 t	4253 t	8.39 m	-0.40 m	2.96 m
LD35	100% HFO, 20% PW, 100%GW	13048 t	999 t	3823 t	647 t	8.57 m	0.16 m	3.37 m
LD200	100% Consumables max. Draught	14763 t	0 t	3822 t	4259 t	8.75 m	-0.17 m	3.21 m
LD230	50% Consumables	11543 t	1132 t	1958 t	1587 t	8.46 m	-0.34 m	3.04 m
LD250	10% Consumables	9722 t	1639 t	411 t	433 t	8.27 m	-0.06 m	2.98 m
LD330	20% HFO, 100% PW, 20%GW	12264 t	637 t	768 t	4253 t	8.53 m	-0.39 m	2.95 m
LD350	100% HFO, 20% PW, 100%GW	14738 t	1189 t	3823 t	647 t	8.73 m	0.01 m	3.35 m

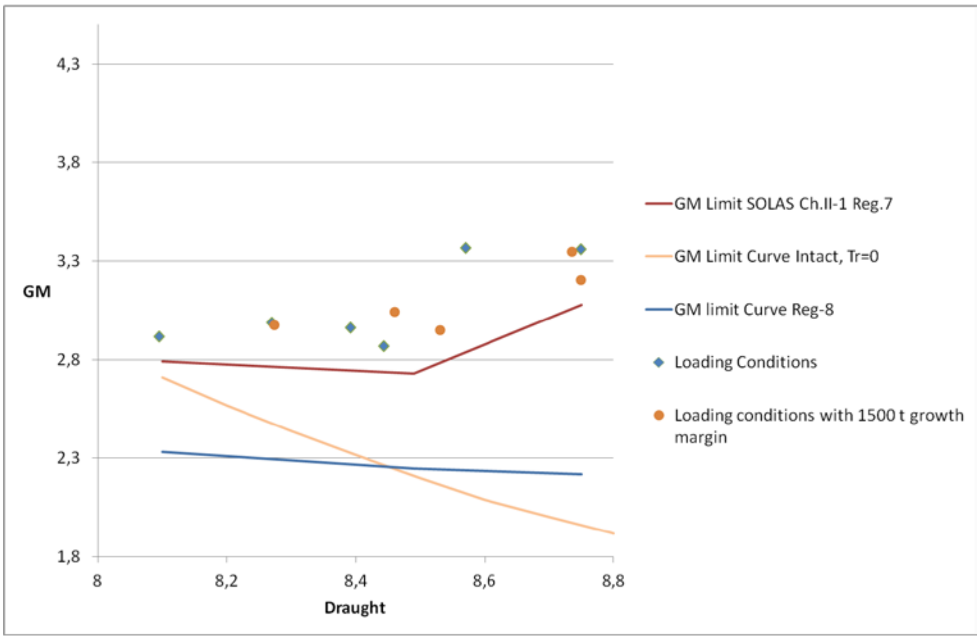


Fig. 13-20 GM limiting curves – design version L1

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	316.467 m
Breadth at the load line	41.000 m
Breadth at the bulkhead deck	41.000 m
Number of persons N1	5422
Number of persons N2	1308
Required subdivision index R	0.85969
Attained subdivision index A	0.87740

13.2.3 Cost Benefit Assessment

Following cost assumptions have been used for this vessel, which are based on analysed recent new build ships of the shipyard:

- Steel weight, including piping, ducting, painting 6000€/t
- Public areas including ducting, cabling etc 2600 €/m2
- Cabin areas including ducting, cabling etc 2400 €/m2
- Technical areas, like galley, laundry including ducting, cabling etc 5000 €/m2
- Additional installed power of main engines, taking into account any discrete step in engine size 380 €/kW
- Additional installed propulsion power 700€/kW
- Estimation of more complex piping and ducting due to complicated watertight subdivision based on experience

For the costs of the fuel a typical annual operating profile has been used to calculate the change in fuel oil consumption per year. Based on the distribution of the different operational modes with different speed a mean propulsion power has been calculated. The hotel load, which is mainly depends on the size of the vessel has been adjusted linear to the change in gross tonnage. The following table shows the overview of the design variations and the FOC:

Table 13-12 Fuel oil consumption – design alternatives

Version	G2	H4	I3	J1	L1
GT	153400	154671	158127	155225	153744.9597
Duration	8640 hrs	8640 hrs	8640 hrs	8640 hrs	8640 hrs
speed	0.0 kn	0.0 kn	0.0 kn	0.0 kn	0.0 kn
percentage	17%	17%	17%	17%	17%
prop power	0 kW	0 kW	0 kW	0 kW	0 kW
speed	12.0 kn	12.0 kn	12.0 kn	12.0 kn	12.0 kn
percentage	17%	17%	17%	17%	17%
prop power	5957 kW	6026 kW	6059 kW	6006 kW	5982 kW
speed	18.0 kn	18.0 kn	18.0 kn	18.0 kn	18.0 kn
percentage	30%	30%	30%	30%	30%
prop power	19039 kW	19187 kW	19330 kW	19164 kW	19115 kW
speed	21.0 kn	21.0 kn	21.0 kn	21.0 kn	21.0 kn
percentage	36%	36%	36%	36%	36%
prop power	31013 kW	31168 kW	31456 kW	31181 kW	31139 kW
mean mech prop power	17889 kW	18001 kW	18153 kW	17995 kW	17961 kW
efficiency PEM	0.92	0.92	0.92	0.92	0.92
mean electrical prop power	19445 kW	19566 kW	19732 kW	19560 kW	19523 kW
Hotel load	12501 kW	12604 kW	12886 kW	12649 kW	12529 kW
efficiency generators	0.97	0.97	0.97	0.97	0.97
Total diesel load	32933 kW	33165 kW	33626 kW	33206 kW	33043 kW
SFOC	0.200 kg/kWh	0.200 kg/kWh	0.200 kg/kWh	0.200 kg/kWh	0.200 kg/kWh
SFOC Boiler	150 kg/h	150 kg/h	150 kg/h	150 kg/h	150 kg/h
total consumption per hour	6.74 t	6.78 t	6.88 t	6.79 t	6.76 t
Fuel consumption per year	58204.95 t	58605.90 t	59402.51 t	58675.35 t	58394.82 t
relative	100.0%	100.7%	102.1%	100.8%	100.3%
Change of FOC per year	**0.00 t**	**400.96 t**	**1197.56 t**	**470.40 t**	**189.88 t**

For the variants K1, K2, K3 no change in fuel consumption has been calculated as the hull form has not been changed.

The anticipated fuel mix can be seen from the following diagram. It is assumed that scrubber technology has been installed in this ship, but as the availability of high sulphur heavy fuel maybe limited in the future a small portion of low sulphur HFO is assumed to be used as well.

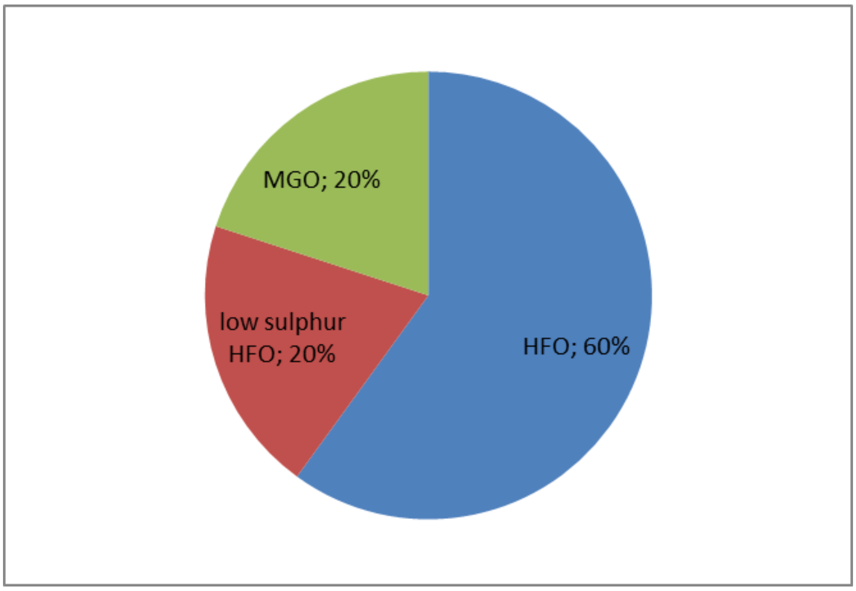


Fig. 13-21 Distribution of fuel types

In one of the variants there has been a small loss of passenger cabins. This marginal loss does not significantly change the business model as such, but the loss of revenue has been accounted for by using the published values for revenue per passenger day of three major cruise lines for 2013.

Table 13-13 Effect of loss of cabin spaces

Company	1	2	3	Sum
Passengerdays 2013 [Mio]	11,401	77,797	35,562	124.76
Revenue [Mio USD]	2,570.3	15,457.0	7,959.9	25,987.2
Revenue / pass.day [USD]	225.45	198.68	223.83	**208.30**

For each cabin double occupancy is assumed with an average rate of occupancy of 95% of the time. With assumed 360 days of service per year this results in a change of revenue per cabin to be 142,477 USD per year.

13.2.3.1 Basic results

Using the assumptions above following costs presented as net present values are achieved for the different design variations:

Table 13-14 Summary of results

Version	G2	H4	I3	J1	K1	K2	K3	L1
Description	original design	Breadth + 1 m	B+1, DK4(Z+0.8)	B+0.6, DK4(Z+0.2)	change subdivision	change subd. + wt deck	change subd. + increaase freeboard +40cm	change sunbdivision B0+.2
Loa	320	320	320	320	320	320	320	320
B	40.8	41.8	41.8	41.4	40.8	40.8	40.8	41.0
T	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75
Height BHD	11.8	11.8	12.6	12.0	11.8	11.8	12.2	11.,8
Gross Tonnage	153,400	154,671	158,127	155,225	153,400	153,400	155,000	153,745
Change of fuel consumption	0	401	1,198	470	0	0	0	190
Net Present Value NPV	**0 $**	**13.192.654 $**	**33.312.852 $**	**12.972.084 $**	**485.931 $**	**7.647.567 $**	**1.589.220 $**	**5.439.515 $**

At the same time following changes of the attained index can be achieved with the design modifications.

Table 13-15 Overview attained index A for design modifications

Version	G2	H4	I3	J1	K1	K2	K3	L1
required index R	0.8597	0.8597	0.8597	0.8597	0.8597	0.8597	0.8597	0.8597
attained index A	0.8621	0.9087	0.9288	0.9004	0.8719	0.8777	0.8754	0.8774
change A	0.0000	0.0466	0.0667	0.0383	0.0098	0.0156	0.0133	0.0153

The cost effectiveness can be easily demonstrated in the diagram below, where the costs as net present values are plotted against the attained index A. Also included are limits for allowable costs to match the netCAF limits of 4 Mio$ and 8 Mio$ including the 5% and 95% uncertainty limits.

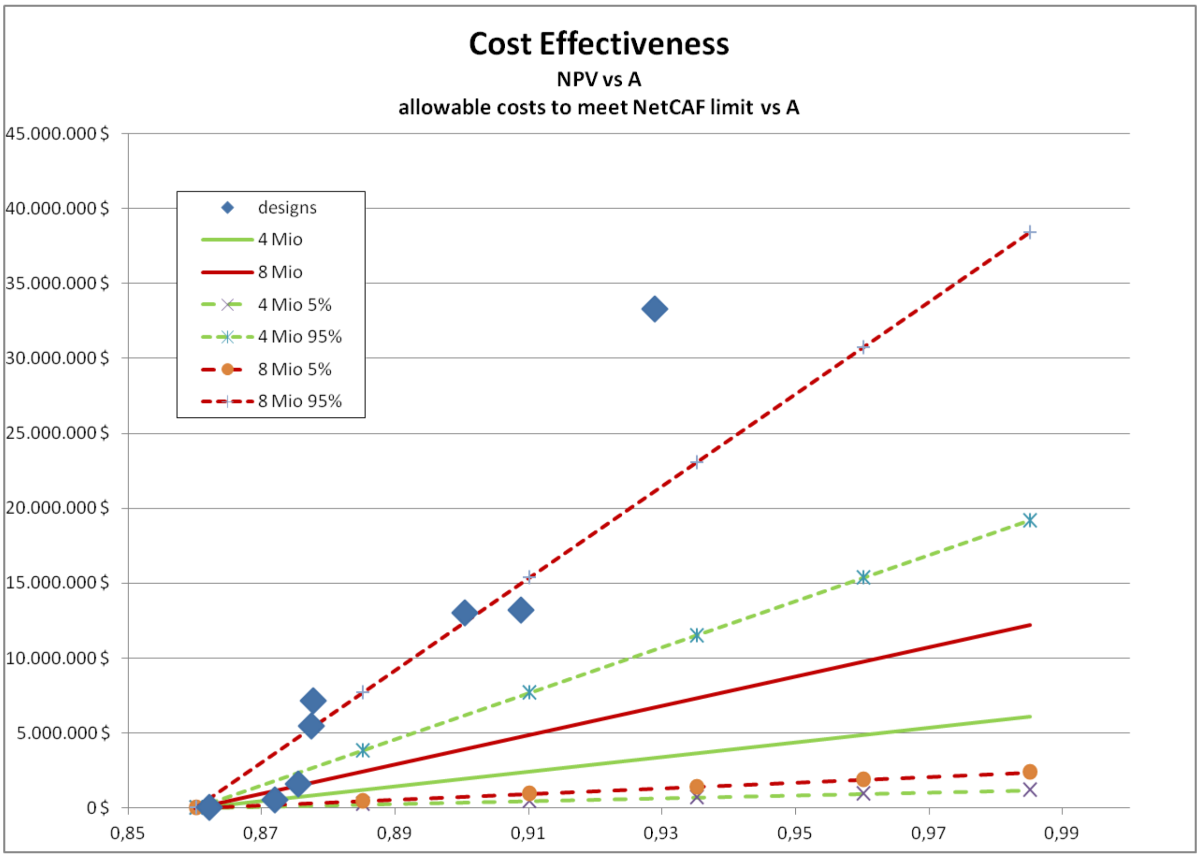


Fig. 13-22: Cost limit curves – Large cruise

It can be seen that the increase of fuel costs or the loss of cabins are the main drivers for the costs and only the two options are below the limits, where the breadth and number of cabins will be kept unchanged.

13.2.3.2 Sensitivity analysis

Due to the high impact of the fuel costs on the overall life-cycle costs a sensitivity analysis has been made to apply on the cost model the high and low estimates for the fuel price development and simultaneously to reduce and increase all other costs and revenue by ±20%.

This leads to following net present values:

Table 13-16 Overview NPV mean, high and low

Version	H4	I3	J1	K1	K2	K3	L1
Net Present Value NPV	13.192.654 $	33.312.852 $	12.972.084 $	485.931 $	7.647.567 $	1.589.220 $	5.439.515 $
Net present value NPV low	9.867.139 $	24.779.603 $	9.587.385 $	297.350 $	6.026.658 $	995.001 $	3.612.078 $
Net present value NPV high	15.639.393 $	39.221.434 $	15.325.819 $	674.513 $	9.268.475 $	1.722.814 $	5.935.274 $

Or in the diagram representation as shown in the following:

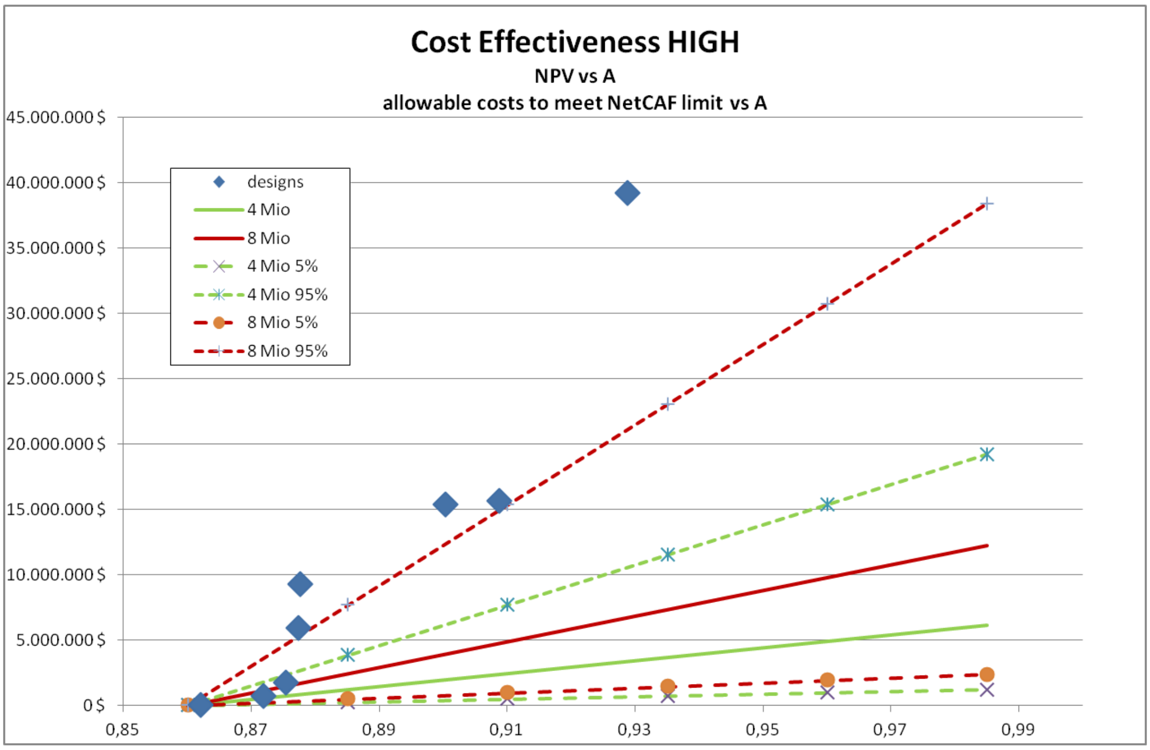


Fig. 13-23 Cost limit curves – Large cruise - High

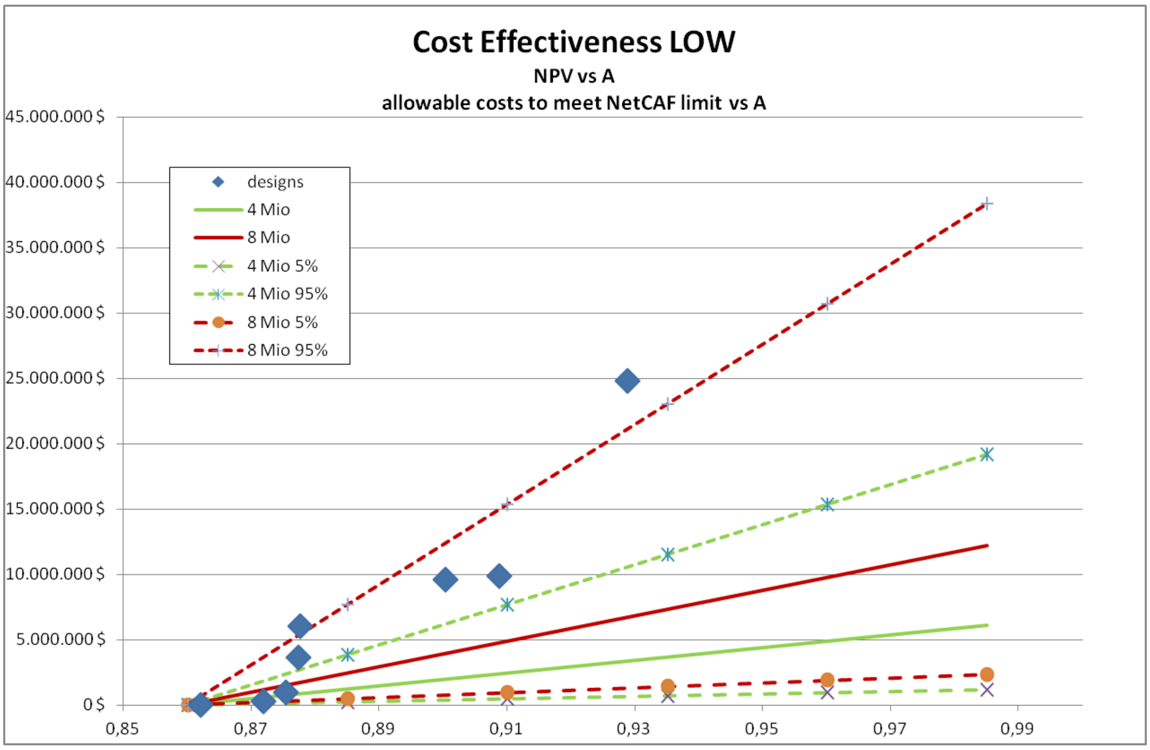


Fig. 13-24 Cost limit curves – Large cruise - Low

Even with the lower figures used for fuel and other costs most of the design options are above the cost limits and only 2 options are feasible.

13.2.3.3 Conclusion and selection of optimized design

As shown above a significant increase of the attained index A can be achieved even by moderate increase of breadth and freeboard. However due to the dominating costs for fuel and loss of cabins only two options can be assumed to meet the CAF limits chosen in this project.

Therefore the **version K3**, with a slight increase of freeboard and an optimized arrangement of heeling tanks and A-class boundaries is selected to be the one, which will be used in the further work of this project as the optimized design with regard to collision.

13.3 Ship #2 Small Cruise Ship

13.3.1 General Approach

The applied approach for defining design variations is divided in two parts.
In the first part, from version 01 to version 04, some improvements for the watertight subdivision of the vessel have been applied. Those improvements have been selected after examination of the detailed results of the damage stability calculation of the reference design.

In the second part, from version 05 to version 09, different options with Beam increase have been added to previous version 04. This approach may have significant impact on the life cycle costs, as the annual fuel consumption may change significantly.

The following table shows an overview of the applied design variations, which will be described in the following sections one by one in more detail.

Table 13-17 Design variations

Version	Description
00	Reference design
01	Sill increased on external weathertight aft doors
02	Vs.01 + Deck 3 made wathertight for comp n.2 and n.3
03	Vs.02 + Cross flooding section within DB void spaces improved adding pipes
04	Vs.03 + Two weathertight door added and a watertight door added on BK deck
05	Vs.04 + Increased Beam by 0.2m (new B=20.2m)
06	Vs.04 + Increased Beam by 0.5m (new B=20.5m)
07	Vs.06 + Increased freeboard by 0.25m
08	Vs.07 + Increased Beam by 0.5m (new B=21m)
09	Vs.04 + Increased Beam by 0.1m (new B=20.1m)

13.3.2 Design Variations

13.3.2.1 Version 01

This RCO has been obtained just by increasing the sill of the weathertight doors connecting the internal spaces on deck 3 with the aft marina. In that way the height of the weathertight openings defined for the damage stability calculations has been increased by 0.5m.

The following figure illustrates the position of the doors where the sills have been increased:

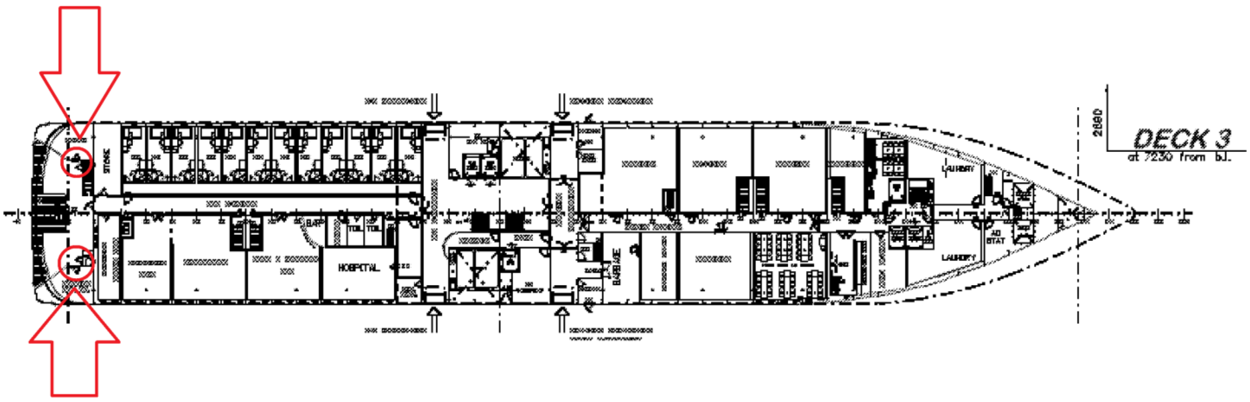


Fig. 13-25 Increase of sill heights

For this modification the effect on Lightship weight and Center of Gravity is negligible.

The following table shows the loading conditions that have been kept constant from the reference design.

Table 13-18 Loading conditions – small cruise

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.09 m	0.04 m	1.38 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.92 m	0.11 m	1.32 m
LD03	100% Consumables max. Draught	1669 t	74 t	503 t	315 t	5.30 m	-0.21 m	1.57 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.19 m	0.26 m	1.38 m

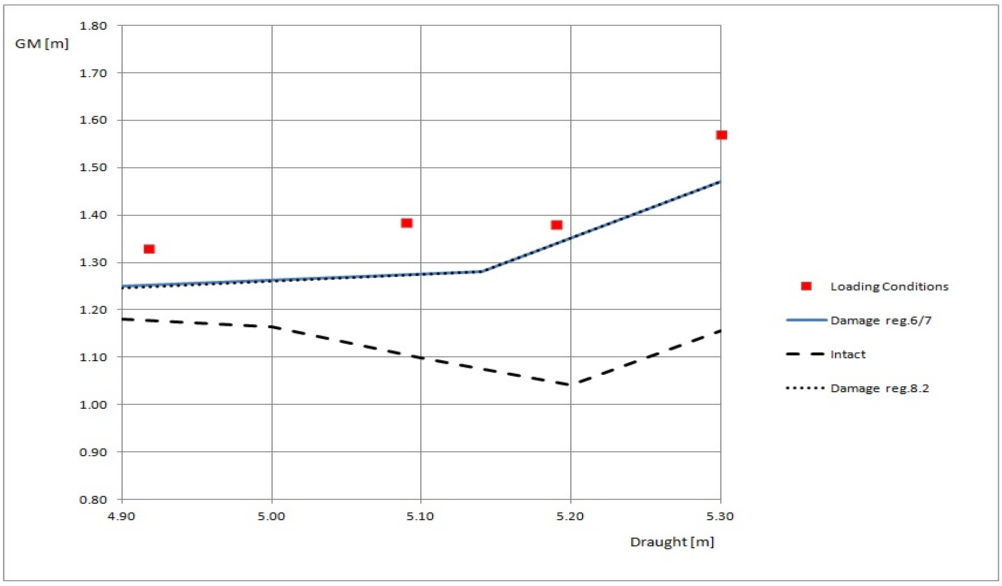


Fig. 13-26 GM limiting curves

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20 m
Breadth at the bulkhead deck	20 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.7263

13.3.2.2 Version 02

In this version, starting from version 01, the floor of the deck 3 in the aft part of the vessel (comp n.2 and n.3) has been made watertight. That improvement permits to avoid the up-flooding from deck 2 to deck 3 in case of a damage case with limited vertical extension.
For this modification some watertight valves (remotely controlled) are to be installed to protect from up-flooding due to breaching pipes passing through the deck.

The following figure illustrates the area of the modification

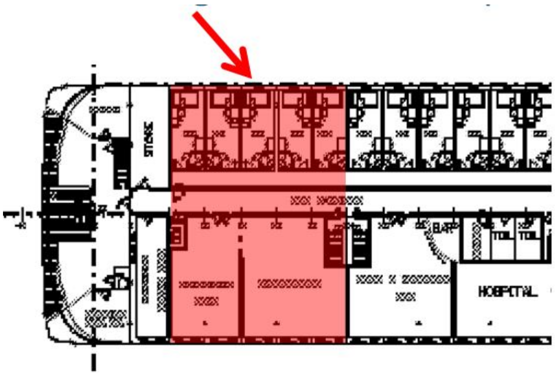


Fig. 13-27 Arrangement of watertight deck

Due to the increase of watertight valves and arrangements needed to make the floor of deck 3 watertight the lightship weight of the vessel has been recalculated.

The following table shows the result of the change with regard to weight.

Table 13-19 Change in weight

Version	Ref.	02	change
GT	11800 GT	11800 GT	0 GT
Lightweight	7185 t	7192 t	7 t

As shown in the above table the effect on the lightweight is negligible therefore the loading conditions have not been modified.

Table 13-20 Loading conditions

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.09 m	0.04 m	1.38 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.92 m	0.11 m	1.32 m
LD03	100% Consumables max. Draught	1669 t	74 t	503 t	315 t	5.30 m	-0.21 m	1.57 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.19 m	0.26 m	1.38 m

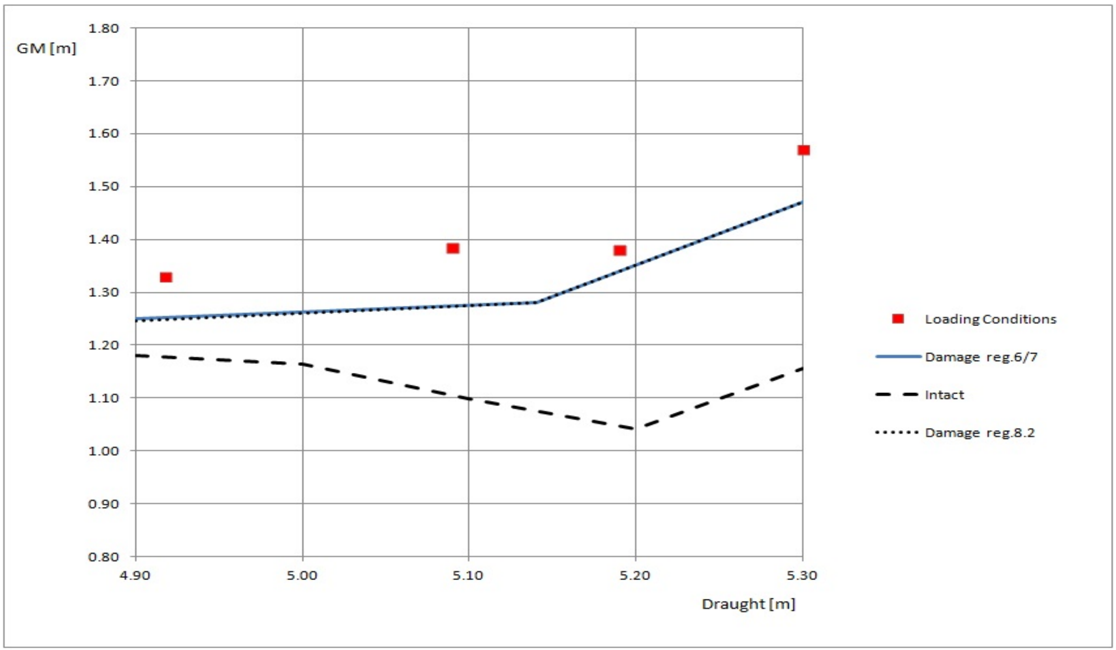


Fig. 13-28 GM Limiting curves

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20 m
Breadth at the bulkhead deck	20 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.7307

13.3.2.3 Version 03

The RCO n.02 has been used as a starting point for version 03. In this version the cross flooding section for void space n.6 has been improved adding two pipes (Diameter=500mm) within the double bottom.

The following figure illustrates the principle of modification:

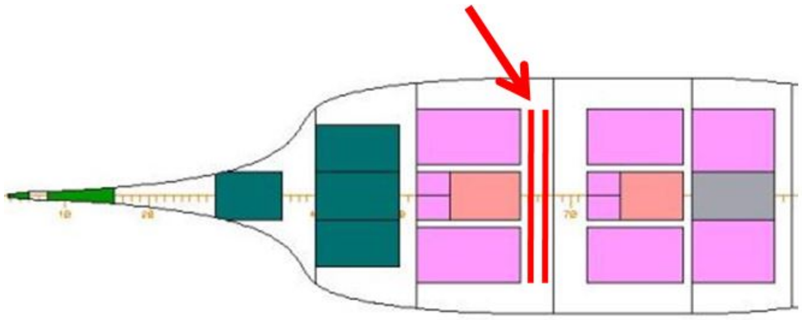


Fig. 13-29 Design modification version 03

Due to the increase of cross-flooding pipes and the longitudinal girders rearrangement the lightship weight of the vessel has been increased.

The following table shows the result of the change with regard to weight.

Table 13-21Table of weight change – design modification 03

Version	Ref.	02	03	Change (from vs.02 to vs.03)
GT	11800 GT	11800 GT	11800 GT	0 GT
Lightweight	7185	7192 t	7201 t	9 t

Due to combination of modification n.2 and n.3 the total increase of the lightship weight equals to about 16t therefore the loading conditions have been updated consequently.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-22 Loading conditions- design modification 03

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.10 m	0.04 m	1.39 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.93 m	0.10 m	1.34 m
LD03	100% Consumables max. Draught	1669 t	74 t	503 t	315 t	5.31 m	-0.21 m	1.57 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.20 m	0.26 m	1.39 m

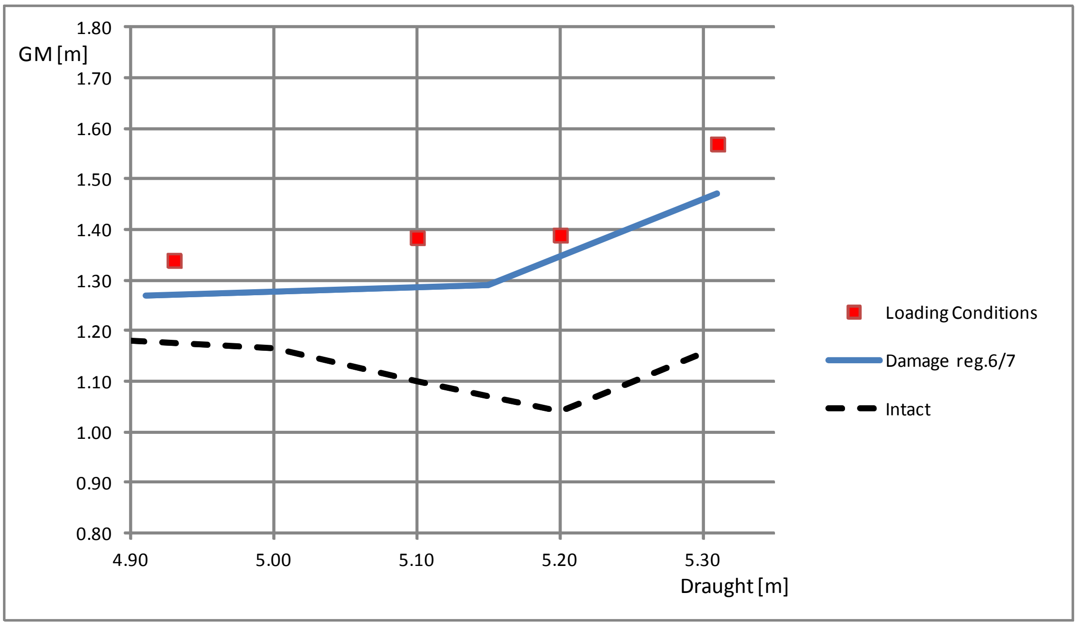


Fig. 13-30 GM Limiting curves – design modification 03

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20 m
Breadth at the bulkhead deck	20 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.7442

13.3.2.4 Version 04

The version 03 has been used as a starting point for version 04. In this version two weathertight door on deck 3 (fr.8 and fr.120) and a watertight door on deck 3 (fr.144) have been added.

The following figure illustrates location of added doors.

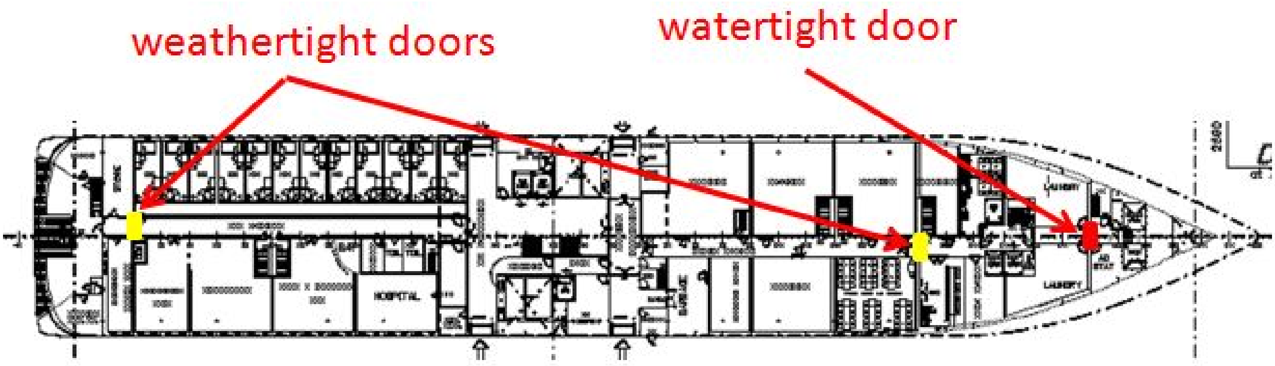


Fig. 13-31 Change in arrangement – design modification 04

Due to the added doors and connected systems the lightship weight of the vessel has been slightly increased.

The following table shows the result of the change with regard to weight.

Table 13-23 Weight changes

Version	Ref.	02	03	04	Change (from vs.03 to vs.04)
GT	11800 GT	11800 GT	11800 GT	11800	0 GT
Lightweight	7185	7192 t	7201 t	7304	3 t

The modification has a negligible effect on the loading condition therefore the GM limiting values are unchanged.

Table 13-24 Loading conditions – design modification 04

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.10 m	0.04 m	1.39 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.93 m	0.10 m	1.34 m
LD03	100% Consumables max. Draught	1669 t	74 t	503 t	315 t	5.31 m	-0.21 m	1.57 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.20 m	0.26 m	1.39 m

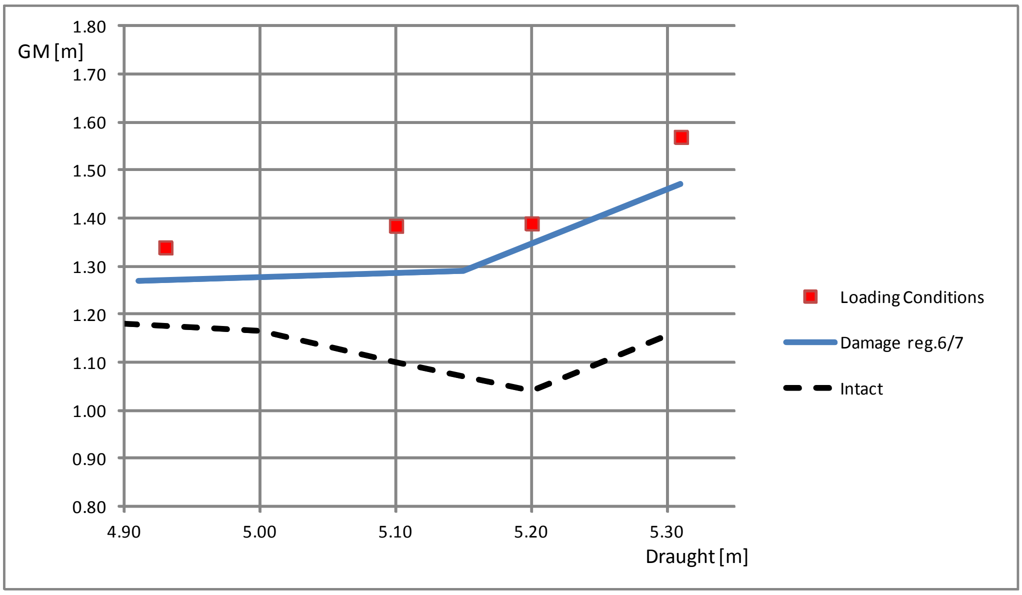


Fig. 13-32 GM Limiting curves design modification 04

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20 m
Breadth at the bulkhead deck	20 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.7544

13.3.2.5 Version 05

After the optimization of the internal subdivision obtained as shown in the previous RCOs, major modifications on the hull have been applied starting from version 05 to version 09, using the version 04 as a basis. In the version 05 the breadth of the hull has been increased by 0.2m. The superstructure above the deck 4 has been kept constant; the interior areas within the hull have been increased due to the changed shape. In particular the crew cabins areas located on deck 3 and the technical rooms located on deck 1,2 and 3 have been increased but the pax cabins areas (located from deck 4 to upper decks) remain unchanged.

The following figure illustrates the principle of modification

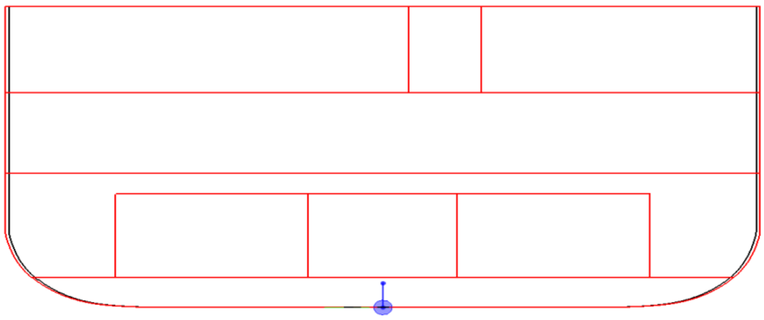


Fig. 13-33 Arrangement – design modification 05

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas.

Table 13-25 Change in weight and areas

Data	Change (from vs.04 to vs.05)
GT	69 GT
Lightweight	42 t
Public area	4 m^2
Crew Cabin	12 m^2
Tech spaces	25 m^2

Due the wider hull form the deck spaces used for crew cabins and public rooms, as well as for some technical spaces are increased. These additional areas require additional efforts for outfitting and interior work, however the increased spaces do not result in additional revenue. The changes are too small to fit additional cabins, and also the gained space in public rooms does not generate additional income as there are no additional guests on board to spend money.

Even if the increase of the hull caused an increase of propulsion power to maintain the required trial speed it is not necessary to change the main engine plant in this version as there was sufficient margin in the reference version between required and installed power.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-26 Loading conditions – design modification 05

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.07 m	0.05 m	1.58 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.90 m	0.12 m	1.55 m
LD03	100% Consumables max. Draught	1669 t	74 t	503 t	315 t	5.28 m	-0.20 m	1.76 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.18 m	0.27 m	1.57 m

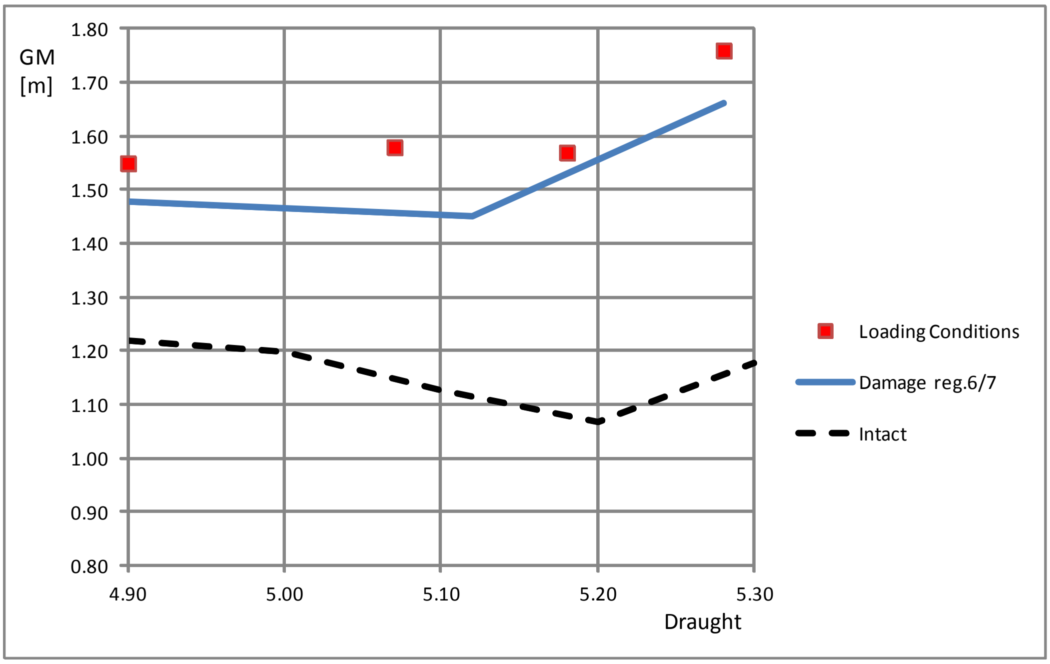


Fig. 13-34 GM Limiting curves – design modification 05

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20.2 m
Breadth at the bulkhead deck	20.2 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.7944

13.3.2.6 Version 06

In this version the breadth of the ship has been increased by 0.3m further. In this version also the superstructure above the deck 4 has been kept constant; the interior areas within the hull has been increased due to the changed shape. The crew cabins areas located on deck 3 and the technical rooms located on deck 1,2 and 3 have been increased but the pax cabins areas (located from deck 4 to upper decks) remains unchanged.

The following figure illustrates the principle of modification with reference to original version.

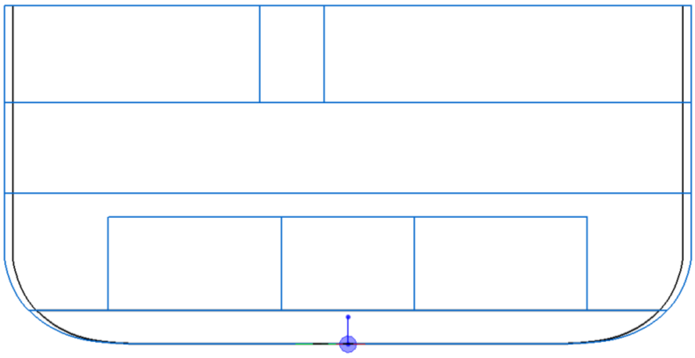


Fig. 13-35 Design change version 06

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas.

Table 13-27 Change in weight- design version 06

Data	Change (from vs.05 to vs.06)
GT	102 GT
Lightweight	62 t
Public area	7 m^2
Crew Cabin	17 m^2
Tech spaces	38 m^2

Due the wider hull form the deck spaces used for crew cabins and public rooms, as well as for some technical spaces are increased. These additional areas require additional efforts for outfitting and interior work, however the increased spaces do not result in additional revenue. The changes are too small to fit additional cabins, and also the gained space in public rooms does not generate additional income as there are no additional guests on board to spend money.

Even if the increase of the hull caused an increase of propulsion power to maintain the required trial speed it is not necessary to change the main engine plant in this version as there was sufficient margin in the reference version between required and installed power.

These hull increase is the maximum achievable without changing the power plant. Any further increase of the hull resistance will require a new main engine plant.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-28 Loading condition – design version 06

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.05 m	0.08 m	1.87 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.88 m	0.14 m	1.83 m
LD03	100% Consumables max. Draught	1691 t	94 t	503 t	315 t	5.26 m	-0.12 m	2.04 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.15 m	0.30 m	1.86 m

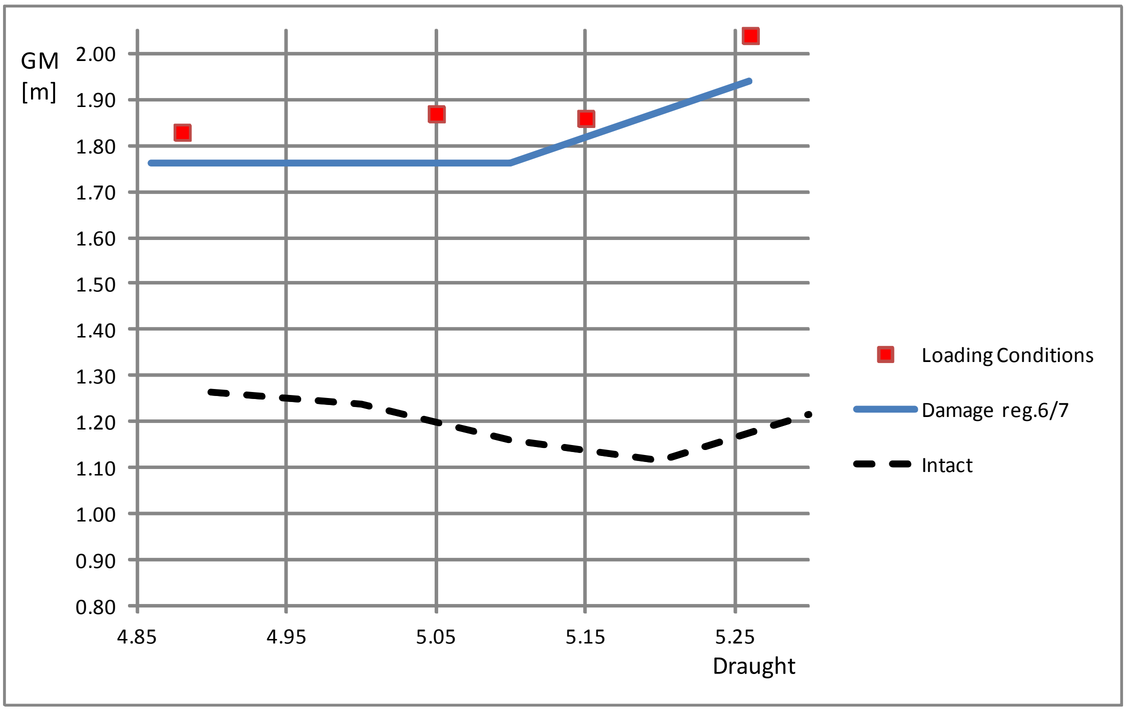


Fig. 13-36 GM limiting curves – design modification 06

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20.5 m
Breadth at the bulkhead deck	20.5 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.8281

13.3.2.7 Version 07

This version is based on version 06 with the addition of the freeboard increase by 0.25m. That alteration has been obtained by increasing the height of the bulkhead deck (deck 3) from 7.23m to 7.48m. As a consequence all the decks above deck 3 have been translated vertically by 0.25m.
The height of deck 1 and deck 2 has not been changed.

The following figure illustrates the principle of modification with reference to original version

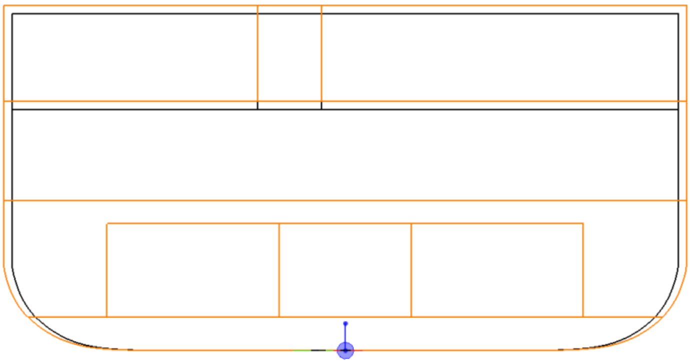


Fig. 13-37 Design modification version 07

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index. The vertically increase of the height of the higher decks generate a relevant increase of the vertical center of gravity of the lightship.

The following table shows the result of the change with regard to weight and vertical centre of gravity of the ship for different versions.

Table 13-29 Change in weight

Version	04	05	06	07	Change (from vs.06 to vs.07)
GT	11800 GT	11869 GT	11971 GT	12173 GT	202 GT
Lightweight	7204 t	7246 t	7308 t	7465 t	157 t
VCG	10.28m	10.25m	10.22m	10.36m	0.16m

As the deck 1 and deck 2 have been maintained constant no change has been obtained for the tanks volume.

The weight increase caused an increase of propulsion power to maintain the required trial speed and as a consequence two main engines required the next step cylinder. The main engine plant has been changed from 4x8L to 2x8L and 2x9L.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-30 Loading condition – design modification 07

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.12 m	0.05 m	1.67 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.96 m	0.12 m	1.64 m
LD03	100% Consumables max. Draught	1670 t	74 t	504 t	315 t	5.32 m	-0.19 m	1.83 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.22 m	0.27 m	1.66 m

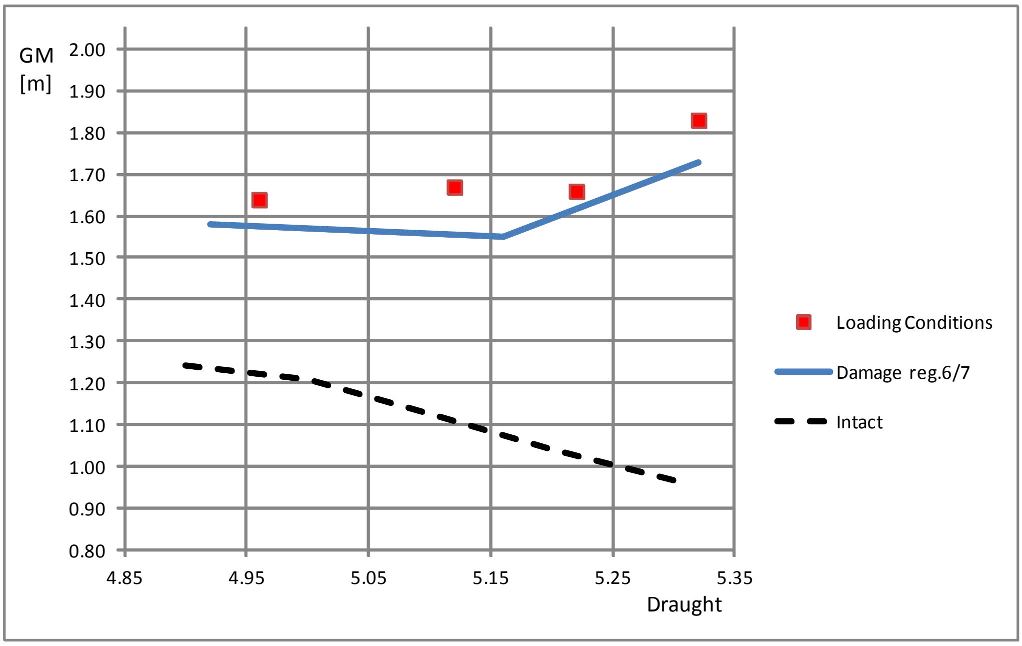


Fig. 13-38 GM limiting curves – design modification 07

As shown the increase of VCG of the lightship generates a reduction of the GM of the loading conditions and consequently a reduction of the GM used for the A index calculation compared to previous version.

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20.5 m
Breadth at the bulkhead deck	20.5 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.8187

13.3.2.8 Version 08

This version is based on RCO n.07 but the breadth of the ship has been increased by 0.5m further. As for the previous versions the superstructure above the deck 4 has been kept constant; the interior areas within the hull have been increased due to the changed shape. The crew cabins areas located on deck 3 and the technical rooms located on deck 1,2 and 3 have been increased but the pax cabins areas (located from deck 4 to upper decks) remains unchanged.

The following figure illustrates the principle of modification with reference to version 4

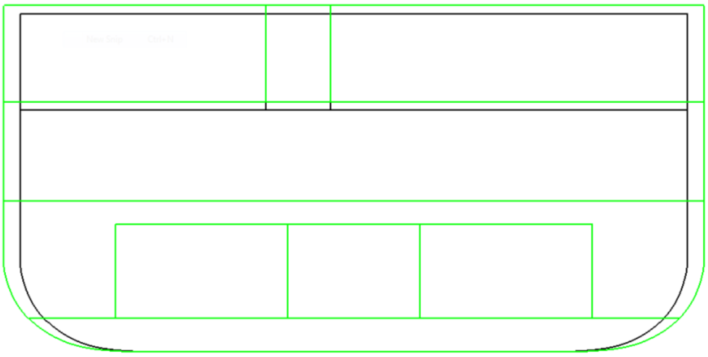


Fig. 13-39 Design change 08

For the new hull a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas.

Table 13-31 Change in weight and areas – design modification 08

Data	Change (from vs.07 to vs.08)
GT	176 GT
Lightweight	108 t
Public area	11 m^2
Crew Cabin	29 m^2
Tech spaces	63 m^2

The increased spaces do not result in additional revenue as the changes are too small to fit additional cabins, and also the gained space in public rooms does not generate additional income as there are no additional guests on board to spend money.

Even if the increase of the hull caused an increase of propulsion power to maintain the required trial speed it is not necessary to change the main engine plant in this version as the next step cylinder for two main engines applied for version 07 is sufficient to cover the last increase of propulsion power.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-32 Loading conditions – design modification 08

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.07 m	0.09 m	2.17 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.91 m	0.16 m	2.16 m
LD03	100% Consumables max. Draught	1671 t	74 t	505 t	315 t	5.27 m	-0.15 m	2.31 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.17 m	0.31 m	2.13 m

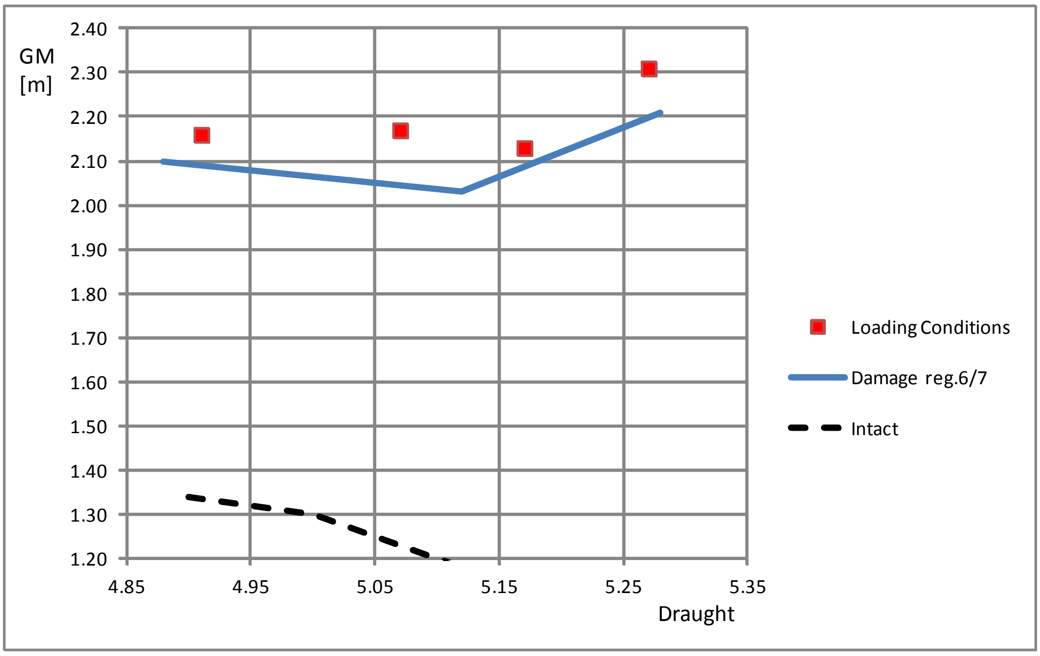


Fig. 13-40 GM limiting curves –design modification 08

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	21.0 m
Breadth at the bulkhead deck	21.0 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.8752

13.3.2.9 Version 09

This version is based on version 04, but the breadth of the vessel has been increased by 0.1m only in order to avoid excessive fuel costs.
As a summary here following the modification applied with reference to the basic version:

- Increased sill height of aft weathertight doors up to 500mm on bulkhead deck
- Bulkhead deck made watertight within compartments n.2 and n.3
- Cross flooding section improved adding pipes within the double bottom void space n.6
- Two weathertight door and one watertight door added on bulkhead deck
- Increased Beam by 0.1m up to Deck 4

For this version a new light weight has been calculated and the loading conditions have been updated to assess the new GM limit curve to be used for the calculation of the attained index.

The following table shows the result of the change with regard to weight and areas with reference to basic version.

Table 13-33 Change in weight and areas – design modification 09

Data	Change (from Ref.vs. to vs.09)
GT	34 GT
Lightweight	40 t
VCG	-0.03m
Public area	2 m^2
Crew Cabin	6 m^2
Tech spaces	13 m^2

As explained in the previous versions these small areas added do not result in additional revenue.

As expected the limited increase of the hull permits to maintain the main engine plant in this version as there was sufficient margin in the reference version between required and installed power.

With these figures the following loading conditions have been created resulting in the GM limiting curve shown below.

Table 13-34 Loading conditions – design modification 09

NAME	TEXT	DW	BW	GO	PW	T	TR	GM
LD01	Contractual deadweight	1240 t	81 t	470 t	200 t	5.09 m	0.04 m	1.47 m
LD02	10% Consumables	893 t	202 t	50 t	31 t	4.92 m	0.11 m	1.43 m
LD03	100% Consumables max. Draught	1669 t	74 t	503 t	315 t	5.30 m	-0.20 m	1.66 m
LD04	ICE Condition	1504 t	114 t	405 t	200 t	5.19 m	0.27 m	1.47 m

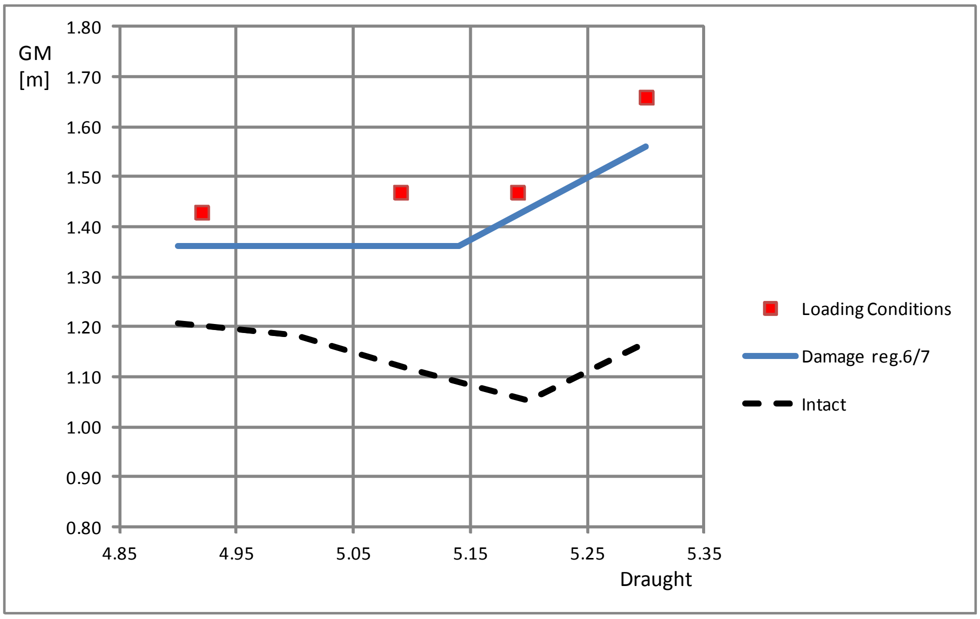


Fig. 13-41 GM limiting curves – design modification 09

With this GM limiting values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	125.8 m
Breadth at the load line	20.1 m
Breadth at the bulkhead deck	20.1 m
Number of persons N1	478
Number of persons N2	0
Required subdivision index R	0.6978
Attained subdivision index A	0.7789

13.3.3 Cost Benefit Assessment

In order to estimate the costs for the shown RCOs the following elements have been evaluated:

- Steel weight increase (including piping, ducting, painting etc)
- Increase of remote operated valves for vs.02
- Steel pipes addition for vs.03
- Watertight door and Splash doors addition for vs.04
- Technical area increase
- Crew cabin area increase
- Public area increase
- HVAC, Piping, Valves, ducting, painting, insulation (based on GT variation)
- Two Main Engine increased (from 8L to 9L), including aux. Systems, for vs.7

For the costs of the fuel a typical annual operating profile has been used to calculate the change in Gas oil consumption per year. Based on the distribution of the different operational modes with different speed a mean propulsion power has been calculated.

For the hotel load it has been estimated that the 35% only of the increase of the gross tonnage generates a linear increase of the consumption. This is due to fact that the majority of increased spaces need more power for light and HVAC only not for machinery. The following table shows the overview of the design variations and the GOC:

Table 13-35 Summary change in Fuel oil consumptions – small cruise

Version	reference design	vs.01	vs.02	vs.03	vs.04	vs.05	vs.06	vs.07	vs.08	vs.09
Speed [kn]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percentage	36%	36%	36%	36%	36%	36%	36%	36%	36%	36%
Propulsion power [kW]	0	0	0	0	0	0	0	0	0	0
Speed [kn]	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Percentage	32%	32%	32%	32%	32%	32%	32%	32%	32%	32%
Propulsion power [kW]	390	390	390	391	391	393	398	402	409	391
Speed [kn]	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Percentage	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%
Propulsion power [kW]	1864	1864	1864	1868	1868	1878	1901	1924	1958	1871
Speed [kn]	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Percentage	13%	13%	13%	13%	13%	13%	13%	13%	13%	13%
Propulsion power [kW]	5567	5567	5567	5577	5577	5607	5676	5746	5846	5588
Mean mech prop power [kW]	1203	1203	1203	1206	1206	1212	1227	1242	1264	1208
Efficiency PEM	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Electrical prop power [KW]	1286	1286	1286	1288	1288	1295	1311	1327	1350	1290
Hotel load navigation [kW]	2800	2800	2800	2800	2800	2806	2814	2831	2846	2802
Hotel load port [kW]	2000	2000	2000	2000	2000	2004	2010	2022	2033	2002
Efficiency generators	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Total diesel load [kW]	3957	3957	3957	3959	3959	3972	3996	4028	4066	3964
GO consumption per year [t]	7327	7327	7327	7331	7331	7355	7400	7460	7530	7340
Relative	100%	100%	100%	100.1%	100.1%	100.4%	101.0%	101.8%	102.8%	100.2%
Change of GOC per year [t]	**0**	**0**	**0**	**4**	**4**	**28**	**73**	**133**	**203**	**13**

For the versions 01 and 02 no change in GO consumption has been calculated as the hull was unchanged and the lightship weight variation was negligible.

On this ship no fuel mix is presented as it is using MGO only.

13.3.3.1 Basic results

Using the assumptions above, following costs, presented as net present values, are achieved for the different design variations:

Table 13-36 Summary table NPV for design modifications

Version	Ref.	01	02	03	04	05	06	07	08	09
Description	basic design	Sill increased on external weathertight aft doors	Deck 3 wathertight for comp 2 and 3	Cross flooding section within DB void spaces improved adding pipes	Two weathertight doors added and one watertight door added on BH deck	Increased Beam up to 20.2m	Increased Beam up to 20.5m	Increased freeboard by 0.25m	Increased Beam up to 21m	Beam 20.1m
Loa	128	128	128	128	128	128	128	128	128	128
B	20	20.0	20	20.0	20.0	20.2	20.5	20.5	21.0	20.1
T	5.09	5.09	5.09	5.10	5.10	5.07	5.05	5.12	5.07	5.09
Height BHD	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.48	7.48	7.23
Gross Tonnage	11800	11800	11800	11800	11800	11870	11970	12170	12350	11830
Change of fuel consumption	0	0	0	4	4	28	73	133	203	13
Net Present Value NPV	**0 $**	**-932 $**	**93'642 $**	**289'682 $**	**357'859 $**	**992'910 $**	**2'114'136 $**	**4'199'107 $**	**5'996'737 $**	**617'889 $**

At the same time following changes of the attained index can be achieved with the design modifications.

Table 13-37 Summary change in A for design modifications

Version	Ref.	01	02	03	04	05	06	07	08	09
required index R	0.6978	0.6978	0.6978	0.6978	0.6978	0.6978	0.6978	0.6978	0.6978	0.6978
attained index A	0.7202	0.7263	0.7307	0.7442	0.7544	0.7944	0.8281	0.8187	0.8752	0.7789
change A	0.0000	0.0061	0.0105	0.0240	0.0342	0.0742	0.1079	0.0985	0.1550	0.0587

The cost effectiveness can be easily demonstrated in the diagram below, where the costs as net present values are plotted against the attained index A. Also included are limits for allowable costs to match the netCAF limits of 4 Mio$ and 8 Mio$ including the 5% and 95% uncertainty limits.

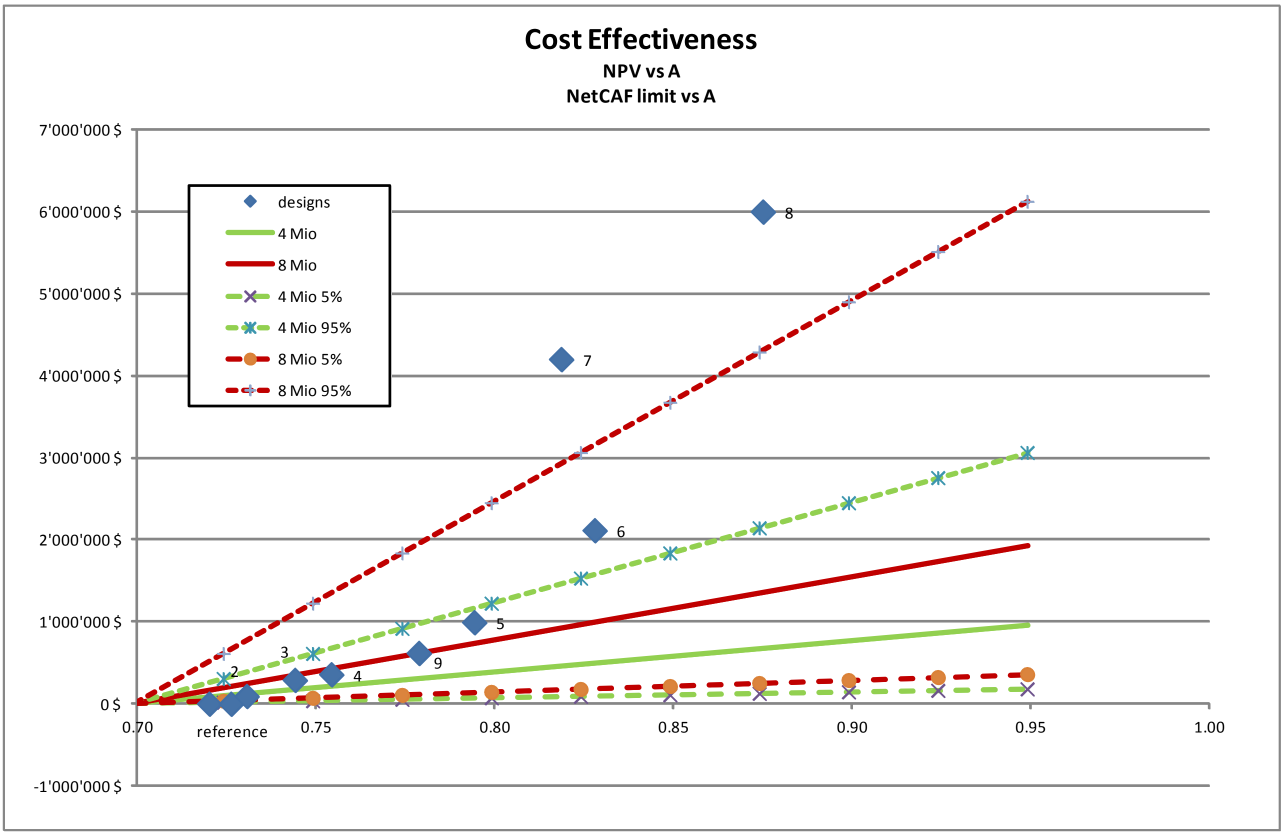


Fig. 13-42Cost limit curves – small cruise

The diagram shows that all the RCO with the increase of breadth and consequent increase of fuel cost consumption are above the limits except version 9 that includes a little increase of breadth (0.1m only).

13.3.3.2 Sensitivity analysis

Due to the high impact of the fuel costs on the overall life-cycle costs a sensitivity analysis has been made to apply on the cost model the high and low estimates for the fuel price development and simultaneously to reduce and increase all other costs and revenue by ±20%.

This leads to following net present values:

Table 13-38 NPV of design modifications – High and Low

Version	01	02	03	04	05	06	07	08	09
net Present Value NPV	-932 $	93'642 $	289'682 $	357'859 $	992'910 $	2'114'136 $	4'199'107 $	5'996'737 $	617'889 $
net present value NPV low	-2'340 $	72'169 $	218'285 $	270'160 $	724'538 $	1'531'640 $	3'093'965 $	4'390'725 $	455'580 $
net present value NPV high	476 $	115'116 $	350'465 $	434'945 $	1'186'988 $	2'502'936 $	4'951'353 $	7'064'116 $	745'705 $

Or in the diagram representation as shown below:

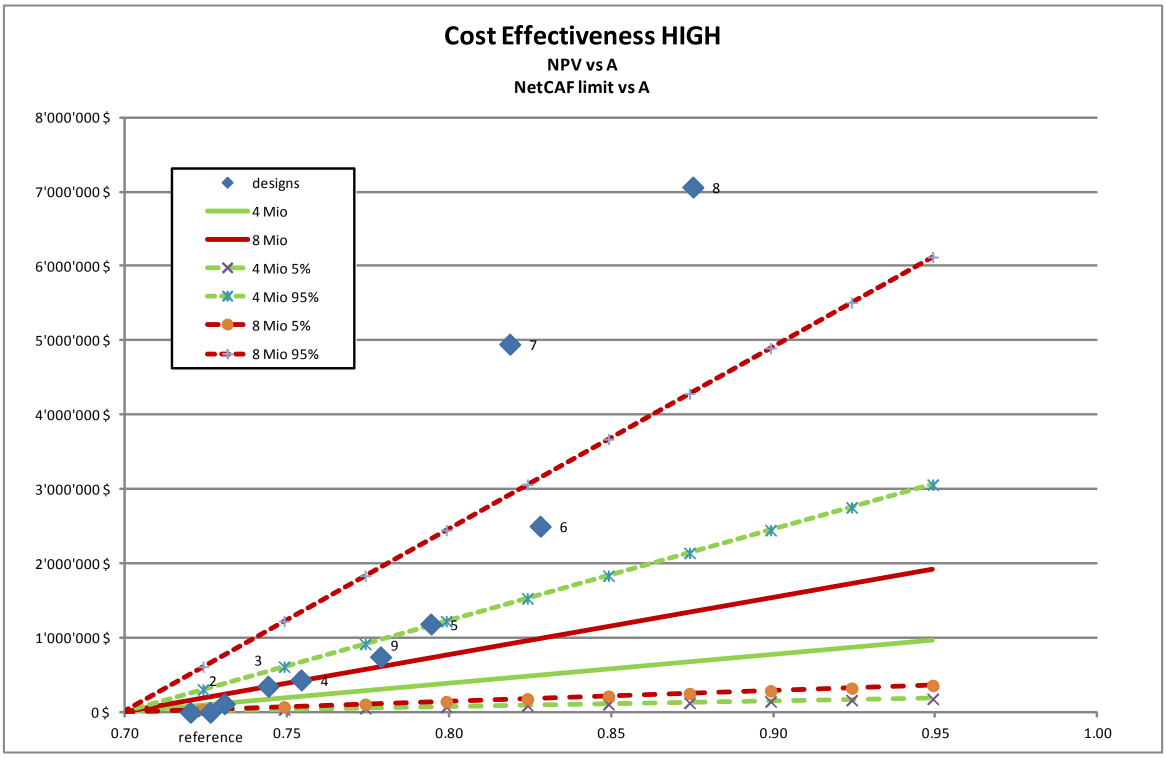


Fig. 13-43 Cost limit curves – Small cruise - High

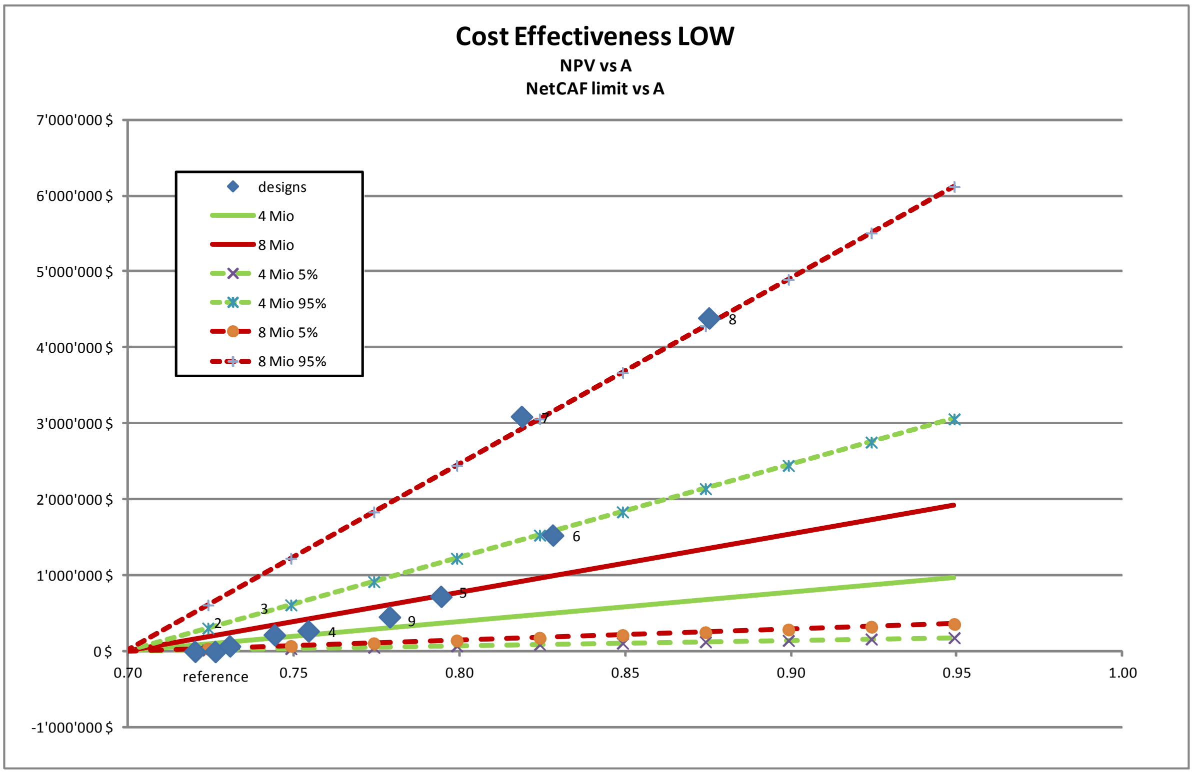


Fig. 13-44 Cost limit curves – Small cruise - Low

13.3.3.3 Conclusion and selection of optimized design

All the RCOs investigated show that a significant increase of the attained index A can be achieved by a combination of an optimization of the internal subdivision (i.e. cross-flooding, watertight deck, weathertight/watertight doors, etc.) and an increase of the breadth, but in order to meet the CAF limits chosen in this project, the versions with a relevant increase of the breadth cannot be selected.

Based on the above considerations the **version 9**, that combines all the RCOs with internal improvements and a slight increase of the breadth, is selected to be the one, which will be used in the further work of this project as the optimized design with regard to collision.

13.4 Ship #3 Baltic Cruise ferry

13.4.1 General Approach

One of the most important targets to optimize a Baltic Cruise Ferry is to maintain the GM-level at a relatively low level to avoid too high acceleration due to movements at sea. Secondly it should be avoided to increase freeboard too much, which could make it difficult to load the ship. These are for example too big slope of embarking ramp and height of the quays.

The optimization has been divided into four different phases as follows;

Phase 1;

In phase 1 different variations for breadth and freeboard have been performed while keeping the inner subdivision constant. By increasing breadth this may have large impact on damage stability. Therefore the optimum variation of breadth and freeboard was searched for while keeping in mind the restrictive factors due to operation. Four different options have been calculated, versions B, C, D and E, which variations are described in table 1. An increase of breadth by 40 cm and an increase of freeboard by 20 cm is most optimum variation, which is version D.

Phase 2;

The impact of the internal watertight subdivision has been studied in phase 2. It has been noticed that the biggest increase in A-index can be achieved by adding a subdivided double hull on the car deck, which will allow additional intact buoyancy for most of damage cases contributing to A-index.

The effect of the subdivided double hull on the car deck has been performed on top of the selected most optimum variants received in phase 1 (version D). This is version F, which is described in table 1.

Phase 3;

The impact of the internal watertight subdivision has been further investigated in phase 3. Three different options have been calculated. Version F was a base for these options.

First option was to calculate impact of Long Lower Hold below bulkhead deck. This is version I.
Second option was to calculate impact of subdivided car deck. This is version J.
Third option was to calculate impact of normally subdivided compartments instead of B/5 lower hold. This is version K2.

Phase 4;

Based on the options calculated in phases 1-3 the most optimum version with regarding CBA has been found version F (an increase of 40 cm in breadth and 20 cm in freeboard with subdivided double hull on car deck). However, it has been decided to achieve a further increase of the attained index by increasing the breadth while keeping the CAF limits. Based on version F the breadth has been increased by 40 cm. This option is version L.

Table 13-39 shows an overview of the applied design variations, which will be described in the following sections one by one in more detail.

Table 13-39 Description of different risk control options

Phase	Version	Description
	A	Reference design
Phase 1	B (Option 1)	Breadth increased by 40 cm
Phase 1	C (Option 2)	Breadth increased by 20 cm Freeboard increased by 20 cm
Phase 1	D (Option 3)	Breadth increased by 40 cm Freeboard increased by 20 cm
Phase 1	E (Option 4)	Breadth increased by 40 cm Freeboard increased by 40 cm
Phase 2	F (Option 5)	as version D (opt. 3) subdivided double hull on bulkhead deck
Phase 3	I (Option 6)	as version F (opt. 5) impact of LLH
Phase 3	J (Option 7)	as version F (opt. 5) Subdivided Car Deck
Phase 3	K2 (Option 8)	as version F (opt. 5) No Lower Hold
Phase 4	L (Option 9)	as version F (opt. 5) + 40 cm more breadth = Breadth increased by 80 cm Freeboard increased by 20 cm subdivided double hull on bulkhead deck

13.4.2 Design Variations

13.4.2.1 Version A - Reference Design

Damage Stability calculations for basic design and for all options have been performed according to the regulation 7-2.3 of SOLAS II.1 (SOLAS2009) and to the revised regulation 7-2.3 (SLF55) with increased GZ requirements; TGZmax 0.20 m and Trange 20 deg for each damage case that involves a Ro-Ro space.

General remarks related to cargo capacity and machinery of the ship;

Trailer lane meters of 1200 m and car lane meters of 1350 m has been kept constant in all options except in those versions, where the impact of LLH has been investigated (version I) or the Car Deck has been subdivided (version J).

The sample ship 3 is designed to be an overnight passenger RoPax operating in the Baltic Sea with high passenger amount. The high passenger amount means that there are spaces needed for stores and provision in the ship compared to a ship that is dedicated more to transport cargo. Environmental requirements of the operation are tighter in the operation area during the coming years and these raised also demands for the machinery arrangement of the ship. These environmental issues can be solved either by the choosing of more green fuel like LNG or clean the exhaust gas by scrubbers.

To fulfil these different demands the available space below the bulkhead deck is chosen to be utilized for LNG tanks and stores instead of a long lower hold for the cargo in this case. The advantage of long hold for storage purposes is that the area can be operated without open the water tight doors. The machinery using LNG as bunker fuel is an advanced solution. By this solution the ship will fulfil all coming environmental requirements and at same time machinery maintenance will be reduced for different components due the use of a cleaner fuel.

LNG has been assumed in all RCOs, even in the version, where long lower hold has been investigated. Then LNG-tanks have been designed to be located in open upper deck in aft part of the ship. Loading conditions shown in Table 13-40 have been studied for reference design;

Table 13-40 Loading condition details for reference design

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	50 t	350 t	750 t	7.00 m	-0.01 m	2.75 m
L2	Trailers + Cars Specified Arrival	4018 t	175 t	35 t	75 t	6.75 m	0.02 m	2.56 m
L3	Departure, passengers no cargo 100% bunkers	2900 t	50 t	350 t	750 t	6.55 m	0.01 m	2.76 m
L4	Arrival, passengers, no cargo, 10% bunkers	1755 t	413 t	35 t	75 t	6.35 m	0.01 m	2.69 m
L5	As L1 + Ice load	5821 t	150 t	350 t	750 t	7.06 m	0.01 m	2.66 m
L6	As L2 + Ice load	4600 t	486 t	35 t	75 t	6.85 m	-0.01 m	2.54 m
L7	As L3 + Ice load	3448 t	328 t	350 t	750 t	6.65 m	-0.03 m	2.66 m
L8	As L4 + Ice load	2419 t	806 t	35 t	75 t	6.47 m	0.00 m	2.64 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.01 m	2.65 m

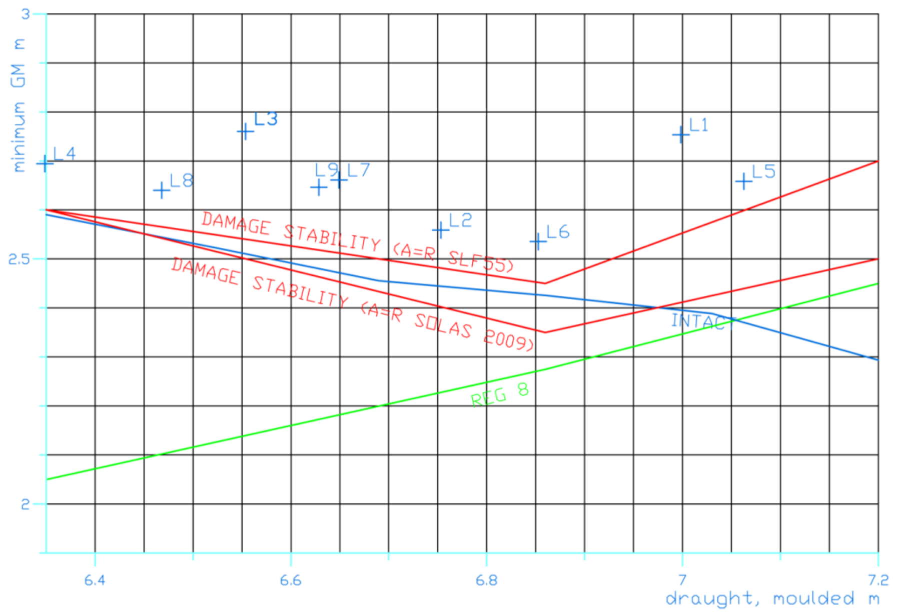


Fig. 13-45 GM Limiting curves for reference design A

With GM limiting values as shown in figure 1 the attained index ($A_{SOLAS2009}$ and A_{SLF55}) is equal to the required index for reference design. $A_{SOLAS2009}$ has been shown only for reference. All calculations have been carried out according to A_{SLF55}.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length			250.96 m
Breadth at the load line			29.00 m
Number of persons N1			984
Number of persons N2			2296
Required subdivision index R			0.830
Attained subdivision index $A_{SOLAS2009}$			0.85270
Draft / GM:	6.35 / 2.6	6.86 / 2.35	7.2 / 2.5
		A_{SLF55}	**0.83261**
Draft / GM:	6.35 / 2.6	6.86 / 2.45	7.2 / 2.7

13.4.2.2 Phase 1; Variation of breadth and freeboard - Versions B, C, D and E

When changing the breadth of the ship, the hull was modified in such a way to keep the breadth of the superstructure constant by introducing a “tumblehome”. The sideshell is inclined above the waterline to reach the old breadth again. By this way it is possible to minimize an increase in total volumes of different options. Fig. **13-46** shows the principal of “tumblehome”.

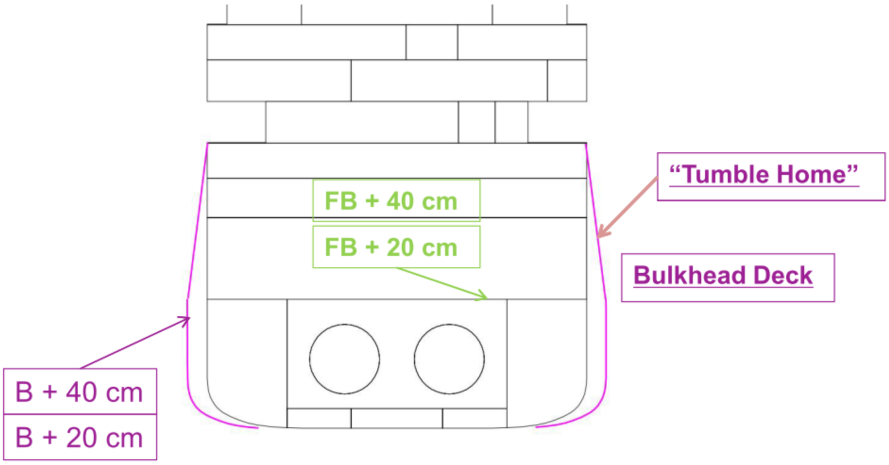


Fig. 13-46 Principle of "tumble home"

During phase 1 following options have been investigated;

1. version B - breadth increased by 40 cm
2. version C - breadth increased by 20 cm and freeboard increased by 20 cm
3. version D - breadth increased by 40 cm and freeboard increased by 20 cm
4. version E - breadth increased by 40 cm and freeboard increased by 40 cm

Fig. 13-47 shows cross sections of different versions. Loading conditions details are presented in Table 13-41, Table 13-42, Table 13-43 and Table 13-44. GM-limiting curves for versions B, C, D and E are presented in Fig. 13-48. GM-limiting curves based on damage stability and IMO weather criterion are shown. Other limiting curves like curve based on regulation 8 are well below presented ones.

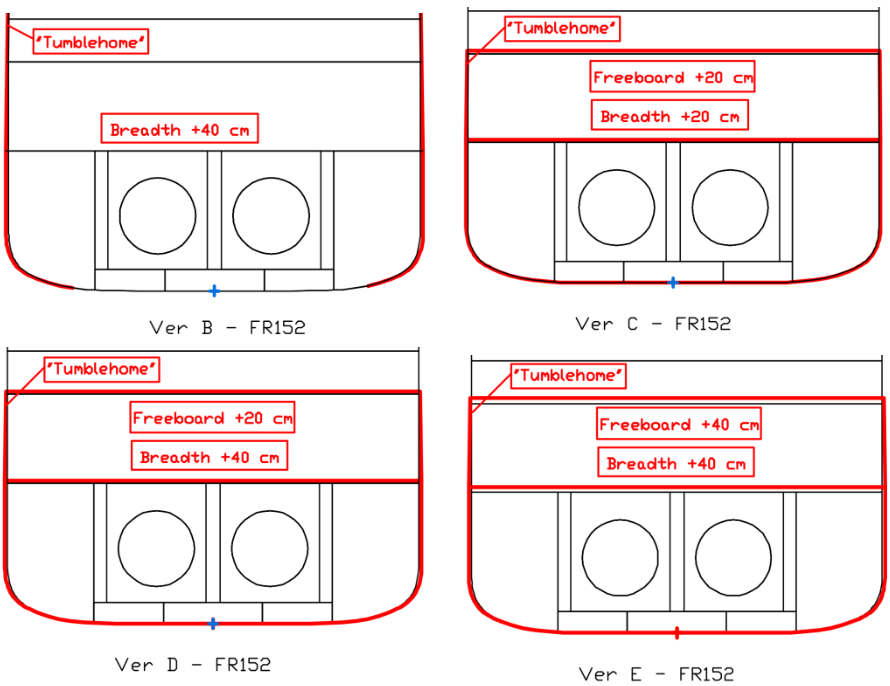


Fig. 13-47 Cross section of breadth/freeboard variations – Versions B, C, D and E

Table 13-41 - Loading condition details for version B – (Breadth + 40 cm)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5550 t	150 t	350 t	750 t	7.01 m	-0.04 m	3.18 m
L2	Trailers + Cars Specified Arrival	4018 t	175 t	35 t	75 t	6.75 m	-0.04 m	2.99 m
L3	Departure, passengers no cargo 100% bunkers	2950 t	150 t	350 t	750 t	6.57 m	-0.03 m	3.18 m
L4	Arrival, passengers, no cargo, 10% bunkers	1906 t	563 t	35 t	75 t	6.38 m	-0.02 m	3.16 m
L5	As L1 + Ice load	5921 t	250 t	350 t	750 t	7.07 m	-0.09 m	3.11 m
L6	As L2 + Ice load	4600 t	486 t	35 t	75 t	6.85 m	-0.07 m	2.98 m
L7	As L3 + Ice load	3548 t	428 t	350 t	750 t	6.67 m	-0.10 m	3.12 m
L8	As L4 + Ice load	2419 t	956 t	35 t	75 t	6.47 m	-0.15 m	3.11 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.16 m	3.12 m

Table 13-42 Loading condition details for version C – (Breadth + 20 cm , Freeboard +20 cm)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5500 t	100 t	350 t	750 t	7.00 m	-0.13 m	2.90 m
L2	Trailers + Cars Specified Arrival	4168 t	500 t	35 t	75 t	6.78 m	-0.03 m	2.71 m
L3	Departure, passengers no cargo 100% bunkers	2900 t	50 t	350 t	750 t	6.55 m	-0.16 m	2.91 m
L4	Arrival, passengers, no cargo, 10% bunkers	3194 t	2263 t	35 t	75 t	6.61 m	-0.02 m	3.25 m
L5	As L1 + Ice load	5871 t	200 t	350 t	750 t	7.06 m	-0.14 m	2.80 m
L6	As L2 + Ice load	4925 t	811 t	35 t	75 t	6.91 m	0.07 m	2.68 m
L7	As L3 + Ice load	3448 t	328 t	350 t	750 t	6.64 m	-0.20 m	2.82 m
L8	As L4 + Ice load	3231 t	2193 t	35 t	75 t	6.62 m	0.00 m	3.02 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.65 m	-0.18 m	2.81 m

Table 13-43 Loading condition details for version D – (Breadth + 40 cm, Freeboard +20 cm)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	100 t	350 t	750 t	6.99 m	-0.10 m	3.08 m
L2	Trailers + Cars Specified Arrival	4244 t	576 t	35 t	75 t	6.80 m	0.03 m	2.92 m
L3	Departure, passengers no cargo 100% bunkers	2900 t	100 t	350 t	750 t	6.56 m	-0.09 m	3.08 m
L4	Arrival, passengers, no cargo, 10% bunkers	1956 t	613 t	35 t	75 t	6.39 m	0.01 m	3.06 m
L5	As L1 + Ice load	5721 t	50 t	350 t	750 t	7.04 m	-0.05 m	2.96 m
L6	As L2 + Ice load	5001 t	887 t	35 t	75 t	6.93 m	0.13 m	2.89 m
L7	As L3 + Ice load	3373 t	256 t	350 t	750 t	6.64 m	-0.03 m	2.91 m
L8	As L4 + Ice load	2718 t	1304 t	35 t	75 t	6.53 m	-0.04 m	3.09 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.10 m	2.98 m

Table 13-44 Loading condition details for version E – (Breadth + 40 cm, Freeboard +40 cm)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	100 t	350 t	750 t	6.99 m	-0.12 m	2.99 m
L2	Trailers + Cars Specified Arrival	4118 t	450 t	35 t	75 t	6.77 m	-0.09 m	2.70 m
L3	Departure, passengers no cargo 100% bunkers	3000 t	200 t	350 t	750 t	6.58 m	-0.03 m	2.97 m
L4	Arrival, passengers, no cargo, 10% bunkers	1956 t	613 t	35 t	75 t	6.39 m	-0.02 m	2.99 m
L5	As L1 + Ice load	5971 t	50 t	350 t	750 t	7.09 m	0.03 m	2.90 m
L6	As L2 + Ice load	4875 t	761 t	35 t	75 t	6.90 m	0.00 m	2.83 m
L7	As L3 + Ice load	3598 t	478 t	350 t	750 t	6.68 m	-0.11 m	2.85 m
L8	As L4 + Ice load	2319 t	906 t	35 t	75 t	6.48 m	0.04 m	2.83 m
L9	50% Cargo/Bunkers/Stores	3473 t	200 t	175 t	375 t	6.66 m	-0.01 m	2.84 m

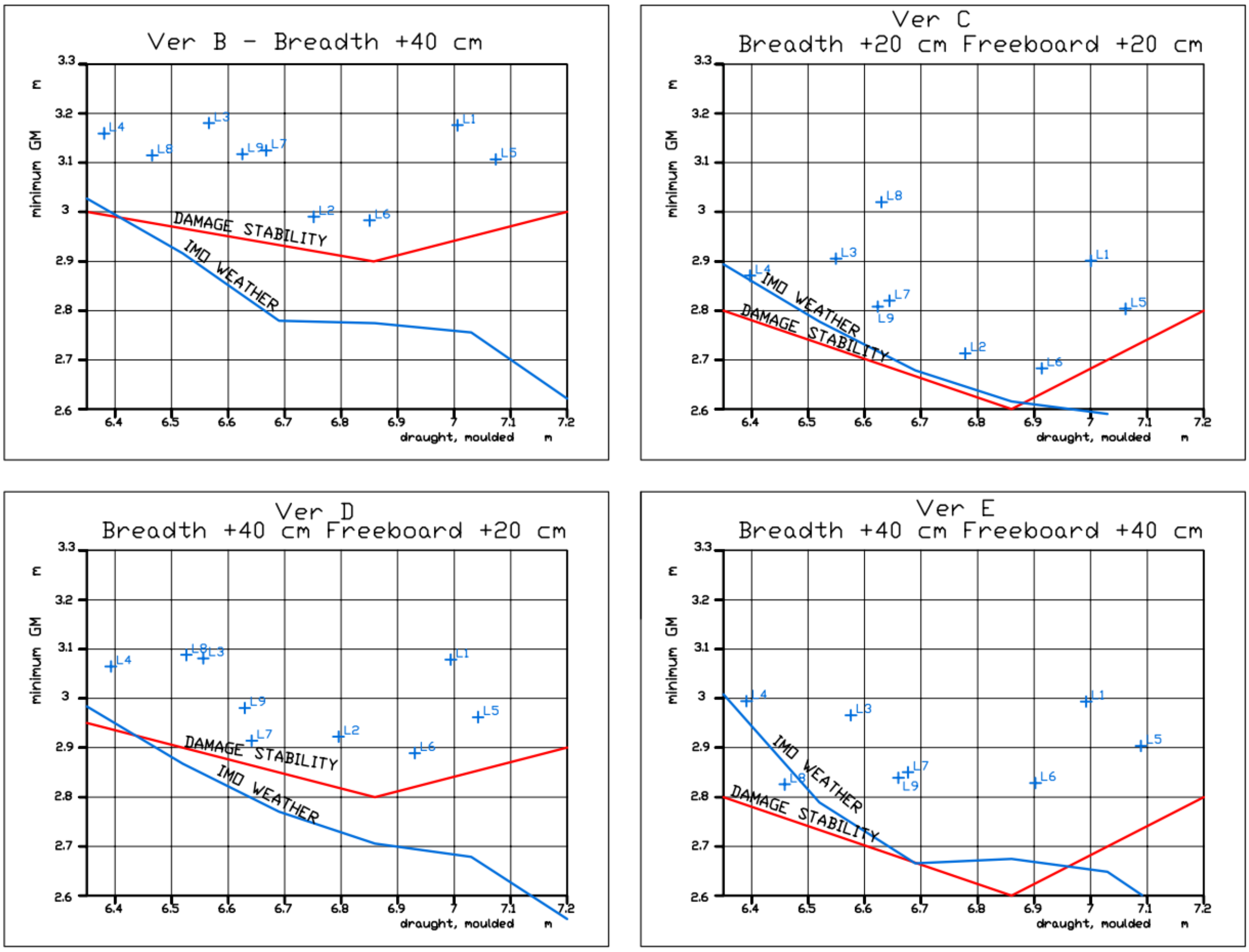


Fig. 13-48 GM limiting curves – versions B, C, D and E

Table 13-45 Attained index – Versions B, C, D and E

Version	A reference	B opt. 1	C opt. 2	D opt. 3	E opt. 4
Required Index	**0.8300**	**0.8300**	**0.8300**	**0.8300**	**0.8300**
Attained Index $A_{SOLAS2009}$	0.8527	0.8855	0.8801	0.8942	0.8887
Attained Index A_{SLF55}	**0.8326**	**0.8703**	**0.8670**	**0.8824**	**0.8786**
Intact GM at initial draft 6,35 /6,86/7,20 m	2.6/2.45/ 2.7 m	3.0/2.9/ 3.0 m	2.8/2.6/ 2.8 m	2.95/2.8/ 2.9 m	2.8/2.6/ 2.8 m
Change A	0	0.0377	0.0344	0.0498	0.0460
Change A in percentage	0	4,53 %	4,13%	5,99%	5,55%

Table 13-46 Summary of changes in weight and areas – Versions B, C, D and E

Version	A - reference	B opt. 1	C opt. 2	D opt. 3	E opt. 4
Steel weight	12953 t	+ 114 t	+ 156 t	+ 246 t	+ 414 t
GT	59800 GT	+ 310 GT	+ 662 GT	+ 850 GT	+ 1320 GT
Outfitting	5070 t	+ 11 t	+ 14 t	+ 20 t	+ 27 t
Machinery	3313 t	+ 4 t	+ 8 t	+ 10 t	+ 23 t
Lightweight	22337 t	+ 131 t	+ 180 t	+ 276 t	+ 465 t
Pax Public	8246 m2	+ 16 m2	+ 12 m2	+ 16 m2	+ 16 m2
Cabins	11885 m2	+ 20 m2	+ 5 m2	+ 20 m2	+ 20 m2
Service Area	6541 m2	+ 18 m2	+ 11 m2	+ 20 m2	+ 20 m2
Tech spaces +Hotel Stores	39500 m2	+ 148 m2	+ 84 m2	+ 158 m2	+ 179 m2
Stabilizers		+ 3 m2	+ 1 m2	+ 2 m2	+ 1 m2
Machinery Power		+ 176 kW	+ 221 kW	+ 342 kW	+ 397 kW

Table 13-45 shows attained index and intact GM at initial draft. Biggest increase in attained index (A_{SLF55}) is in version D 5.99%. By increasing only breadth by 40 cm this will result less index as being 4.53% (B version).

In version C both breadth and freeboard has been increased by 20 cm and this will result less index compared to version B (4.13 %).

In version E both breadth and freeboard has been increased by 40 cm. This will give more index than in version C (5.55 %). Best possible variation is to increase more breadth than freeboard.

Table 13-46 shows weight, gross tonnage and areas for reference ship. Changes compared to reference A-versions for different options are presented. An additional increase in areas of stabilizers due to increased GM and machinery power are presented for each option. Biggest changes in weight is in steel and biggest changes in areas is in technical and store areas. Due to inclined side shell form “tumblehome” passenger public areas and cabins will have only minor changes. These minor increases in areas are due to passenger cabins located in deck 6 and public spaces located in forward part of deck 5, which are shown in figure 5 with light and dark green.

As a result from phase 1 it has been decided to choose version D (increased breadth by 40 cm and freeboard by 20 cm) as a base for further investigations.

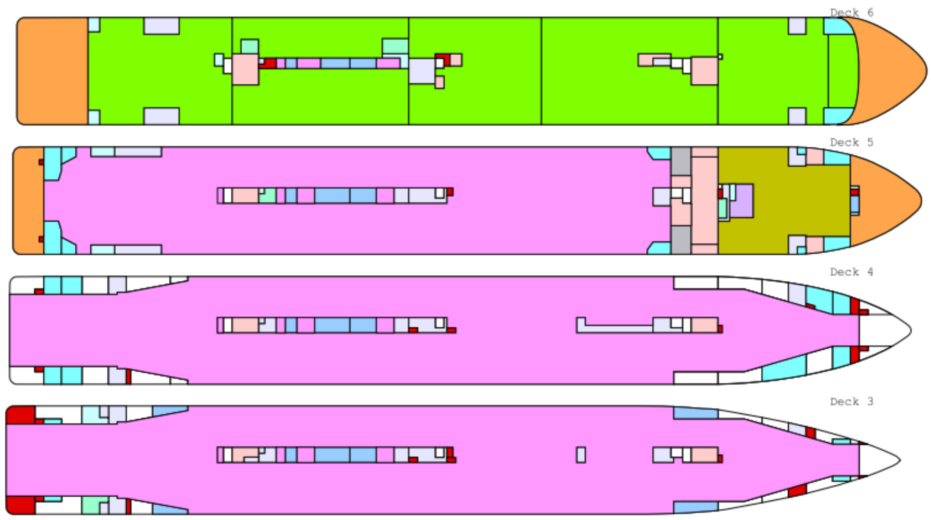


Fig. 13-49 Decks 3-6, located within “tumblehome” area

13.4.2.3 Phase 2; Optimized Breadth / Freeboard + improved subdivision Version F

To improve further A-index for optimized breadth/freeboard variation calculated in phase 1 (D-version) internal subdivision will be changed. Most optimum way is to build double hull on car deck, which is subdivided at each watertight transversal bulkhead. This double hull is 900 mm breadth. Height of this structure need not be extended within whole car deck height. Car and trailer lane meters will be same in this double hull structure. Most important is that the reserved buoyancy extends up to worst equilibrium floating position plus required positive stability range. In this sample ship double hull is extended up to next deck (4. deck) above bulkhead deck. Principle of subdivided double hull is shown in figures 6 and 7 below.

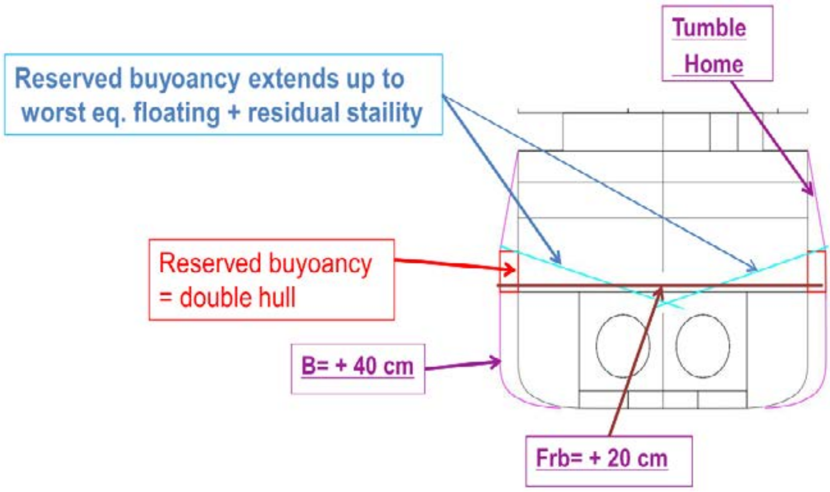


Fig. 13-50 Principle cross section of additional buoyancy on car deck version F

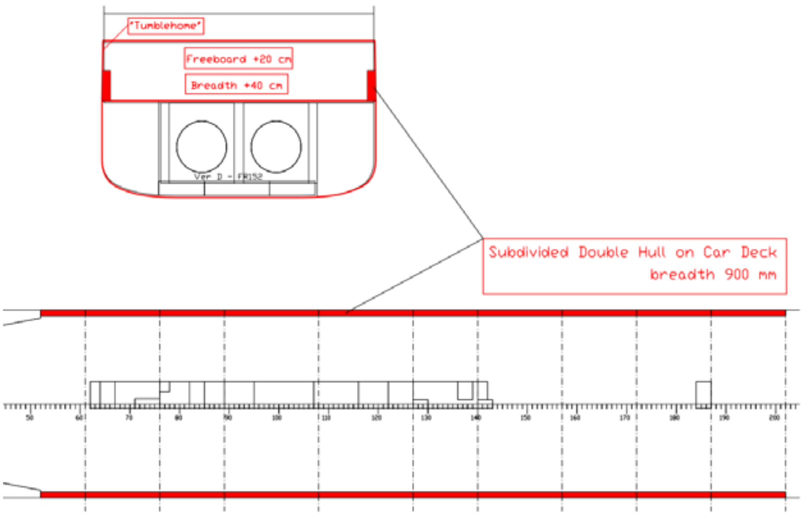


Fig. 13-51 Principle deck plan of additional buoyancy on car deck version F

Table 13-47 Loading condition details for version F – (Breadth + 40 cm, Freeboard + 20 cm + Subdivided Double Hull on Car Deck)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	100 t	350 t	750 t	6.99 m	-0.15 m	3.11 m
L2	Trailers + Cars Specified Arrival	4218 t	550 t	35 t	75 t	6.79 m	-0.04 m	2.95 m
L3	Departure, passengers no cargo 100% bunkers	2900 t	100 t	350 t	750 t	6.55 m	-0.15 m	3.12 m
L4	Arrival, passengers, no cargo, 10% bunkers	1956 t	613 t	35 t	75 t	6.39 m	-0.06 m	3.11 m
L5	As L1 + Ice load	5921 t	300 t	350 t	750 t	7.08 m	0.04 m	3.00 m
L6	As L2 + Ice load	4975 t	861 t	35 t	75 t	6.92 m	0.05 m	2.92 m
L7	As L3 + Ice load	3698 t	628 t	350 t	750 t	6.70 m	-0.06 m	3.06 m
L8	As L4 + Ice load	2701 t	1287 t	35 t	75 t	6.52 m	-0.01 m	3.05 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.16 m	3.02 m

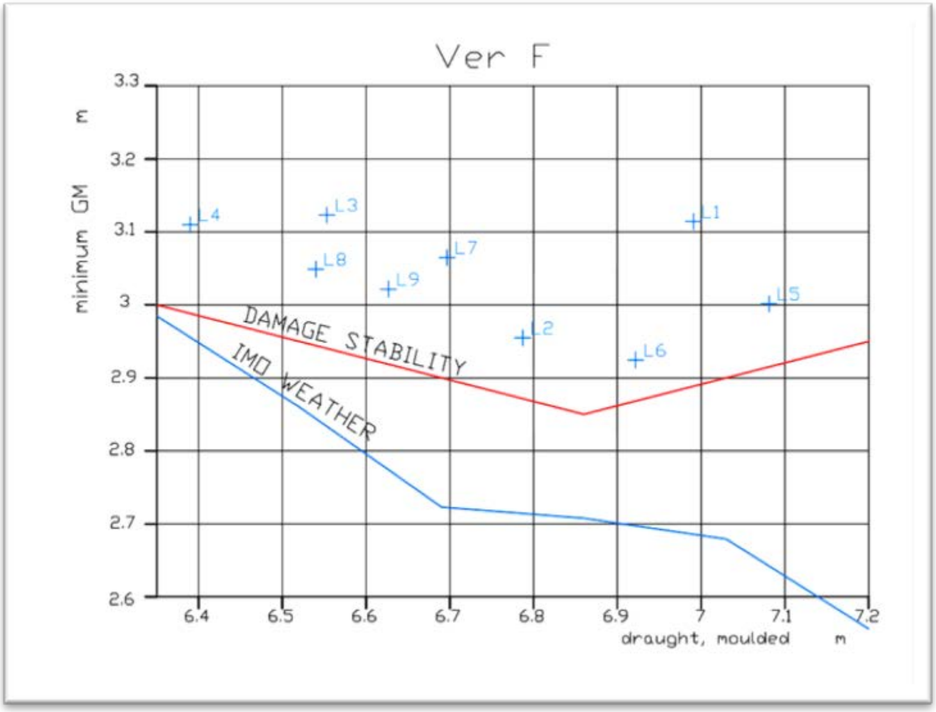


Fig. 13-52 GM limit curve for version F

Table 13-48 Attained index version F

Version	A reference	D opt. 4	F opt. 5
Required Index	**0.8300**	**0.8300**	**0.8300**
Attained Index A $_{SOLAS2009}$	0.8527	0.8942	0.9061
Attained Index A $_{SLF55}$	**0.8326**	**0.8824**	**0.8997**
Intact GM at initial draft 6,35 /6,86/7,20 m	2.6/2.45/ 2.7 m	2.95/2.8/ 2.9 m	3.0/2.85/ 2.95 m
Change A	0	0.0498	0.0671
Change A in percentage	0	5.99%	8.06%

Table 13-49 Summary of changes in weight and areas – Version F

Version	A - reference	D opt. 4	F opt. 5
Steel weight	12953 t	+ 246 t	+ 317 t
GT	59800 GT	+ 850 GT	+ 850 GT
Outfitting	5070 t	+ 20 t	+ 20 t
Machinery	3313 t	+ 10 t	+ 20 t
Lightweight	22337 t	+ 276 t	+ 358 t
Pax Public	8246 m2	+ 16 m2	+ 16 m2
Cabins	11885 m2	+ 20 m2	+ 20 m2
Service Area	6541 m2	+ 20 m2	+ 22 m2
Tech spaces+ Hotel stores	39500 m2	+ 158 m2	-30 m2
Stabilizers		+ 2 m2	+ 3 m2
Machinery Power		+ 342 kW	+ 342 kW

In addition to the reference ship, the D-version is also presented in combined Table 13-48. The subdivided double hull has an increase in A-index from 5.99 % into 8.06 %. Increase in steel weight is due to additional longitudinal bulkhead (=double hull). Small decrease in areas of technical spaces is due to decrease in area of car space. Summary of changes are shown in Table 13-49. Due to increase in GM-level stabilizers have to be increased by 1 m^2.
Because the impact on A-index is quite big with only minor changes in internal subdivision, version F has been decided to be a base for other investigations during phases 3 and 4.

13.4.2.4 Phase 3; As version F + Impact of LLH Version I

The Baltic overnight ferries have also typically very short port time and there is not practical time to operate long lower hold, because the loading of this space is quite slow. For these reasons it is already quite common practise in the Baltic area that there are not lower holds for the cargo in this kind of ship. Therefore basic design has no long lower hold (LLH).
But to have knowledge about the impact of LLH for Baltic Ferry in this version I such space have been added, which have added 200 m more lanemeters.
LNG tanks have been shifted upward into open deck on deck 6 aft. Layout of LLH is shown in Fig. 13-53.

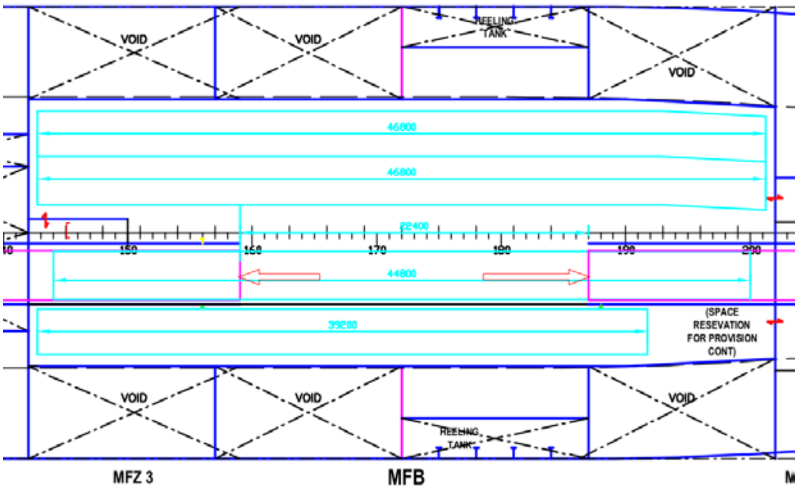


Fig. 13-53 Layout of LLH version I

Table 13-50 Loading condition details for version I – (As Version F + Impact of LLH)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	100 t	350 t	750 t	6.99 m	-0.12 m	2.58 m
L2	Trailers + Cars Specified Arrival	4503 t	835 t	35 t	75 t	6.84 m	0.00 m	2.65 m
L3	Departure, passengers no cargo 100% bunkers	2887 t	100 t	350 t	750 t	6.52 m	-0.57 m	2.68 m
L4	Arrival, passengers, no cargo, 10% bunkers	1913 t	613 t	35 t	75 t	6.38 m	0.09 m	2.67 m
L5	As L1 + Ice load	6554 t	983 t	350 t	750 t	7.18 m	-0.04 m	2.62 m
L6	As L2 + Ice load	6011 t	2282 t	35 t	75 t	7.09 m	0.01 m	2.88 m
L7	As L3 + Ice load	4441 t	1433 t	350 t	750 t	6.82 m	-0.15 m	2.70 m
L8	As L4 + Ice load	2537 t	1124 t	35 t	75 t	6.49 m	-0.06 m	2.65 m
L9	50% Cargo/Bunkers/Stores	3298 t	50 t	175 t	375 t	6.61 m	-0.29 m	2.56 m

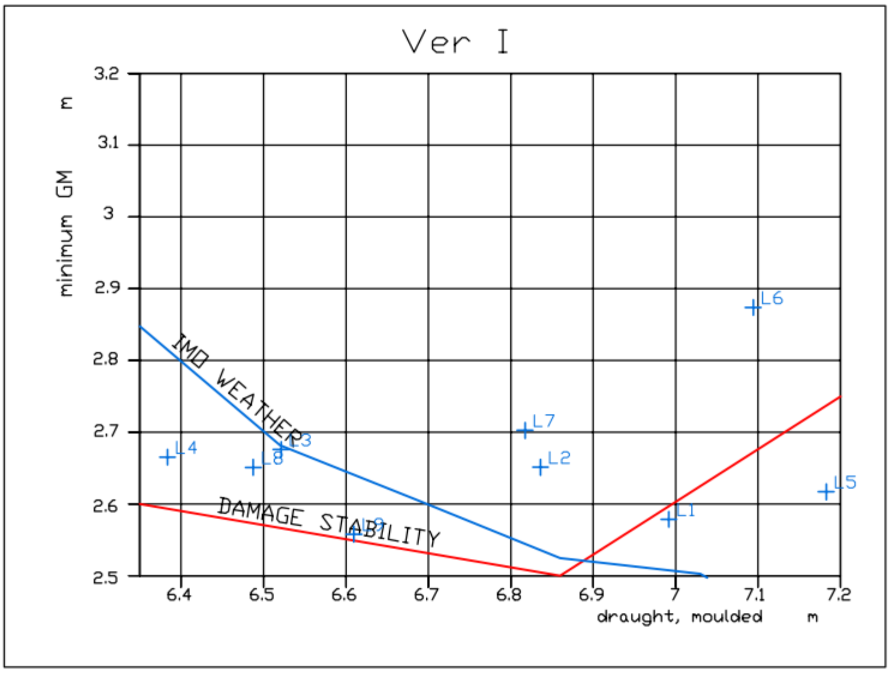


Fig. 13-54 GM Limiting curve version I

Table 13-51 Attained index version I

Version	A reference	F opt. 5	I opt. 6
Required Index	**0.8300**	**0.8300**	**0.8300**
Attained Index A $_{SOLAS2009}$	0.8527	0.9061	0.8623
Attained Index A $_{SLF55}$	**0.8326**	**0.8997**	**0.8494**
Intact GM at initial draft 6,35 /6,86/7,20 m	2.6/2.45/2.7 m	3.0/2.85/2.95 m	2.6/2.5/2.75 m
Change A	0	0.0671	0.0168
Change A in percentage	0	8.06%	2.02%

Table 13-52 Summary of changes in weight and areas – Version I

Version	A - reference	F opt. 5	I opt. 6
Steel weight	12953 t	+ 317 t	+ 441 t
GT	59800 GT	+ 850 GT	+ 740 GT
Outfitting	5070 t	+ 20 t	-87 t
Machinery	3313 t	+ 20 t	+ 6 t
Lightweight	22337 t	+ 358 t	+ 379 t
Pax Public	8246 m2	+ 16 m2	-134 m2
Cabins	11885 m2	+ 20 m2	-203 m2
Service Area	6541 m2	+ 22 m2	-168 m2
Tech spaces+ Hotel stores	39500 m2	-30 m2	+ 620 m2
Stabilizers		+ 3 m2	+ 0 m2
Machinery Power		+ 342 kW	+ 346 kW
Ro-Ro equipment	720 t	+ 0 t	+ 58 t

In addition to reference ship also F-version is presented in combined Table 13-51. Optimized breadth/freeboard variations (+40 cm/+20cm) added with subdivided double hull will cause decrease in A-index from 8.06 % into 2.02 %, when LLH will be added and LNG tanks has been shifted upwards.

Long Lower Hold will have very negative impact on A-index. As it can be seen from GM-limiting curves shown in Fig. 13-54 most of the loading conditions will not fulfil IMO weather criterion and two cases will be below damage stability limiting curve.

13.4.2.5 Phase 3; As version F + Subdivided Car DeckVersion J

In this version J optimized version F has been modified by subdividing the car deck into three different compartments as shown in Fig. 13-53.
By subdividing car deck it has commonly been proposed to increase survivability, but due to operational factors this proposal has been very clearly rejected. Loading/unloading time will be duplicated. In order to keep the operation profile service speed has to be increased while at sea. This will increase fuel costs considerably.

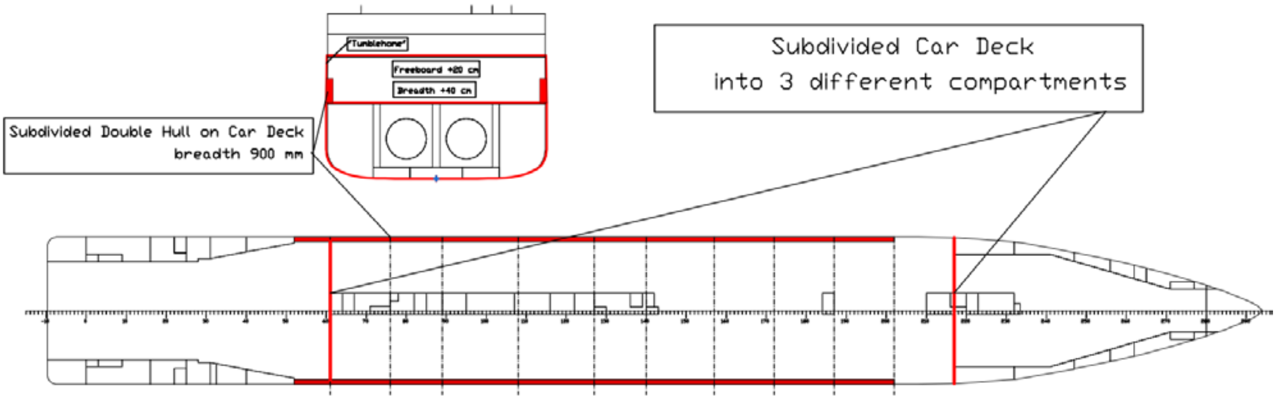


Fig. 13-55 Layout of Subdivided Car Deck version J

Table 13-53 Loading condition details for version J – (As Version F + Subdivided Car Deck)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	100 t	350 t	750 t	6.99 m	-0.15 m	3.11 m
L2	Trailers + Cars Specified Arrival	4218 t	550 t	35 t	75 t	6.79 m	-0.04 m	2.95 m
L3	Departure, passengers no cargo 100% bunkers	2900 t	100 t	350 t	750 t	6.55 m	-0.15 m	3.12 m
L4	Arrival, passengers, no cargo, 10% bunkers	1956 t	613 t	35 t	75 t	6.39 m	-0.06 m	3.11 m
L5	As L1 + Ice load	5921 t	300 t	350 t	750 t	7.08 m	0.04 m	3.00 m
L6	As L2 + Ice load	4975 t	861 t	35 t	75 t	6.92 m	0.05 m	2.92 m
L7	As L3 + Ice load	3698 t	628 t	350 t	750 t	6.70 m	-0.06 m	3.06 m
L8	As L4 + Ice load	2781 t	1368 t	35 t	75 t	6.54 m	-0.07 m	3.06 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.16 m	3.02 m

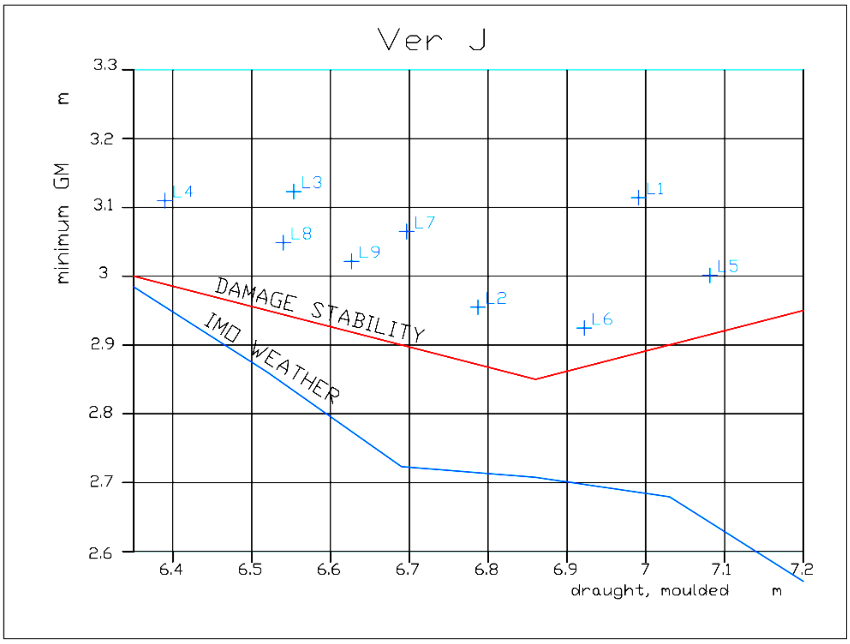


Fig. 13-56 GM Limiting curve version J

Table 13-54 Attained index version J

Version	A reference	F opt. 5	J opt. 7
Required Index	**0.8300**	**0.8300**	**0.8300**
Attained Index A $_{SOLAS2009}$	0.8527	0.9061	0.9188
Attained Index A $_{SLF55}$	**0.8326**	**0.8997**	**0.9184**
Intact GM at initial draft 6,35 /6,86/7,20 m	2.6/2.45/2.7 m	3.0/2.85/2.95m	3.0/2.85/2.95 m
Change A	0	0.0671	0.0858
Change A in percentage	0	8.06%	10.31%

Table 13-55 Summary of changes in weight and areas – Version J

Version	A - reference	F opt. 5	J opt. 7
Steelweight	12953 t	+ 317 t	+ 317 t
GT	59800 GT	+ 850 GT	+ 850 GT
Outfitting	5070 t	+ 20 t	+ 43 t
Machinery	3313 t	+ 20 t	+ 20 t
Lightweight	22337 t	+ 358 t	+ 380 t
Pax Public	8246 m2	+ 16 m2	+ 16 m2
Cabins	11885 m2	+ 20 m2	+ 20 m2
Service Area	6541 m2	+ 22 m2	+ 19 m2
Tech spaces + Hotel Stores	39500 m2	-30 m2	-30 m2
Stabilizers		+ 3 m2	+ 3 m2
Machinery Power		+ 342 kW	+ 342 kW
4 pcs barriers on car deck			+ 23 t

Compared to version F attained index will increase from 8.06 % into 10.31 %, which is shown in Table 13-54. Summary of changes in weight and areas are presented in Table 13-55.

Barriers on car deck will have an increase in weight 23 tonnes. By subdivided car deck A-index will really increase considerably, but due to operational factors and due to increased fuel costs this option will have very negative impact as a whole.

13.4.2.6 Phase 3; As version F + lower store area subdivided Version K2

In this version K2 optimized version F has been modified by deleting B/5-lower hold located forward of LNG space. This area has been divided into four normal watertight compartments, which change is shown in Fig. 13-57.

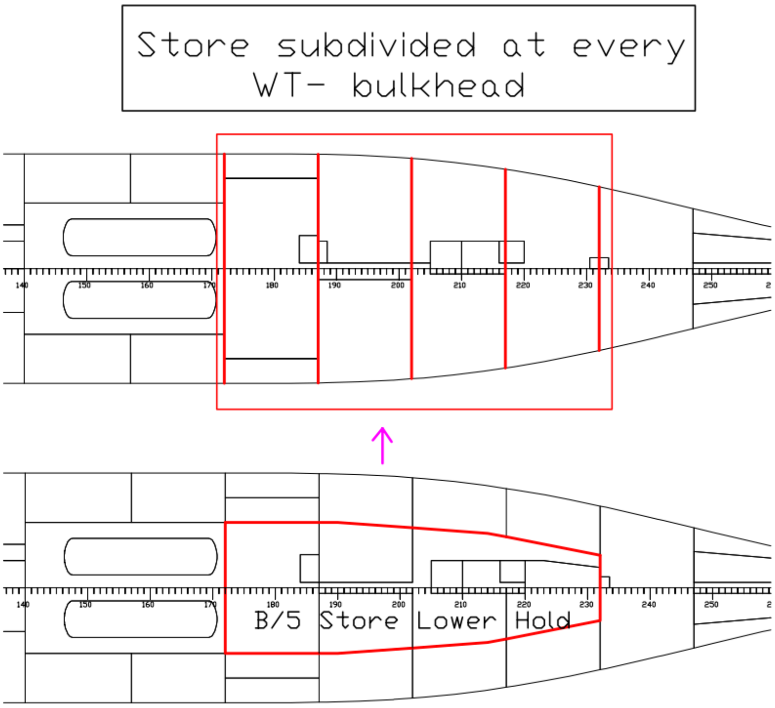


Fig. 13-57 Layout of normally subdivided store area below bulkhead deck version K2

Table 13-56 Loading condition details for version K2 – (As Version F + No lower Hold)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5450 t	100 t	350 t	750 t	6.99 m	-0.15 m	3.11 m
L2	Trailers + Cars Specified Arrival	4218 t	550 t	35 t	75 t	6.79 m	-0.04 m	2.95 m
L3	Departure, passengers no cargo 100% bunkers	2900 t	100 t	350 t	750 t	6.55 m	-0.15 m	3.12 m
L4	Arrival, passengers, no cargo, 10% bunkers	1956 t	613 t	35 t	75 t	6.39 m	-0.06 m	3.11 m
L5	As L1 + Ice load	5921 t	300 t	350 t	750 t	7.08 m	0.04 m	3.00 m
L6	As L2 + Ice load	4975 t	861 t	35 t	75 t	6.92 m	0.05 m	2.92 m
L7	As L3 + Ice load	3698 t	628 t	350 t	750 t	6.70 m	-0.06 m	3.06 m
L8	As L4 + Ice load	2751 t	1337 t	35 t	75 t	6.53 m	-0.05 m	3.04 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.16 m	3.02 m

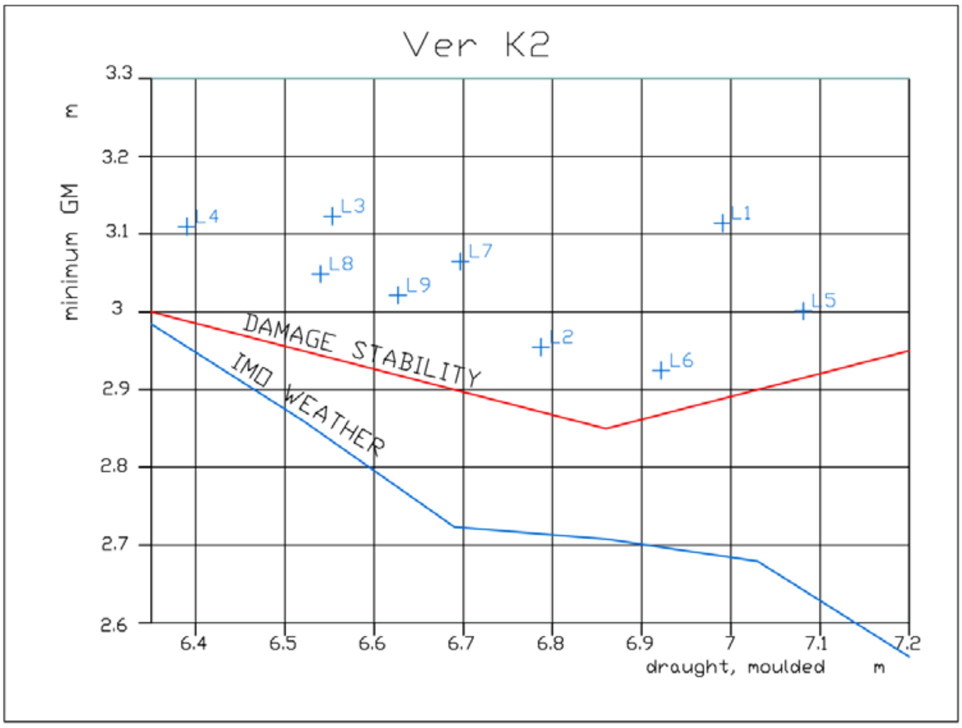


Fig. 13-58 GM Limiting curve version K2

Table 13-57 Attained index version K2

Version	A reference	F opt. 5	K2 opt. 8
Required Index	**0.8300**	**0.8300**	**0.8300**
Attained Index A $_{SOLAS2009}$	0.8527	0.9061	0.9097
Attained Index A $_{SLF55}$	**0.8326**	**0.8997**	**0.9042**
Intact GM at initial draft 6,35 /6,86/7,20 m	2.6/2.45/2.7 m	3.0/2.85/2.95 m	3.0/2.85/2.95 m
Change A	0	0.0671	0.0716
Change A in percentage	0	8.06%	8.60%

Table 13-58 Summary of changes in weight and areas – Version K2

Version	A - reference	F opt. 5	K2 opt. 8
Steelweight	12953 t	+ 317 t	+ 340 t
GT	59800 GT	+ 850 GT	+ 850 GT
Outfitting	5070 t	+ 20 t	+ 24 t
Machinery	3313 t	+ 20 t	+ 20 t
Lightweight	22337 t	+ 358 t	+ 384 t
Pax Public	8246 m2	+ 16 m2	+ 16 m2
Cabins	11885 m2	+ 20 m2	+ 20 m2
Service Area	6541 m2	+ 22 m2	+ 55 m2
Tech spaces + Hotel Stores	39500 m2	-30 m2	+382 m2
Stabilizers		+ 3 m2	+ 3 m2
Machinery Power		+ 342 kW	+ 145 kW
WT-doors on Lower Hold 3 pcs			+ 4 t

Compared to version F attained index will increase from 8.06 % into 8.60 %, which is shown in Table 13-57. Summary of changes in weight and areas are presented in Table 13-58.

Due to normal subdivision three watertight sliding doors have been added on store area. From operational point of view this option will have negative impact on survivability due to open kept watertight doors while at sea.

13.4.2.7 Phase 4; As version F + further increased breadth by + 40 cm Version L

It has been decided to achieve a further increase of the attained index by increasing the breadth while keeping the CAF limits. Based on version F the breadth has been increased by 40 cm.

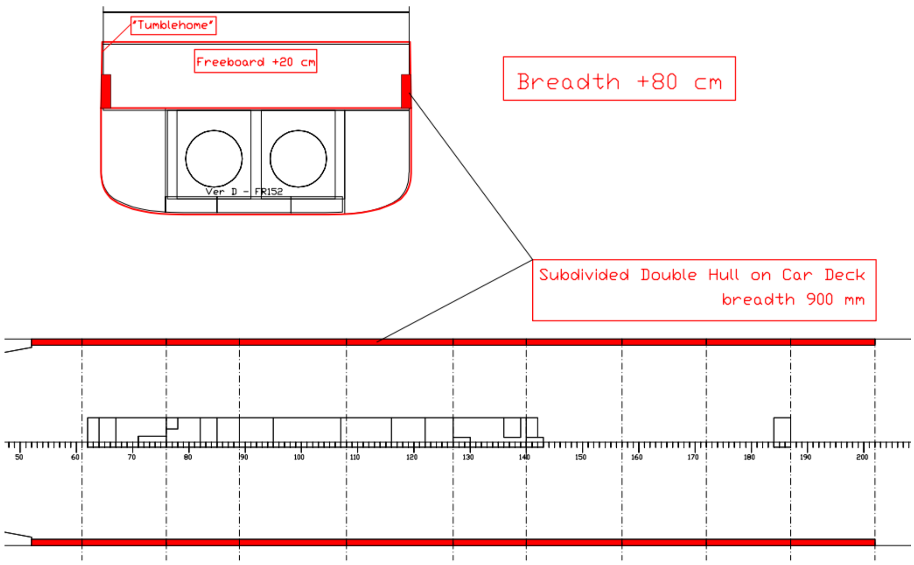


Fig. 13-59 Layout of subdivided double hull on car deck version L(as version F + 40 cm breadth more)

Table 13-59 Loading condition details for version L – (As Version F + 40 cm breadth more)

NAME	TEXT	DW	BW	LNG	PW	T	TR	GM
L1	Trailers + Cars Specified	5500 t	100 t	350 t	750 t	7.00 m	-0.18 m	3.60 m
L2	Trailers + Cars Specified Arrival	4218 t	550 t	35 t	75 t	6.79 m	-0.05 m	3.43 m
L3	Departure, passengers no cargo 100% bunkers	2950 t	100 t	350 t	750 t	6.56 m	-0.20 m	3.64 m
L4	Arrival, passengers, no cargo, 10% bunkers	1956 t	613 t	35 t	75 t	6.39 m	-0.06 m	3.58 m
L5	As L1 + Ice load	5921 t	300 t	350 t	750 t	7.08 m	0.04 m	3.46 m
L6	As L2 + Ice load	4975 t	861 t	35 t	75 t	6.92 m	0.05 m	3.40 m
L7	As L3 + Ice load	3698 t	628 t	350 t	750 t	6.70 m	-0.07 m	3.54 m
L8	As L4 + Ice load	2498 t	1084 t	35 t	75 t	6.47 m	-0.03 m	3.42 m
L9	50% Cargo/Bunkers/Stores	3323 t	50 t	175 t	375 t	6.63 m	-0.17 m	3.50 m

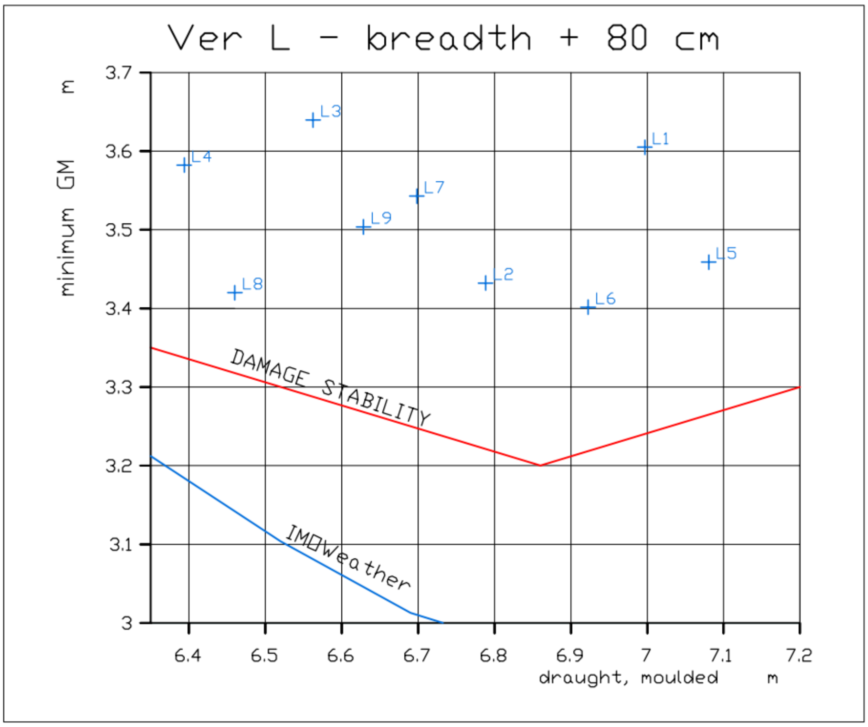


Fig. 13-60 GM Limiting curve version L

Table 13-60 Attained index version L

Version	A reference	F opt. 5	L opt. 9
Required Index	**0.8300**	**0.8300**	**0.8300**
Attained Index A $_{SOLAS2009}$	0.8527	0.9061	0.9195
Attained Index A $_{SLF55}$	**0.8326**	**0.8997**	**0.9152**
Intact GM at initial draft 6,35 /6,86/7,20 m	2.6/2.45/2.7 m	3.0/2.85/2.95 m	3.35/3.2/3.3 m
Change A	0	0.0671	0.0826
Change A in percentage	0	8.06%	9.92%

Table 13-61 Summary of changes in weight and areas – Version L

Version	A - reference	F opt. 5	L opt. 9
Steel weight	12953 t	+ 317 t	+ 340 t
GT	59800 GT	+ 850 GT	+ 1097 GT
Outfitting	5070 t	+ 20 t	+ 28 t
Machinery	3313 t	+ 20 t	+ 20 t
Lightweight	22337 t	+ 358 t	+ 388 t
Pax Public	8246 m2	+ 16 m2	+ 30 m2
Cabins	11885 m2	+ 20 m2	+ 35 m2
Service Area	6541 m2	+ 22 m2	+ 17 m2
Tech spaces + hotel stores	39500 m2	-30 m2	+135 m2
Stabilizers		+ 3 m2	+ 4 m2
Machinery Power		+ 342 kW	+ 420 kW

Compared to version F attained index will increase from 8.06 % into 9.92 %, which is shown in Table 13-61. Summary of changes in weight and areas are presented in Table 13-62.

Intact GM at calculated drafts are increased by 35 cm compared to version F. This means that also operational GM-level is about 0.5 m higher. Operational GM-level is shown in table Table 13-60.

13.4.3 Cost Benefit Assessment

Following costs for investment assumptions have been used for Baltic Ferry, which are based on analyzed recent new build ships of the shipyard:

- Steel weight, including piping, ducting, painting 6000 €/t
- Public areas including ducting, cabling etc 3000 €/m2
- Cabin areas including ducting, cabling etc 2500 €/m2
- Service areas, like galley, laundry including ducting, cabling etc 2500 €/m2
- Technical areas, like spaces in car deck including ducting, cabling etc 1500 €/m2
- Additional installed propulsion power 700 €/kW
- Additional increase of stabilizers due to increase in GM 100000 €/m2
- Additional watertight sliding doors 25000 €/pcs
- Additional cargo equipment like fixed ramps due to LLH in version I -total 800000 €
- Additional cargo equipment due to subdivided car deck
  4 pcs barriers on car deck in version J 200000 €/pcs

For the costs of the fuel a typical annual operating profile has been used to calculate the change in fuel oil consumption per year. Based on the distribution of the different operational modes with different speed a mean propulsion power has been calculated. The hotel load is assumed constant 2800 kW except in LLH version 2775 kW due to decrease in cabins.

The following table shows the overview of the calculations for the fuel costs. They are based on the normal best practice of the shipyard to estimate the speed power performance of new ships.

Table 13-62 - Summary of FOC calculation

Condition version	Reference design basic design	option 1 -b B+40 cm	option 2 - c B+20 cm,F+20 cm	option 3 - d B+40 cm,F+20 cm	option 4 -e B+40 cm,F+40 cm
speed	0.0 kn	0.0 kn	0.0 kn	0.0 kn	0.0 kn
percentage	25 %	25 %	25 %	25 %	25 %
prop power	0 kW	0 kW	0 kW	0 kW	0 kW
speed	8 kn	8 kn	8 kn	8 kn	8 kn
percentage	4 %	4 %	4 %	4 %	4 %
prop power	988 kW	993 kW	994 kW	998 kW	999 kW
speed	12 kn	12 kn	12 kn	12 kn	12 kn
percentage	17 %	17 %	17 %	17 %	17 %
prop power	3121 kW	3137 kW	3141 kW	3152 kW	3157 kW
speed	21 kn	21 kn	21 kn	21 kn	21 kn
percentage	54 %	54 %	54 %	54 %	54 %
prop power	15829 kW	15910 kw	15930 kW	15986 kW	16011 kW
mean mech prop power	9078 kW	9164 kW	9176 kW	9208 kW	9223 kW
efficiency PEM	0,92	0,92	0,92	0,92	0,92
electrical prop power	9868 kW	9961 kW	9974 kW	10009 kW	10025 kW
Hotel Load	2800 kW	2800 kW	2800 kW	2800 kW	2800 kW
efficiency generators	0,97	0,97	0,97	0,97	0,97
Total diesel load	13059 kW	13156 kW	13169 kW	13205 kW	13221 kW
Fuel consumption per year	20310 ton	20460 ton	20480 ton	20537 ton	20561 kW
relative	100,00 %	100,74 %	100,84 %	101,12 %	101,24 %
Change of FOC per year	**0,00 ton**	**150 ton**	**170 ton**	**227 ton**	**251 ton**

Condition version	option 5 - f as option 3 + Double hull	option 6 - i option 5 + impact of LLH	option 7 - j as opt 5+Subdivided Car Deck	option 8 -k2 as option 5+No Lower Hold	option 9 - l as option 5 + 40 cm breadth
speed	0.0 kn	0.0 kn	0.0 kn	0.0 kn	0.0 kn
percentage	25 %	25 %	27 %	25 %	25 %
prop power	0 kW	0 kW	0 kW	0 kW	0 kW
speed	8 kn	8 kn	8 kn	8 kn	8 kn
percentage	4 %	4 %	4 %	4 %	4 %
prop power	998 kW	998 kW	998 kW	992 kW	1000 kW
speed	12 kn	12 kn	12 kn	12 kn	12 kn
percentage	17 %	17 %	17 %	17 %	17 %
prop power	3152 kW	3152 kW	3152 kW	3134 kW	3158 kW
speed	21 kn	21 kn	22 kn	21 kn	21 kn
percentage	54 %	54 %	52 %	54 %	54 %
prop power	15986 kW	15986 kW	18451 kW	15895 kW	16022 kW
mean mech prop power	9208 kW	9208 kW	10170 kW	9156 kW	9230 kW
efficiency PEM	0,92	0,92	0,92	0,92	0,92
electrical prop power	10009 kW	10009 kW	11055 kW	9952 kW	10032 kW
Hotel Load	2800 kW	2775 kW	2800 kW	2800 kW	2800 kW
efficiency generators	0,97	0,97	0,97	0,97	0,97
Total diesel load	13205 kW	13179 kW	14283 kW	13146 kW	13228 kW
Fuel consumption per year	20537 ton	20497 kW	22213 ton	20445 ton	20573 ton
relative	101,12 %	100.09 %	109,40 %	100,67 %	101,29 %
Change of FOC per year	**227 ton**	**187 ton**	**1903 ton**	**135 ton**	**263 ton**

Because the fuel in sample ship and in all presented options is assumed to be LNG, the anticipated fuel mix is expected to be fallen 95 % LNG and 5 % Marine Gas Oil during 30 years life time.

The operational costs during life time are assumed to be same in all other options except in subdivided car deck option (version J). Maintenance of cargo ports (4 pcs barriers) are expected to increase the operational costs by 180000 euros.

The costs for revenue are assumed to be same as in reference ship in all other options, except in LLH and subdivided car deck options (versions I and J).

In LLH options LNG tanks are located in upper open deck in aft. Therefore 14 cabins are lost and loss of public spaces by 135 m2. LLH will increase lane meters by 200 m.

In the subdivided car deck due to barriers it is assumed to lose 30 m lane meters.

The changes in costs for revenue in versions I and J are based on the information received from the owner;

1. loss of one cabin -154.5 €/leg 24 h
2. loss of public area -12250 €/m2 per year
3. loss or addition of trailers - 33.25 €/lane meter per leg 24 h

13.4.3.1 Basic results

The following table shows the results of the cost calculation for the investigated design variations.

Table 13-63 Summary of cost calculations

Version	reference	option 1 - b	option 2 - c	option 3 - d	option 4 -e
description	basic design	Breadth + 40 cm	Breadth +20 cm, Freeboard + 20 cm	Breadth +40 cm, Freeboard + 20 cm	Breadth +40 cm, Freeboard + 40 cm
Loa	252,85	252,85	252,85	252,85	252,85
Lbp	232,20	232,20	232,20	232,20	232,20
L subd	250,96	250,96	250,96	250,96	250,96
B	29,00	29,40	29,20	29,40	29,40
T	7,20	7,20	7,20	7,20	7,20
Height BHD	9,90	9,90	10,10	10,10	10,30
DW	5450	5450	5450	5450	5450
Trailer lane meters	1200	1200	1200	1200	1200
Car lane meters	1350	1350	1350	1350	1350
Volume Design T=7.0 m/m3	28460	28670	28732	28880	28950
dl/GM	6,35 m/2,6 m	6,35 m/3,0 m	6,35 m/2,8 m	6,35 m/2,95 m	6,35 m/2,8 m
dp/GM	6,86 m/2,45 m	6,86 m/2,9 m	6,86 m/2,60 m	6,86 m/2,8 m	6,86 m/2,6 m
ds/GM	7,20 m/2,7 m	7,20 m/3,0 m	7,20 m/2,8 m	7,20 m/2,9 m	7,20 m/2,8 m
Gross Tonnnage	59800	60110	60462	60650	61120
Number Pass	3060	3060	3060	3060	3060
Number Crew	220	220	220	220	220
Lifeboat capacity	984	984	984	984	984
N1	984	984	984	984	984
N2	2296	2296	2296	2296	2296
Change of fuel consumption	0	150	170	227	251
required index R	0,8300	0,8300	0,8300	0,8300	0,8300
attained index As2009	0,8527	0,8855	0,8801	0,8942	0,8887
attained index Aslf55	0,8326	0,8703	0,8670	0,8824	0,8786
change A	0,0000	0,0377	0,0344	0,0498	0,0460
net Present Value NPV	**0 $**	**4 358 868 $**	**4 563 097 $**	**6 721 889 $**	**8 464 220 $**

Version	option 5 - f	option 6 - i	option 7 - j	option 8 - k2	option 9 - l
description	As version 3 + double hull on blh deck	As vers 5 +Impact of LLH	As vers 5 + Subdivided Car Deck	As version 5 + No lower Hold	As version F + 40cm Breadth
Loa	252,85	252,85	252,85	252,85	252,85
Lbp	232,20	232,20	232,20	232,20	232,20
L subd	250,96	250,96	250,96	250,96	250,96
B	29,40	29,40	29,40	29,40	29,80
T	7,20	7,20	7,20	7,20	7,20
Height BHD	10,10	10,10	10,10	10,10	10,10
DW	5450	5450	5450	5450	5450
Trailer lane meters	1200	1400	1170	1200	1200
Car lane meters	1350	1350	1350	1350	1350
Volume Design T=7.0 m/m3	28880	28880	28670	28880	28975
dl/GM	6,35 m/3,0 m	6,35 m/2,6 m	6,35 m/3,0 m	6,35 m/3,0 m	6,35 m/3,35 m
dp/GM	6,86 m/2,85 m	6,86 m/2,5 m	6,86 m/2,85 m	6,86 m/2,85 m	6,86 m/3,2 m
ds/GM	7,20 m/2,95 m	7,20 m/2,75 m	7,20 m/2,95 m	7,20 m/2,95 m	7,20 m/3,3 m
Gross Tonnnage	60650	60540	60650	60650	60897
Number Pass	3060	3060	3060	3060	3060
Number Crew	220	220	220	220	220
Lifeboat capacity	984	984	984	984	984
N1	984	984	984	984	984
N2	2296	2296	2296	2296	2296
Change of fuel consumption	227	187	1903	135	263
required index R	0,8300	0,8300	0,8300	0,8300	0,8300
attained index As2009	0,9061	0,8623	0,9188	0,9097	0,9195
attained index Aslf55	0,8997	0,8494	0,9184	0,9042	0,9152
change A	0,0671	0,0168	0,0858	0,0716	0,0826
net Present Value NPV	**7 067 644 $**	**8 250 355 $**	**48 878 800 $**	**6 694 565 $**	**8 444 391 $**

In combined Table 13-64 are shown attained index and net present value (NPV) for each option.

As it has been decided to select option L due to have biggest improvement in A-index keeping the CAF limits it should be noticed also an increase in operational GM level as shown in the table below.

Table 13-64 Summary of NPV

Version	A	B opt 1	C opt 2	D opt 3	E opt 4	F opt 5	I opt 6	J opt 7	K2 opt 8	L opt 9
Required index R	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300	0.8300
Attained index A_{SLF55}	0.8326	0.8703	0.8670	0.8824	0.8786	**0.8997**	0.8494	0.9184	0.9042	**0.9152**
Change A	0.0000	0.0377	0.0344	0.0498	0.0460	**0.0671**	0.0168	0.0858	0.0716	**0.0826**
Change A %	0.0000	4.53%	4.13%	5.99%	5.55%	**8.06%**	2.02%	10.3%	8.60%	**9.92%**
NPV	0 $	4,359 mill $	4,563 mill $	6,722 mill $	8,464 mill $	**7,068 mill $**	8,250 mill $	48,879 mill $	6,695 mill $	**8,444 mill $**
change NPV	-	-48.4%	-46.0%	-20.4%	+0.2%	**-16.3%**	-2.30%	+419%	-20.7%	**0.00**
operational GM level	(2,55-2,75) m	(3.0-3.2) m	(2.7-2.9) m	(2.9-3.1) m	(2.8-3.0) m	**(2.95-3.1) m**	(2.55-2.75) m	(2.95-3.13) m	(2.95-3.13)m	**(3.45-3.6) m**

The cost effectiveness can be easily demonstrated in the diagram below, where the costs as net present values are plotted against the attained index A. Also included are limits for allowable costs to match the netCAF limits of 4 Mio$ and 8 Mio$ including the 5% and 95% uncertainty limits.

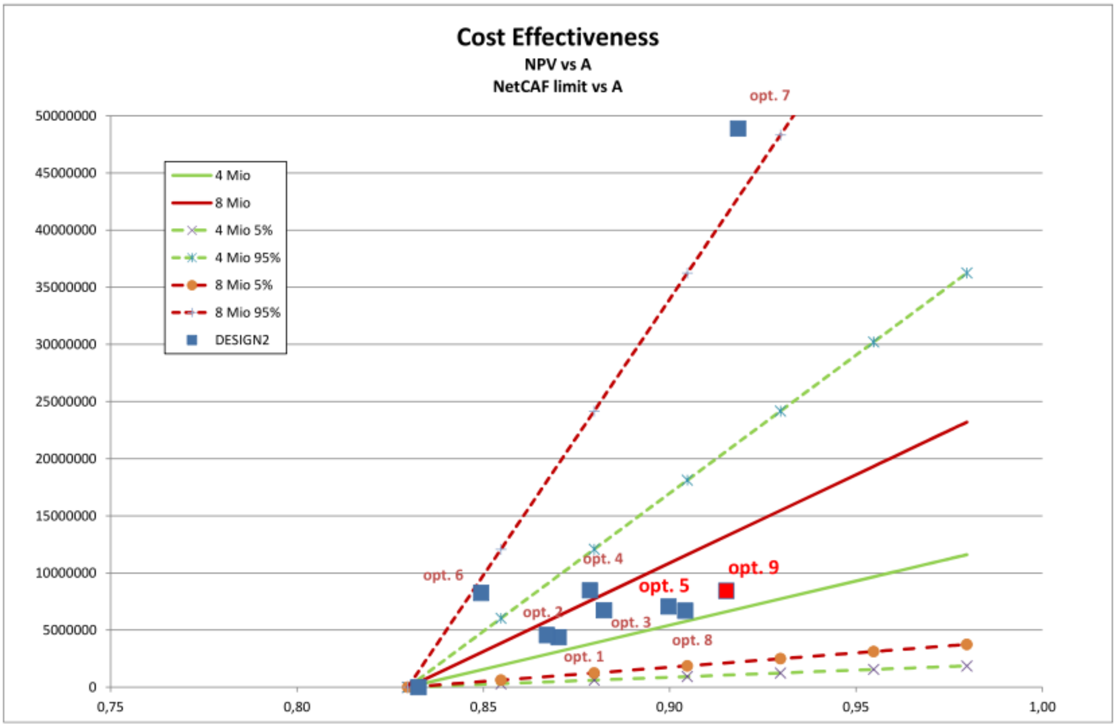


Fig. 13-61 Cost effectiveness

From the table and figure above it can be seen that option 9 is the most promising one, with the best increase of the attained index while staying below the 8Mio € limit.

Option 7 (version J) subdivided car deck has NPV considerably high compared to other options. Further; option 6 (version I) LLH has the least A-index compared to other options.

13.4.3.2 Sensitivity analysis

Due to the high impact of the fuel costs on the overall life-cycle costs a sensitivity analysis has been made to apply on the cost model the high and low estimates for the fuel price development and simultaneously to reduce and increase all other costs and revenue between by ±15-25%.

This leads to following net present values:

Table 13-65 Sensitivity of NPV results

Version	B - opt 1	C - opt 2	D - opt 3	E – opt 4	F – opt 5
net Present Value NPV	4 358 868 $	4 563 097 $	6 721 889 $	8 464 220 $	7 067 644 $
net present value NPV low	3 219 509 $	3 349 012 $	4 979 633 $	6 332 835 $	5 256 237 $
net present value NPV high	5 123 636 $	5 352 644 $	7 897 262 $	9 968 787 $	8 312 168 $
Version	I – opt 6	J – opt 7	K2 –opt8	L – opt 9	
net Present Value NPV	8 250 355 $	48 878 800 $	6 694 565 $	8 444 391 $	
net present value NPV low	6 485 393 $	38 630 474 $	5 113 335 $	6 296 719 $	
net present value NPV high	9 548 324 $	54 374 797 $	7 938 661 $	9 935 276 $	

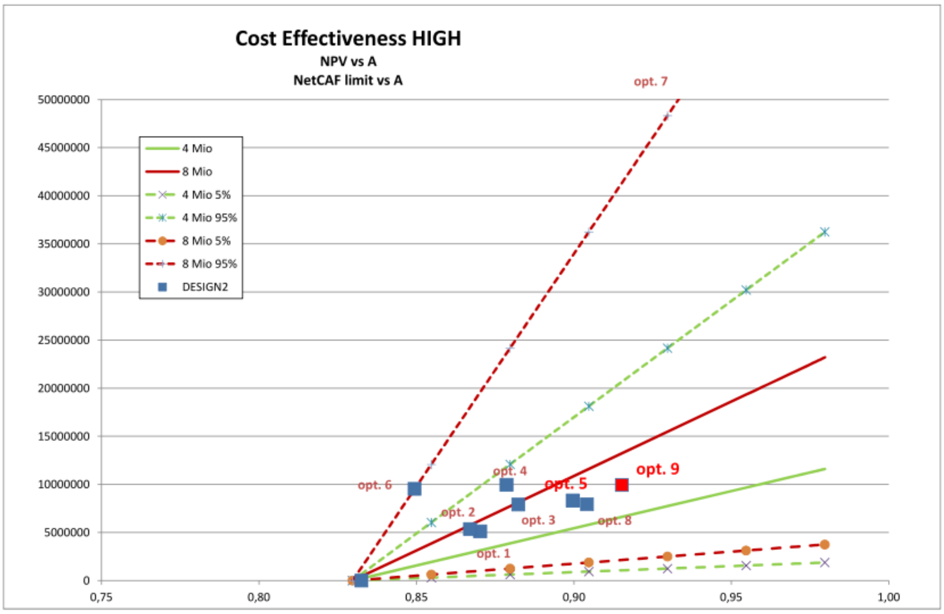


Fig. 13-62 Cost effectiveness HIGH

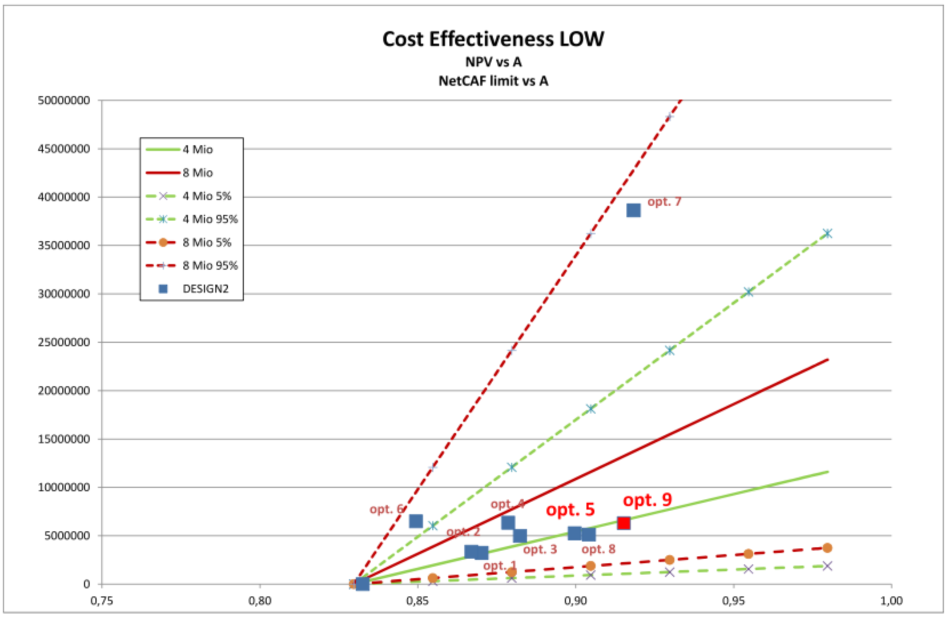


Fig. 13-63 Cost effectiveness LOW

Even with the higher figures used for fuel and other costs most of the design options except options 6 and 7 (subdivided car deck and LLH) are below the 8Mio € limit.

13.4.3.3 Conclusion and selection of optimized design

Based on the results of the CBA the options 5 and 9 are the most suitable ones. Although it seems more reasonable to continue with option 5, which is closer to the real ship requirements it has been decided to use option 9 as the selected version for further work in this project, as it offers the biggest improvement of A, while staying inside the limits of cost effectiveness. Also it should be noticed that operational GM level will increase about 0.5 m in option 9 being between 3.45 m - 3.6 m.

Option 8 (version K2), normally subdivided lower store hold has a little bit better A than in option 5. This has been rejected due to difficulties with watertight open kept doors while at sea between different stores and due to increase in vulnerability of the ship.

13.5 Ship #4 Mediterranean RoPax

13.5.1 General Approach

For this optimization, one has to keep in mind that the GM needs to be kept relatively low for a Ro-Pax, in order to maintain the acceleration values in an acceptable range.

Therefore, we have proceeded with following enhancement phases:

Phase 1:

- Increase the depth :
  This will lead to increase the KG and decrease the GM but at the same time it should bring more volume and stability reserve after flooding. We will look for the best compromise.
  This depth increase may be also limited by operational constraints like the height of the quay and the maximal slope of the embarking ramp.

- Add some internal subdivision :
  In the frame of the "Stockholm agreement" rule, the watertight bulkheads positions were determined by the deterministic breach.
  The new regulation gives the opportunity to play with the positions and number of the watertight bulkheads and look for the optimal configuration.

Phase 2:

- Add some subdivision above bulkhead deck => probably not acceptable today for new buildings due to operational constraints but it is interesting to know how far the index can be raised by this way.

- Test alternative design solutions like side casings.

- Increase the breadth :
  From our experience and from the GOALDS-project, this solution is one of the most efficient to increase the index. It can be combined with a depth increase in order to keep the GM under a certain acceptable threshold.

The following table shows an overview of the applied design variations, which will be described in the following sections one by one in more detail.

Table 13-66 Design variations – Med RoPax

Version	Description
Initial design	Calculated with “Stockholm agreement”
V0	New S Ropax (SLF55 formulation)
V1	Depth + 10cm
V12	Additional WT bulkheads below bulkhead deck
V21	Additional WT subdivisions above bulkhead deck
V13	Side casing based on V12
V14	Increase in breadth + 20cm based on V12

13.5.2 Design Variations

13.5.2.1 Version V0

Before describing more in detail the modifications proposed, we would like to remind briefly the initial calculation results of the sample ship used:

In the context of this EMSA3 study, the calculation has been performed according to the new regulation 7-2.3 of SOLAS II.1 with TGZmax 0.20m and TRange 20deg for each damage case that involves a Ro-Ro space.

Total persons on board used for R calculation : 1700

Total persons in lifeboats used for R calculation: 568

Subdivision length 184.997 m

Breadth at the load line 31.000 m

Breadth at the bulkhead deck 31.000 m

Required subdivision index R = 0.778

Draft / GM: 6.7 / 3.4 6.34 / 3 5.8 / 4.1

Attained subdivision index A = 0.83982

⇨ Margin on the index = 0.061

It is to be noted that this initial reserve is a relatively high but it may be useful for a real project to take account for progressive flooding at a later design stage. Any addition of a gas tank of significant size, would also lead to loss of some index.

This also reflects the fact that our sample ship is carrying a relatively small number of persons compared to its size. It corresponds to a polyvalent use with more freight in winter and more passengers in summer with some additional pedestrian passengers who are sailing during the day.

13.5.2.2 Version V1 – Increase in depth by 10cm

The idea is to increase the floatability, while keeping the GM in an acceptable range for a Ro-Pax ship.

The following figure illustrates the principle of modification:

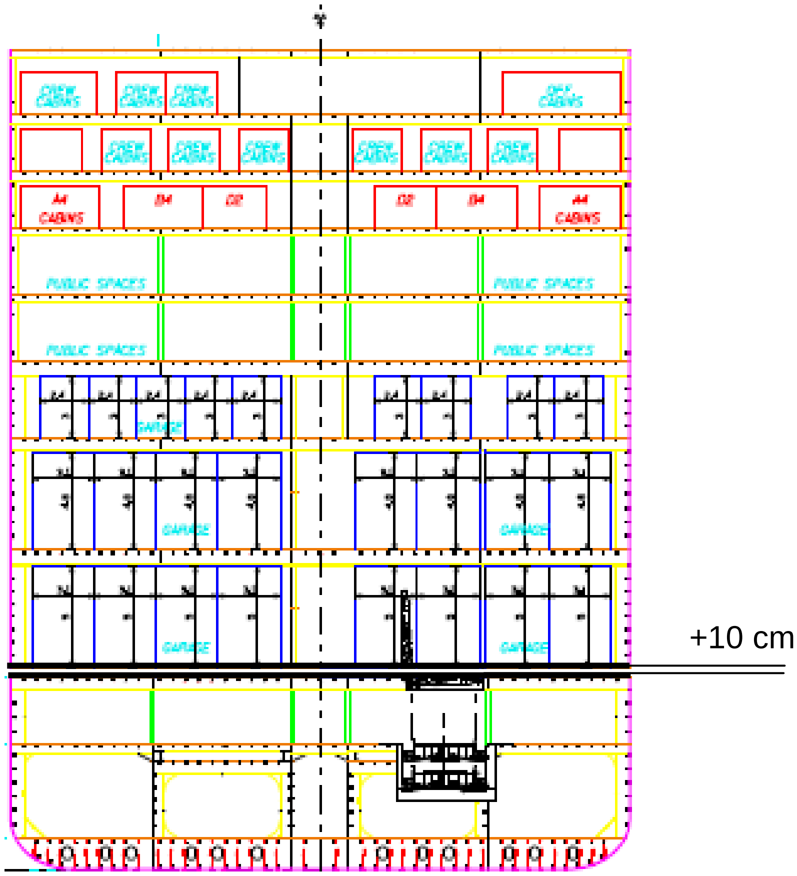


Fig. 13-64 Design modification V1

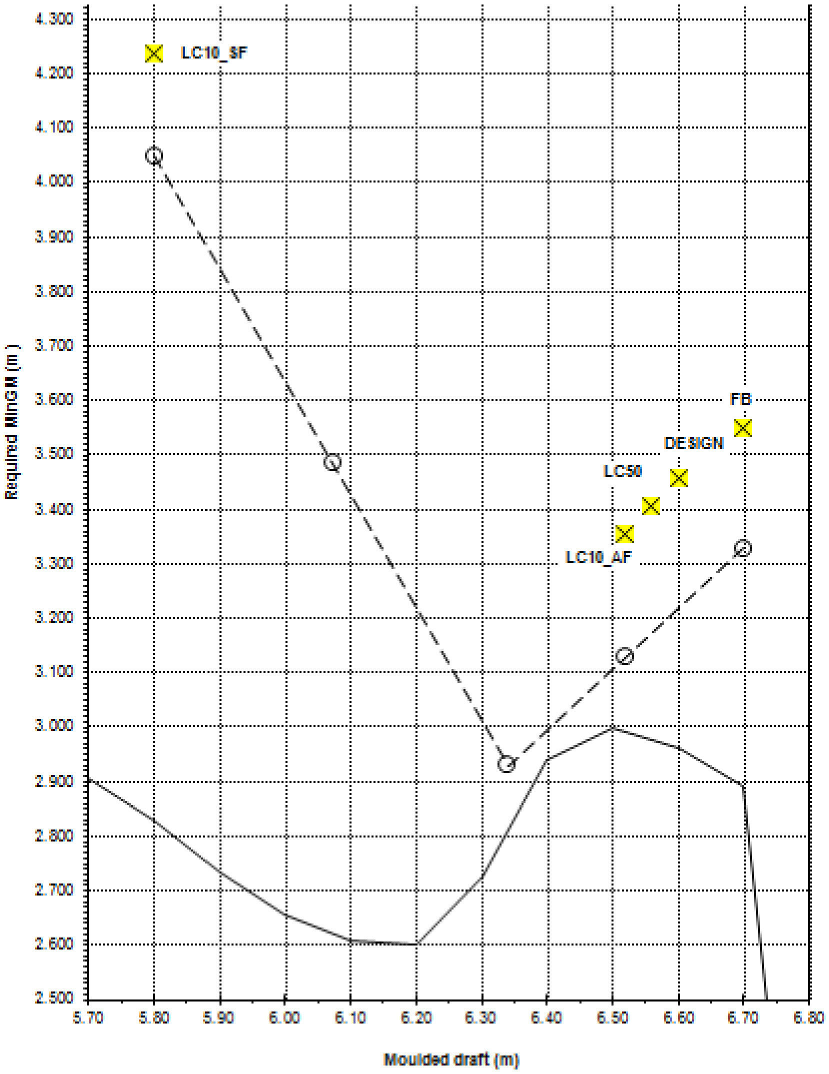
The required GM has been reduced to keep the same margin on the loading cases, considering the increase in KG induced by the depth increase.

The weight increase due to this modification is relatively low: about 10 t in steel, which has a very small impact on the draft (1cm for 40t in the hydrostatics) and on the fuel consumption.

The following loading conditions have been updated to take into account the elevation of centre of gravity, resulting in the GM limiting curve shown below.

Table 13-67 Loading conditions

Loading conditions		Draft	TRIM	GM cor.	KG cor.
NAPA code	**Name**	(m)	(m)	(m)	(m)
DESIGN	Design_DW=6 755t	6.600	-0.007	3.459	15.053
FB	Max load FB	6.700	0.001	3.551	14.879
LC10_AF	With cars & trailers_10% consumables	6.519	0.000	3.355	15.190
LC50	With cars & trailers_10% consumables - no WB	6.558	-0.001	3.410	15.122
LC10_SF	Without cars & trailers_10% loading	5.800	-0.005	4.237	14.270



———	Intact stability GM-curve
– – – – –	Min GM – SOLAS Ch.II-1 Reg.7

Fig. 13-65 LIMITING GM Curve – Design Modification V1

With this GM limiting values the attained index has been calculated:

Required subdivision index R = 0.778

Draft / GM : 6.7 / 3.33 6.34 / 2.93 5.8 / 4.05

Attained subdivision index A = 0.84036

- ⇨ Margin on the index = 0.062
- ⇨ Slight increase of index of 0.0005 compared to V0

Note: during this optimization study, a version V2 with an increase of the depth by 20cm has been also calculated on the same principle. The calculation of the attained index shows no additional increase of the attained index compared to this version V1 with 10cm depth increase. Therefore, this version has not been detailed in this final report.

13.5.2.3 Version V12 - Additional bulkheads below bulkhead deck

In the frame of the "Stockholm agreement" rule, the watertight bulkheads positions were limited by the deterministic breach. The new regulation gives the opportunity to play with the positions and number of the watertight bulkheads and look for the optimal configuration.

In this version we have added two watertight bulkheads below the bulkhead-deck:

- o Addition of Watertight zone in the aft part (addition of watertight bulkhead at Frame 11 and shift of watertight bulkhead Frame 5 to 2)

- o Addition of Watertight zone in the fore part (addition of watertight bulkhead at Frame 134, shift of watertight bulkheads Frame 128 to 125 and Frame 140 to 143)

The following figure illustrates the principle of this modification:

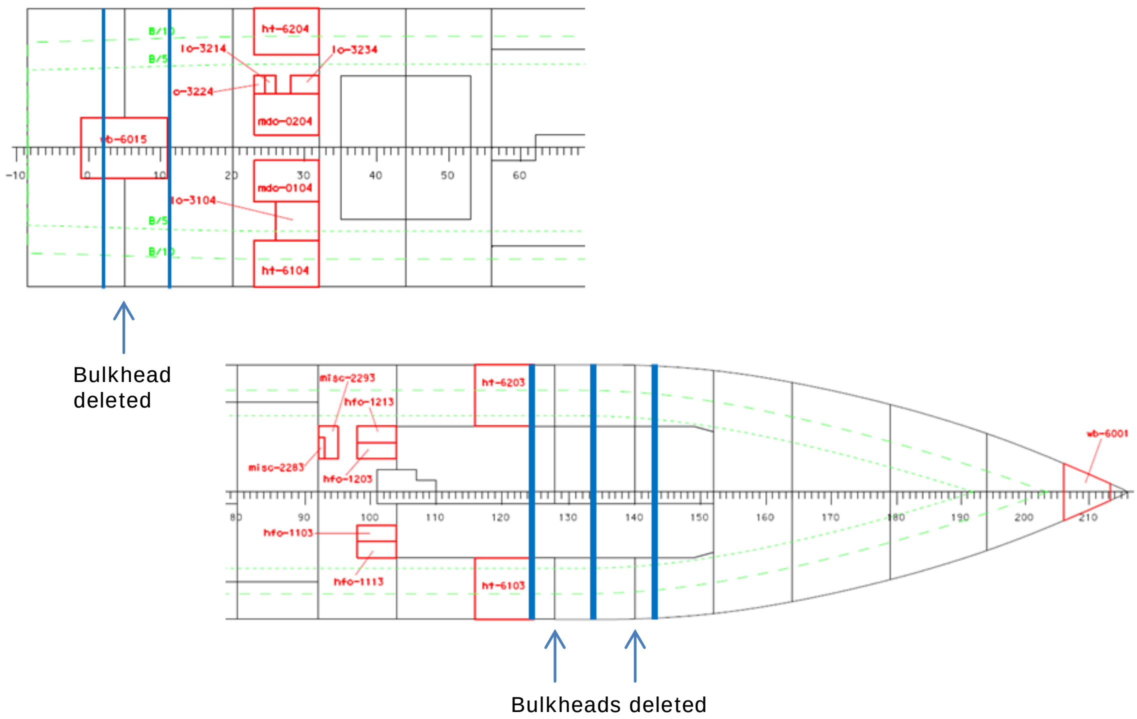


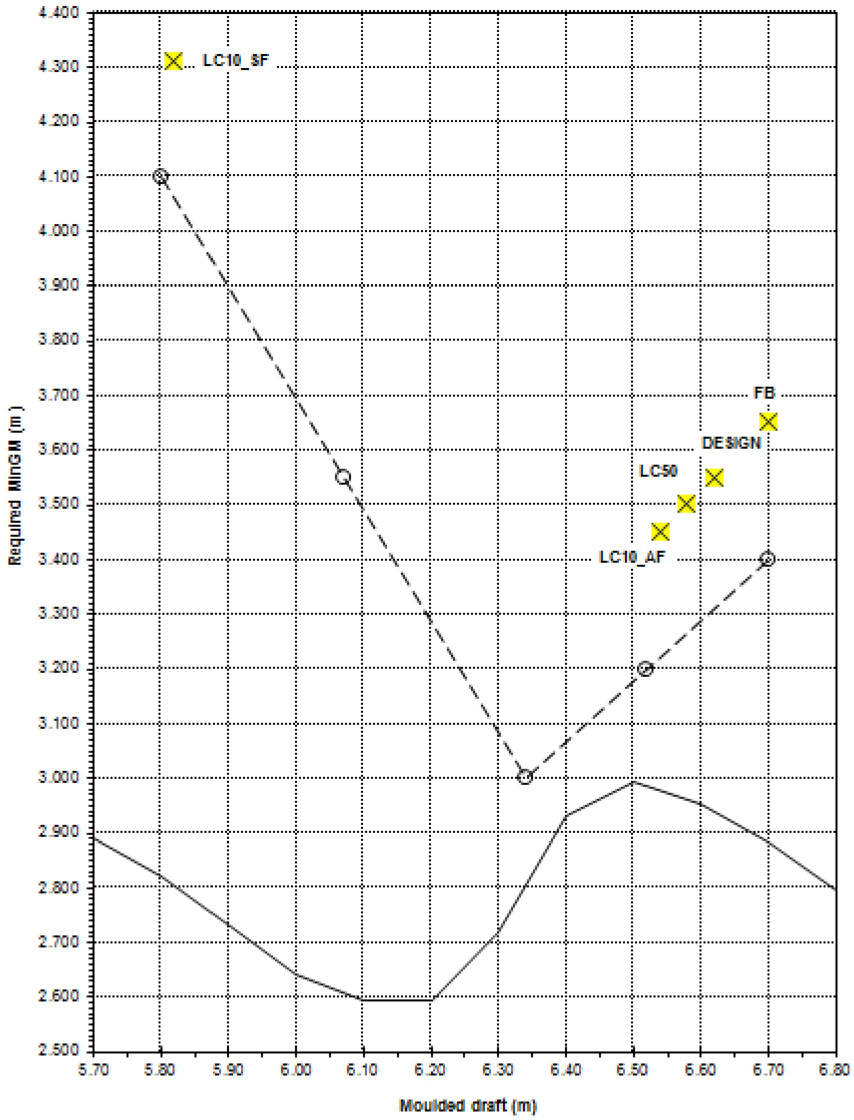
Fig. 13-66 Illustration of Design modification V12

The weight increase due to these additional transversal bulkheads has been calculated, based on the areas of each bulkhead, which is about 280m² for the aft one and 180m² for the forward one. The additional outfitting weight can be neglected, compared to the additional steel weight.
This additional weight has been used for the calculation of the propulsion power increase and the associated fuel consumption.

The updated loading conditions and the resulting GM limiting curve are as follows:

Table 13-68 Loading conditions – design modification V12

Loading conditions		Draft	TRIM	GM cor.	KG cor.
NAPA code	**Name**	(m)	(m)	(m)	(m)
DESIGN	Design_DW=6 755t	6.620	0.000	3.549	14.949
FB	Max load FB	6.700	0.000	3.654	14.776
LC10_AF	With cars & trailers_10% consumables	6.539	0.000	3.453	15.085
LC50	With cars & trailers_10% consumables - no WB	6.578	0.000	3.503	15.017
LC10_SF	Without cars & trailers_10% loading	5.820	0.000	4.313	14.181



———	Intact stability GM-curve
- - - - - - - - -	Min GM – SOLAS Ch.II-1 Reg.7

Fig. 13-67 Limiting GM curve – Design modification V12

With this GM limiting values the attained index has been calculated:

Required subdivision index R = 0.778

Draft / GM: 6.7 / 3.4 6.34 / 3 5.8 / 4.1

Attained subdivision index A = 0.84956

- ⇨ Margin on the index = 0.072
- ⇨ Increase of index of 0.010 compared to V0

13.5.2.4 Version V21: Addition of subdivisions on the car deck – at Fr56 and Fr116

Although it is generally considered as not acceptable by the operators, this version has been studied for following reasons:

- This solution had been mentioned during the GOALDS project, as a radical solution to improve the survivability of RoPax ships

- We know that this solution is technically feasible (if not economically), and sometimes applied for the refitting of ships.

- It is interesting to know how far the attained index can be raised by applying this solution.

- One could imagine finding one day some technical mean and associated operational process, which could lead to an easier implementation of this type of solution.

The following figure illustrates the principle of the modification:

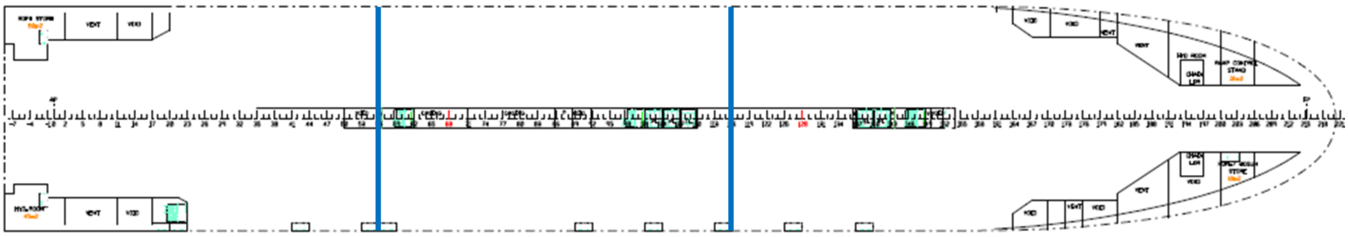


Fig. 13-68 Illustration of design modification V21

Following hypothesis have been taken into account for the cost estimate of this solution:

- Steel, manufacturing and outfitting extra costs
- Additional stay in ports for loading / unloading (hypothesis: 30min more)

In order to keep the same business model (which is a basic premise in the EMSA3 project):

Speed increase to compensate for this loss of time (=same distance covered)

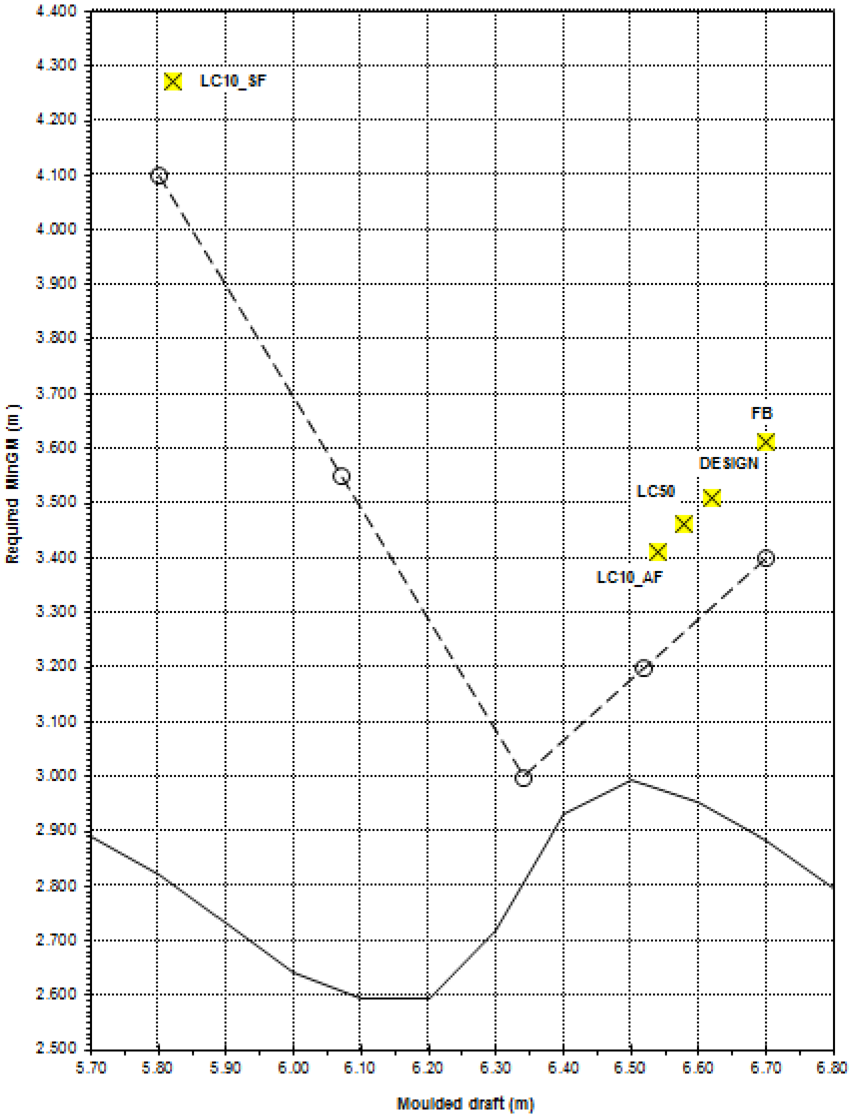
⇨ **Significant impact on the fuel consumption**

Some additional lane meters could be provided in the aft in order to compensate for the loss of LM due to the bulkheads.

The loading conditions and the resulting GM limiting curve remain as follows:

Table 13-69 Loading conditions –design modification V21

Loading conditions		Draft	TRIM	GM cor.	KG cor.
NAPA code	Name	(m)	(m)	(m)	(m)
DESIGN	Design_DW=6 755t	6.620	0.000	3.509	14.989
FB	Max load FB	6.700	0.000	3.614	14.816
LC10_AF	With cars & trailers_10% consumables	6.539	0.000	3.413	15.125
LC50	With cars & trailers_10% consumables - no WB	6.578	0.000	3.463	15.057
LC10_SF	Without cars & trailers_10% loading	5.820	0.000	4.273	14.221



———	Intact stability GM-curve
– – – – –	Min GM – SOLAS Ch.II-1 Reg.7

Fig. 13-69 GM limiting curves design modification V21

With this GM limiting values the attained index has been calculated:

Required subdivision index R = 0.778

Draft / GM: 6.7 / 3.4 6.34 / 3 5.8 / 4.1

Attained subdivision index A = 0.87784

- ⇨ Margin on the index = 0.0998
- ⇨ Significant increase of index of 0.038 compared to V0

13.5.2.5 Version V13 – Test of partial side casing

This version is based on the V12, with the additional subdivisions below the bulkhead deck.

The idea of introducing a side casing is to create additional floatability on the sides.
There are many technical changes with such a solution and it would result in a fully new design. The main purpose of this test consists in estimating the potential index increase, which could be reached with this solution.

The added volumes on the sides are shown on the figure here below:

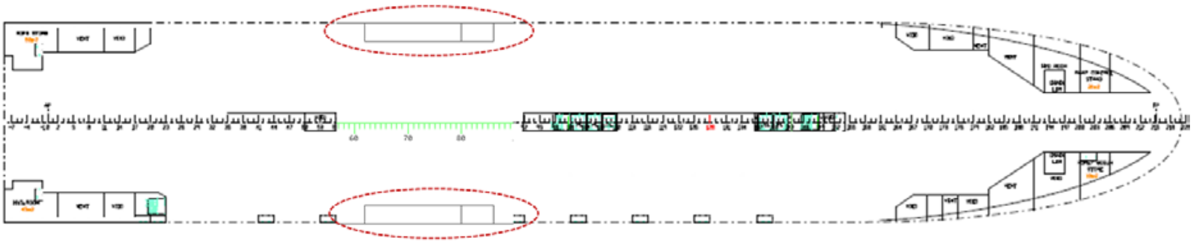
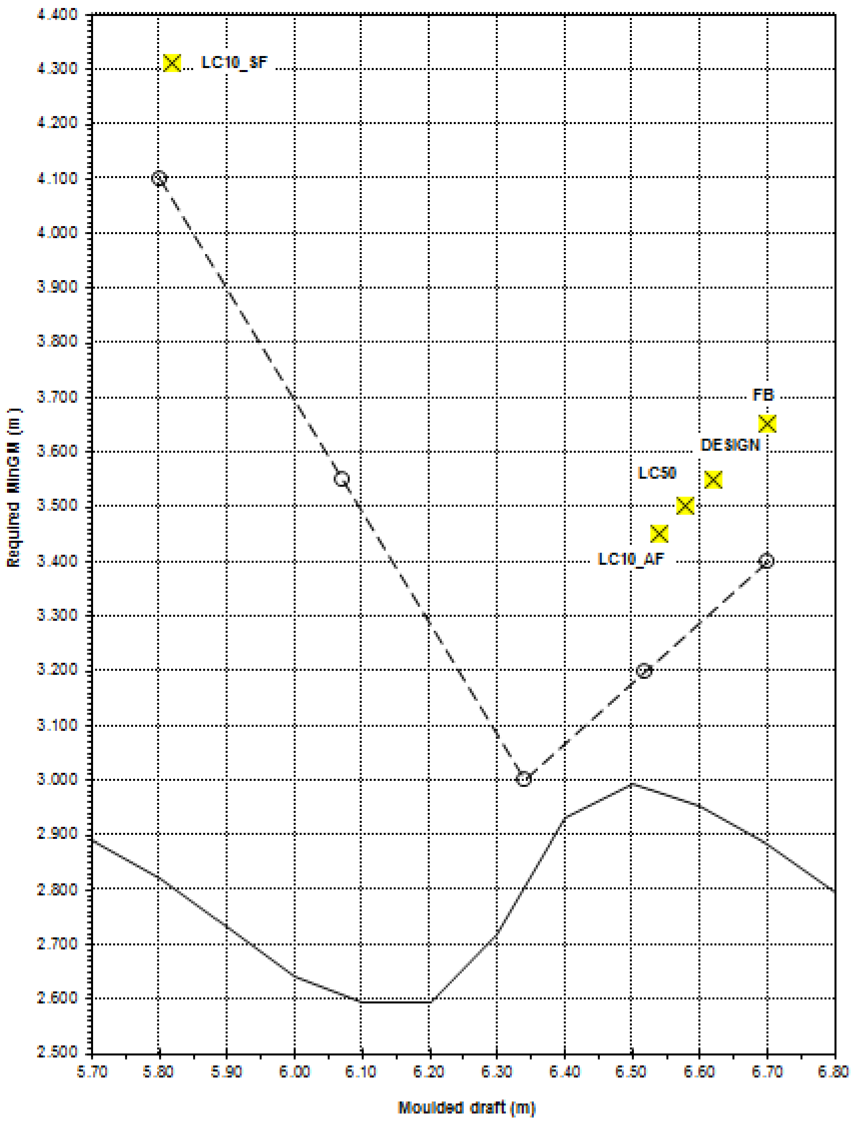


Fig. 13-70 Illustration of design modification V13

The loading conditions and the resulting GM limiting curve are as follows:

Table 13-70 Loading condition V13

Loading conditions		Draft	TRIM	GM cor.	KG cor.
NAPA code	**Name**	(m)	(m)	(m)	(m)
DESIGN	Design_DW=6 755t	6.620	0.000	3.549	14.949
FB	Max load FB	6.700	0.000	3.654	14.776
LC10_AF	With cars & trailers_10% consumables	6.539	0.000	3.453	15.085
LC50	With cars & trailers_10% consumables - no WB	6.578	0.000	3.503	15.017
LC10_SF	Without cars & trailers_10% loading	5.820	0.000	4.313	14.181



———	Intact stability GM-curve
- - - - - - - - -	Min GM – SOLAS Ch.II-1 Reg.7

Fig. 13-71 GM Limiting curve Design version V13

With this GM limiting values the attained index has been calculated:

Required subdivision index R = 0.778

Draft / GM: 6.7 / 3.4 6.34 / 3 5.8 / 4.1

Attained subdivision index A = 0.85373

- ⇨ Margin on the index = 0.076
- ⇨ Increase of index of 0.014 compared to V0
- ⇨ Additional index increase due to partial side casings is only **0.004**, compared to V12

This solution will not be studied further in the framework of this project, as far as it does not bring much enhancement on the index.

13.5.2.6 Version 14 = V12 + Increase in breadth by 20cm

From our experience and from the GOALDS-project, the increase in breadth is one of the most efficient ways for increasing the index. It could be combined with a depth increase in order to keep the GM under a certain acceptable threshold for a RoPax.

- Increase of breadth from 31.00m to 31.20m
- Addition of Watertight zone in the aft part (addition of watertight bulkhead at Frame 11 and shift of watertight bulkhead Frame 5 to 2)
- Addition of Watertight zone in the fore part (addition of watertight bulkhead at Frame 134, shift of watertight bulkheads Frame 128 to 125 and Frame 140 to 143)

The weight increase has been calculated using the additional square meters of the decks.
- 60 m² in technical areas
- 100 m² car decks
- 100 m² public spaces and cabins areas.

Then ratios in kg/m² have been applied, as described in the Cost Benefit Assessment chapter. This additional weight has been used for the calculation of the propulsion power increase and the associated fuel consumption.

The loading conditions have been recalculated. The loading conditions and the resulting GM limiting curve are as follows:

Table 13-71 Loading conditions

Loading conditions		Draft	TRIM	GM cor.	KG cor.
NAPA code	**Name**	(m)	(m)	(m)	(m)
DESIGN	Design_DW=6 755t	6.650	-0.004	3.772	14.949
FB	Max load FB	6.700	0.004	3.902	14.776
LC10_AF	With cars & trailers_10% consumables	6.569	0.001	3.688	15.085
LC50	With cars & trailers_10% consumables - no WB	6.608	0.001	3.734	15.017
LC10_SF	Without cars & trailers_10% loading	5.850	0.002	4.469	14.186

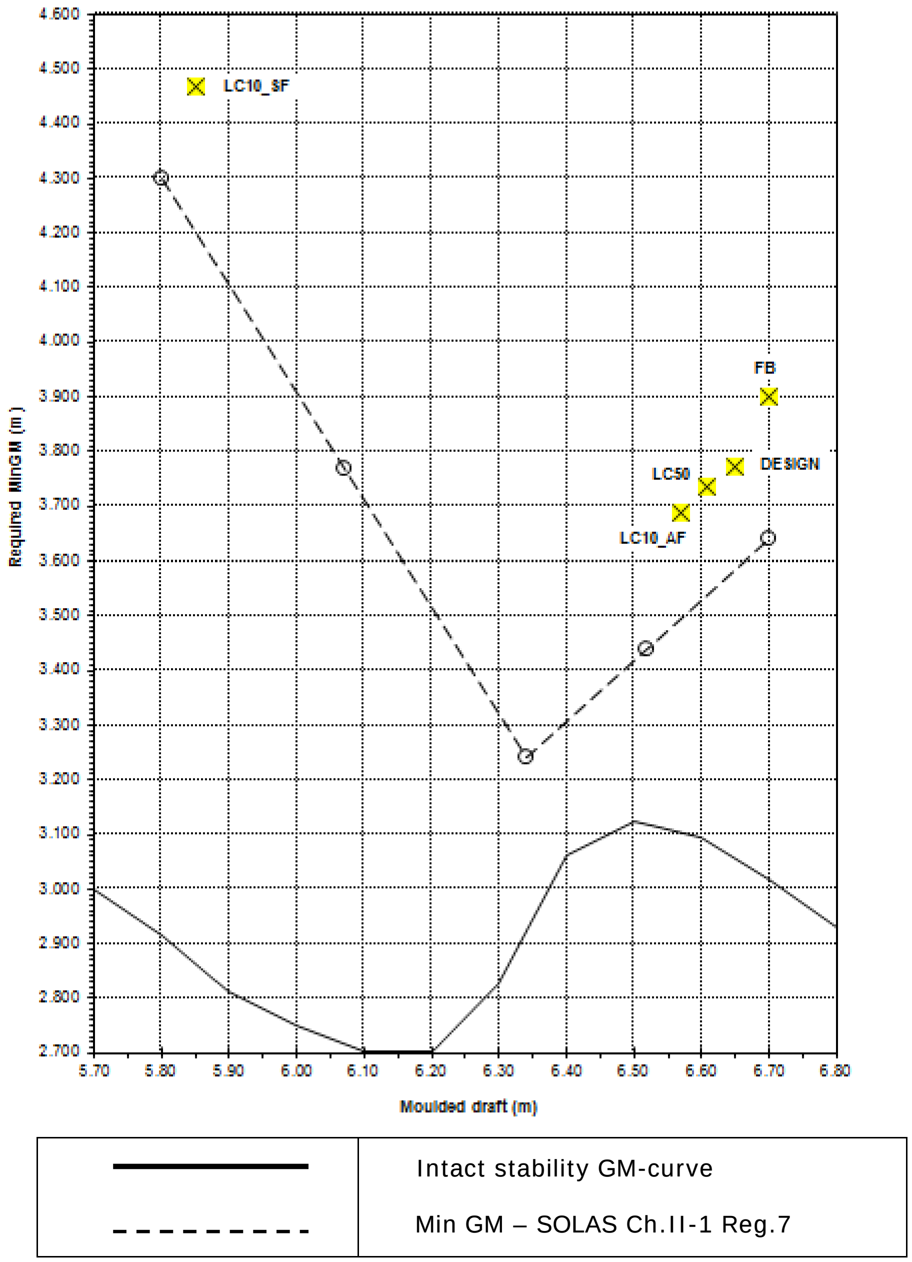


Fig. 13-72 Gm Limiting curves – design version V12 + increased breadth

With this GM limiting values the attained index has been calculated:

Required subdivision index R = 0.778

Draft / GM: 6.7 / 3.63 6.34 / 3.23 5.8 / 4.3

Attained subdivision index A = 0.87176

- ⇨ Margin on the index = 0.094
- ⇨ Increase of index of 0.032 compared to V0

13.5.3 Cost Benefit Assessment

Following cost assumptions have been used for this vessel are based on analysed recent new build ships of the shipyard:

- Steel weight, including painting 4500 €/t
- Public areas including ducting, cabling etc 2600 e/m2
- Cabin areas including ducting, cabling etc 2400 e/m2
- Technical areas, like galley, laundry including ducting, cabling etc 5000 e/m2
- Additional installed propulsion power 700€/kW

For the costs of the fuel a typical annual operating profile has been used to calculate the change in fuel oil consumption per year. Based on the distribution of the different operational modes with different speed a mean propulsion power has been calculated. The variations in hotel load, which mainly depends on the size of the vessel, have been adjusted linear to the change in gross tonnage. The following table shows the overview of the design variations and the FOC:

Table 13-72 Overview changes in FOC

	reference design	1 design step	2nd design step	3rd design step	4th design step
version	Initial version V0	V1 - depth +10	V12 - Add bkds below BHD	V21 - Add bkds on the car deck	V14 - Breadth increased
speed	0,0 kn	0,0 kn	0,0 kn	0,0 kn	0,0 kn
percentage	20%	20%	20%	23%	23%
prop power	0 kW	0 kW	0 kW	0 kW	0 kW
speed (kn)	20.4	20.4	20.4	21.8	20.4
percentage	33%	33%	33%	32%	33%
prop power	16700	16708	16751	24300	16827
speed (kn)	19	19	19	19	19
percentage	25%	25%	25%	24%	25%
prop power	13700	13706	13742	13700	13804
speed (kn)	12	12	12	12	12
percentage	13%	13%	13%	13%	13%
prop power	3000	3001	3009	3000	3023
speed - chanelling (kn)	5	5	5	5	5
percentage	9%	9%	9%	8%	9%
prop power	237	237	238	237	239
mean mech prop power (kW)	9347	9352	9376	11473	9418
Sea margin	15%	15%	15%	15%	15%
efficiency PEM	0.92	0.92	0.92	0.92	0.92
electrical prop power (kW)	11684	11689	11720	14341	11773
Hotel load (kW)	3000	3008	3000	3000	3019
efficiency generators	0.97	0.97	0.97	0.97	0.97
Total diesel load (kW)	15138	15152	15175	17878	15249
SFOC (g/kW/h)	200	200	200	200	200
Fuel consumption per year (t)	26522	26547	26586	31321	26716
relative increase	100,0%	100.09%	100.24%	118.09%	100.73%
Change of FOC per year	**0**	**25**	**64**	**4799**	**194**

The variations in FOC are mainly due to the draft increase for each version, excepted for the version 21 where the increased FOC is due to the increase in speed.

The anticipated fuel mix can be seen from the following diagram. It is assumed that scrubber technology has been installed in this ship, but as the availability of high sulphur heavy fuel maybe limited in the future a small portion of low sulphur HFO is assumed to be used as well.

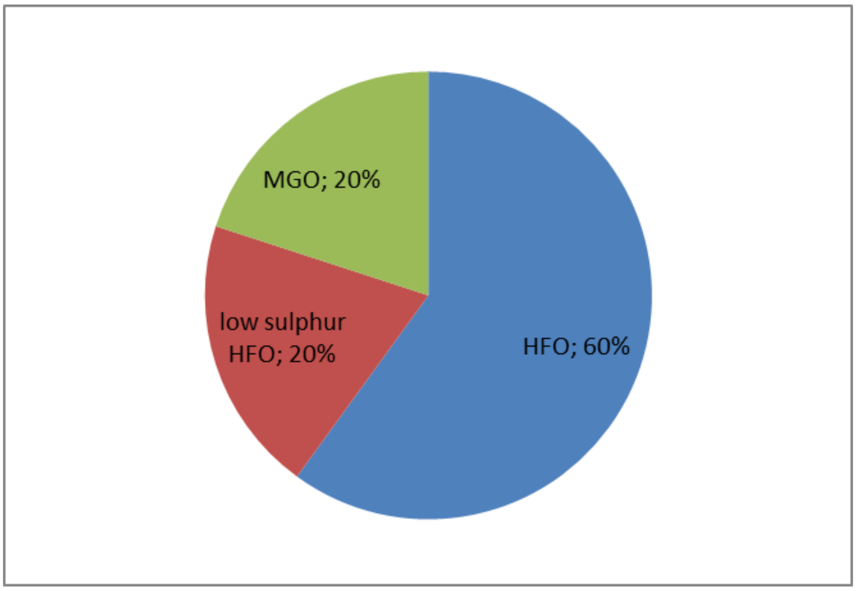


Fig. 13-73 Distribution - Fuel mix

13.5.3.1 Basic results

Using the assumptions above following costs presented as net present values are achieved for the different design variations:

Table 13-73 Summary of results

Version	reference design	1 design step	2nd design step	3rd design step	4th design step
Description	V0	V1 - depth +10	V12 - Add bkds below BHD	V21 - Add bkds on car deck	V14 – Internal subdivision + Breadth increased
Loa	185	185	185	185	185
B	31	31	31	31	31.2
T	6.6	6.603	6.62	6.64	6.65
Height BHD	9.6	9.7	9.6	9.6	9.6
Gross Tonnnage	43000	43120	43000	43000	43270
Change of fuel consumption	0	25	64	4799	194
net Present Value NPV	**0 $**	**448 746 $**	**1 640 844 $**	**76 271 158 $**	**5 232 058 $**

At the same time following changes of the attained index can be achieved with the design modifications.

Table 13-74 Summary – Attained A for design modifications

Version	reference design	1 design step	2nd design step	3rd design step	4th design step
Description		V1 - depth +10	V12 - Add bkds below BHD	V21 - Add bkds on car deck	V14 - Breadth increased
Required index R	0.7777	0.7777	0.7777	0.7777	0.7777
Attained index A	0.8398	0.8404	0.8496	0.8778	0.8718
change A	0.0000	0.0005	0.0097	0.0380	0.0319

The cost effectiveness can be easily demonstrated in the diagram below, where the costs as net present values are plotted against the attained index A. Also included are limits for allowable costs to match the netCAF limits of 4 Mio$ and 8 Mio$ including the 5% and 95% uncertainty limits.

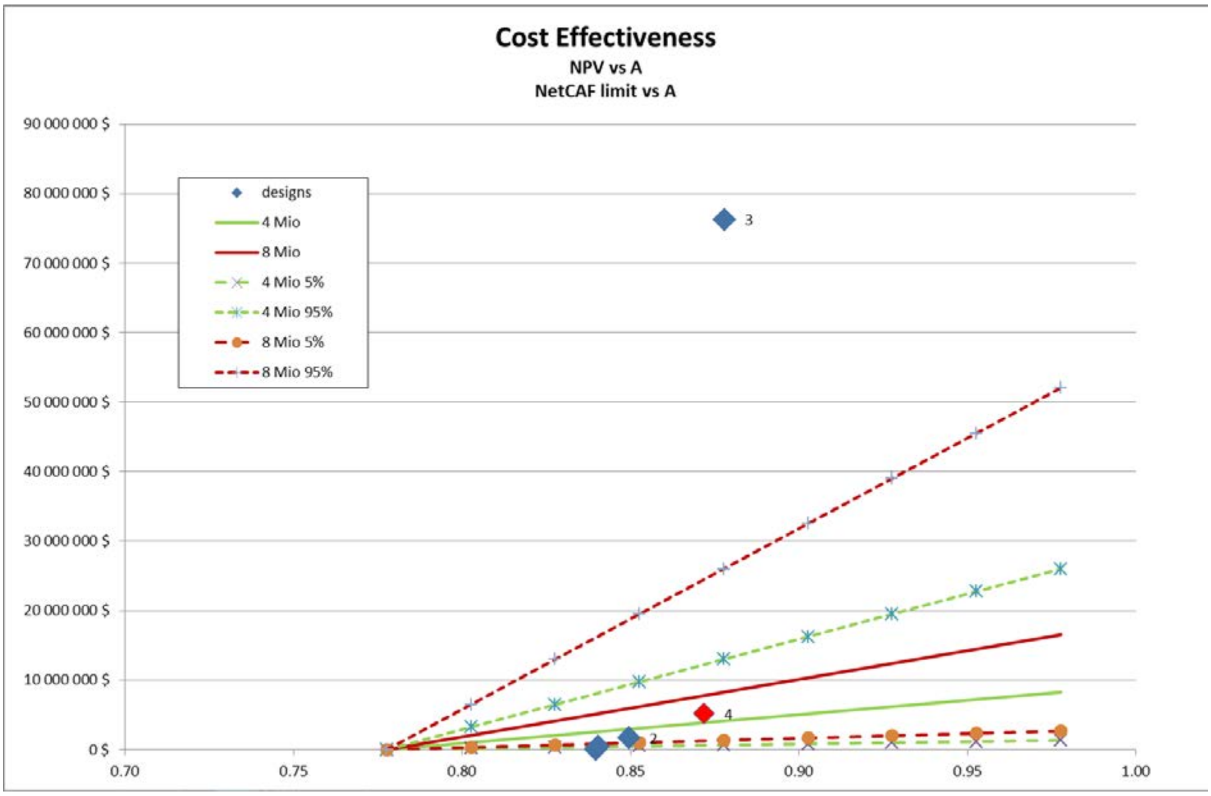


Fig. 13-74 Cost effectivess

It can be seen that the option 3, which consists in adding some subdivisions on the car deck, is not realistic if it leads to a loss of time in loading and unloading. The increase in fuel costs is far too high if the same business model needs to be kept, with the same stays in ports.

The 4th design step remains below the 8 Mio$ Net CAF limit.

13.5.3.2 Sensitivity analysis

Due to the high impact of the fuel costs on the overall life-cycle costs a sensitivity analysis has been made to apply on the cost model the high and low estimates for the fuel price development and simultaneously to reduce and increase all other costs and revenue by ±20%.

This leads to following net present values:

Table 13-75 NPV overview

Version	reference design	1 design step	2nd design step	3rd design step	4th design step
net Present Value NPV	0 $	448 746 $	1 640 844 $	76 271 158 $	5 232 058 $
net present value NPV low	0 $	314 900 $	1 199 088 $	52 517 200 $	3 841 913 $
net present value NPV high	0 $	520 301 $	1 921 413 $	87 929 147 $	6 133 484 $

Or in the diagram representation as shown in the following:

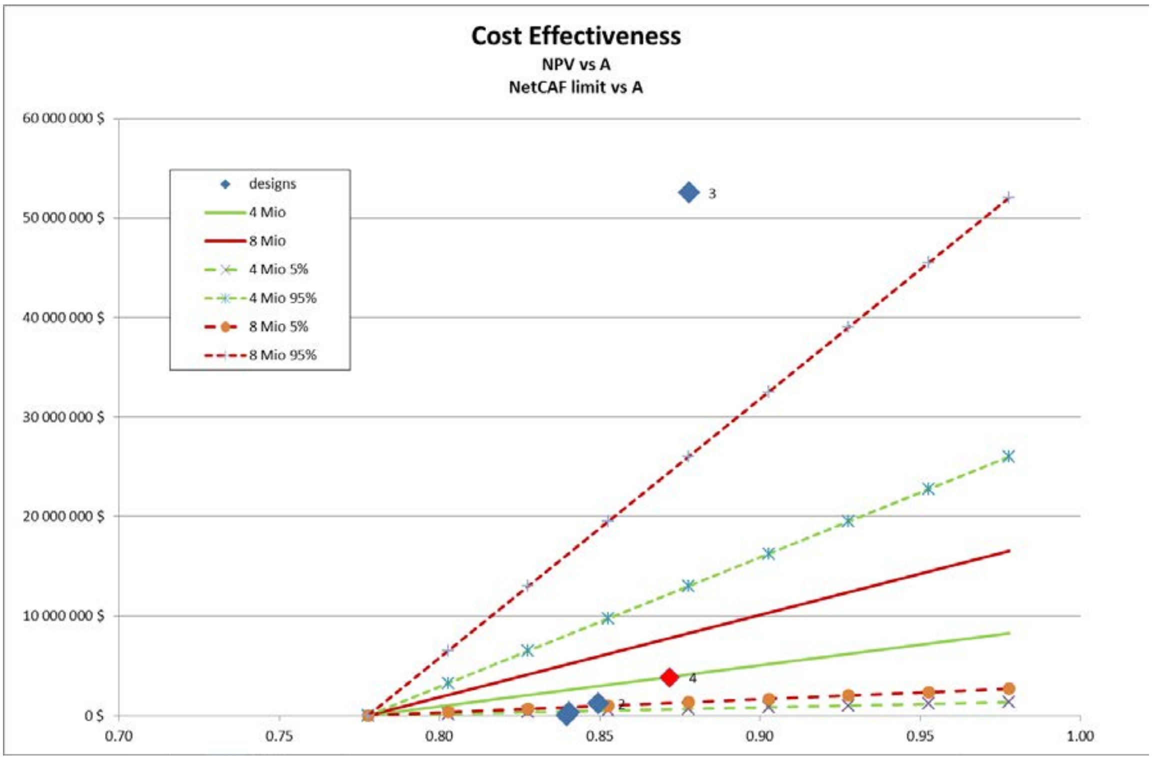


Fig. 13-75 Cost effectiveness - low

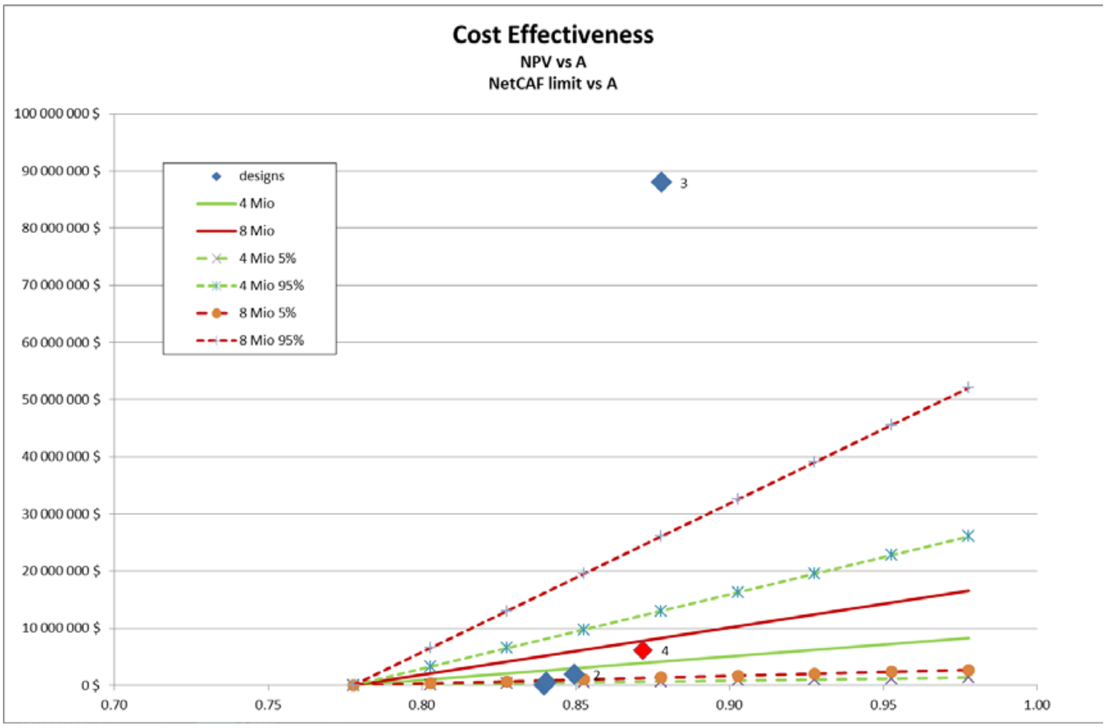


Fig. 13-76 Cost effectiveness - High

13.5.3.3 Conclusion and selection of optimized design

It is to be noted that the original design already has a significant margin on the index, partly due to the relative size of the ship compared to the number of people on board. But according to our experience it is also necessary to keep some margin at the basic design stage, in order to compensate for progressive flooding through pipes and ducts, which are not yet taken into account at this stage.

Concerning the selection of cost effective Risk Control Option, the design step Nr3, which consists in additional subdivisions on the car deck needs to be abandoned, for the reason explained in the chapter “basic results” and operational constraints.

The increase in depth alone did not bring as much improvement as expected on the index and might be realized in combination with another cost-effective enhancement. The same remark applies about the addition of side casings.

The **Design step Nr4**, which consist in a moderate increase of the breath, associated with additional subdivisions below the bulkhead deck gives the best result in term of attained index and meets the CAF limits chosen in this project. Therefore it has been chosen as the optimized design with regard to collision.

13.6 Ship #5 Small RoPax

13.6.1 General Approach

Given the anticipated operational profile for this vessel where size restrictions imposed by small harbours, quayside facilities, etc. would not allow ships of increased length or beam to operate it was decided to investigate improving the stability by increasing the freeboard of the design. This would be achieved by raising the height of the Main Deck. Any possible increase in height would be limited by the capabilities of the current port infrastructure, such as linkspans etc.

An alternative route to achieving improvements in stability would have been to consider additional levels of internal subdivision. However, given the sub-division levels already present in the initial design, necessary to achieve the current required stability standards, investigations failed to produce an enhanced standard whilst still meeting the demands for space, escape routes, etc. and therefore were not considered a satisfactory option.

The following table shows an overview of the applied design variations, which will be described in more detail in the following sections.

Table 13-76 design variations

Version	Description
Basis	Basis design
RCO 1	Freeboard increased by raising Main Dk 0.3 m from 7.1 m to 7.4 m

13.6.2 Design Variations

13.6.2.1 RCO 1

As in the assessment of the Basis Design damage stability calculations been performed according to the SOLAS2009 requirements and to the revised regulation 7-2.3 (SLF55) with increased GZ requirements; TGZmax 0.20 m and Trange 20 deg for each damage case that involves a Ro-Ro space.

This version of the design assumes that the main deck is raised by 0.3 m, from 7.1m to 7.4 m. This is illustrated in the following Figure.

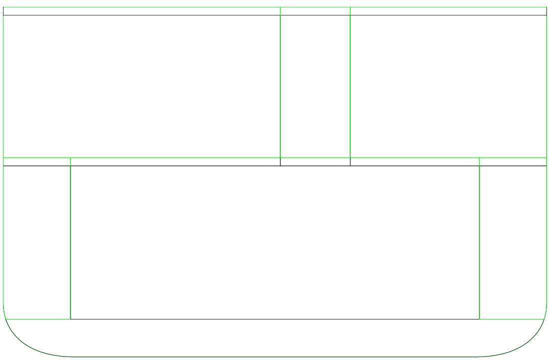


Fig. 13-77 Illustration of design modification

For this this modification a revised lightweight has been calculated and loading conditions have been generated.
The loading conditions were updated to produce the Table 13-78.

Table 13-77 Loading conditions – modified design

NAME	TEXT	Draught mld (m)	Trim (m) (+ve by bow)	GMf (m)
CON02	Design Departure	4.89	0.01	2.02
CON03	Design Arrival	4.76	0.10	1.89
CON04	Full Passengers No Cargo Departure	4.39	0.12	2.30
CON05	Full Passengers No Cargo Arrival	4.22	-0.05	2.27
CON06	Ballast Arrival	4.22	0.09	2.39

These conditions have been plotted against the limiting GM curves Fig. 13-78.

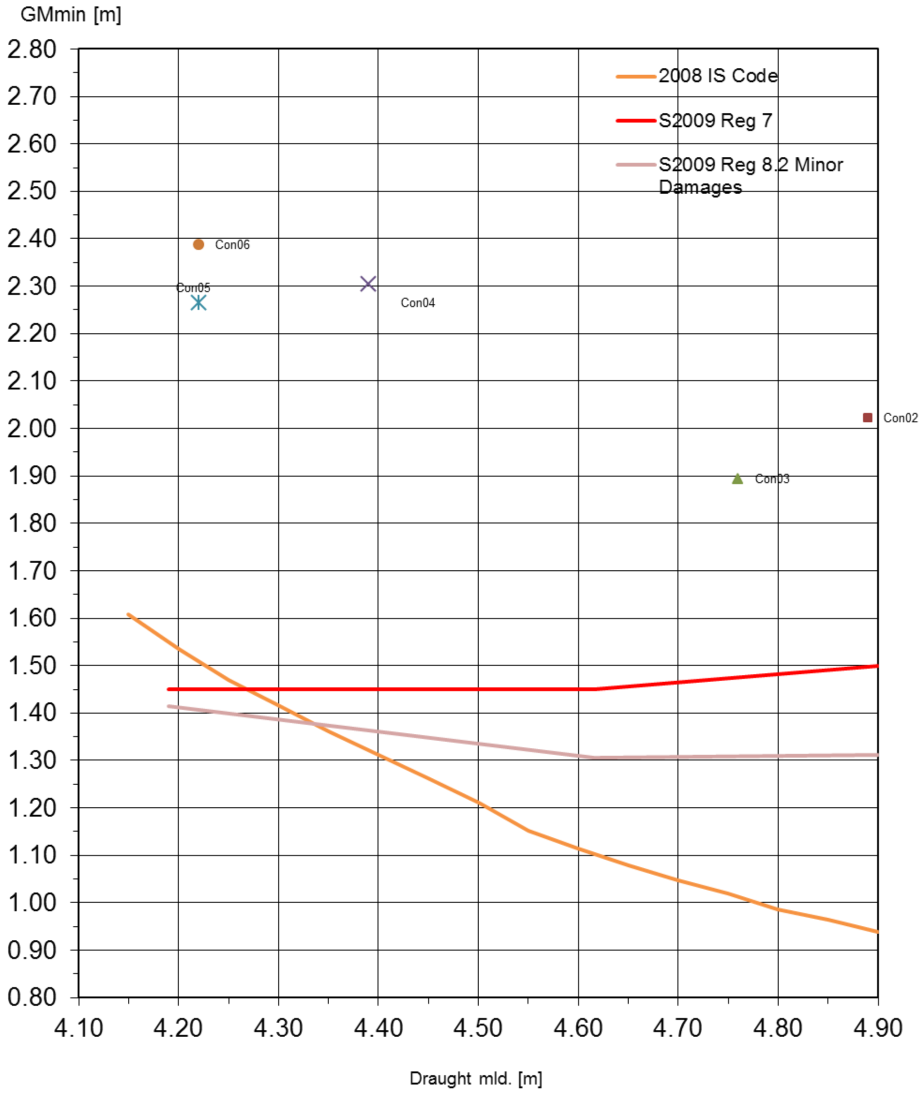


Fig. 13-78 Limiting GM curves

With these limiting GM values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length:	98.528 m
Breadth at the load line:	20.200 m
Breadth at the bulkhead deck:	20.200 m
Number of persons N1:	200
Number of persons N2:	425

Required subdivision index R = 0.72143
Attained subdivision index A = 0.84257
Attained subdivision index AWOD[16] = 0.84257

13.6.3 Cost Benefit Assessment

The following costs assumptions have been used for assessment of the modified design. This information has been provided by the project partners :

- Steel weight, including piping, ducting, painting 6000 €/t

Given that the design modification led to relatively small calculated weight increase of approximately 20 tonnes , which relates to a little over 1cm on the draught, it has been assumed that there will be no increase in fuel consumption due to the design modification.

The original design assumes that the vessel is not operating in a SECA area and that scrubbers or LNG fuel are not part of the design. An initial fuel mix of 80% HFO and 20% MGO was assumed. However, for the cost analysis it has been assumed that during the life of the ship, in anticipation of tightening environmental requirements, the use of HFO will change to Low Sulphur HFO. The level of MGO use, 20% has assumed to remain constant.

13.6.3.1 Basic Results

Using the assumptions above the following costs presented, as net present values, are achieved for the design variation considered.

[16] AWOD denotes use of the formulations for s agreed at SLF55 for cases when ro-ro deck is open to sea

Table 13-78 Table of basic results

Version	Reference Design	RCO1
Description	Original	Raised Main Dk (+0.3m)
Loa	101	101
LBP	95.5	95.5
B	20.2	20.5
T	4.9	4.9
Height BHD	7.1	7.4
Gross Tonnnage	7900	8050
Change of fuel consumption	0	0
net Present Value NPV	**0 $**	**154,464 $**

At the same time the following changes of the attained index can be achieved with the design modification.

Table 13-79 Change in A – Design modification

Version	Reference design	RCO 1
Description	Original	Raised Main Dk (+0.3m)
Required index R	0.7214	0.7214
Attained index A	0.7947	0.8426
Change A	0.0000	0.0479

The cost effectiveness can be easily demonstrated in the diagram below, where the costs as net present values are plotted against the attained index A. Also included are limits for allowable costs to match the netCAF limits of 4 Mio$ and 8 Mio$ including the 5% and 95% uncertainty limits. It should be noted that the cost effectiveness limits are plotted on the diagram from the Required Index value.

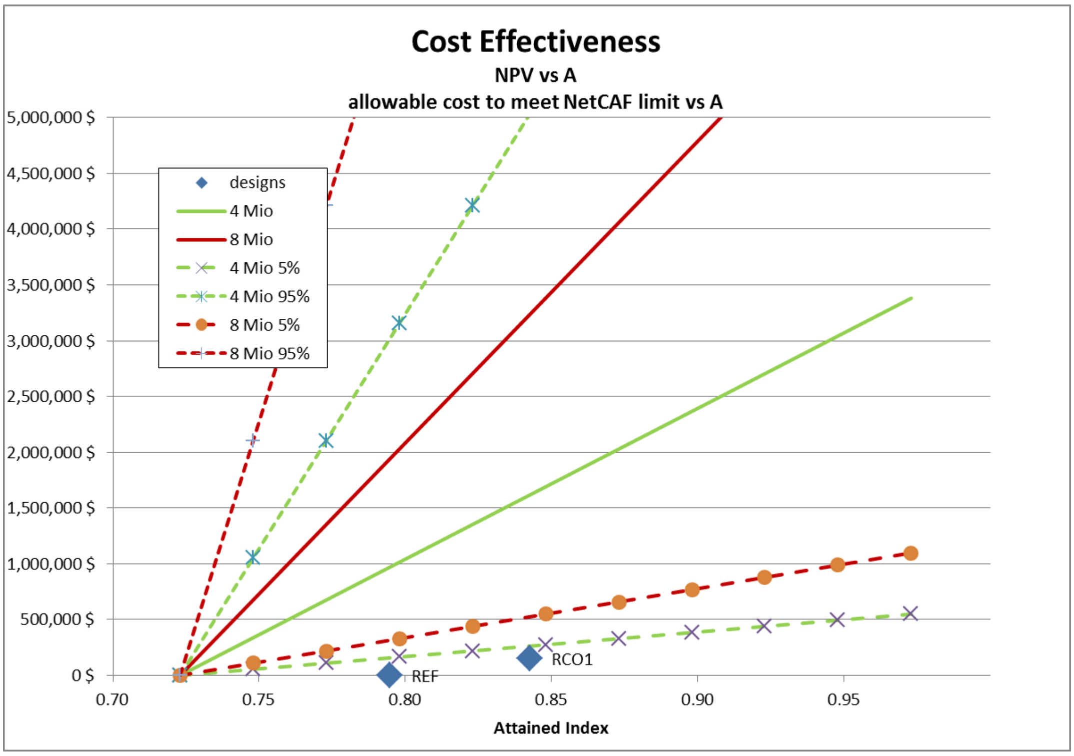


Fig. 13-79 Cost effectiveness

It can be seen that the cost implications of the raised freeboard are below the netCAF limits.

13.6.3.2 Sensitivity Analysis

Due to the high impact of the fuel costs on the overall life-cycle costs a sensitivity analysis has been made to apply on the cost model the high and low estimates for the fuel price development and simultaneously to reduce and increase all other costs and revenue by ±20%.

This leads to following net present values:

Table 13-80NPV of design modification

Version	RCO1
net Present Value NPV	154,464 $
net present value NPV low	115,373 $
net present value NPV high	193,555 $

Or alternatively as shown in the following diagrams:

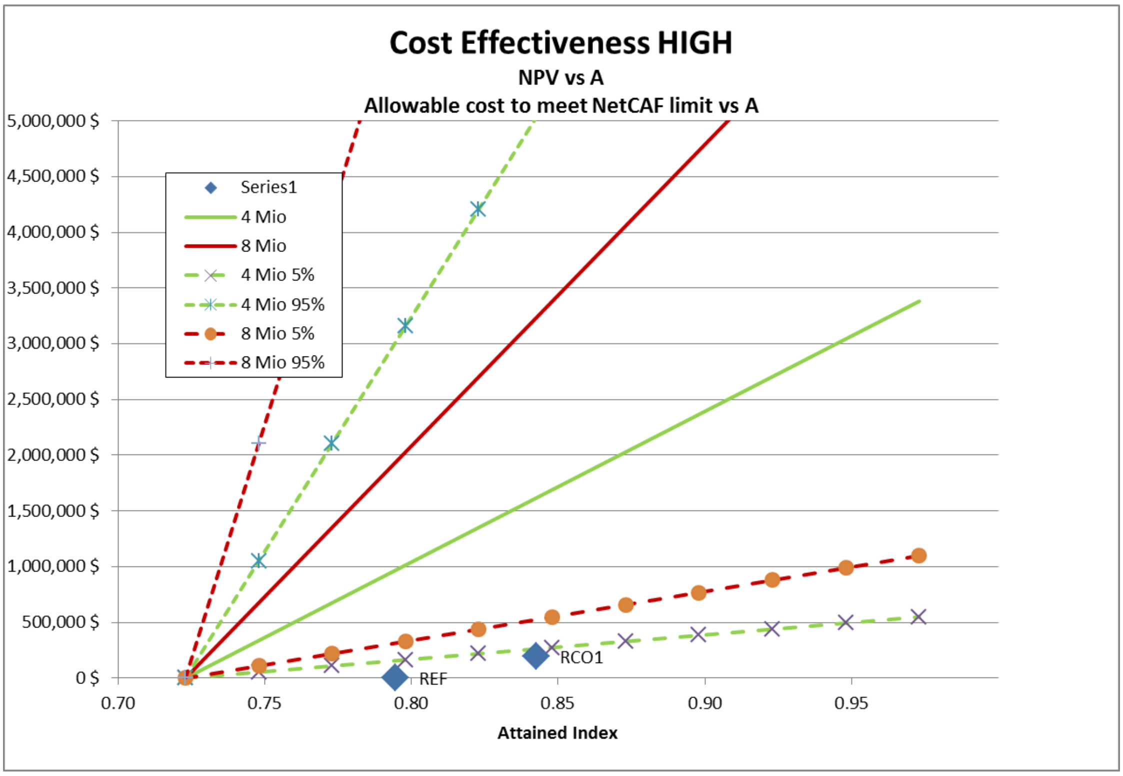


Fig. 13-80 Cost Effectiveness-High

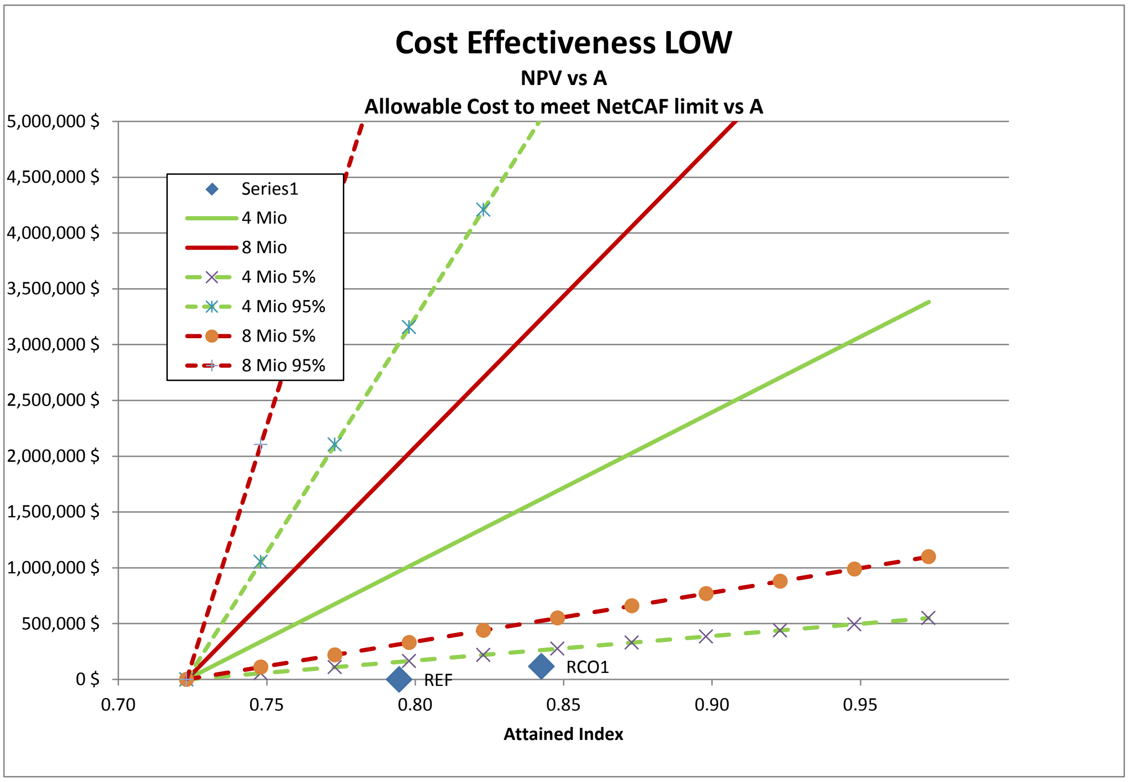


Fig. 13-81 Cost Effectiveness- Low

Even with the high figures applied for fuel and other costs the design modification of raising the main deck is below all the NetCAF limits.

13.6.3.3 Conclusion and selection of optimized design

It should be noted that the original design already had a significant margin on the required subdivision index R due to the requirements of SOLAS Reg. II-1/8.2 producing higher GM limit values. Whilst only one design improvement was considered it can be seen that a substantial increase in Attained Index can be obtained via increasing the freeboard and that this can be done within the CAF limits used in this project.

Therefore RCO1, incorporating the raised main deck, is selected as the optimised design with regard to collision damage and will be used in the further work of this project.

13.7 Ship #6 RoPax double end ferry

13.7.1 General Approach

For this design, investigations into improving stability characteristics by way of additional levels of sub-division, e.g. additional wing voids, transverse bulkheads, etc. proved that it was very difficult to incorporate enhanced subdivision into an already compact design where the demands of equipment space, access/escape were strong drivers.

Therefore, it was decided to investigate improving the stability by increasing the freeboard of the design. This would be achieved by raising the height of the Main Deck. Any increases in height would be limited by the capabilities of the current port infrastructure, such as linkspans, etc.

It was also considered that a small increase in beam of the design would acceptable with regards to port facilities etc., and therefore the effect of this on stability has been investigated.

The following table shows an overview of the applied design variations, which will be described in more detail in the following sections.

Table 13-81 Design variations

Version	Description
Basis	Basis design
RCO 1	Freeboard increased by raising Main Dk 0.3 m from 7.1 m to 7.4 m
RCO 2	Increase in Beam from 17.6 m to 18.0 m; Main Deck as original (5.7 m)

13.7.2 Design Variations

13.7.2.1 RCO 1

As in the assessment of the Basis Design damage stability calculations been performed according to the SOLAS2009 requirements and to the revised regulation 7-2.3 (SLF55) with increased GZ requirements; TGZmax 0.20 m and Trange 20 deg for each damage case that involves a Ro-Ro space.

This version of the design assumes that the main deck is raised by 0.3 m, from 7.1m to 7.4 m. This is illustrated in Fig. 13-82.

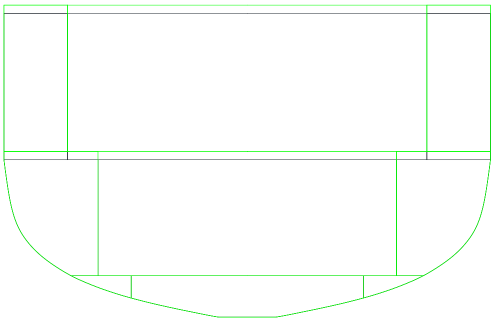


Fig. 13-82 Illustration of design modfication

For this this modification a revised lightweight has been calculated and loading conditions have been generated.

The loading conditions were updated to produce the following Table.

Table 13-82 Loading conditions

NAME	TEXT	Draught mld (m)	Trim (m) (+ve by bow)	GMf (m)
LD01	Design Departure	4.00	0.02	1.81
LD02	Design Arrival	4.00	0.00	1.74
LD03	Ballast Arrival	3.54	0.00	2.99
LD04	Scantling Draught Departure	4.30	0.01	2.05
LD05	Full Passengers No Cargo Departure	3.57	-0.01	2.26
LD06	Full Passengers No Cargo Arrival	3.55	-0.04	2.89

These conditions have been plotted against the limiting GM curves.

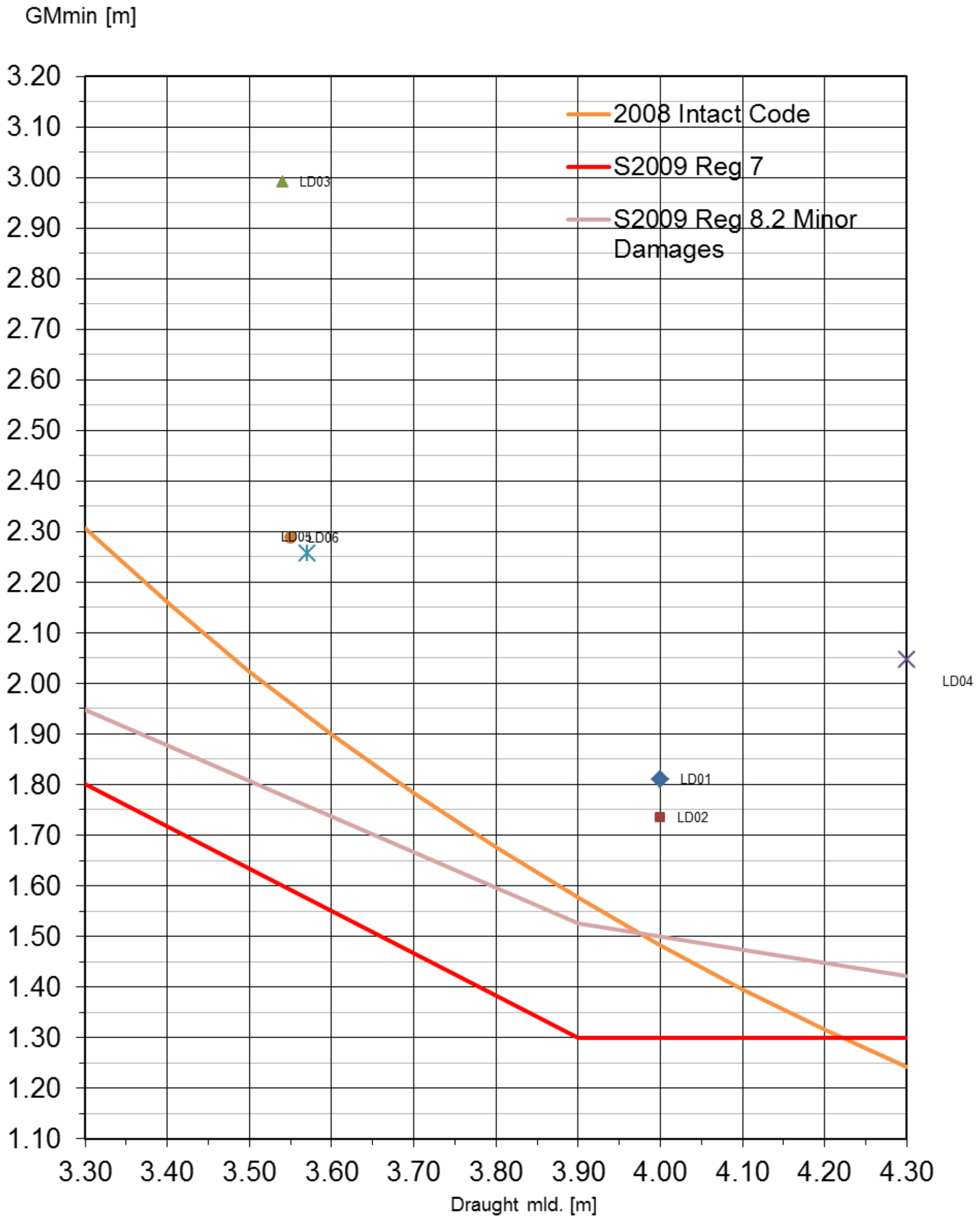


Fig. 13-83 Limiting GM curves – design modification RCO1

With these limiting GM values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length:	102.219 m
Breadth at the load line:	17.189 m
Breadth at the bulkhead deck:	17.600 m
Number of persons N1:	0
Number of persons N2:	610

Required subdivision index R = 0.72792
Attained subdivision index A = 0.87082
Attained subdivision index AWOD[17] = 0.86005

[17] AWOD denotes use of the formulations for s agreed at SLF55 for cases when ro-ro deck is open to sea

13.7.2.2 RCO 2

In this version it was decided to increase the beam from 17.6m to 18.0m. This increase does not increase the cargo capacity of the model which keeps it in line with the business model assumed for the original version.

As in the assessment of the Basis Design damage stability calculations been performed according to the SOLAS2009 requirements and to the revised regulation 7-2.3 (SLF55) with increased GZ requirements; TGZmax 0.20 m and Trange 20 deg for each damage case that involves a Ro-Ro space.

The increase in beam is illustrated in Fig. 13-84.

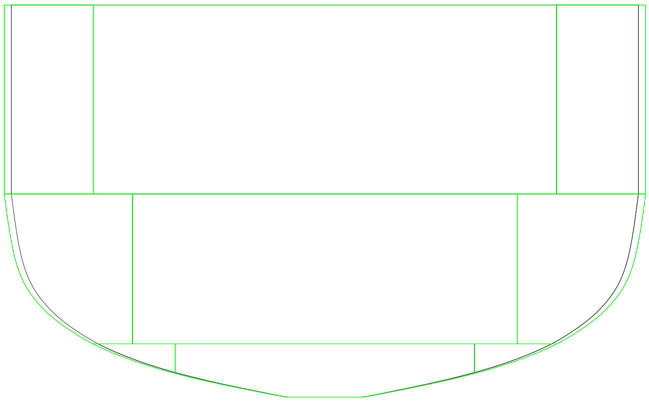


Fig. 13-84 Illustration of design modification RCO2

For this modification a revised lightweight has been calculated and loading conditions have been updated to produce the following Table.

Table 13-83 Loading condition

NAME	TEXT	Draught mld (m)	Trim (m) (+ve by bow)	GMf (m)
LD01	Design Departure	3.96	0.02	2.33
LD02	Design Arrival	3.97	0.00	2.21
LD03	Ballast Arrival	3.36	0.00	2.86
LD04	Scantling Draught Departure	4.26	0.01	2.53
LD05	Full Passengers No Cargo Departure	3.52	-0.01	2.78
LD06	Full Passengers No Cargo Arrival	3.42	-0.04	2.68

For the increased beam revised GM limit values for D_L, D_P & D_S to achieve similar margins as those obtained for the original design.

These conditions have been plotted against the limiting GM curves.

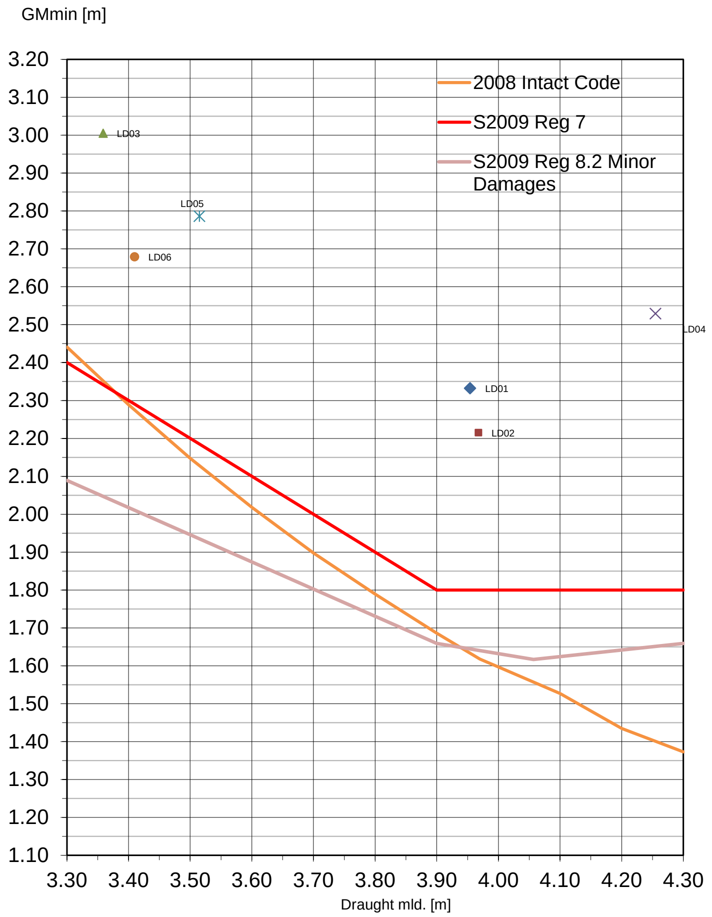


Fig. 13-85 Limiting GM Curves

With these limiting GM values the attained index has been calculated.

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length:	102.219 m
Breadth at the load line:	17.581 m
Breadth at the bulkhead deck:	18.00 m
Number of persons N1:	0
Number of persons N2:	610

Required subdivision index R = 0.72792
Attained subdivision index A = 0.88641
Attained subdivision index AWOD[18] = 0.87816

13.7.3 Cost Benefit Assessment

The following costs assumptions have been used for assessment of the modified design. This information has been provided by the project partners :

- Steel weight, including piping, ducting, painting 6000 €/t

[18] AWOD denotes use of the formulations for s agreed at SLF55 for cases when ro-ro deck is open to sea

- Public areas including ducting, cabling etc 2600 €/m2
- Additional installed power of main engines, taking into account any discrete step in engine size 380 €/kW

Given that RCO1 led to only a marginal increase in draught of 1cm it has been assumed that there will be no increase in fuel consumption due to the design modification.

For RCO2 an increase in fuel oil consumption of 296 tonnes/year has been calculated based on the increased power requirement of the larger beam.

The intended area of operation is within the Baltic Sea Sulphur Oxide (SOx) Emission Control Area (SECA). MGO operation is assumed as is the case with the current tonnage in service on the route.

13.7.3.1 Basic Results

Using the assumptions above the following costs, presented as net present values, are achieved for the design variation considered.

Table 13-84 NPV for design variations

Version	Reference Design	RCO1	RCO2
Description	Original	Raised Main Dk (+0.3m)	Increased Beam (+0.4m)
Loa	102.2	102.2	102.2
LBP	96.8	96.8	96.8
B	17.6	17.6	18.0
T	4.3	4.3	4.3
Height BHD	5.7	6.0	5.7
Gross Tonnnage	6245	6388	6392
Change of fuel consumption	0	0	296
net Present Value NPV	**0 $**	**84,180 $**	**5,968,938 $**

At the same time the following changes of the attained index can be achieved with the design modification.

Table 13-85 Summary of attained A for design modifications

Version	Reference design	RCO 1	RCO 2
Description	Original	Raised Main Dk (+0.3 m)	Increased Beam (+0.4 m)
Required index R	0.7279	0.7279	0.7279
Attained index A	0.8412	0.8601	0.8782
Change A	0.0000	0.0189	0.0370

The cost effectiveness can be easily demonstrated in the diagram below, where the costs as net present values are plotted against the attained index A. Also included are limits for allowable costs to match the netCAF limits of 4 Mio$ and 8 Mio$ including the 5% and 95% uncertainty limits. It should be noted that the cost effectiveness limits are plotted on the diagram from the Required Index value.

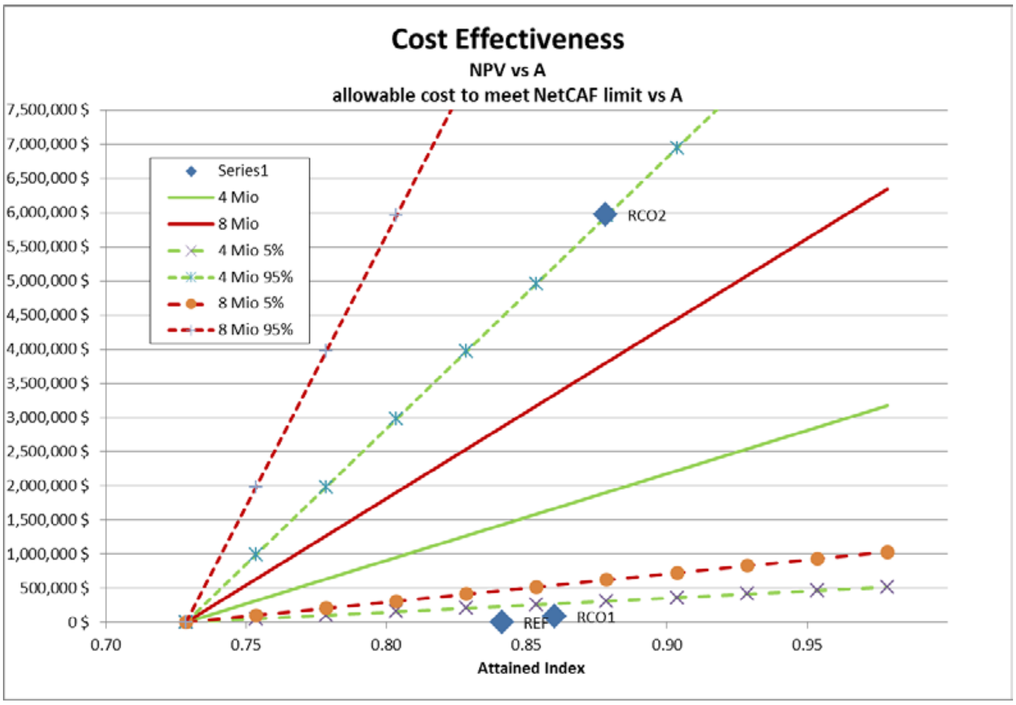


Fig. 13-86 Cost effectiveness

It can be seen that the cost implications of the raised freeboard are below the netCAF limits whilst the higher fuel costs is the primary driver for the increased beam design being just above the 4 Mio $ 95% uncertainty level.

13.7.3.2 Sensitivity Analysis

Due to the high impact of the fuel costs on the overall life-cycle costs a sensitivity analysis has been made to apply on the cost model the high and low estimates for the fuel price development and simultaneously to reduce and increase all other costs and revenue by ±20%.

This leads to following net present values:

Table 13-86 NPV of design modifications

Version	RCO1	RCO1
net Present Value NPV	84,180 $	5,968,938 $
net present value NPV low	64,625 $	4,214,058 $
net present value NPV high	103,736 $	6,899,153 $

Or alternatively as shown in the following diagrams:

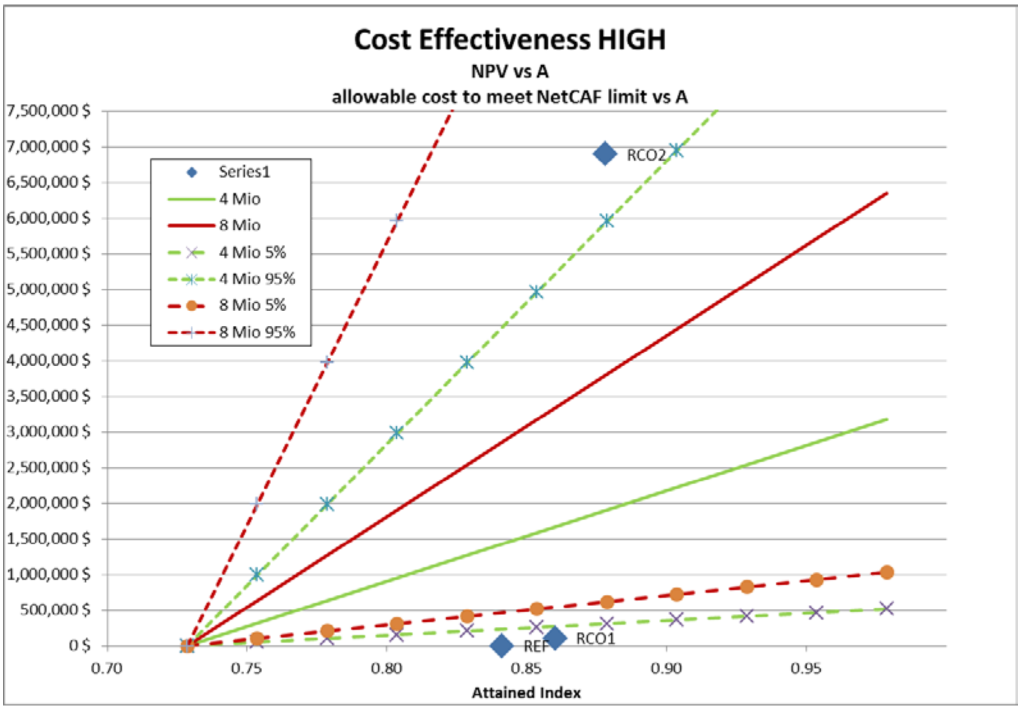


Fig. 13-87 Cost Effectiveness - High

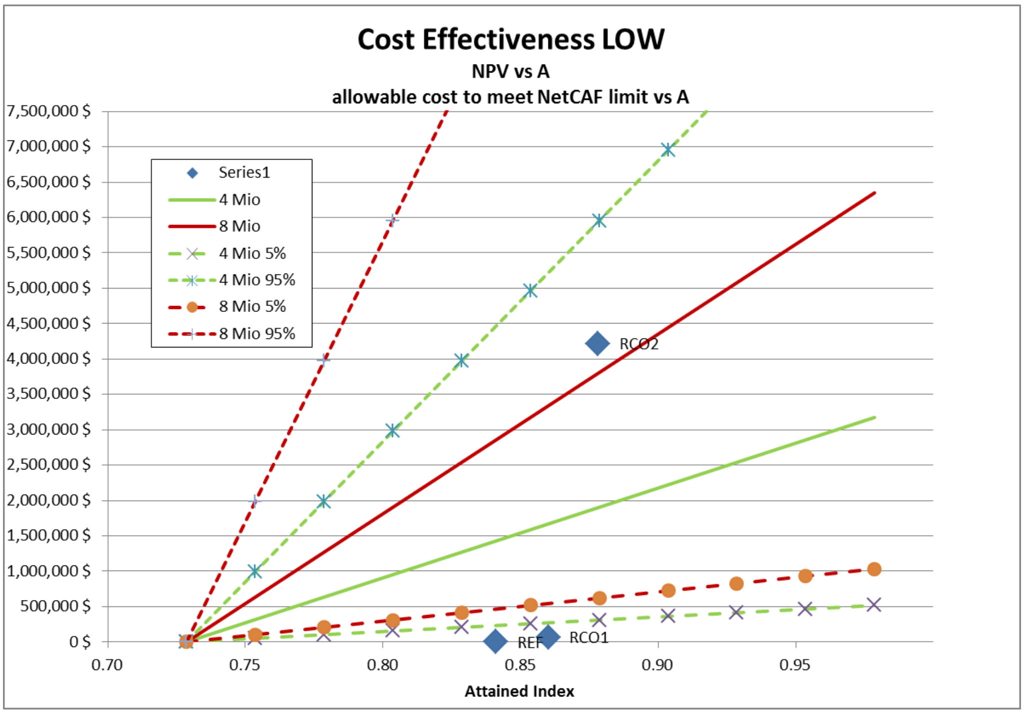


Fig. 13-88 Cost Effectiveness - Low

Even with the low figures used for fuel and other costs RCO2 is still above the cost limits.

13.7.3.3 Conclusion and selection of optimized design

It should be noted that the original design already had a significant margin on the required subdivision index R due to the requirements of SOLAS Reg. II-1/8.2 producing higher GM limit values.

The analysis shows that with a moderate increase in beam a significant increase in attained index can be achieved. However, the associated costs, due primarily to the increase in fuel usage, mean that this option is beyond the CAF limits chosen in this project.

Increasing the freeboard by raising the main deck can be seen as a relatively simple way of improving the Attained Index and whilst this produces an increase in index which is approximately half of that seen from the increased beam this option remains within the chosen CAF limits.

Therefore RCO1, incorporating the raised main deck, is selected as the optimised design with regard to collision damage and will be used in the further work of this project.

14 SUMMARISING AND SUGGESTING LEVEL OF R

14.1 Introduction

The results from the Cost Benefit Assessments presented in Sec. 13 are summarised in Table 14-1.

Table 14-1 Summary of results from the CBA on EMSA sample ships

	Small Cruise	Large cruise	DE Ferry	Small RoPax	Med RoPax	Baltic Ropax
Persons on board	478	6730	610	625	1700	3280
Value of A for the Initial Design	0.7202	0.8621	0.8412	0.7947	0.8398	0.8326
Value of A for RCO where CAF less than 4 Mill USD	0.7307	0.8719	0.8601	0.8426	0.8496	0.8326
Value of A for RCO where CAF less than 4 mill USD 95 % Conf Int	0.7944	0.8754	0.8782	0.8426	0.8718	0.9152
Value of A for RCO where CAF less than 8 mill USD	0.7544	0.8754	0.8601	0.8426	0.8718	0.9152
Value of A for RCO where CAF less than 8mill USD 95% Conf Int	0.8281	0.9087	0.8782	0.8426	0.8718	0.9152
Highest A of all RCOs investigated	0.8752	0.9288	0.8782	0.8426	0.8778	0.9184

The results are also included in Fig. 14-1with the respective trend lines.

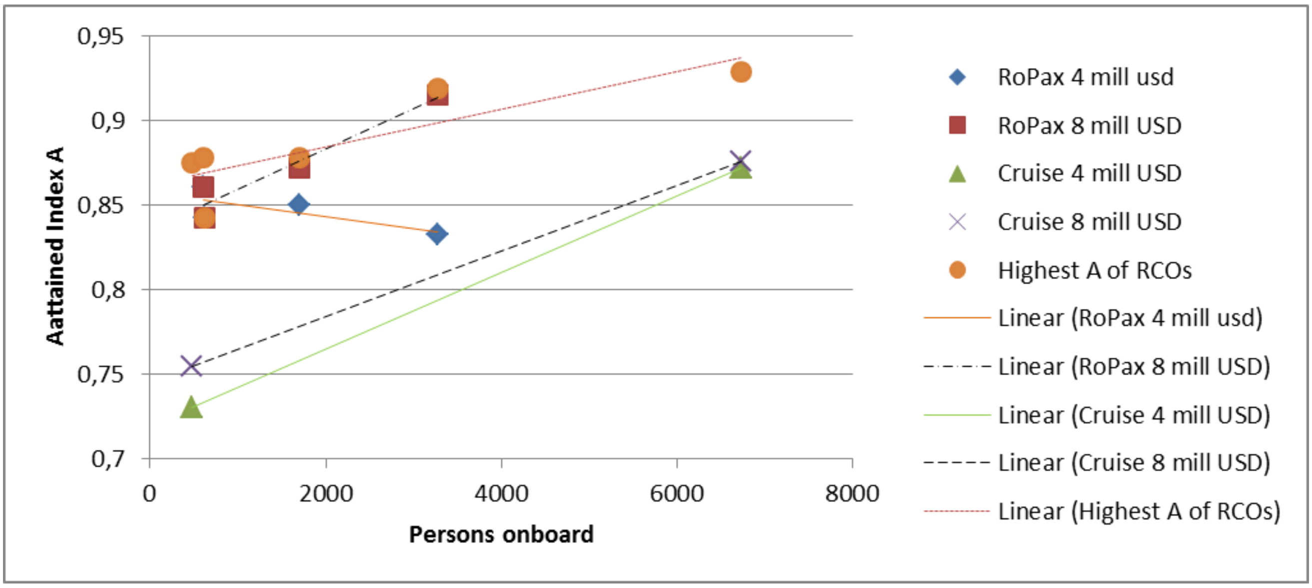


Fig. 14-1 Summary of results from the CBA on EMSA sample ships

The following observations are made when considering the results:

For RoPax ships:

- If the CAF threshold of 4 mill USD is applied the regression line has a downward trend for increased number of persons on board
- If the CAF threshold of 8 mil USD is applied the regression line has an upward trend for increased number of persons on board
- The small RoPax ships have a significantly higher A than the current level of R. This is due to the required compliance with SOLAS Reg.II-1/8.

For Cruise ships:

- No significant difference is shown between CAF thresholds of 4 and 8 mill USD
- By considering the highest A of all RCOs investigated it is seen that it is possible to achieve a significantly higher A than current standard but these are not found to be cost-effective.

For Cruise and RoPax ships in combination:

- There is a significant difference in A-values between RoPax and Cruise ship designs found to be cost effective.

14.2 Basis for suggesting a new level of R based on the available results.

The results represents a wide spread of points and are too few to define a mathematical correct formulation. Instead the level of R has to be suggested based on sound engineering practice.

In line with the general perception of the level of R and the risks associated with carrying a high number of persons onboard the principle for suggesting the level of R should be an increase with increased number of persons onboard.

14.2.1 Suggesting the level of R when only RoPax ships are considered

By selecting only the RoPax ships included in the study the level of R can be proposed as shown in Fig. 14-2. The level of R suggested by the US is included for reference.

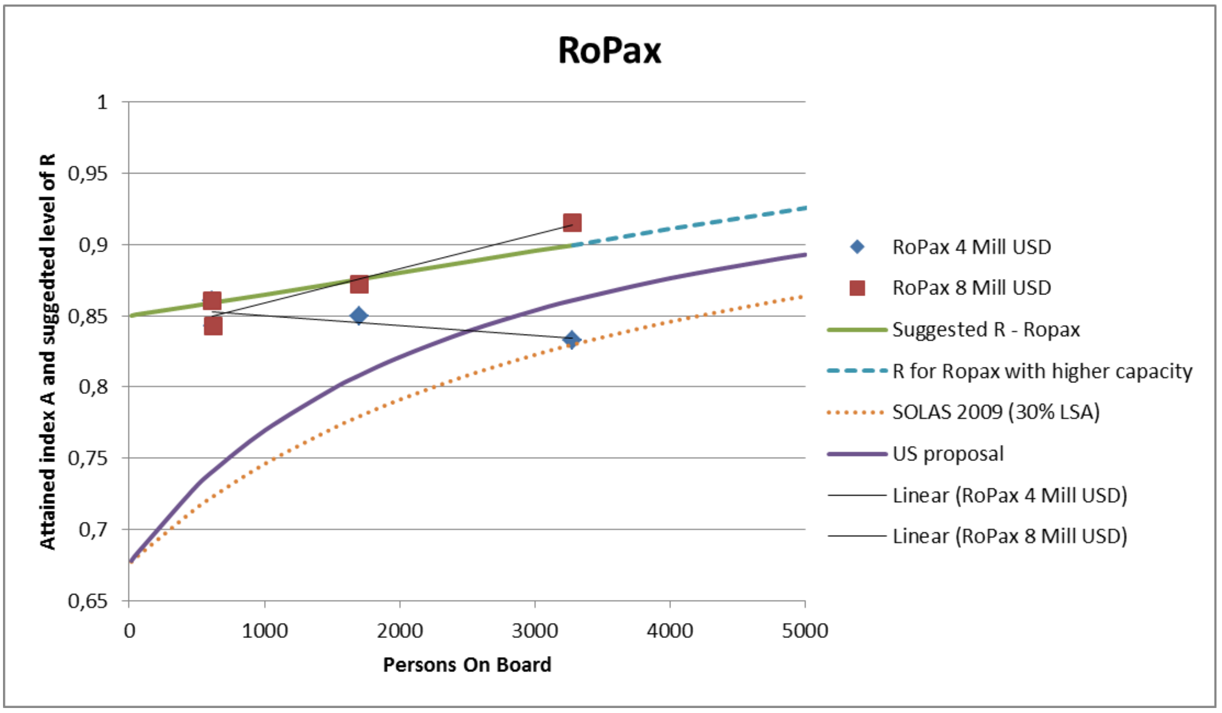


Fig. 14-2 Suggested formulation of R based on RoPax ships

The formulation for R is as follows:

$$R = 0.85 + 1.56E\text{-}05 * POB \quad (1)$$

The bases for the suggestion are as follows:

- It is assumed that R can be defined as a linear function
- the starting point is R=0.85 for a RoPax with 16 persons on boards (12 passengers and 4 crew)
- It is to be observed that the highest A for the small RoPax is slightly below the suggested value (A=0.8426)
- the level of R is slightly below the attained A for the Baltic RoPax ship to allow for some margin due to shipyards experience.
- for RoPax ships with more than 3280 persons on board there is no data available. The continued level of R for ships with larger number has therefore been indicated in a different colour. If applied there need to be an upper limit of R in the formulation.

The formula in (1) may be adjusted in such a way that the RoPax sample ships have approximately the same margin to the suggested level of R to account for the design margins indicated by the designers. If this is based on the margin for the large RoPax the formulation for R may read:

R = 0.81 + 2.64E-05*POB (2)

14.2.2 Suggesting the level of R when only Cruise ships are considered

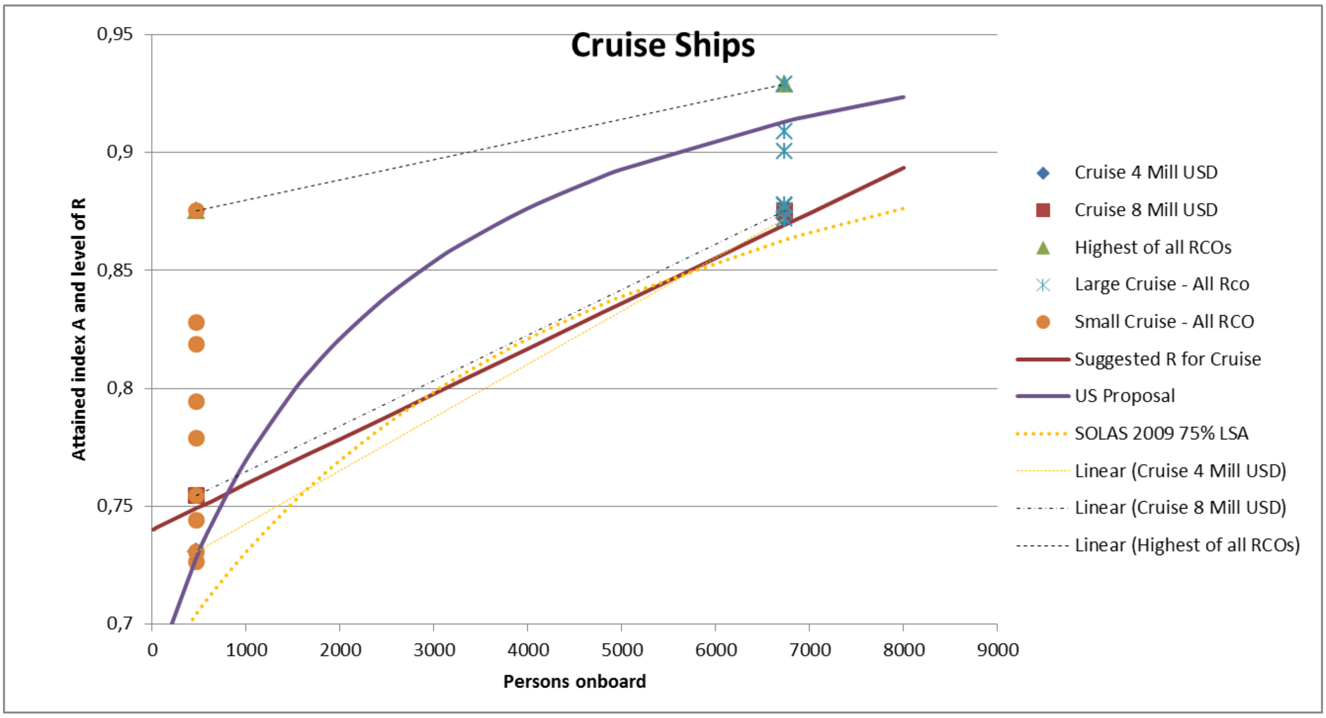


Fig. 14-3 Suggested formulation of R based on Cruise Ships

There are only two sample ships available for suggesting the level of R in this project; one large and one small. When considering these ships separately a straight line slightly below the corresponding A for the two designs found to meet the CAF criterion of 8 mill USD may be suggested as the level of R for cruise ships. However it must be noted that several design modifications have been assessed giving higher values of A, but has not been found to meet the CAF criteria. The results are shown in Fig. 14-3

The suggested formulation for cruise is as follows:

R =0.74 + 1.92E-05*POB (3)

14.2.3 Suggesting the level of R for RoPax and Cruise in combination

Based on the previous sections where the RoPax ships and the Cruise ships have been considered separately it is seen that there is a significant difference between the suggested R for the two ship types.

If a level of R is suggested based on the results for the Cruise ships, there will be no incentives to raise the level of R for the RoPax ships, and the fact that raising the R by RCOs found cost effective will not be taken into account. When combining the two ship types there are several reasons for putting more weight on the RoPax ships than on the Cruise ships as is discussed later.

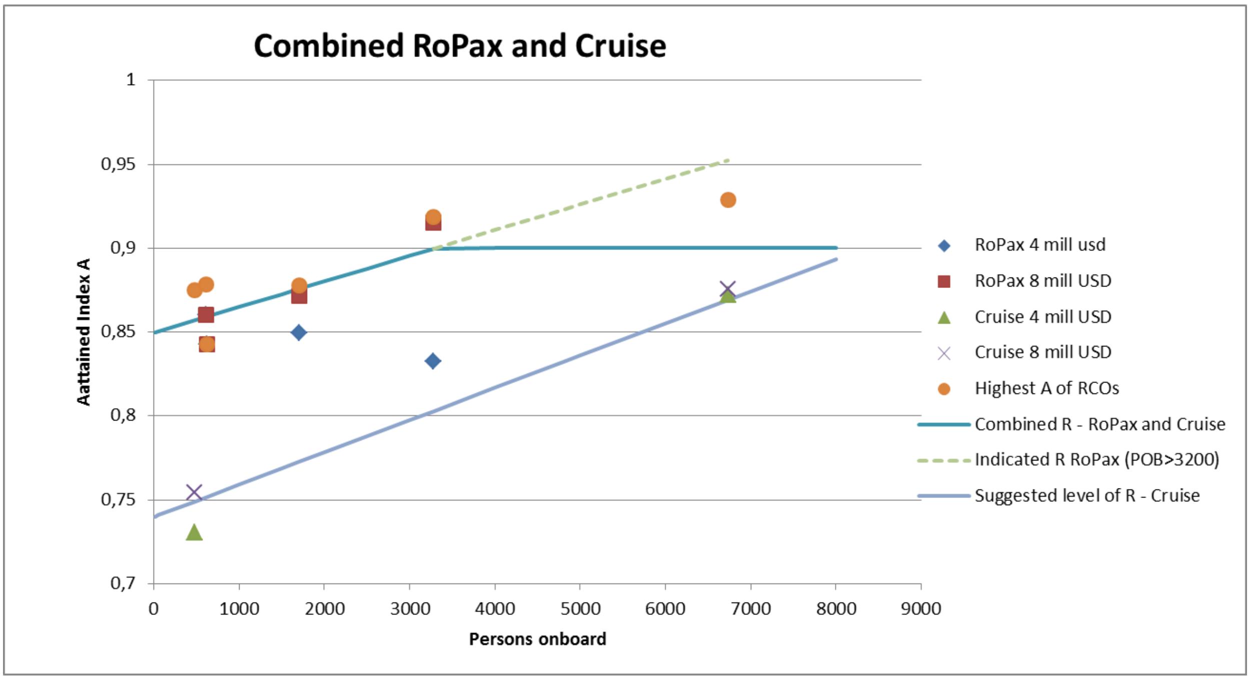


Fig. 14-4 Suggested formulation of R for RoPax and Cruise combined

The basis for the suggested level of R as shown in Fig. 14-4 is to use the same R as suggested for RoPax ships (1) however where the required level shall not exceed 0.9. This is based on results for the RoPax ships and the CAF criterion of 8 Mill USD. For the cruise ships that are part of this study the implications are different.

For the small cruise ship the suggested R will be equal to 0.857. This implies that only the design versions 08 as documented in 13.3.2.8 will comply. However this design option has a NPV far beyond the 95 % confidence interval for the CAF threshold of 8 Mill USD. Design option 06 obtains an A equal to 0.821 and is within the 95 % confidence limit of 8 Mill USD.

For the large cruise where the R will be 0.9, three design options as presented in 13.2.2 obtain a higher A. However only one of them, version H4 having an A of 0.9087, is within the 95 % confidence limit of 8 Mill USD.

The level of R for ships carrying more than 3000 persons on board may need special considerations. In this study we have no results for RoPax ships with more than 3280 persons on board.

Further, when considering the societal risks, the aversion towards large accidents is handled by the FN Diagrams. Reference is made to the IMO FSA Guidelines and part 1 of the final report. For passenger ships, the societal risk is close to and above the tolerable limit. This implies that it may be considered to implement risk control options that are above the VPF used in the cost benefit analysis. It can be argued that the logic of the FN diagrams should be considered when the required index is decided: For a doubling (2) of the number of fatalities, the frequency needs to be reduced to half (1/2). If an R = 0.9 can be reached for N=3,000, it should therefore reach R=0.95 for N=6,000 and R=0.975 for N=12,000. This line extended to R=1 is reached for N=18,000.

It is noted that the application of this approach would lead to higher required level of R than the corresponding to the indicated level of R curve for RoPax ships for more than 3000 persons on board.

1.1.1 The results from the GOALDS study.

The partly EU funded research project GOALDS included cost benefit assessments of two RoPax ships and two Cruise vessels. However the results from the CBA carried out at that time cannot be used directly in this context due to the following differences:

- For both RoPax and Cruise the collision risk models have been updated.
- For both RoPax and Cruise the CBA was carried out taking into account the grounding risk as well. It was assumed that the A for grounding is a function of the A for collision.
- For both RoPax and Cruise vessels, the CBA was carried out using different formulation of survival factor s.
- In addition to the GOALDS s-factor, attained index A according to SOLAS 2009 was also calculated. However, the s-factor for RoPax ships used in this study has been updated.

While noting the above differences, the cost assessments in GOALDS were following the same principles and the GOALDS Cruise ships have been re-visited by use of the updated risk model.

The large cruise ship investigated in GOALDS has a capacity of 5600 person on board. The initial design has an A equal to 0.8901 calculated in accordance with SOLAS 2009. It is noted that this ship has a higher A than required as it was a design that was further developed in the partly EU funded project FLOODSTAND. In the GOALDS study six design modifications were investigated, obtaining an A according to SOLAS 2009 ranging from 0.881 to 0.976. When investigating using the updated risk model developed in this study which covers collisions only, none of the design options are found to have a CAF of less than 8 Mill USD. However, the large cruise ship was in addition subject to optimisation studies where a value of A equal to 0.93 was obtained. Details of the cost elements are however not available for a detailed comparison in line with this study.

The medium cruise ship investigated in GOALDS has 2400 persons on board. The initial design has a value of A equal to 0.782 calculated in accordance with SOLAS 2009. In total 11 design modifications were investigated, obtaining an A according to SOLAS 2009 ranging from 0.798 to 0.951. When investigating using the updated risk model covering collision only, none of the design options are found to meet the CAF criterion of 8 Mill USD.

A Panmax cruise ship was also subject to an optimisation study. The ship has a capacity of 4000 persons and the attained index A in the initial design is 0.84622. The first round of optimisation gave an A of 0.89224. This option is reported to have a negative NPV over 30 years. In addition another round of optimisation gave an A equal 0.92884. However a CBA in the same way has for the ships in this study has not been performed.

The GOALDS optimised cruise ships are included in Fig. 14-5 for reference.

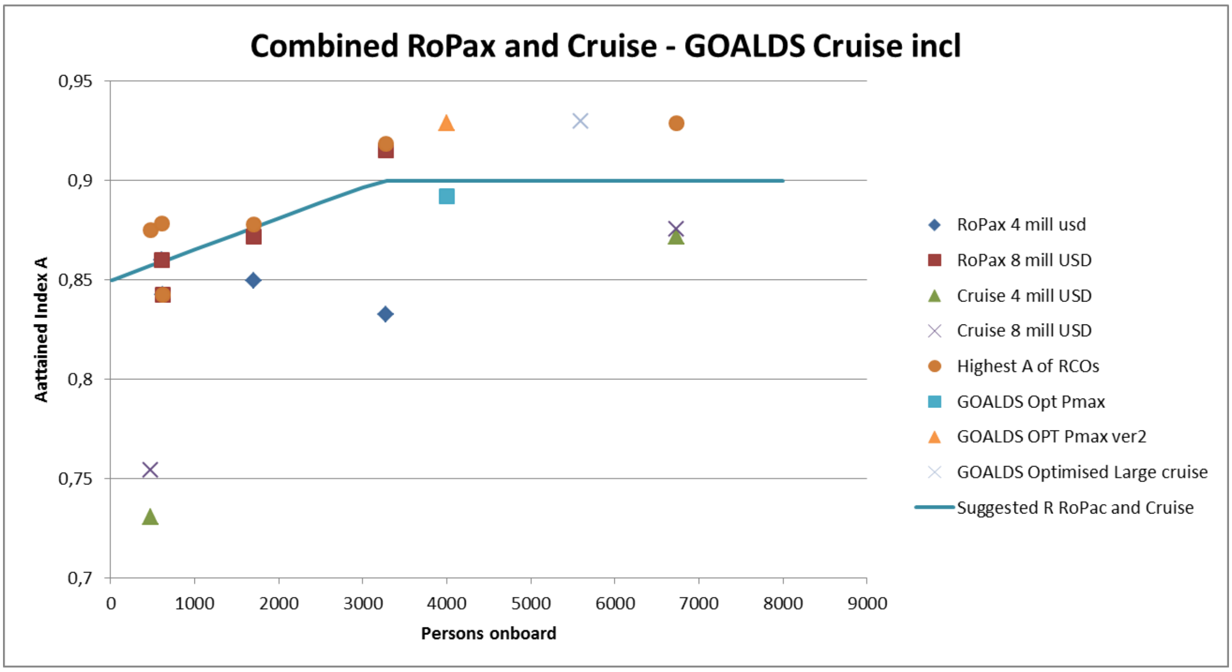


Fig. 14-5 Level of R – RoPax and Cruise – including GOALDS Cruise

14.3 Difference in results between Cruise and RoPax.

The results indicate that even though it is seen that the attained index A for cruise ships can be increased significantly by change in design it is concluded that it is difficult to find these solutions to meet the CAF criterion. While on the other hand it is seen that for RoPax ships design modifications that give a higher A are found to be cost effective.

One of the main sources for this difference is the difference in the collision risk model for RoPax and for Cruise. There is in particular a difference in the distribution of fast/slow sinking and the corresponding fatality rates, see Fig. 14-6 and in Table 14-2.

It should be noted that the assumed occupancy rate on RoPax is lower than for Cruise therefore the difference in risk is less than indicated.

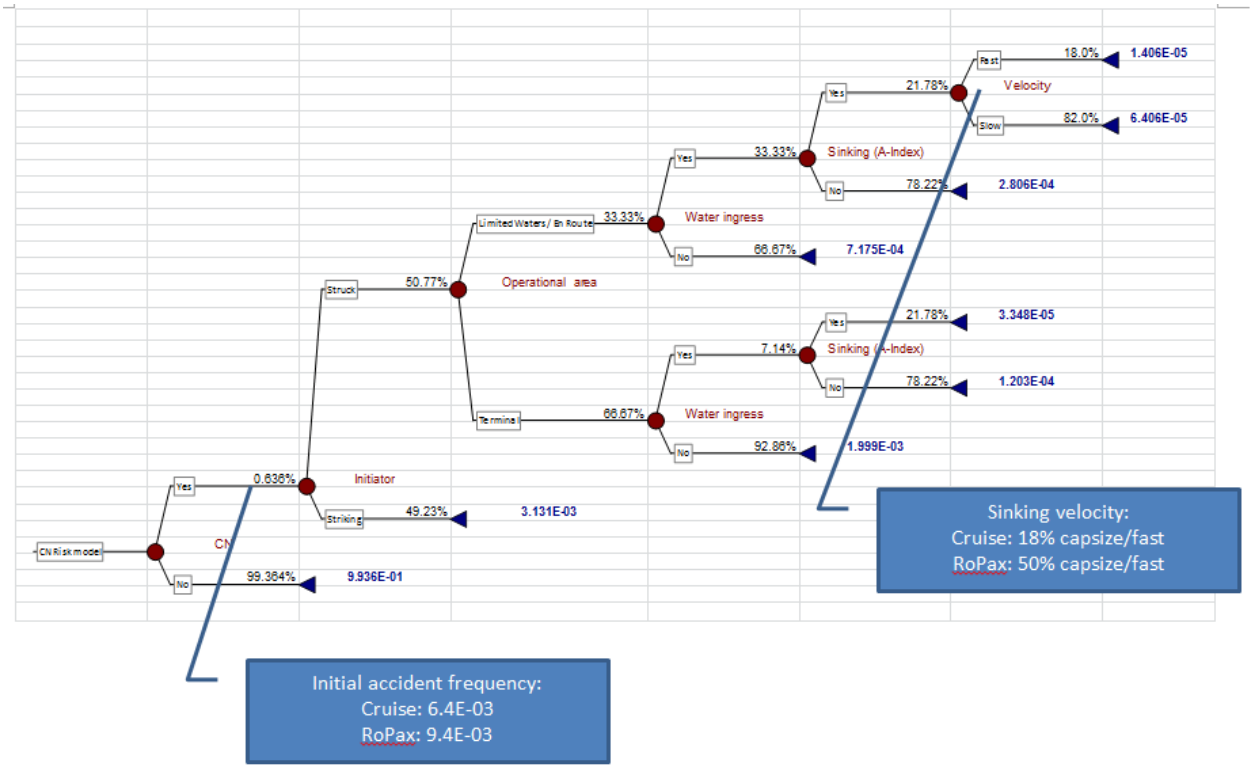


Fig. 14-6 Differences in risk model – RoPax and Cruise

Table 14-2 Difference in risk – Cruise and Ropax

Acc. Freq.	Event Tree				Prob. Scenario		Rel. Fat	Pax	Fat	PLL
Cruise										
6.40E-03	50.77%	33.33%	33.33%	21.78%	18%	0.0014%	80%	1000	800	0.011321
					82%	6.45E-05	5%	1000	50	0.003223
		66.67%	7.14%	21.78%	100%	3.36879E-05	5%	1000	50	0.001684
										0.016229
RoPax										
9.40E-03	50.77%	33.33%	33.33%	21.78%	50%	0.0058%	80%	1000	800	0.046187
					50%	5.77E-05	5%	1000	50	0.002887
		66.67%	7.14%	21.78%	100%	4.94791E-05	5%	1000	50	0.002474
										0.051548

The other main factor that influence is the effect of the s-factor for in particular the large cruise ship. The current formulation of the s-factor found in SOLAS Reg.II-1/7-2 is based on

- The angle of heel after damage: if this angle exceeds 15 degrees the s-value is set equal to zero, but the ship may still remain afloat.

- The height and range of the GZ-curve after flooding: The required range of stability may in particular influence the results and have as a consequence that much strengthening of the watertight integrity takes place towards the side of the ship while towards the centreline the watertight integrity is in fact much more lenient.

It is however not within the scope here to apply any other parameters than those included in current SOLAS.

14.3.1 Alternative formulations

As shown in the previous graphs there are several proposals on the level of R.

As a starting point the proposal of EC, proposed prior to SDC1, but not submitted to IMO, may be used:

$$R = 1 - C1 * \frac{5000}{2{,}5 * N + 15225}$$

Where

N = total persons on board

C1 = reduction factor for the risk equal to 0.63 in the EC proposal

Based on the results of the study a large increase for smaller ships may seem suitable, while keeping a moderate increase for larger ships.

Based on this the factor C1 could be varied with the number of persons on board

$$C1 = 0.8 - \frac{0.25}{10{,}000} * (10{,}000 - N)$$

The C1 factor may also be used for the purpose of adjusting the level of R to special ship types. This is shown as the “Alternative Project Proposal” in Fig. 14-7

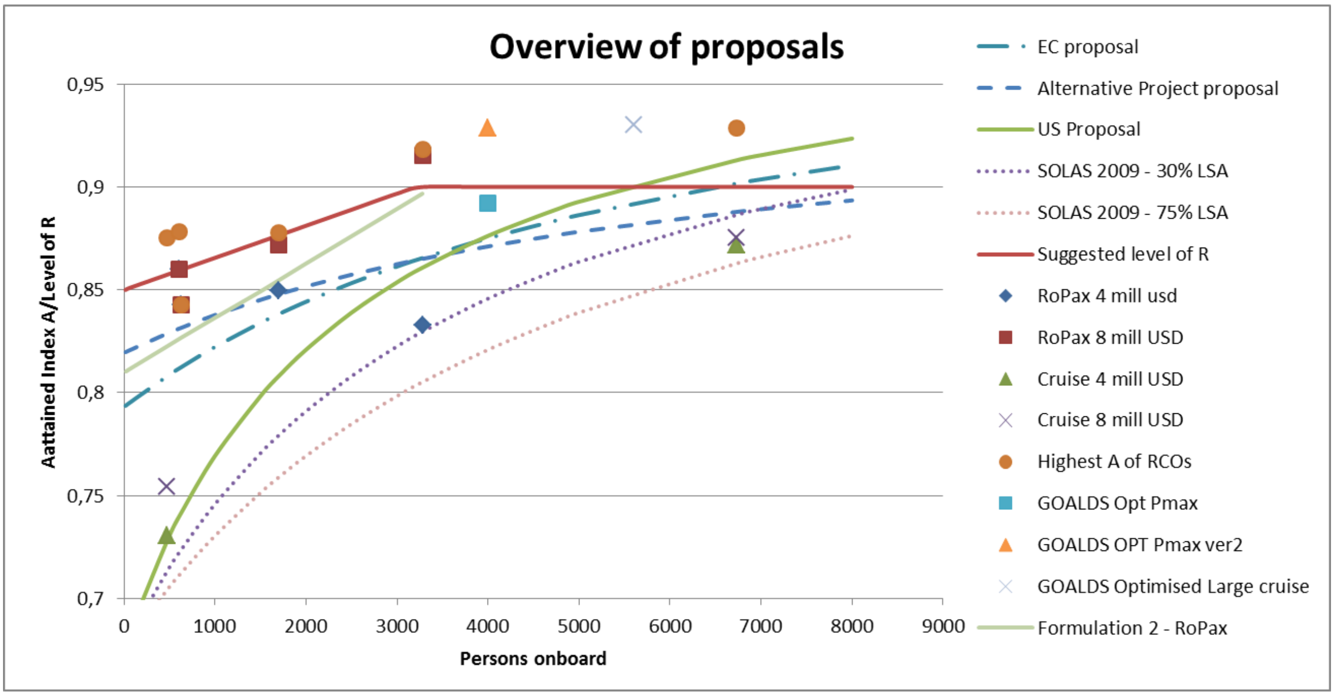


Fig. 14-7 Alternative proposals for level of R

14.4 Recommendations

Preliminary; the suggestion is to consider the combined level of R as shown in Fig. 14-4 and Fig. 14-5 as the level of R for both RoPax and Cruise. That implies the use of the formulation in (1) with a maximum value of R corresponding to 0.9. It is however strongly emphasised that this should be seen as a preliminary suggestion and is pending the decisions of how to take into consideration the results from the grounding studies and the risk from watertight doors. In the GOALDS study it was shown that ship designs with a high level of A were cost effective when taking into account the effect from grounding. Within this project, the proper instruments to assess the risk from grounding are now available. The designs that did not meet the CAF criterion for collision should be assessed with respect to grounding before the final recommendation is made.

Considerations from a risk perspective:

It is observed that the preliminary results from the Cost Benefit Analysis do not support an increase in the R from 3,000 persons on board and above. In relation to the FN diagrams, the public perception, existing requirements and proposals already forwarded to IMO, an increased level of R with increased number of person on board should be expected. The results from the RoPax studies supports this trend, however there is no data for RoPax having more than 3,280 persons on board. For cruise ships, if considered separately, the same trend is observed however the designs found to be cost–effective obtain a lower A than for RoPax. The possible reasons for these differences between have been discussed in 14.3.

The procedure leading to this proposal has been carried out in accordance with the IMO FSA Guidelines. It is however noted that the cost from a large scale accident is not covered in the current assessment. The impact of such an accident can be covered by ensuring that the occurrence of such an accident is highly unlikely.

Considerations from industry perspective:

It is stated by the shipyards/designers that the sample ships are not considered as fully developed, which means that a reduction in the attained A of approximately 0.02 to 0.03 for the investigated design options is recommended accounted for. This is to a certain degree reflected for by the formulation (2).

In this study, sample ships having less than 400 persons on board have not been included. It is noted that SOLAS Reg.II-1/8 is dominating the attained level of A for the small ships having 400 persons on board. Possible effects from the suggested R on ships having less than 400 persons on board are not considered in this study.

15 CONCLUSIONS

In this study an FSA based approach has been followed to form a basis for suggesting the level of the required index R for passenger ships. A revisit of the HazIds carried out in the SAFEDOR project has been carried out, concluding that there are no new causes of accidents that have been recorded since these HazIds were carried out. An updated collision risk model has been developed. The risk model developed in GOALDS is the basis but has now been further updated with recent statistics. By use of the updated collision risk model, the grounding/contact model developed in Task 3 and by revisiting the risk model developed in SAFEDOR for e.g. fire/explosion has both the societal and individual risk been assessed for the segments of passenger ships covered in this study assuming that they are in compliance with SOLAS 2009. For the purpose of this study 5 passenger ships have been designed in compliance with SOLAS 2009 and other applicable regulations and these ships have then been subject to investigation of design modifications that can give an higher attained index A. The design modifications have been subject to Cost- Benefit Assessment and those redesigned ships that meet the CAF criteria are used as a basis for the development of a formulation for level of R. The following preliminary conclusions can be drawn from these studies:

The small RoPax ships have a significantly higher A than the current level of R. This is due to the required compliance with SOLAS Reg.II-1/8.

For Cruise ships it is seen that it is possible to achieve a significantly higher A than current standard but these are not found to be cost-effective.

There is a significant difference in A-values between RoPax and Cruise ship designs found to be cost effective.

Suggestions on the new level of R have been made however it is strongly emphasized that these are preliminary as further studies on in particular the risk for grounding and how this shall be handled in combination with the collision are needed.

16 REFERENCES

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5 DNVGL 2015-0165 Risk Acceptance Criteria an Risk Based Damage Stability. Final Report, part 1: Risk Acceptance Criteria,

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APPENDIX A

Description of Collision & Grounding Incidents, 2005 onwards Contrasting with Causes included in the HAZIDs

Table of contents

A.1 CRUISE SHIPS - GROUNDINGS

Cruise Ships – Groundings (3)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
1	8406731 SEA DIAMOND 05/04/2007	The Sea Diamond, a Greek-flagged passenger cruise ship, hit a reef near the port of Santorini late Thursday 05 April, and sank at dawn on Friday, 6 April 2007. In total, 1,156 passengers and 391 crew were on board at the time of the collision. All but the two passengers, whom were unaccounted for, were evacuated and removed to safety. An oil slick approximately 100 m wide appeared on Thursday, in the aftermath of the collision. An immediate response was launched and all the initial oil was recovered. A remotely operated submarine was launched, in an attempt to locate the two lost passengers, as well as to conduct an overall assessment of the current state of the sunken vessel. Estimates indicate that some 50 tonnes of oil have leaked out. In spite of clean-up efforts have been 2 km of pebbled shoreline has been oiled on Santorini. Passenger cruise ship "SEA DIAMOND", sailed from the port of "HERAKLION" (Crete Island, Greece) on April 05, 2007 with 1155 passengers and 391 crewmembers. At the same day and while the above ship was navigating near the west coast of Santorini Island, Greece, in order to proceed in the port of "FIRA" (Santorini Island, Greece), at 15.40 hrs (L.T.) approximately, ran aground. The next morning, April 06, 2007, she sunk. All the passengers and the crew were rescued except of two passengers who are still reported missing. The above incident is under investigation.	No mention of causes, incident is under investigation. Hazards 8-1 and 8-2 of the SAFEDOR RoPax HAZID refer to emergency evacuations when the ship is trimmed and heeled and to evacuation equipment failure. It should be highlighted that hazard 8-2 was the top-ranked hazard in this HAZID. The causes for these hazards included in the HAZID are: difficulties in launching lifeboat and MES; slow reaction/awareness by passengers; inappropriate assistance to passengers from crew; lack of plans, training and experience; poor maintenance; lack of training; faulty equipment; too extreme heel and trim; human error.
2	8506373 ASTOR 15/05/2009	During unmooring operations/departure from the pier Nordre Toldbod (Port of Copenhagen) the vessel touched bottom by aft starboard quarter, causing no damage to the hull or propulsion system. The Master informed the Authorities immediately and they prohibited any further attempt to move the vessel. After agreement with the towage company was reached, the tugboat pulled the vessel from the seabed and the ship was moored at another berth for diver's inspection. On completion of diver inspection the vessel was cleared for sailing by Port Authorities and finally left the port in the early morning of 16/05/09. The major reason for grounding seems to be human error. The Master	For Hazard 2.3 (grounding) in the SAFEDOR Cruise HAZID one of the possible causes included is “lack of pilot knowledge/VTS information”. Also, in NAV49/INF.2 – Hazard No. 43 “difficult local conditions (poor quay, port layout, marking, anchoring conditions, etc.)” Causes of the incident not mention. All HAZIDs include a great variety of possible causes for incidents when navigating

		did not position the vessel towards outbound direction on arrival and did not use tug or pilot service for departure due to good weather conditions. However, the area of shallow water of 6 metres depth at the north area of the pier was not safeguarded by any navigational means, which actually had a negative impact on the conditions of unmooring operations.	in restricted waters.
3	9320544 COSTA CONCORDIA 13/01/2012	On 13th January 2012 the Italian passenger ship Costa Concordia departed Civitavecchia en route to Savona, Italy, where it was scheduled to arrive the following morning. A few hours and 40 miles later, the ship struck a rock formation about 450 feet from the coast of Giglio in Tuscany. It began taking on water at about 9:45 pm local time. The rocks left a 165-foot gash on the port side of Concordia's hull; after the impact, the ship listed at 20 degrees before partially sinking on Saturday morning. Some passengers jumped into the water and swam to safety, but there were delays in getting others into life boats, especially as the vessel had by then rolled over onto her side and many of the lifeboats were inaccessible. Thirty two lives were lost. Some reports indicated that the ship had also suffered a major electrical fault. There are 2,500 tonnes of oil on board, and booms have been placed around the vessel to contain any leaks, but worsening weather conditions and the shifting of the vessel will render these measures less effective. Offloading the fuel cannot be initiated until all rescue operations have been completed. **Violations and error types:** Violation (deliberate decision to act against a rule or plan): Routine (cutting corners, taking path of least effort, etc...) Lapse (unintentional action where failure involves memory): Other Mistake (an intentional action where there is an error in the planning process; there is no deliberate decision to act against a rule or procedure): Error in judgement; Inappropriate choice of route; Other **Underlying factors:** Psychological: Standards of personal competence; Lack of familiarity or training; Boredom	Hazards 8-1 and 8-2 of the SAFEDOR RoPax HAZID refer to emergency evacuations when the ship is trimmed and heeled and to evacuation equipment failure. It should be highlighted that hazard 8-2 was the top-ranked hazard in this HAZID. The causes for these hazards included in the HAZID are: difficulties in launching lifeboat and MES; slow reaction/awareness by passengers; inappropriate assistance to passengers from crew; lack of plans, training and experience; poor maintenance; lack of training; faulty equipment; too extreme heel and trim; human error. NAV49/INF.2 – Hazard No. 30 "technical failure of power supply" SAFEDOR Cruise HAZID –under the "planning, departure/arrival & voyage" section, HAZARD A is "black-out" Hazards included in NAV49/INF.2 • Hazard No. 1 – "OOW distractions", one of the causes mentioned is "human: telephone calls, other crew members, passengers" • Hazard No. 10 – "poor company policy/culture" • Hazard No. 19 – "communication between navigators, misunderstandings" • Hazard No. 32 – "large vessels, difficult to manoeuvre" • A number of hazards relating to use of bridge equipment: No. 15 "incorrect use of equipment", No. 29 "poor quality of equipment",

		Software: Company policy and standing orders; Less than adequate operating procedures and instruction; Other **Principle findings and form of casualty investigation:** 1. Poor route planning and navigation direction; 2. BTW management shortcomings; 3. Poor management of emergency evacuation procedures; 4. EDG functionality Criticalities. **Action taken:** • More detailed passengers info; • Voyage plan requested by Solas R V/34 should be made available by the Master to the Company prior ship's departure; • Instructions to passengers to be implemented; • Muster of passengers to be performed in each port for embarking passengers; • Company Audit follow up as a consequence of the casualty; • Amending procedures (Emergency instructions / Decision support system for Master); • Creation of a new Maritime Development & Company Dept by the Company; • Implementation of "High Tech Safety Monitoring System"; • Dedicated Fleet Operations Centre in Genoa; • Deck Officers training implementation. **Findings affecting international regulations:** 1. Double-skin for protecting the WTCs containing equipment vital for the propulsion and electrical production; 2. Limiting of the down flooding points on the bulkhead deck; 3. Provision of a computerized stability support for the master in case of flooding; 4. Interface between the flooding detection and monitoring system and the on board stability computer; 5. Discontinuity between compartments containing ship's essential	The SAFEDOR Cruise HAZID includes a whole section for hazards relating to Voyage Planning. We can highlight the following hazards included: • 1.4 – navigational failure with causes mentioned "unreliable electronic charts" • 1.8 – crew resource management • 3.7 – humar error – two of causes included are inappropriate watch changeover and complacency Another section of the SAFEDOR Cruise HAZID is on "Emergency Operations" with hazards included 5.1 "crew ability/training", 5.3 "crew behaviour/reaction/emergency handling", 5.7 "knowledge of emergency procedures", 5.14 "ship movement (list/trim)"; etc. SAFEDOR Cruise HAZID, Workshop II risk register. Hazard on "Grounding" – ship at full speed hitting hard sea-bottom (rock), as causes the following are mentioned: navigational equipment, updated and appropriate sea-charts, trained and competent officer on watch.

		systems; 6. More detailed criteria for the distribution, along the length of the ship, of bilge pumps and requirement for the availability of at least one pump having the capacity to drain huge quantities of water; 7. Relocation of the main switchboard rooms above the bulkhead; 8. Relocation of the UHF radio switchboard above the bulkhead deck; 9. Increasing the emergency generator capacity to feed also the high capacity pump(s); 10. Provision of a second emergency diesel generator located in another main vertical zone in respect to the first emergency generator and above the most continuous deck; 11. Provision of an emergency light (both by UPS and emergency generator) in all cabins in order to directly highlight the life jacket location; 12. Bridge management, considering aspects such as the definition of a more flexible use of the resources; 13. Bridge Team Management course for certifications renewal should be mandatory by the 1st January 2015; 14. Principles of Minimum Safe Manning (resolution A.1047(27) as amended by resolution A.955(23)) that should be updated to better suit to large passenger ships; 15. Muster list, showing the proper certification/documentary evidence necessary for crew members having safety tasks; 16. Inclusion of the inclinometer measurements in the VDR; 17. SAR patrol boat supplied with fix fenders, blocked in the upper side of the hull, to approach safe other ships/boats in case of extraordinary evacuation of persons. This should be able to load at list 100 passengers in their deck; 18. Divers speleologist, able to rescue, even in dark condition, persons standing into the ravines of ships/wrecks. **ACCIDENT ANALYSIS BY ITALY IN THE 22ND WORKING GROUP** **Event and Consequences:** Grounding of passenger vessel. The master ordered the navigating officer to change the passage plan to allow for the vessel to pass close to	

		the entrance to a port. The master agreed to the navigating officer's amended plan for the vessel to alter course to starboard and then pass 0.5 mile clear of land near the port entrance. The first officer on watch did not voice his concern to the master over the proposed plan. The first officer altered the vessel's course to starboard but did not continue the turn onto the planned track. The master took the con from the first officer before gaining full situation awareness. After a delay, the master resumed altering the vessel's course to starboard. The vessel deviated inshore of the planned track and grounded. Emergency generator power was automatically activated but was then quickly lost. Sounding of the emergency signal, transmission of a distress message and broadcast of an order to abandon ship were delayed. Consequential underwater damage resulted in the vessel flooding and grounding a second time, after which she was abandoned. A total of 32 passengers and crew died, 157 persons were injured. A total of 2,042.5 cubic metres of oil was spilt. **Contributing factors:** Insufficient risk assessment and passage planning. Illusion of control. Distraction caused by presence of additional persons on the bridge and a mobile telephone call. Insufficient bridge resource management. Lack of appropriate large-scaled chart. Insufficient position monitoring. Damage in excess of survivability standard. **Issues Raised/Lessons Learned:** Need for comprehensive risk assessment, passage planning and position monitoring. Need to remove distractions.	

		Need for effective bridge resource management. Need to consider protection of propulsion and electrical production compartments. Need to consider functional integrity of essential systems. Need to consider improvement and redundancy of emergency power generation. Need to consider detection and monitoring system interfacing with on board stability computer. Need to consider inclusion of inclinometer measurements within VDR. Need to consider more detailed assessment criteria for recognising Manning Agencies. Need to assign appropriately trained crew to emergency duties. **Observations on the Human Element:** Illusion of control. Distraction caused by presence of additional persons on the bridge and a mobile telephone call. Insufficient bridge and emergency resource management.	

A.2 PASSENGER SHIPS - GROUNDINGS

Passenger Ships – Grounding (1)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
1	8913916 OCEAN NOVA 17/02/2009	At approximately 01.30 hours LT on February 17th 2009 the passenger ferry OCEAN NOVA grounded on the rocks in Marguerite Bay, west of Debenham Island, approximately two kilometres from the Argentine research station San Martin. An initial assessment of damage indicated that there was no imminent danger, and no threat to lives. There was no sign of leakage from the vessel. No evironmental damage was caused. As a precaution, the Captain issued a distress signal which was picked up by the Argentine emergency services. The vessel, with 74 passengers on board, was waiting for high tide in the hope that the vessel could be floated off the rocks without damage. Preparations were made to evacuate the passengers and 30 crew members to Argentina's Ushuaia, the world's southernmost city. Three vessels were en route to assist, if required. ***Investigation report by Bahamas not available for download.***	No mention of causes.

A.3 PASSENGER-RORO SHIPS (VEHICLES) – COLLISION AND GROUNDING

Passenger-RoRo Ships (Vehicles) – Collision (1)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
1	9293404 NURAGHES 21/06/2006	On June 21st 2006, at 12:56 pm a collision occurred between M/V Moby Fantasy and M/V Nuraghes. Weather conditions were: absence of wind, calm water, and strong fog (visibility < 100 metres). The M/V Moby Fantasy had just left from Olbia Port and was proceeding to Civitavecchia Port at a speed of 18.2 knots, and M/V Nuraghes was on the opposite route at a speed of 25 knots. M/V Moby Fantasy's bow hit the Nuraghes' starboard side. Heavy damages resulted to the hulls and superstructures of both ships. The M/V Nuraghes was able to enter Olbia Port using its own means of propulsion, while M/V Moby Fantasy has to be towed to Golfo Aranci Port by a local tug boat. **On Moby Fantasy:** Number of crew being seriously injured in the casualty: 4 Number of passengers being seriously injured in the casualty: 1 Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: Human violations; Human error Structural failures of the ship: No External causes (outside the ship): Yes Another ship or ships (improper actions, etc.): No	No details for causes included. From the descriptions available we can only deduct that the collision occurred in strong fog due to human violations and errors of the crew of one of the ships involved.

Passenger-RoRo Ships (Vehicles) – Grounding (1)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
1	9372987 ILE DE GROIX 28/07/2008	Le lundi 28 Juillet 2008, à 07:48 heures, les transbordeurs Ile de Groix et Saint Tudy assurant les liaisons Ile de Groix –Lorient, entre en collision entre la Citadelle de Port-Louis et la bouée N°1, dite «bouée de l'Amiral».	No details for causes included.

		Google Translation: On Monday, July 28, 2008 at 7:48 pm ferries Ile de Croix and St. Tudy ensuring the Ile de Croix links -Lorient collided between the Citadel of Port Louis and Buoy No. 1, known as "life Admiral". ***Investigation report by IMO Secreteriat not available for download.***	

A.4 ROPAX SHIPS – COLLISIONS

RoPax Ships – Collisions (10)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
1	9162150 PANSTAR DREAM 03/11/2005	At 05:00 hours LT on 3rd November 2005 the passenger Ship Panstrar Dream (registered Republic of Korea, 9690 gt, built 1997), with 42 crew members on board (South Korean: 23, Filipino: 19), and general cargo ship Korex Incheon (2658 gt, built 1995), with 12 crew members on board (South Korean: 8, Myanmarese: 4), were in collision in Kanmon Passage, Kanmon Port, Japan. Panstrar Dream sustained damage to its shell plate of port quarter, and all passengers had to disembark at Kanmon Port. Ship rendered unfit to proceed. The starboard bow of Korex Incheon was destroyed. For Panstar Dream: Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: human error Violations and errors types: Mistake (an intentional action where there is an error in the planning process; there is no deliberate decision to act against a rule or procedure): error in judgement Principle findings and form of casualty investigation: (Principle findings) Panstar Dream attempted to overtake the Korex Incheon Investigators investigated the casualty, and then brought the case to the Japan Marine Accident Inquiry Agency. As a result of the court of inquiry, a judgment was pronounced.	No details for causes included, only human error by the crew is mentioned as cause.
2	8401444 FINNSAILOR 13/11/2005	The ro-ro passenger ship Finnsailor, en route from Travemünde, Germany, to Malmö, Sweden, was approaching the traffic separation scheme rounding the Gedser Reef. In good time before entering the separation scheme the Officer of Watch (OOW) on the bridge of the Finnsailor observed, visually and on the radar, three ships on a parallel	The look-out on board the Finnsailor, and to some extent on board the General Grot-Rowecki was inadequate.

		course heading east in the separation scheme. The OOW steered aft of the three ships and laid the Finnsailor on a parallel course between the northernmost ship and the one in the middle. In his mind all three ships would continue in the direction of the separation lane and turn where the direction changes from approximately east-west to approximately northeast-southwest. The southernmost of the four ships, the General Grot-Rowecki began to turn to port in order to continue along the new running of the separation lane. The new course pointed in the front of the stem of the second southernmost ship, Dana 1, which was forced to turn also to port. Since the attention of the OOW of Finnsailor was completely focused on the northernmost ship, Protector, he did not notice until late that the General Grot-Rowecki had turned to port with her course in front of the stem. When Finnsailor realised that a hazardous close-quarters situation was a fact, the OOW tried to turn away by hard to port rudder. The manoeuvre failed and the starboard quarter of the Finnsailor hit the port side of the General Grot-Rowecki in way of hatch no. 6. The hulls of the two ships were seriously damaged and both had to proceed to a shipyard for repairs. ***For General Grot-Rowecki:*** Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: Human error Violations and error types Mistake (an intentional action where there is an error in the planning process; there is no deliberate decision to act against a rule or procedure): Error in judgement Underlying factors Psychological: Standards of personal competence Software: Management and supervision **Principle findings and form of casualty investigation:** This casualty has been classified as serious, in accordance with MSC-MEPC.3/Circ.1 – Reports on Marine Casualties and Incidents. A safety investigation was carried out in accordance with the guidelines	The Finnsailor, which was overtaking the other three ships, sailed into a hazardous close-quarter situation at a speed, which was high for the prevailing situation and cannot be considered to be a safe speed in accordance with Rule 6 of the collision regulations. Although not necessarily a contributing factor to the collision, the hours of rest on board the General Grot-Rowecki were not in accordance with the requirements of the STCW Convention. SAFEDOR RoPax FSA – Hazard 4.2 – collision, listed current safeguards include adherence to COLREG and STCW provisions. NAV49/INF.2 includes the following relevant hazards: • 5 – tired crew, under pressure, not sufficient rest • 9 – high speed – one of the causes mentioned is attitude • 18 – misjudgement of traffic situations – unpredicted action by other vessel

		prescribed in the IMO Assembly Resolution A.849(20), as amended. Sweden acted as the lead investigating State, following consultation with Malta and Germany, which were substantially interested States. The principle findings presented in this Annex, which have been extracted from the Swedish Maritime Safety Inspectorate accident report, were gathered by the Swedish Maritime Safety Inspectorate, the Malta Maritime Authority and the German Federal Bureau of Maritime Casualty Investigation. 1. The main cause of the collision was the turn to port of the General Grot-Rowecki ahead of a ship, being overtaken and going in the same direction. The port turn caused a collision with another ship, also going in the same direction and at a speed higher than that of the General Grot-Rowecki. 2. The General Grot-Rowecki did not adjust her speed in accordance with Rule 6 of the Collision Regulations. Instead, she turned to port ahead of the bows of the vessel being overtaken, in such a way that the latter had to make an evasive manoeuvre. 3. The look-out on board the Finnsailor, and to some extent on board the General Grot-Rowecki was inadequate. 4. The OOW of the General Grot-Rowecki did not appreciate the importance of Rule 10(a) of the Collision Regulations. 5. The Finnsailor, which was overtaking the other three ships, sailed into a hazardous close-quarter situation at a speed, which was high for the prevailing situation and cannot be considered to be a safe speed in accordance with Rule 6 of the collision regulations. 6. The OOW of the Finnsailor was not aware of the change of course of the General Grot-Rowecki until at a very late stage. 7. Two other vessels, the Dana 1 and the Protector were leaving the TSS to maintain their original intended courses against Rule 10(b)(iii). 8. The Finnsailor and the General Grot-Rowecki did not imagine that the Dana 1 and the Protector were to leave the TSS rather than proceed in the traffic lane. 9. Although not necessarily a contributing factor to the collision, the hours of rest on board the General Grot-Rowecki were not in accordance with the requirements of the STCW Convention.	

		Investigation report from Maltese Authority not available for download.	
3	9220330 OLYMPIA PALACE 07/12/2005	On December 7^{th} 2005 at 14:15 hrs, during mooring operation at the Port of Ancona, the stern of M/N "Olympia Palace" collided with the portside of the tug "Conero" moored at Berth No. 3 which suffered serious damages with the subsequent introduction of a considerable quantity of water. Ship rendered unfit to proceed. **Action taken:** called the firemen for assistance. Assistance given (SAR operations) coastguard patrol boat in assistance to the tug.	No details for causes included.
4	8611685 MERCANDIA IV 11/09/2006	In dense fog Mercadia IV had just left Helsinore and Sundbuss Pernille was on her way to enter the port. The port bow of Mercadia IV hit the port side of Sundbuss Pernille. Mercadia IV had some scratches and a dent and fracture in the port bow port. She returned to Helsingoer. Sundbuss Pernille had a dent in her port side and her wheelhouse smashed. 4 passenger got minor injuries when the vessel heeled over when being hit. Sundbuss Pernille sailed into the port on her own. ***Investigation report from Danish Authority not available for download.*** **SUMMARY INFORMATION FROM EMSA's WEBSITE** Mercadia IV departed the berth in Helsingor at 06:15 hours as normal and with 12 passengers and 9 vehicles on board. The master and the chief officer were on the bridge. The visibility was very poor and the master could not from the berth see the two lights on the jetty. Before the departure the master had on the radar detected an echo approx. ¾ miles from the port entrance in ESE direction. The master assumed the echo to be Sundbuss Pernille (in the following Pernille), because normally a sundbus will enter the port just after the departure of the HH-ferry at 0615 hours. The master transmitted the departure on channel K and transmitted again, when the ferry was between the jetties. From the port entrance the course was set to 065°-70° to give more room for Pernille. The current was north about 1 ½ - 2 knots. Shortly	Relevant hazards included in NAV49/INF.2 HAZID include: • 19 – communication between navigators, misunderstandings • 28 – insufficient radar functionality • 31 – communication equipment failure • 39 – poor bridge design, physical work conditions

		after the passage of the entrance the master suddenly saw Pernille head on. The master turned on starboard, but immediately after the ships collided. Pernille departed Helsingborg on 11 September at 0605 hours as normal on the first tour of the day with 52 passengers on board. The master, a helmsman and a look-out were in the wheelhouse. It was foggy and the fog became more and more dense on approaching Helsingor. After having passed 0.35 miles north of the Disken buoy, the course was set towards the entrance to Helsingor. Shortly after they saw Mercadia IV approx. 20° on the port bow and they were not in time for a reaction before ships collided. Pernille was hid in port side around the wheelhouse. The master had not heard the departure transmissions from Mercadia IV on channel K, and he had not detected it on the radar. Pernille got some dents in port side and the port side of the wheel-house was smashed. 4 passengers got minor injuries. Pernille had no leakages and proceeded into port by its own means. Mercadia IV got a minor dent and scratches in the bow. Mercadia IV returned to Helsingor. **Safety Recommendations:** • H-H ferries A/S is recommend to initiate a discussion between the lines on the HH-passage concerning a more secure communication on channel K in whether with restricted visibility including a direct contact between an ingoing and an outgoing ferry. • H-H Ferries is further recommended to initiate a revision of the “Seglationhandboken”, in order to bring the book’s recommendations on navigation in coincidence with the actual used practice. • The Sundbuss-owner is recommended to change the position of the AIS-display from the aft bulkhead of the wheel-house to besides the radar.	
5	8503797 PRIDE OF BRUGES 13/11/2007	At 16:01 hours on 13 November 2007 the roll on, roll off (ro-ro) ferry Ursine made contact with the passenger ferry Pride of Bruges while manoeuvring onto a berth in King Georges Dock, Hull, causing damage to both ships. Ursine was rendered unfit to proceed.	Hazard 3.2 – collision (SAFEDOR RoPax FSA) includes as probable causes improper training on use of bridge equipment and communication problems. Also, hazard 5.3 – human error and lack of training.

		Investigation report from UK Authority not available for download. **ACCIDENT ANALYSIS BY UK IN THE 18TH WORKING GROUP** **Event and Consequences:** Ro-Ro Ferry "Ursine" manoeuvring to berth alongside in King Georg Dock at Hull, collided with passenger ferry Pride of Bruges. Damage was caused to both vessels. **Contributing Factors:** 1. PEC holder was not a fully integrated member of the bridge team and lacking skills and necessary training for handling the vessel. 2. Breach of the condition by CHA ensuring that Art. 8(1) of the UK Pilotage Act 1987 was respected and the vessel added to the PEC holder's certificate. **Issues Raised/Lessons Learned:** 1. The PEC holder was not trained or experienced in handling the vessel and the work he carried out and the CHA did not ensure any verification of his required skill before issuing his certificate. 2. The inner harbour (dock area) is not part of the PEC examination process by the CHA and therefore the vessel should have taken a pilot for berthing. 3. Unawareness of the allocated berth, a procedure should be put in place confirming the berth prior going alongside. 4. The PEC holder was unfamiliar with the handling of the vessel. His presence on board was not in line with the requirements of the CHA. 5. Master and Chief Officer were not familiar nor trained in handling the Ursine, Furthermore no briefing about berthing techniques were carried out. 6. Absence of a valid passage plan. Though existing the SMS checklist for berthing was not used 7. Little was known about the handling skills of similar vessels from	Relevant hazards included in NAV49/INF.2: • 8 – insufficient training • 12 – unfamiliar with vessel/bridge • 16 – misjudgements when approaching quay • 19 – communication between navigators, misunderstanding • 20 – communication with pilot

		the Master and Chief Officer at former assignments. The Charter inspection did not assess if Master and Ch. Mate were able to manoeuvre the Ursine effectively in port areas. **Observations on the Human Element:** The bridge team lacking experience and qualification in handling the vessel effectively. **SUMMARY INFORMATION FROM EMSA's WEBSITE** At 1601 on 13 November 2007 the roll on, roll off (ro-ro) ferry Ursine made contact with the passenger ferry Pride of Bruges while manoeuvring onto a berth in King George Dock, Hull, causing damage to both vessels. Ursine was on her first voyage into Hull, having recently been chartered by P&O Ferries Holdings Ltd (P&O) to undertake a service between Hull and Rotterdam (Europort). In accordance with the terms of the charter party agreement, P&O had placed its representative on board to perform the pilotage duties for both ports. He joined Ursine the evening before the accident, in Europort, but was not signed on the crew agreement. In accordance with local regulations the P&O representative, who held a Pilotage Exemption Certificate (PEC) for the river Humber, was on Ursine's bridge with the vessel's bridge team when the vessel entered the river. As Ursine approached Hull, the PEC holder gave a briefing to the rest of the bridge team on the approach and entry into the lock for King George Dock. The master, who was not experienced in handling ro-ro vessels, assumed that the PEC holder would be in control. However, the PEC holder, who was not an experienced ship handler, assumed that the master would take charge of the manoeuvre. Eventually, with both men involved in the ship handling, Ursine berthed in the lock.	

		In the lock, the PEC holder and the master, who had not been to Hull before, discussed the required approach for berthing at the P&O terminal. Again, there was no clarification as to who would be in control of the vessel. Once the lock had filled, Ursine proceeded stern first towards the berth, with both men handling the controls. From the conning position, on the port bridge wing, neither of them could see the P&O terminal. In the absence of any formal berth allocation, the PEC holder directed Ursine towards the berth which he assumed had been allocated to the vessel. This berth, 5 Quay Middle, was adjacent to the one regularly used by Pride of Bruges. However, on this occasion, for operational reasons, Pride of Bruges had been berthed on 5 Quay Middle. In the confusing situation, during which key bridge team members found themselves undertaking tasks for which they were nadequately prepared, Ursine was manoeuvred stern first towards the berth already occupied by Pride of Bruges until contact was made between the two vessels.	
6	9086588 SKANIA 17/02/2009	At about 01:41 hours on 17 February 2009, the Ro-Ro ferry Skania, sailing under the flag of the Bahamas, collided with the fishing ship Gitte, registered in the Federal Republic of Germany, while en route from Swinoujscie, Poland, to Ystad, Sweden. At the time, the fishing ship anchored approximately 13 n, east of Rügen because of engine failure. For unknown reasons, the watchkeepers on the bridge of the ferry failed to notice the fishing ship, which anchored on the ferry's course line, collided with the starboard forecastle and then dragged the fishing with her anchor line until it broke shortly afterwards. The Gitte was damaged above the waterline, however, she remained buoyant and sailed to the port of Sassnitz under her own steam after the engine was repaired. The ferry also continued her voyage after communicating briefly with the Master of the fishing ship. There were neither injuries nor environmental pollution. ***Investigation report from German Authority not available for download.*** **ACCIDENT ANALYSIS BY GERMANY IN THE 19TH**	Hazard 3.2 – collision (SAFEDOR RoPax FSA) includes as probable causes improper training on use of bridge equipment and communication problems. Also, hazard 5.3 – human error and lack of training. SAFEDOR RoPax FSA – Hazard 4.2 – collision, listed current safeguards include adherence to COLREG and STCW provisions. Also, in Hazards 3.2 and 4.2 (SAFEDOR RoPax FSA) listed causes of collisions include "improper training on use of bridge equipment", "communication problems – sometimes hard to reach the other ship on radio". Relevant hazards included in NAV49/INF.2: • 8 – insufficient training • 10 – poor company policy/culture

		WORKING GROUP **Type of Casualty:** Less serious casualty: Collision between Ro-Ro ferry under way and anchored fishing vessel **Event and Consequences:** At 0141 hrs (UTC+1) on 17 February 2009 , the northwards Ro-Ro Ferry Skania collided with the fishing ship Gitte anchored approximately 13 nm east of island of Rugen . As a result of the collision the Skania reported some paint abrasions and scratches on the port side of the stem and the Gitte suffered no serious damage to the starboard bow and to the waterline . Neither injuries nor environmental pollution. **Contributing Factors:** As the VDR data has not been obtained, in order to check the data to help the investigators to find the cause of the collision, many questions remain open. But it is clear that the human elements have been a determining contributing factor, e.g. VHF communications between both side, the inadequacy in watch-keeping of both vessels that not took the due attention required in that area considered. The fishing vessel was with an engine failure anchored in position on the track of the ferry and other ships. It was not prohibited to anchor there, but the choice of the anchor position itself posed a hazard, especially during night time. **Issues Raised/Lessons Learned:** Personnel on watch on both ships did not observe several COLREG 72 rules: Look-out (rule 5); Risk of collision(rule 7); (additionally on the F/V) not under command and anchor lights (rules 27, 30 and 36) Personnel on watch on both vessels did show inadequate knowledge of	• 15 – incorrect use of equipment • 18 – misjudgement of traffic situations • 19 – communication between navigators, misunderstanding • 22 – interaction, minor/leisure/fishing traffic • 28 – insufficient radar functionality

		procedures, instructions and bridge instruments (proper use of the radar, including long range scanning). **Observations on the Human Element:** The Officers on Watch on both ships should have a good knowledge of the contents of COLREG 72 and of all electronic navigation apparatus; The ship management company should make sure that OOWs would comply strictly with the specified operating procedures in the area of radar observation. **SUMMARY INFORMATION FROM EMSA's WEBSITE** At about 0141 on 17 February 20091, the Ro/Ro ferry2 SKANIA, sailing under the flag of the Bahamas, collided with the fishing vessel GITTE, registered in the Federal Republic of Germany, while en route from Świnoujście, Poland, to Ystad, Sweden. At the time, the fishing vessel anchored approx. 13 nm east of Rügen because of engine failure. For unknown reasons, the watchkeepers on the bridge of the ferry failed to notice the fishing vessel, which anchored on the ferry's course line, collided with the starboard forecastle and then dragged the fishing vessel with her anchor line until it broke shortly afterwards. The GITTE was damaged above the waterline; however, she remained buoyant and sailed to the port of Sassnitz under her own steam after the engine was repaired. The ferry also continued her voyage after communicating briefly with the Master of the fishing vessel. There were neither injuries nor environmental pollution. **Safety Recommendations:** Following the internal investigation of the accident, the measures shown below were recommended for the shipping company: 1. Implementation of additional training programmes for all Masters and Officers on Watch in the area of bridge watch duty and preventing collisions in relation to small vessels; 2. Implementation of additional training programmes in the area of radar observation for all Officers on Watch.	
7	9223796	On 23 July 2009 the roro cargo ferry Gotland was outbound from	

	GOTLAND 23/07/2009	Nynäshamn when she collided with the inbound roro cargo ferry Gotlandia 2 at 11.20 hours LT. The accident was investigated by the Swedish Accident Investigating Board and the report will be forwarded to IMO. Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: Human error Structural failures of the ship: No ***Investigation report from Swedish Authority available for download. (Report in Swedish).***	No details for causes included, only human error by the crew is mentioned as cause.
8	9435454 SCOTTISH VIKING 05/08/2010	At 19:46 hours on 5 August 2010, the Italian registered ro-ro passenger ferry Scottish Viking was in collision with the UK registered fishing vessel Homeland about 4 miles off St Abb's Head. As a result of the collision the fishing vessel sank. The skipper was recovered from the sea but, despite an extensive search by the rescue services and a large number of local fishing vessels, the remaining crew member, was lost. **For Scottish Viking:** Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: human error Underlying factors: Psychological: Standards of personal competence **Principle findings and form of casualty investigation:** Factors that led to the collision included: • Scottish Viking's watchkeeper did not: determine at an early stage if there was a risk of collision with Homeland; sufficiently monitor or plot Homeland's track; and, once a risk of collision was deemed to exist, take sufficient action to avoid collision. • Homeland's watchkeeper did not: determine at an early stage if there was a risk of collision with Scottish Viking; maintain a proper lookout from the wheelhouse; or detect or recognise a risk of collision with Scottish Viking until it was too late to take effective action.	Hazard 3.2 – collision (SAFEDOR RoPax FSA) includes as probable causes improper training on use of bridge equipment and communication problems. Also, hazard 5.3 – human error and lack of training. SAFEDOR RoPax FSA – Hazard 4.2 – collision, listed current safeguards include adherence to COLREG and STCW provisions. Also, in Hazards 3.2 and 4.2 (SAFEDOR RoPax FSA) listed causes of collisions include "improper training on use of bridge equipment", "communication problems – sometimes hard to reach the other ship on radio". Relevant hazards included in NAV49/INF.2: • 1 – OOW distractions (too many tasks for navigators, high stress level) • 8 – insufficient training • 10 – poor company policy/culture • 14 – incapacitation (illness, intoxicated, asleep, absorbed in other tasks, etc.) • 15 – incorrect use of equipment • 18 – misjudgement of traffic situations

		• The investigation identified the following other contributing factors: Scottish Viking – complacency and lack of precautionary thought; ineffective implementation of the company's navigation policy and procedures. • Homeland – restricted all-round visibility from the aft deck; conflicting task priorities and possible lack of watchkeeping proficiency. **Action taken:** The manager of Scottish Viking has taken a number of actions aimed at improving the performance of the company's bridge teams. These include: reiterating the importance of following the company's navigational procedures; introducing a procedure for masters to report on the competence of a newly joined officer; carrying out unscheduled navigational audits at sea; and randomly scrutinising VDR data to verify compliance with its procedures. Both the International Chamber of Shipping (ICS) and the MAIB have distributed the safety lessons arising from this investigation to the merchant shipping and fishing industry sectors respectively. In view of the actions that have been taken, the MAIB has issued no safety recommendations. **Assistance given (SAR Operations):** Yes. The skipper was recovered from the sea but, despite an extensive search by the rescue services and a large number of local fishing vessels, the remaining crew member was lost. ***Investigation report from UK Authority not available for download.*** **ACCIDENT ANALYSIS BY UK IN THE 22ND WORKING GROUP** **Event and Consequences:** Collision between RoRo passenger ship and fishing vessel due to poor	• 19 – communication between navigators, misunderstanding • 22 – interaction, minor/leisure/fishing traffic

		lookout and collision avoidance. One crewmember of the fishing vessel remained missing **Contributing Factors:** Both watchkeepers did not determine at an early stage if there was a risk of collision with the other vessel. No proper lookout was maintained and no sufficient action taken to avoid a collision. Company procedures and legislation in respect to safe navigation were not followed. The fishing vessel had a restricted all-round visibility from the aft deck. No lifejackets were worn by the fishing vessel crew, lowering the chance of survival once in the water. **Issues Raised/Lessons Learned:** Though the company had provided comprehensive guidance and well-documented procedures for the vessel to maintain a safe navigational watch. Internal audits were held to determine compliance. In practice it has turned out that the navigation procedures were not always followed in practice. It is concluded that the operational procedures of a navigational nature are best audited while the vessel is underway, providing a better opportunity to assess if the company's policies and procedures are being followed and, if not, to identify appropriate corrective action. **Observations on the Human Element:** The events that led to the collision may have been influenced by task priorities and possible lack of watchkeeping proficiency.	
9	9136022 STENA FERONIA 07/03/2012	The outbound vessel Union Moon collided with the inbound ferry Stena Feronia in the vicinity of the fairway buoy. Ship rendered unfit to proceed. Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the pilot: Yes Structural failures of the ship: No	Hazard 3.2 – collision (SAFEDOR RoPax FSA) includes as probable causes improper training on use of bridge equipment and communication problems. Also, hazard 5.3 – human error and lack of training.

		Violations and errors types: Mistake (an intentional action where there is an error in the planning process; there is no deliberate decision to act against a rule or procedure): error in judgement **Underlying factors:** Software: Company policy and standing orders **SUMMARY INFORMATION FROM EMSA's WEBSITE** At 18:58 on 7 March 2012, the outbound general cargo vessel Union Moon collided with the inbound ferry Stena Feronia, in the vicinity of the fairway buoy that marks the harbour limit of Belfast Harbour. Both vessels suffered major structural damage; however, there were no injuries or pollution and each vessel managed to proceed into port without assistance. Once alongside in Belfast, both vessels were visited by officers from the Police Service of Northern Ireland, who breathalysed the bridge teams. Union Moon's master was found to have an alcohol level of 123µg of alcohol per 100ml of breath, in breach of the permitted maximum of 35µg of alcohol per 100ml of breath. He was arrested and, on 31 May 2012, was sentenced to 1 year's imprisonment for breaching the Railways and Transport Safety Act 2003. The investigation found that although Union Moon's master had been under the influence of alcohol and had altered course to port resulting in a collision course with Stena Feronia, several other factors contributed to the accident, including: • A lack of clear guidance regarding traffic flow around the fairway buoy. • No action taken by the bridge teams of either vessel to prevent a close quarters situation from developing. • Action taken on board Stena Feronia to avoid collision. • Sub-standard VHF communications.	SAFEDOR RoPax FSA – Hazard 4.2 – collision, listed current safeguards include adherence to COLREG and STCW provisions. Also, in Hazards 3.2 and 4.2 (SAFEDOR RoPax FSA) listed causes of collisions include "improper training on use of bridge equipment", "communication problems – sometimes hard to reach the other ship on radio". Relevant hazards included in NAV49/INF.2: • 8 – insufficient training • 10 – poor company policy/culture • 15 – incorrect use of equipment • 18 – misjudgement of traffic situations • 19 – communication between navigators, misunderstanding • 28 – insufficient radar functionality

		Belfast Harbour has reviewed the accident with its Safety, Environmental and Security Committee, harbourmasters, Vessel Traffic Services staff and a representative of the Belfast pilots. It has taken measures to ensure its required radio procedures are followed, and has changed the point at which pilots disembark outbound vessels. As part of its comprehensive review of port operations, which was ongoing at the time of the accident, Belfast Harbour has since laid four new buoys which address the pinch point at the fairway buoy, introduced new routeing advice for mariners approaching Belfast Harbour, updated its Navigational Risk Assessment, and incorporated the findings of this report into its regular programme of Vessel Traffic Services emergency training. Northern Marine Management Ltd has issued a fleet guidance notice to its masters, reminding them of the importance that al deck officers have a clear understanding of the International Regulations for Preventing Collisions at Sea and of the manoeuvring characteristics of their vessels. Continental Ship Management AS has, inter alia, reviewed the manning levels of its vessels and issued a circular letter to its fleet to reiterate its instructions on watchkeeping, including the need to ensure the bridge is manned by an additional lookout during the hours of darkness. Northern Marine Management Ltd has been recommended to amend its safety management system to provide clarity on the roles and responsibilities of the bridge team when a Pilotage Exemption Certificate holder is acting solely as a pilot. **Safety Recommendations:** 2012/149 Amend its SMS to make clear the roles and responsibilities of the bridge team when conducting pilotage with a PEC holder who is not part of the normal ship's complement and is performing an act of pilotage.	
10	9217230 NILS HOLGERSSON 03/05/2012	On the evening of 3 May 2012, the German-flagged ferry Nils Holgersson sailed into the port of Travemunde, where she was to make fast with her stern at pier 6a of the Skandinavienkai. The turning manoeuvre in the Siechenbucht (turning basin) necessary for this failed because the two pod propulsors were still being operated in "Sea	The SAFEDOR RoPax HAZID includes the following causes relevant to this incident:

		mode". Because only one hydraulic pump was activated per propulsor, instead of two. The ship's command was unable to stop in the turning basin and the ferry headed towards the opposite pier at a speed over ground of 6.51 kts. The Danish ferry URD, whose crew was occupied with making proparations for the scheduled voyage to Liepaja, was made fast there at pier. Most of the passengers and the cargo were already on board. The collision occurred at 18:14 hrs. The port side of the URD was pressed in by the bow of the Nils Holgersson, causing the URD to take on water and heel to port. It was possible to stabilise the ship by flooding the forward ballast water tanks, which enabled the evacuation of people and much of the cargo via stern ramp. The Nils Holgersson was able to move to her berth under her own power after the controls were switched to harbour mode. Nobody came to physical harm and the environment was not damaged due to the collision. ***Investigation report from German Authority not available for download.*** **SUMMARY INFORMATION FROM EMSA's WEBSITE** On the evening of 3 May 2012, the German-flagged ferry Nils Holgersson sailed into the port of Travemünde, where she was to make fast with her stern at pier 6a of the Skandinavienkai. The turning manoeuvre in the Siechenbucht (turning basin) necessary for this failed because the two pod propulsors1 were still being operated in 'Sea mode'. Because of that, the rudder angle was limited to +/- 35° and the rotation of the pods retarded because only one hydraulic pump was activated per propulsor, instead of two. The ship's command was unable to stop in the turning basin and the ferry headed towards the opposite pier at a speed over ground of 6.51 kts. The Danish ferry Urd, whose crew was occupied with making preparations for the scheduled voyage to Liepaja, Latvia, was made fast there at pier 3. Most of the passengers and the cargo were already on board. The collision occurred at 1814372. The port side of the Urd was pressed in by the bow of the Nils Holgersson, causing the Urd to take on water and heel to port. It was possible to stabilise the ship by flooding the	• 3-2 – collision when arriving/departing from port – technical and human failure, improper training on use of bridge equipment (maybe too much equipment on bridge) • 8-3 – human error and lack of training – improvements in company policy, error The NAV49/INF.2 HAZID also includes causes relevant to this incident: • 15 – incorrect use of equipment – new, difficult equipment • 27 – wrong procedures – procedures not adapted to current ship • 8 – insufficient simulator training – insufficient training with respect to emergency situations

		forward ballast water tanks, which enabled the evacuation of people and much of the cargo via the stern ramp. The Nils Holgersson was able to move to her berth under her own power after the controls were switched to 'Harbour mode'. Nobody came to physical harm and the environment was not damaged due to the collision. **Safety Recommendations:** The following safety recommendations do not constitute a presumption of blame or liability in respect of type, number or sequence. 6.1 TT-Line The Federal Bureau of Maritime Casualty Investigation recommends that TT-Line document the regular manoeuvres for operation of the various emergency steering systems for ships with pod propulsor that have been introduced and implement the regular training for improvement of communication and teamwork that is planned accordingly. 6.2 L-3 SAM Electronics The Federal Bureau of Maritime Casualty Investigation recommends that L-3 SAM Electronics work toward eliminating interference identified when testing bridge microphones in the course of the VDR's annual performance test.	

A.5 ROPAX SHIPS – GROUNDINGS

RoPax Ships – Groundings (5)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
1	9246061 HAMNAVOE 16/05/2006	The Ro-Ro ferry was leaving Stromness in the Orkney islands with 31 passengers and 40 crew onboard. The only electrical power source was provided by a single shaft generator. As the ship entered the channel the shaft generator supply breaker failed while port helm was applied. Pitch was taken off the twin controllable pitch propellers but the vessel's stem touched the bottom. About 30 seconds later the emergency generator was connected to the switchboard and electrical power was re-established. The master took the ship out into the channel and then returned to port. Once secured alongside a divers inspection was conducted, the only damage recorded was superficial paint detachment. Internal inspections revealed no damage. The cause of the breaker failure has not been determinate and the failure could not be replicated. The management company are reviewing their guidance on the electrical generation configuration on entering confined navigational areas. The Ro-Ro ferry was leaving Stromness in the Orkney islands with 31 passengers and 40 crew onboard. The only electrical power source was provided by a single shaft generator. As the ship entered the channel the shaft generator supply breaker failed while port helm was applied. Pitch was taken off the twin controllable pitch propellers but the vessel's stem touched the bottom. About 30 seconds later the emergency generator was connected to the switchboard and electrical power was re-established. The master took the ship out into the channel and then returned to port. Once secured alongside a divers inspection was conducted, the only damage recorded was superficial paint detachment. Internal inspections revealed no damage. The cause of the breaker failure has not been determinate and the failure	SAFEDOR RoPax HAZID, hazard 3.1 – grounding, one of the causes included is propulsion or steering failure (technical) during acceleration or deceleration

		could not be replicated. The management company are reviewing their guidance on the electrical generation configuration on entering confined navigational areas. Subsequent inspection and testing of the electrical breaker failed to identify any defects.	
2	7907245 STENA DANICA 10/01/2008	On 10th January 2008 the roro cargo ferry Stena Danica was outbound from Gothenburg when she grounded at Gaveskar at 19.20 hours LT. The accident was investigated by the Swedish Accident Investigating Board and the report will be forwarded to IMO. Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: human error ***Investigation report from Danish Authority available for download. (Report in Danish).***	No details for causes included, only human error by the crew is mentioned as cause.
3	9007295 PRIDE OF CANTERBURY 31/01/2008	On 31st January 2008 the port of Dover was closed during a period of high winds Force 10/11. The ro-ro cargo ship Pride of Canterbury was inbound at the time the port closed, and deviated to The Downs to steam round awaiting the port to re-open. During the morning the vessel made three circuits of the area, but on the last circuit she went further North than planned, and on making the turn to go South struck a charted wreck at approximately 12.50 hours LT. Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: Human violations; Human error **Violations and error types:** Violation (deliberate decision to act against a rule or plan): Routine (cutting corners, taking path of least effort, etc...); Necessary(due to inadequate tools or equipment, improper procedures or regulations) Mistake (an intentional action where there is an error in the planning process; there is no deliberate decision to act against a rule or procedure): Error in judgement; Inappropriate choice of route **Underlying factors:** Physiological: Stress	Hazards 2-2 and 3-1 (SAFEDOR RoPax FSA) include as causes of grounding presence of current and wind, swell and bad weather (possible effects of leeway) and human error on the interactions between captain and other members of the crew. As existing safeguards, the following are listed: ISM (familiarisation) and passage planning. Hazard 3-10 (SAFEDOR RoPax FSA) errors due to inadequate display of navigational information (ECDIS/ARPA). Hazard 9-1 (SAFEDOR RoPax FSA) irrational behaviour by crew – lack of training, stress, fatigue, communication problems, all resulting in wrong operation of equipment Relevant hazards included in NAV49/INF.2: • 1 – OOW distractions (captain became distracted whilst on phone for a non-navigational issue) • 8 – insufficient simulation training • 10 – poor company policy/culture

		Psychological: Boredom Hardware: Ergonomics Software: Company policy and standing orders; Less than adequate operating procedures and instruction Environment: Ship movement/Weather effects **Principle findings and form of casualty investigation:** Use of non approved ENC (VMS) as primary means of navigation. No training in use of VMS No passage plan made after vessel deviated Lack of Bridge Team Management training Master influences OOW actions even though OOW has officially got the con **Action taken:** Company recommended to re introduce training in BTM and ECDIS Also to review passage plans for waiting areas when ports are closed. Flyer to be issued highlighting the issues. ***Investigation report from UK Authority not available for download.*** **ACCIDENT ANALYSIS BY UK IN THE 19TH WORKING GROUP** **Event and Consequences:** The vessel was on her way from Calais to Dover on a scheduled crossing in severe weather. During this crossing the vessel was informed that the Port of Dover would be temporarily closed due to severe weather conditions and seas. Under the instructions of the Master the vessel proceeded to The Downs and commenced 'slow steaming' while waiting for the port to reopen. The vessel had been in the area for about 4 hours and while approaching a turn at the northern extremity there was a fire alarm and a number of telephone calls to the bridge of a non-navigational nature. Due to these distractions the vessel overshot the northern limit of the safe area before the turn was even started.	• 15 – incorrect use of equipment

		At 12:51 on January 31st 2008 the vessel struck a charted wreck which had been wire swept to a depth of 1.8m. The location was at Lat 51 14.48N Long 001 28.7E. The vessel had 275 Passengers on board and 101 Crew. There were no injuries or fatalities. The vessel was subsequently able to berth at Dover later in the day when the Port reopened. Weather conditions at the time of accident were as follows: Wind SW 10 to 11 Sea/Swell High Tide: 1.5-2.0 kts from the north-east Visibility: Fair with sea spray A divers survey reported severe damage to the port CPP. After approval by Class the vessel proceeded to Falmouth and an inspection revealed: Loss of the port CPP hub Loss of about 1 m of the port tail shaft Port after stern tube, centre stern tube, stern tube bearings-all damaged and misaligned. Two sections of the port intermediate tail shaft bent. Misalignment of associated framing, extending to gearbox and main engines. Port rudder stock bent. **Contributing Factors:** The basic cause of the grounding: (Root Cause) Lack of effective Bridge Team Management. Contributing factors • Distractions to the Bridge Team. The bridge team was distracted several times, including a request from a driver of a refrigerated truck to run his engine so the truck could run its cooling plant. The exhaust from the truck led to the activation of the fire detection system, which then cascaded into further distractions to the bridge team, including discussions on starting up the ventilation system so	

		that the truck's exhaust does not keep setting off the fire alarm. A series of telephone calls to the bridge took place and the Master himself took another 4 telephone calls to the bridge, before returning to the important aspect of navigating the vessel. • Use of non-approved ENC (Electronic Navigation Chart)—Voyage Management System (VMS) as primary means of navigation. The navigation during the period was almost entirely carried out with reference to the Sperry Voyage Management System (VMS) and by eye. The lack of proper training in the use of ECDIS possibly led to the wreck being undetected, and the paper chart, which was marked with "no go" areas, was never re-assessed or amended. • No training in use of VMS. Subsequently it was revealed that the bridge officers had received no training on the VMS system. • Master influences OOW actions even though OOW has officially got con. • No passage plan made after vessel deviated. • The bridge team was never on stand by or "red bridge" operating condition. **Issues Raised/Lessons Learned:** • The Bridge team members were required to provide administrative information and respond to non-navigational issues at a time when the Bridge team's attention should have been solely focussed on the navigation of the vessel. • Contingency Planning: There was no contingency plan onboard. The company provided plans for normal operations. However, a contingency plan in the actions that the vessel would require during port closure, slow steaming would have been very helpful. • Bridge teams were not on standby or "red bridge" operating condition. This is important and is fairly standard operating procedure to have the bridge on stand by during slow steaming, especially where manoeuvres are required. • Similarly, watch handing over procedures were done on an as need basis. Basically to conform to meal times or additional duties that officers were performing. Therefore, handovers were not structured and important information was not passed along. Nonchalance and	

		malaise was tolerated. Strict rigorous procedures must always be followed, especially when operating in close quarters. • Electronic chart systems or other such navigational aids should be used as aids and not as the primary navigational tool. In addition specific training should be provided to all navigational officers at regular intervals, so that they have a thorough understanding of the equipments functionality. • The vessels speed was adjusted, on an ad hoc basis. The criteria being to maintain steerage. Therefore, at a critical moment when danger was imminent, the vessels speed was increased, thus giving the crew less time to react. • Between 1995 and 2008 at least 4 similar incidents have been reported within these waters. Therefore; the lessons learned must be promulgated aggressively to vessel operators. In addition further analysis of similar accidents should be initiated world wide. **Observations on the Human Element:** • The investigation has revealed the importance of training, drills and contingency planning to handle emergencies including false alarms. In this accident the Bridge Management Team (BTM) was ineffective and training was discontinued. It is well known that training, drills and effective contingency planning increase the likelihood of efficient and rational action if a real emergency or near emergency should occur. • Lack of awareness, knowledge, education (ignorance), malaise and overconfidence may have caused the information exchange at watch handovers to be not performed in a systematic way. Similarly, the vessels position was not systematically plotted on the paper chart. • Although fatigue has not been identified in this case as a cause, it could be a contributory factor given the fact anecdotally that the officers were at the end of their 7 day duty period. This extra day of duty and increased workload due to discussions with contractors could have contributed towards fatigue. • The Master took several phone calls on the bridge during the lead up to this situation; similarly the Officer on Watch was also dealing	

		with a situation on the trailer deck which would have resulted in lower situational awareness to the primary duty function of navigating the vessel. **SUMMARY INFORMATION FROM EMSA's WEBSITE** On 31 January 2008, the Roll on Roll off Passenger ferry, Pride of Canterbury, grounded on a charted wreck while sheltering from heavy weather in an area known as 'The Downs' off Deal, Kent. The vessel suffered severe damage to her port propeller system but was able to proceed unaided to Dover, where she berthed with the assistance of two tugs. The vessel was on a scheduled crossing from Calais to Dover in severe weather when she learned that Dover Port was to be temporarily closed due to the weather and sea conditions. She proceeded to The Downs to wait for the reopening of the port. The master instructed the bridge team to slow steam in the area and he gave verbal instructions on the geographic limits to be imposed. No formal passage plan was formulated and nothing was marked on the paper or electronic chart. The vessel had been in the area for over 4 hours when, while approaching a turn at the northern extremity, the bridge team became distracted by a fire alarm and a number of telephone calls for information of a non-navigational nature. The vessel overshot the northern limit of the safe area before the turn was started. The officer of the watch (OOW) became aware that the vessel was passing close to a charted shoal, but he was unaware that there was a charted wreck on the shoal. The officer was navigating by eye and with reference to an electronic chart system which was sited prominently at the front of the bridge, but he was untrained in the use and limitations of the system. The wreck would not have been displayed on the electronic chart due to the user settings in use at the time. A paper chart was available, but positions had only been plotted on it sporadically and it was not referred	

		to at the crucial time. The vessel's owner has reviewed its training programme and implemented a number of measures to prevent a re-occurrence of the accident. The MAIB has published a Safety Flyer, for circulation to ferry and other ship operators, which details the lessons learned from the accident and advises operators: • To review their training requirements/provision with respect to the use of electronic chart systems, especially where a system that is not approved as the primary means of navigation is provided and sited prominently on the bridge. • Where navigating bridges are the focus for frequent requests for nonnavigation related information, to ensure that systems are in place to prevent watchkeepers from becoming distracted at critical times. • To ensure that plans are in place to identify likely contingency areas in advance of the intended voyage, and that any dangers or hazards within these areas are clearly identified. • Of the need to ensure that the principles of effective bridge team management are understood and practised by bridge teams at all times. **Safety Recommendations:** Interferry and the International Chamber of Shipping are recommended to: 2009/101 Promulgate to ship owners/managers the MAIB Safety Flyer describing this accident and the principal lessons to be learned from it.	
4	8323161 PRINCESS OF THE STARS 21/06/2008	The ro-ro ferry Princess of the Stars departed Manila, Philippines, on the evening of 20 June 2008, bound for Cebu City, Philippines, with hundreds of passengers on board. The ferry sent a distress signal at midday on 21 June 2008 when its engines stalled in rough seas near Sibuyan. The ship capsized at the height of the typhoon "Frank" (International Code Name: Fengshen) in an area approximately 1,500	No details for causes included, only that the incident occurred at the pick of a typhoon.

		metres off the coast of Sitio Cabitangahanan, Barangay Taclobo, San Fernando, Romblon, Philippines, with the loss of many lives.	
5	8219554 ISLE OF ARRAN 28/03/2009	The inter island ro-ro passenger ferry Isle of Arran was operating a route on which she was not normally engaged. Weather conditions over the preceding two days had been poor and resulted in a disturbed sleep pattern for the crew. The vessel arrived in port and sailed about five minutes late on the allocated 25 minute turnaround time, with 19 passengers on board. The bridge organisation consisted of the master on the port bridge wing with the con, the second officer as the officer of the watch, and a quartermaster stood by the helm. The master manoeuvred the vessel clear of the berth and headed out towards a reef, five cables away, marked by north and south cardinal marks. Speed was increased to 4 knots. The second officer was monitoring the master's actions in case of error and, was responsible for monitoring the vessel's position. The master then instructed that control of engines, bow thrust, and helm, be taken inside the bridge. Once inside the master stood behind a dirty bridge window and with the sun directly ahead his vision was obscured and he arranged for the window to be cleaned but became distracted whilst in conversation; speed was increased to 8 knots. With the window still dirty, but the buoy visual, he then altered course to port with the intention of leaving the reef and the south cardinal mark to starboard. Inexplicably the turn was stopped early, possibly to counter the effects of leeway, with the buoy still on the port bow. Fast approaching the reef, the master was alerted to the danger by the second officer who questioned his intentions. The master immediately recognised the danger and applied full astern pitch and full port thrust. Unfortunately his actions were too late. The vessel momentarily grounded on the reef only six minutes after slipping from the berth.	Hazards 2-2 and 3-1 (SAFEDOR RoPax FSA) include as causes of grounding presence of current and wind, swell and bad weather (possible effects of leeway) and human error on the interactions between captain and other members of the crew. As existing safeguards, the following are listed: ISM (familiarisation) and passage planning. Relevant hazards included in NAV49/INF.2: • 1 – OOW distractions (captain became distracted whilst in conversation) • 4 – Time pressure – keep schedule • 5 – Tired, pressure, not sufficient rest • 14 – incapacitation (absorbed in other tasks) • 16 – misjudgements when approaching quay, in narrow waters • 19 – communication between navigators, misunderstandings

		The vessel suffered substantial hull damage but was able to return to her berth without assistance. Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: human violations External causes (outside the ship): Sun directly in the line of sight **Violations and error types:** Violation (deliberate decision to act against a rule or plan): Routine (cutting corners, taking path of least effort, etc...) Slip (unintentional action where failure involves attention): Failure to report due to distraction Lapse (unintentional action where failure involves memory): Forgetting to report information Mistake (an intentional action where there is an error in the planning process; there is no deliberate decision to act against a rule or procedure): Error in judgement; Deciding not to pass on information; Failure to respond appropriately **Underlying factors:** Physiological: Stress Hardware: Ergonomics Software: Management and supervision Environment: Ship movement/Weather effects **Principle findings and form of casualty investigation:** Distraction of the master. Vision hindered by salt water on the bridge window and direct sunlight in the master's line of sight. Passing of information from the OOW delayed. No proper monitoring of the passage plan.	

A.6 ROPAXRAIL SHIPS – COLLISION

RoPaxRail Ships – Collision (1)

#	IMO No. Name Incident Date	Incident Description *IMO GISIS (with additional information from EMSA website, where available)*	Comments – Contrasting with causes included in HAZIDs
	9151539 SCHLESWIG-HOLSTEIN 24/08/2009	At 04:00 hours on 24 August 2009, the Schleswig-Holstein, a Roro-Ferry flying the flag of Germany, which was sailing on a north-easterly course towards Rödby (Denmark) collided with the American yacht Mahdi about 15 minutes after departing from Puttgarden ferry port. The yacht was proceeding under sail on a westerly course towards Kiel with two people on board. Her skipper observed the departure of the ferry, but saw only her green sidelight up until the very last. Therefore, in spite of the approaching and planned close quarter situation, he was confident that the ferry would observe his right of way and realised they were on a collision course only second before the impact. Accordingly, he did not have sufficient time for the usual procedure in critical situations of illuminating his sail with spotlights and calling over VHF. The hazardous approach was only recognised just before the collision, at the moment that the yacht was first identified visually, on the bridge of the ferry as well. In spite of the last-moment action initiated on each ship, there was not enough time left (approximately 30 seconds) until the collision to avoid the accident. The fore section on the port side of the Mahdi was hit with considerable force by the bow of the ferry. The yacht heeled very quickly and heavily to starboard side of the ferry and righted herself after parting from the ferry. The skipper, who along with the female co-sailor did not suffer any injuries, managed to start the engine and put the bilge pump into operation. A general alarm was sounded on the Schleswig-Holstein and a lifeboat was lowered into the water. Contact between the crew of the lifeboat and the yacht revealed the people on board had survived the accident unhurt and that the yacht was still buoyant in spite of strong deformations on her outer skin. There was no environmental pollution. A search and rescue ship, the Emil Zimmermann, and a Danish tug, the Baltsund, promptly sailed from Puttgarden to the scene of the accident.	Hazard 3.2 – collision (SAFEDOR RoPax FSA) includes as probable causes improper training on use of bridge equipment and communication problems. Also, hazard 5.3 – human error and lack of training. SAFEDOR RoPax FSA – Hazard 4.2 – collision, listed current safeguards include adherence to COLREG and STCW provisions. Also, in Hazards 3.2 and 4.2 (SAFEDOR RoPax FSA) listed causes of collisions include “improper training on use of bridge equipment”, “communication problems – sometimes hard to reach the other ship on radio”. Hazard 2.1 (SAFEDOR RoPax FSA) as cause of collision includes poor knowledge of presence of pleasure craft. Relevant hazards included in NAV49/INF.2: • 1 – OOW distractions (too many tasks for navigators, high stress level) • 8 – insufficient training • 10 – poor company policy/culture • 15 – incorrect use of equipment • 18 – misjudgement of traffic situations • 19 – communication between navigators, misunderstanding • 22 – interaction, minor/leisure/fishing traffic

		The Baltsund, accompanied by the search and rescue ship, then towed the yacht to Puttgarden. Internal causes (related to the ship where the casualty occurred): Yes Human violations or errors by the crew: Human violations; Human error Violations and error types: Violation (deliberate decision to act against a rule or plan): Routine (cutting corners, taking path of least effort, etc...) Slip (unintentional action where failure involves attention): Other ***Investigation report from German Authority not available for download.*** **ACCIDENT ANALYSIS BY GERMANY IN THE 20TH WORKING GROUP** **Type of Casualty:** Serious marine casualty Collision between a Ro-Ro ferry and a sailing yacht **Event and Consequences:** The ferry, which operates between Puttgarden and Rodby, was on a north-easterly course after departing from Puttgarden port at night, while the yacht was proceeding under sail on a westerly course crossing the ferry route. The visibility was good and the sea was calm. It was not until just before the collision that the yacht was identified visually by the ferry. The echo of the yacht on the radar display was weak and not visible at times. The ferry crew heard the yacht asking an east-bound vessel on VHF if she could see the yacht, but there was no answer. The ferry also had no idea where the yacht was. Suddenly, a high red light was detected at a distance of about 200 meters. The crew of the yacht observed the busy traffic and tried to make oncoming vessels aware of their presence on VHF at different times but	

		did not receive an answer. They also observed the departure of the ferry and saw only her green sidelight up until the very last. They thought the ferry would give way to the yacht and did not realise both vessels were on a collision course until a few seconds before the collision. The fore section of the port side of the yacht was hit by the bow of the ferry with considerable force. The yacht heeled heavily to starboard and took on a large amount of water, but the crew did not suffer any injuries. There was no environmental pollution. **Contributing Factors:** Vessels were coming from both the east and the west. In addition, a drilling platform together with auxiliary vessels was in close proximity to the ferry. The yacht approached the ferry in the shadow of the drilling platform. It can be assumed that the ferry crew focused primarily on other vessels, and the yacht's tricolour light was apparently overlooked. The echo of the yacht was hardly distinguishable from radar interference on both the X-band radar and the S-band radar on the ferry, and no attention was paid to the weak echo on the displays. None of the radar settings on the ferry were changed apart from the range. The yacht gave no information about her own position when asking another vessel on VHF if she could be seen. **Issues Raised/Lessons Learned:** • Effective lookout and radar observation • Better understanding of the other vessel's perspective • Risk of passing large vessels in their immediate vicinity • Detectability of a small vessel; it would be increased by providing information about her own position on VHF communication or by being equipped with AIS or a radar reflector. **Observations on the Human Element:** The human eye focuses more or less inevitably on very bright spots in darkness.	

		A light mounted at the top of the mast of a sailing boat nearby is easily confused with a navigation light much further away on the horizon. The current coexistence of vessels with and without AIS increases the risk of the radar operator's attention being focused too much on clearly identifiable objects. **SUMMARY INFORMATION FROM EMSA's WEBSITE** At 04:01 on 24 August 2009, the Schleswig-Holstein, a ro/ro ferry2 flying the flag of Germany, which was sailing on a north-easterly course towards Rödby (Denmark), collided with the American yacht Mahdi about 15 minutes after departing from the Puttgarden ferry port. The yacht was proceeding under sail on a westerly course towards Kiel with two people on board. Her skipper observed the departure of the ferry, but saw only her green sidelight up until the very last. Therefore, in spite of the approaching and planned close quarters situation, he was confident that the ferry would observe his right of way and realised they were on a collision course only seconds before the impact. Accordingly, he did not have sufficient time for the usual procedure in critical situations of illuminating his sail with spotlights and calling over VHF. The hazardous approach was only recognised just before the collision, at the moment that the yacht was first identified visually, on the bridge of the ferry as well. In spite of the last-moment action initiated on each vessel, there was not enough time left (approximately 30 seconds) until the collision to avoid the accident. The fore section on the port side of the Mahdi was hit with considerable force by the bow of the ferry. The yacht heeled very quickly and heavily to starboard, took on a large amount of water in the process, scraped along the starboard side of the ferry and righted herself after parting from the ferry. The skipper, who along with the female co-sailor did not suffer any injuries, managed to start the engine and put the bilge pump into operation. A general alarm was sounded on the Schleswig-Holstein and a lifeboat was lowered into the water. Contact between the crew of the lifeboat and the yacht revealed the people on board had survived the accident unhurt and that the yacht was still buoyant in spite of strong deformations on her outer skin. There was no environmental pollution.	

		A search and rescue vessel, the Emil Zimmermann, and a Danish tug, the Baltsund, promptly sailed from Puttgarden to the scene of the accident. The Baltsund, accompanied by the search and rescue vessel, then towed the yacht to Puttgarden. **Safety Recommendations:** The BSU has already commented at length in an investigation report on the use of active or passive radar reflectors to increase safety for pleasure craft.27 Therefore, the publication of safety recommendations can be dispensed with. Instead, the BSU is limiting itself to publishing a summary investigation report on the accident.	

APPENDIX B

Fleet at Risk

Table of contents

B.1 INTRODUCTION

In order to characterise the fleets of both ship types under consideration, some basic analyses of fleet data are summarised in the following for the different fleets at risk and the sample used for the subsequent determination of accident frequencies in the investigation period. For instance, such characteristics are the number of ships or the annual growth rate (indicating the introduction into world fleet of recent changes in regulations). It should be mentioned that for later risk analysis two ship type categories will be used, one consisting of Cruise and passenger ships, the other consisting of RoPax and RoPaxRail, and therefore relevant data will be merged.

B.2 CRUISE SHIPS

In total 266 cruise ships (≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC) were reported to be active between 1982 and 2012. Of these 258 vessels are classed by an IACS society. The development of the Cruise ship fleet in terms of number of ships and annual relative growth rate is shown in Fig. 2.1 using the criteria summarised above. As shown the Cruise ship world fleet grew continuously in the observation period (doubling its number every decade after 1990) and today comprises nearly 250 ships or about five times the number of 1990. In the same time the fleet size in terms of gross tonnage grew by a factor of 13 and in terms of passenger capacity by a factor of 12 (Fig. 2.2). The average ship size in 1990 was about 26,000 GT with number of passengers of 1,000; until 2000 the average ship size increased by nearly 70% and of passenger capacity by 50%. Between 1990 and 2012 a similar growth with respect to gross tonnage and passenger capacity is observed yielding a total passenger capacity of nearly 490,000. Finally, the number of ship years plotted versus year is shown in Fig. 2.3 providing also detailed data for each year. The cumulative number of ship years over the reporting period 1990-2012 is 3404 considering ships complying with selection criteria. Compared to FSAs of other ship types this number of ship years is relatively small, for instance for containerships the number of ship years for this period is about 15 times higher. In this context it is therefore mentioned that such small number of ship years has an influence on the certainty of the results which has to be considered when interpreting the results.

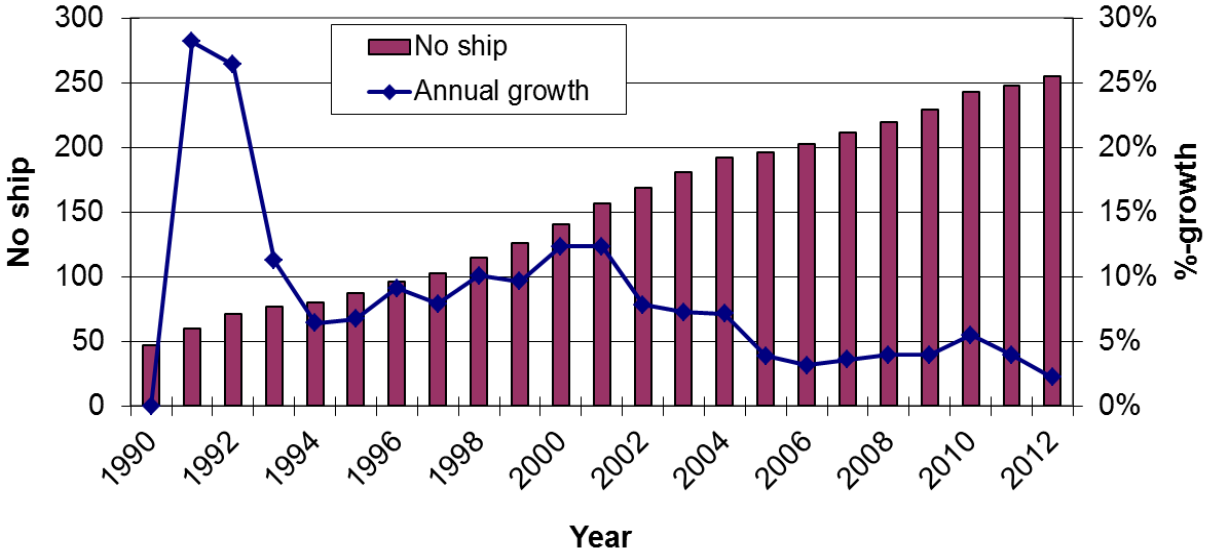


Fig. 2.1: Development of Cruise ship fleet considering ships ≥ 1,000 GT; ≥ 80 m, built after 1981 (excluding HSC) and only IACS class in terms of number of ships vs. year and annual growth rate.

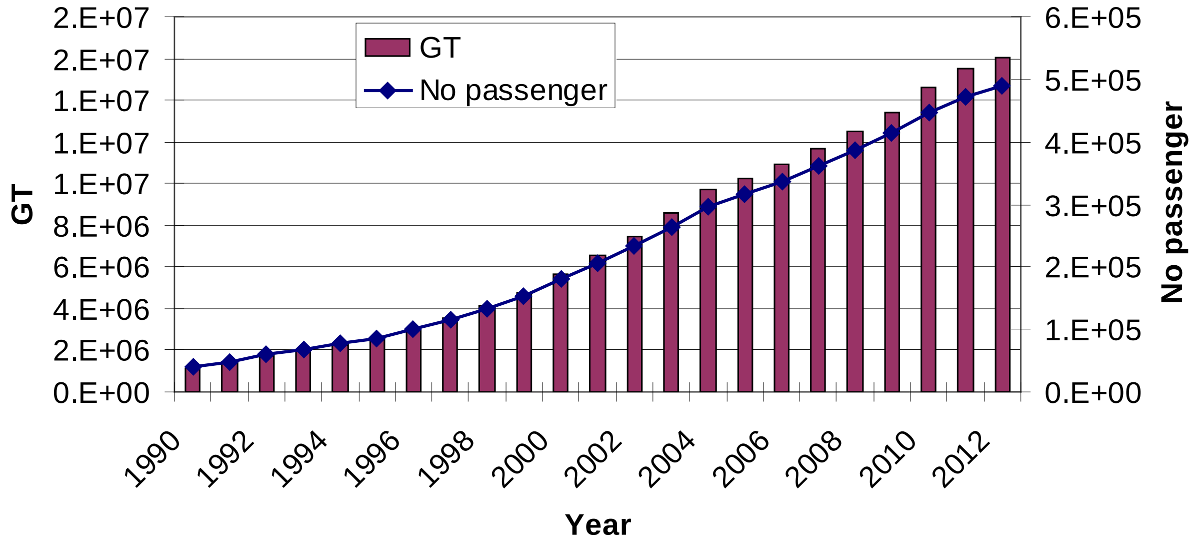
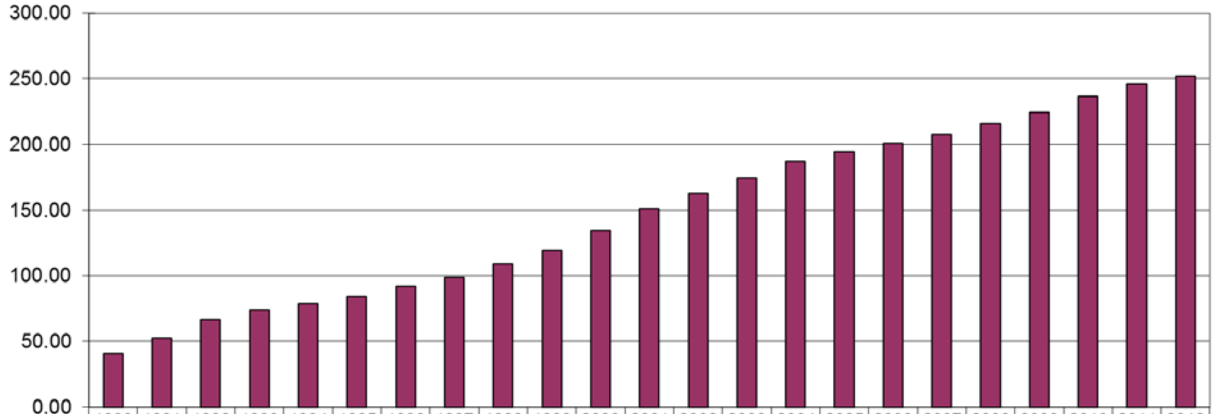


Fig. 2.2: Development of Cruise ship fleet with respect to gross tonnage and passenger capacity (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ship years	41.09	52.67	66.59	74.08	78.84	84.16	91.83	99.08	109.0	119.5	134.3	150.9	162.7	174.5	187.0	194.3	200.5	207.6	215.9	224.5	236.8	246.2	251.7

Fig. 2.3: Number of ship years per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising Cruise ship fleet by ship's nominal passenger capacity, the following can be observed (Fig. 2.4, Fig. 2.5 and Fig. 2.6):

- The larger part of Cruise ship fleet is coming from ships having a passenger capacity of 1,500-2,500 persons.
- Cruise ships carrying 2,500-3,500 passengers are the second largest part of Cruise operational ship fleet.
- Cruise ships with passenger capacity larger than 4,500 persons appeared after 2009 thus the particular capacity presents the higher percentage of growth.

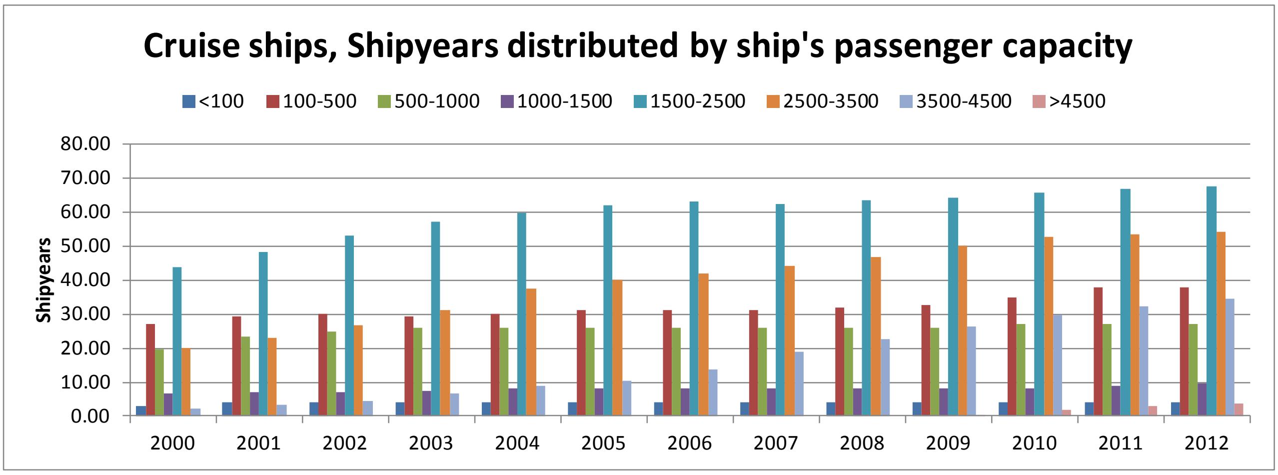


Fig. 2.4: Number of ship years per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

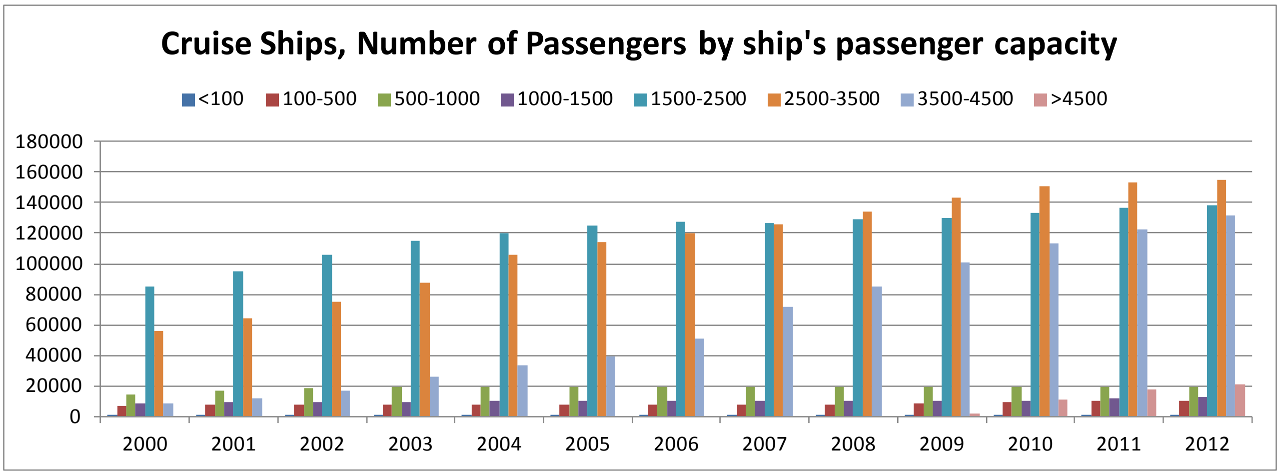


Fig. 2.5: Number of Passengers per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

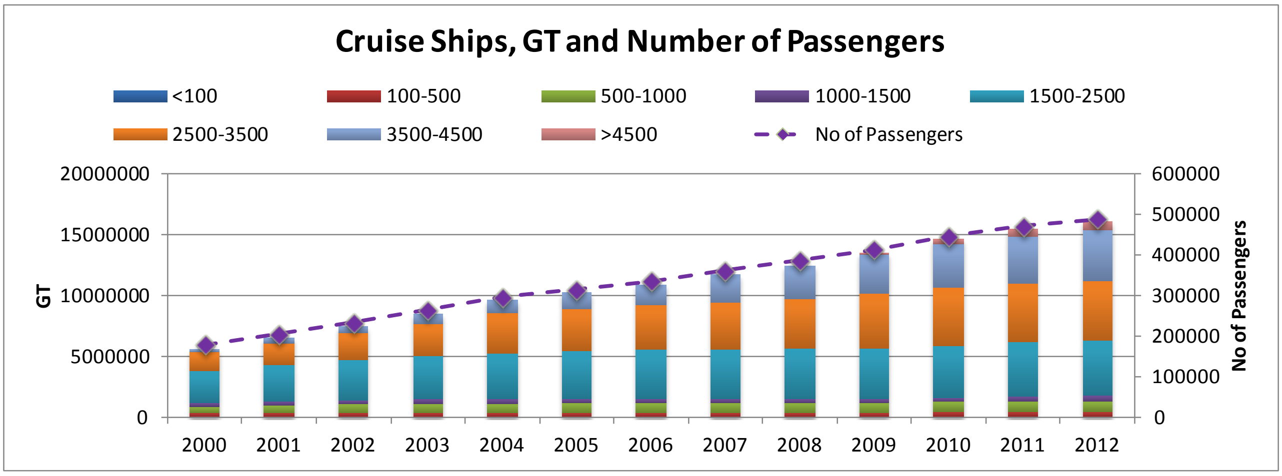
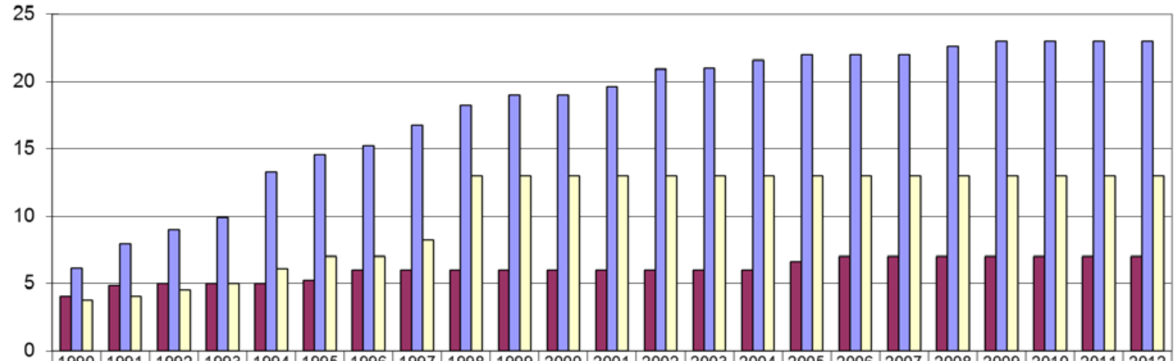


Fig. 2.6: GT and Number of Passengers per year for Cruise ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

B.3 PASSENGER SHIPS

The number of pure passenger (no High Speed Craft, no cruise and RoPax) ships built after 1981, ≥ 1,000 GT, with a length ≥ 80 m, is 32 and thus significantly smaller than that for Cruise ships. Majority of this small world fleet is classed by non-IACS societies (22) or other organisations (7). With respect to gross tonnage (< 14,000) and passenger capacity (< 1,750) IACS passenger ships are smaller than IACS Cruise ships. Similar observations were made with respect to ships in other subsets. All ships are below 150 m of length. For the period 1990 to 2012 the number of ship years has been plotted in Fig. 3.7 considering subsets “IACS”, “Non-IACS” and “Empty”. The cumulative number of ship years for 1990 to 2012 is 139 ship years (“IACS” class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	4	5	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7
Non IACS	6	8	9	10	13	15	15	17	18	19	19	20	21	21	22	22	22	22	23	23	23	23	23
EMPTY	4	4	5	5	6	7	7	8	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13

Fig. 3.1: No ship years versus year for Passenger ship fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class).

The comparison between Cruise and passenger ships fleet shows that the latter will contribute only marginally to a merged category.

B.4 ROPAX SHIPS

In total IHS-Fairplay shipregister contains 735 vessels built after 1981, ≥ 1,000 GT and an L_{OA} ≥ 80 m of which 485 currently classed by an IACS society and 48 for "Non-IACS" society and 202 for "other organisations". The development between 1990 and 2012 of world RoPax fleet in terms of number of ships is shown in Fig. 4.8. Additionally the annual growth rate is plotted.

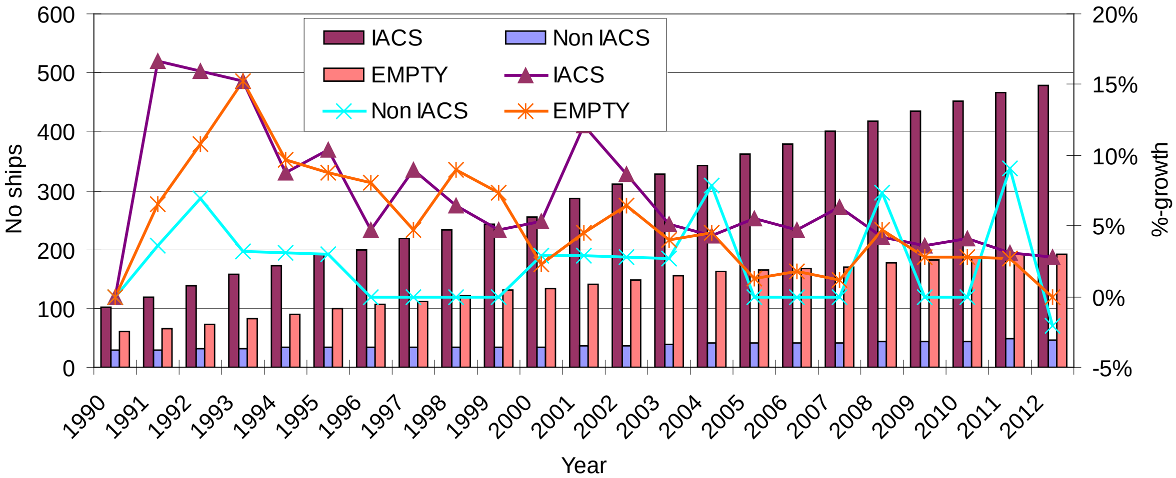


Fig. 4.1: Development of world RoPax fleet classified in categories "IACS", "Non-IACS" and "EMPTY[1]" (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC).

Since 1990 the RoPax fleet classed by IACS societies has grown by about 370 vessels (~370%) which is higher than the growth (total and relative) of the other subsets of "Non-IACS" and "EMPTY" (~210%; ~70%). The average annual growth rate for IACS classed ships is about 5%

[1] EMPTY, mean no information with respect to class is being given in the IHS-Fairplay ship register

since 2003 which is equivalent to an annual newbuilding rate in the last decade between 14 and 24 vessels.

As shown by Fig. 4.9 the subset of Non-IACS ships contains mainly vessels smaller than or equal to 10,000 GT (77%), whereas for IACS ships 63% are between 10,000 and 40,000 gross tonnes. An investigation of the average ship size of the fleet with respect to gross tonnage showed that the gross tonnage per ship increased since 1990 by about 30% or by 5,000 GT to ~20,000 tonnes in 2012.

This difference was also determined for the ship length in terms of L_{OA} (Fig. 4.10). In the IACS subset the majority of ships have a length between 150 m and 200 m, whereas for the other subset nearly 80% are shorter than 150 m. With respect to number of ships in different passenger categories both subsets showed only minor differences (Fig. 4.11). All three subsets show no change in average ship size in terms of passenger capacity between 1990 and 2012 ("IACS" ~ 1000; "Non-IACS" ~ 700; "EMPTY" ~600).

For the average age of the ships an increase from five to six years in 1994 to 14 to 16 years in 2012 was observed. Due to the fact that normal ship life is expected to be about 25 years this observation was expected (considering only ships built after 1981). The average age of the ships in both subsets differ by about two years whereas ships of IACS subset are younger.

The number of ship years per year distributed over the three subsets considered is plotted in Fig. 4.12. IACS classed ships contribute more than 60% of all ship years with slightly increasing percentage towards the end of the observation period (~67% in 2012).

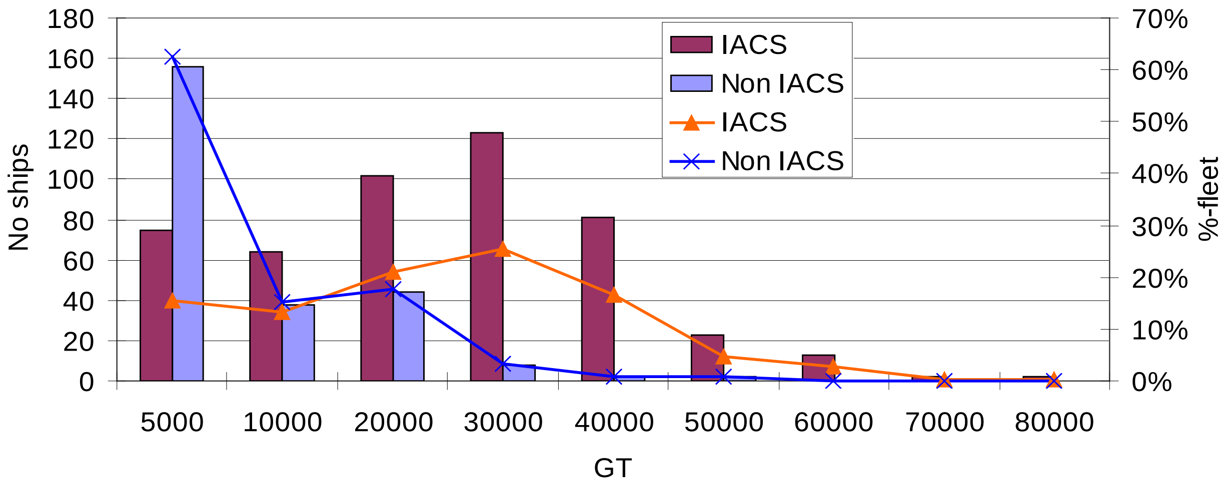


Fig. 4.2: Number of RoPax ships in different size categories (GT) and relative distribution for each subset for "IACS" and "Non-IACS" class ships.

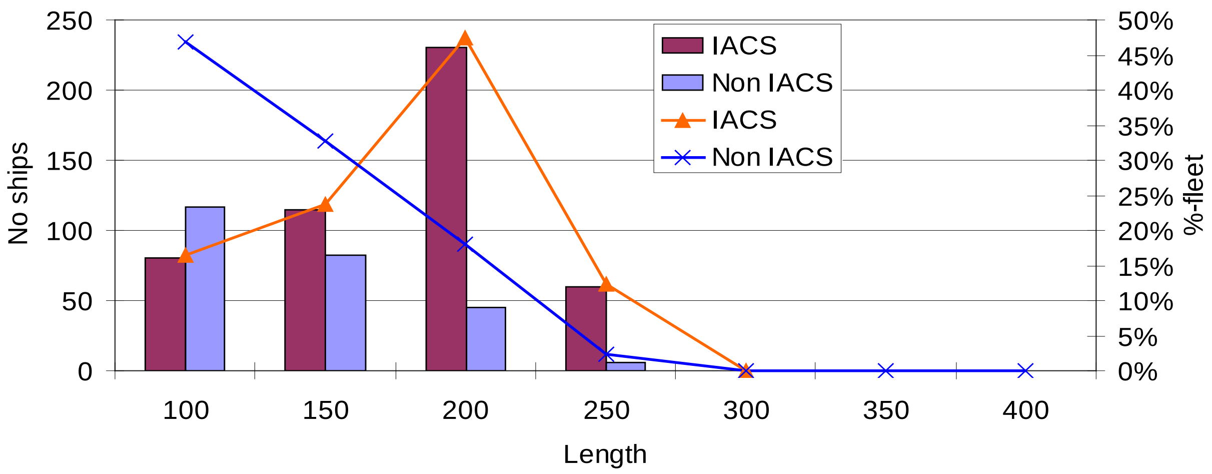


Fig. 4.3: Number of RoPax ships in different size categories (LOA) and relative distribution for each subset for "IACS" and "Non-IACS" class ships.

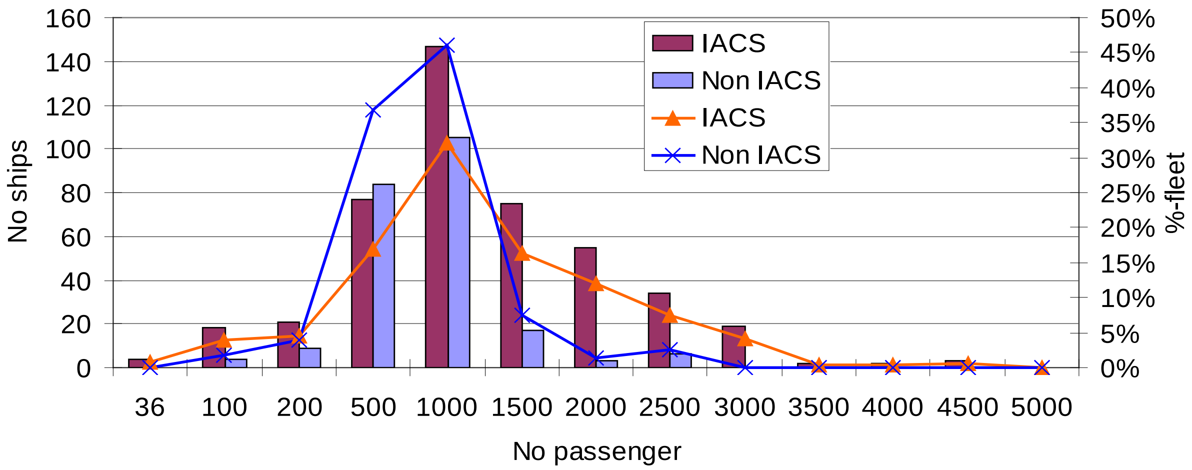
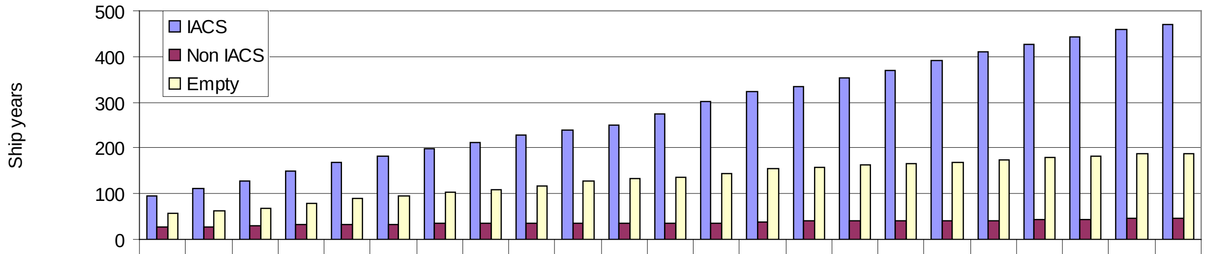


Fig. 4.4: Number of RoPax ships in different size categories (no passenger) and relative distribution for each subset for "IACS" and "Non-IACS" class ships.

The development of the fleet with respect to ship years considering "IACS" and "Non-IACS/EMPTY" class as well as the values for each year are summarised in Fig. 4.12. The cumulative number of ship years between 1994 and 2012 for RoPax ships is 6,520 ("IACS" class).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
IACS	94	112	129	150	168	182	198	211	228	238	249	275	302	322	334	353	371	392	411	426	443	459	471
Non IACS	27	28	30	32	33	34	34	34	34	34	34	35	36	37	40	41	41	41	42	44	44	47	47
Empty	58	64	68	80	88	95	103	109	118	127	133	137	145	154	159	163	167	168	174	180	183	187	189

Year

Fig. 4.5: Number of RoPax ship years for each subset for "IACS" and "Non-IACS" class ships.

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising RoPax fleet by ship's nominal passenger capacity, the following can be observed Fig. 4.14 and Fig. 4.15:

- The larger part of RoPax fleet is coming from ships having a passenger capacity of 500-1,000 persons and it is continuously increasing over the years.
- RoPax ships carrying 1,000-1,500 passengers is the second larger part of RoPax operational ship fleet.
- Growth rates vary up to 10% after year 2005 with respect to the ships up to 2,500 passengers.
- In annual base, the largest number of passengers is carried by RoPax ships with passenger capacity in the range of 1,500-2,500.

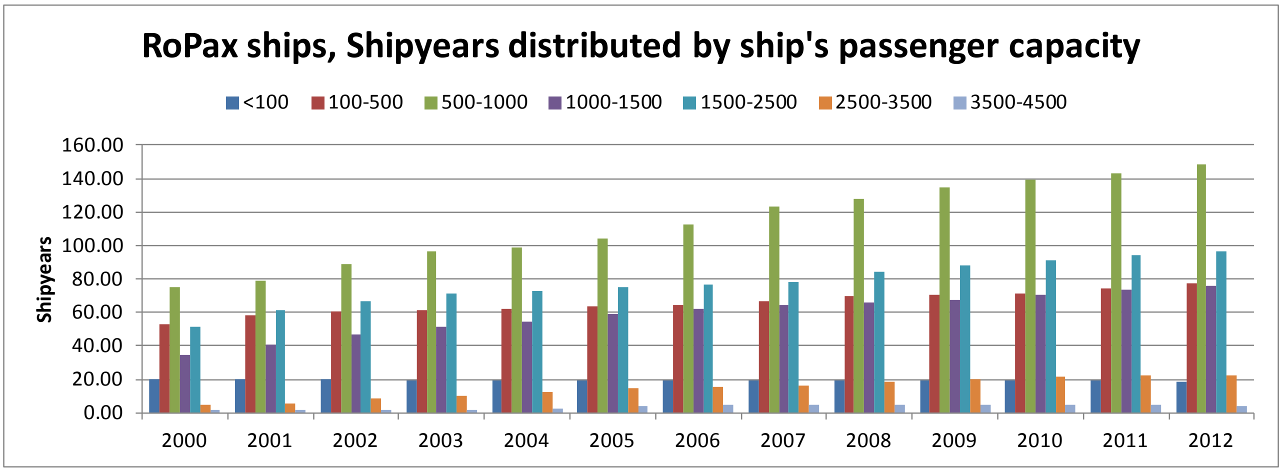


Fig. 4.6: No ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

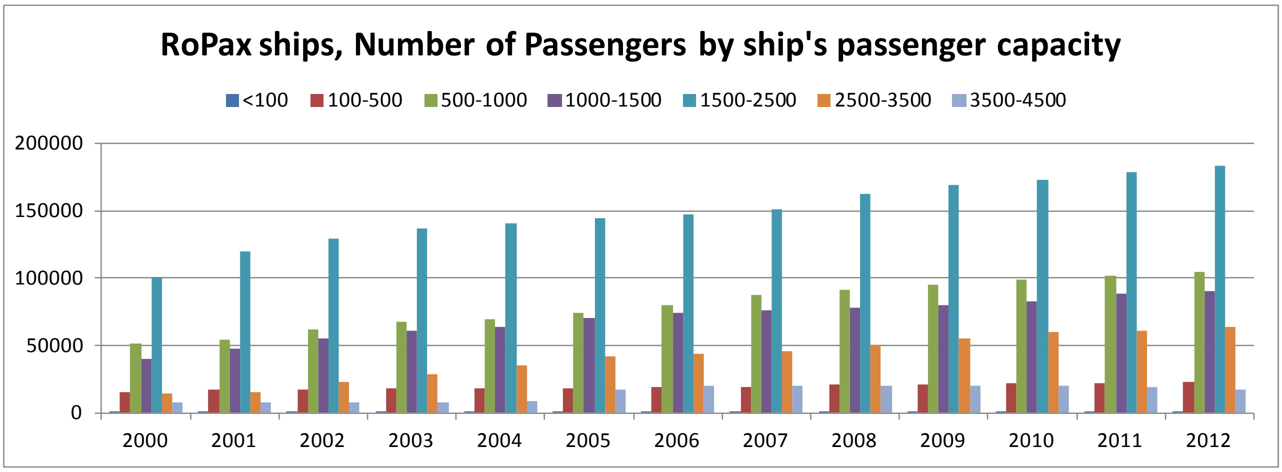


Fig. 4.7: Number of Passengers per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

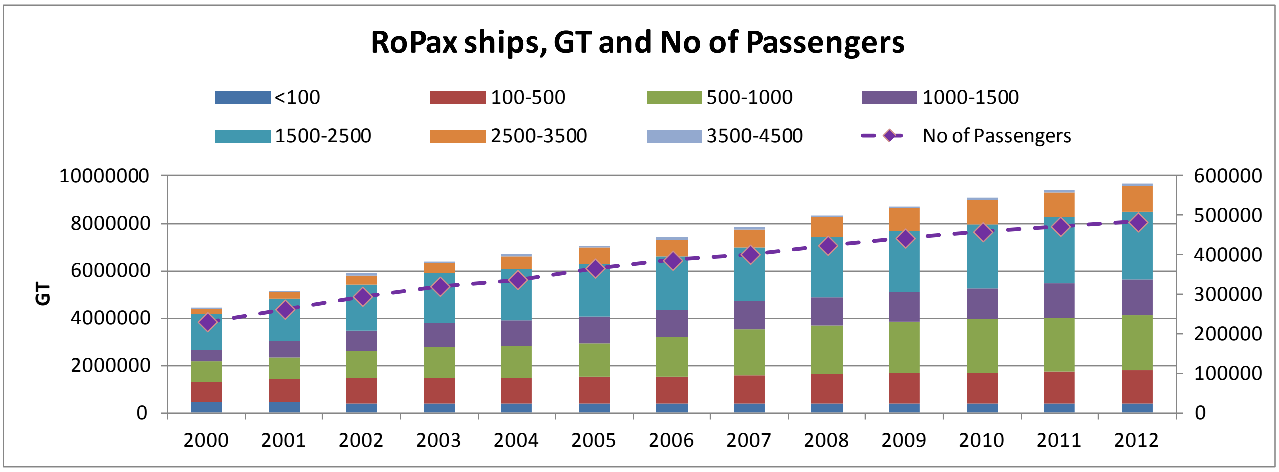


Fig. 4.8: GT and Number of Passengers per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

B.5 ROPAXRAIL SHIPS

The fleet at risk between 1982 and 2012 of RoPaxRail ships satisfying the selection criteria with respect to length, gross tonnage and year of delivery was determined to 47 vessels of which ~94% were classed by an IACS society. The development of the fleet with respect to number of ships after 1990 is shown in Fig. 5.16. Comparison between Fig. 4.8 and Fig. 5.16 showed that RoPaxRail fleet was about one tenth of RoPax fleet (IACS class ships). The annual newbuilding rate of the last decade was between zero and two vessels.

The structure of the fleet with respect to gross tonnage, length and number of passengers is shown in Fig. 5.17, Fig. 5.18 and Fig. 5.19. Compared to RoPax ships (IACS classed), large RoPaxRail vessels with more than 30,000 GT were very few, and like RoPax the majority of vessels (~70%) had a gross tonnage between 10,000 and 30,000 (RoPax 46%). 25% of RoPaxRail ships were smaller than 10,000 GT which was also close to the figure for RoPax ships (IACS: 27%). The average ship size of the fleet with respect to gross tonnage increased since 1990 by about 25% or 3,000 GT to ~16,000 tonnes in 2012.

Also with respect to ship length the fleets of both ship types had large similarities and the typical ship had a length between 150 m and 200 m (RoPaxRail: ~60%; RoPax: ~47%). Finally, passenger capacity of both fleets showed similar characteristics and the vast majority of ships can transport between 200 and 1,500 passengers (RoPaxRail: ~80%; RoPax: ~75%).

The number of ship years per year for RoPaxRail ships over the period 1990 to 2012 is plotted in Fig. 5.20. In total 805 ship years were reported which is about 12% of the IACS RoPax fleet.

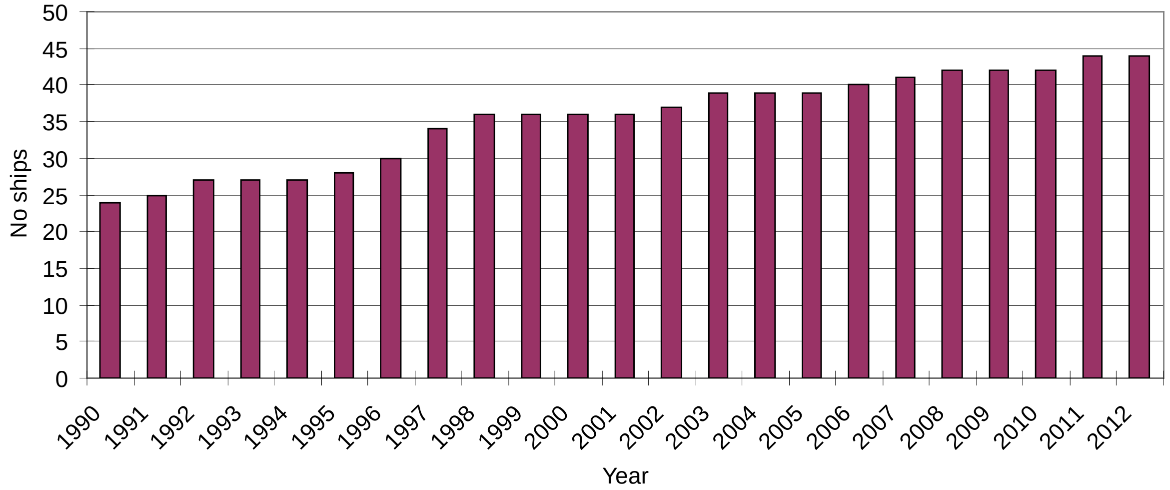


Fig. 5.1: Development of world RoPaxRail fleet after 1990 and IACS class ships only (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, no HSC).

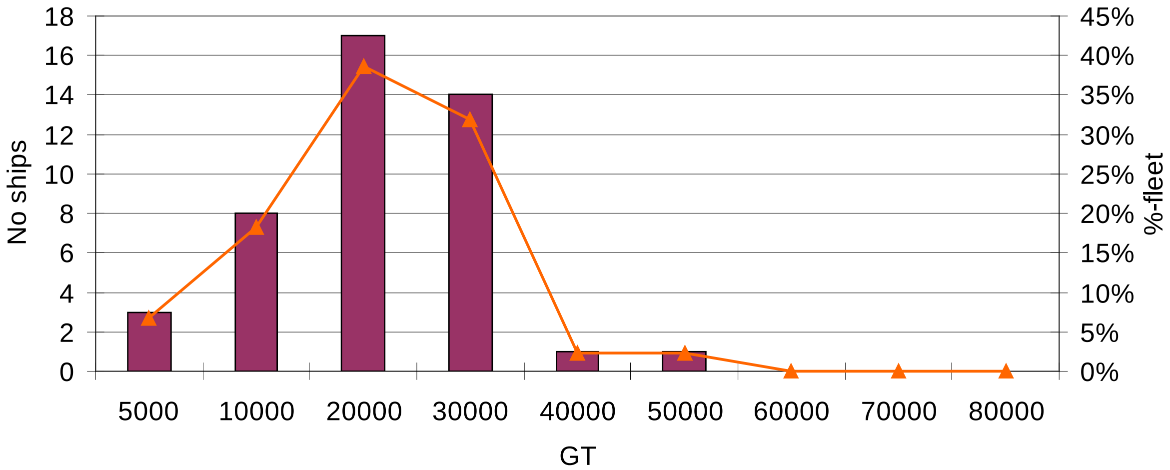


Fig. 5.2: Number of RoPaxRail ships in different size categories (GT) and relative distribution for IACS class ships.

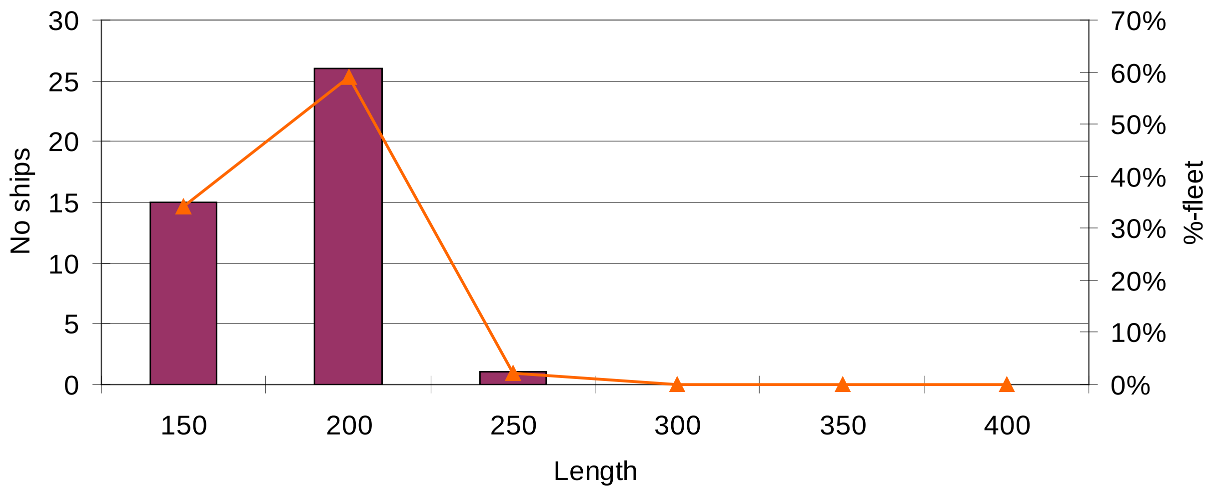


Fig. 5.3: Number of RoPaxRail ships in different size categories (LOA) and relative distribution for IACS class ships.

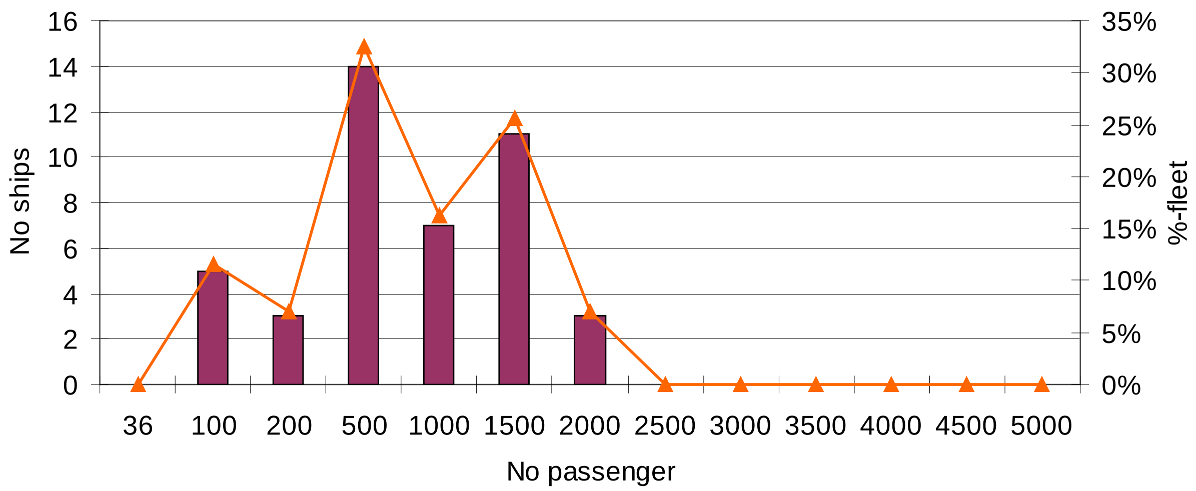


Fig. 5.4: Number of ships in different size categories (no passenger) and relative distribution for IACS class RoPaxRail ships.

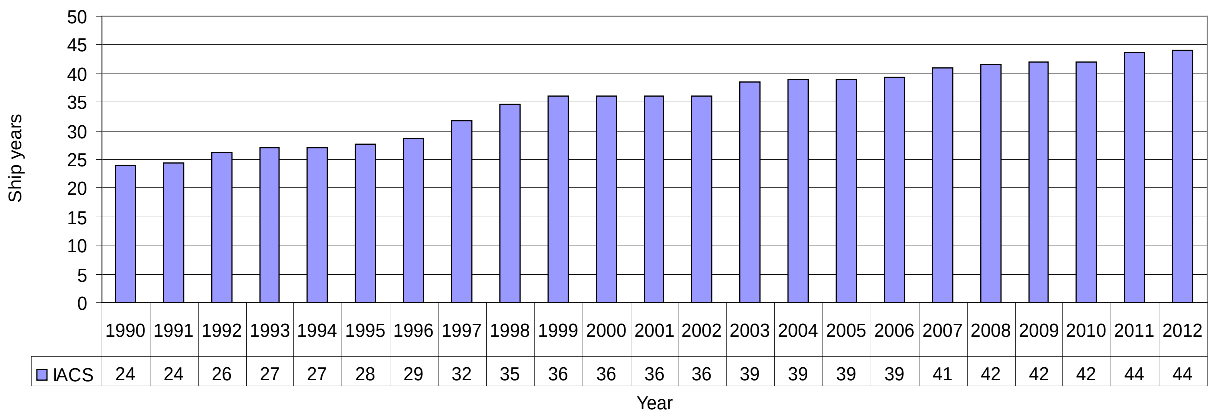


Fig. 5.5: Number of ship years per year for IACS class RoPaxRail ships.

Focusing on the second decade of time period analysis, namely 2000-2012, and categorising RoPaxRail ship fleet by ship's nominal passenger capacity, the following was observed (Fig. 5.21, Fig. 5.22 and Fig. 5.23):

- The major part of RoPaxRail fleet is coming from ships having a passenger capacity of 100-500 persons.
- The fleet of RoPaxRail ships carrying 1000-1500 passengers is the second largest part of RoPaxRail operational ship fleet.
- In annual base, the largest number of passengers is carried by RoPaxRail ships having a passenger capacity in the range of 1,000-1,500.

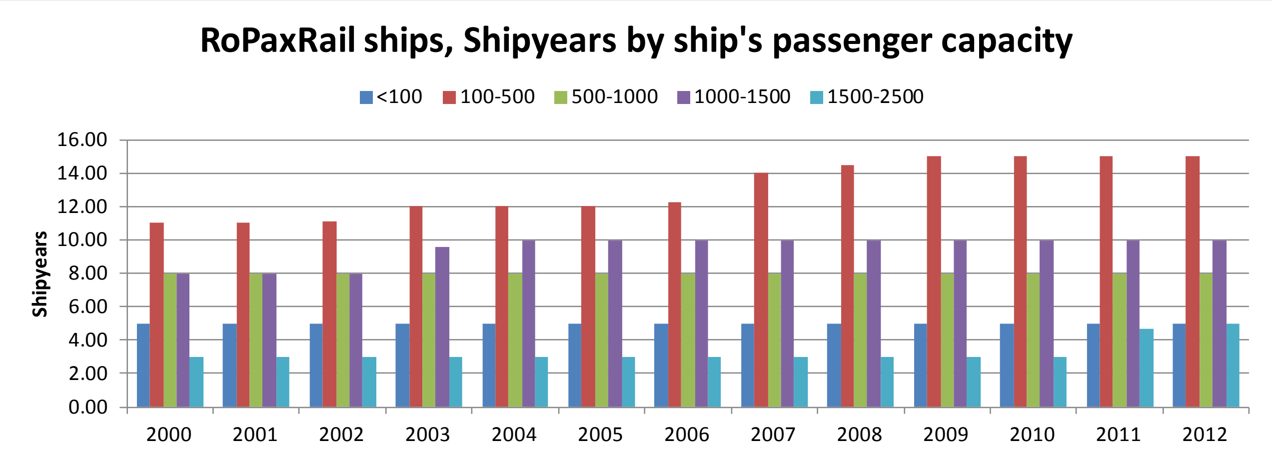


Fig. 5.6: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

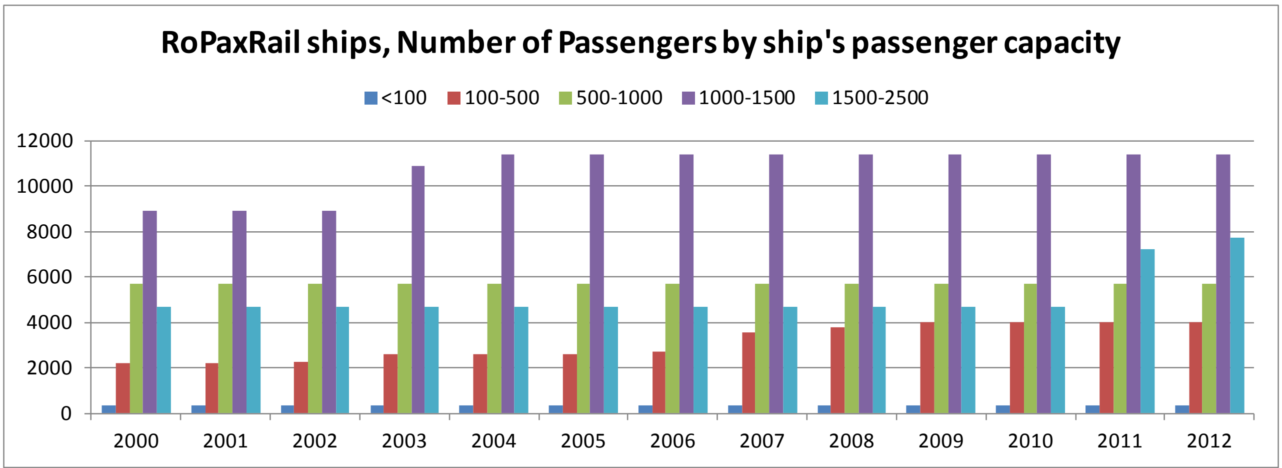


Fig. 5.7: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

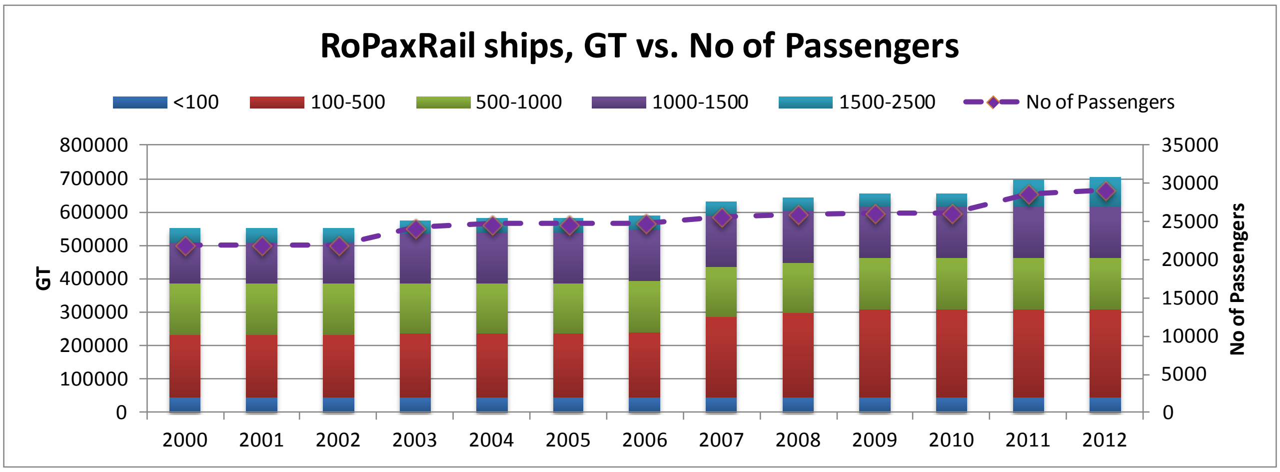


Fig. 5.8: Number of ship years per year for RoPax fleet (ships ≥ 1,000 GT; ≥ 80 m, built after 1981, excluding HSC and only IACS class) by ship's passenger capacity.

APPENDIX C

Information from Casualty Reports

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C.1. INTRODUCTION

Main information collected in the investigation of the casualty reports for the different ship types and distinguishing typical accident categories are summarised in this section. Like in GOALDS project the investigation was started with year 1994 and ended with 2012. The investigation considered characteristics like number of casualty reports, distribution of years, distribution over “IACS”, “Non-IACS” or “serious” and “not-serious”. It should be mentioned that the classification of casualties into serious and not-serious accidents strongly depends on the database used; for instance, in the LMIU database an event is considered serious if one of the following situations applies:

- Serious structural or machinery damage likely to result in a vessel being declared a constructive total loss
- Structural or machinery damage rendering a vessel unseaworthy or requiring extensive repairs
- Disablement or breakdown, resulting in a vessel requiring assistance of salvors or the abandonment of the voyage or a vessel being taken out of service for a reasonable period
- Any other incident resulting in damage considered serious enough to prevent a vessel from continuing in service.

Whereas the criteria in Lloyd Register Fairplay (today IHS Fairplay) use:

- Structural damage, rendering the ship unseaworthy, such as penetration of hull underwater, immobilization of main engines, extensive damage, etc.
- Breakdown
- Actual Total Loss
- Any other undefined situation resulting in damage or financial loss which is considered to be serious.

Furthermore, it was already observed in the GOALDS project that the ratio between serious and not serious casualties in LMIU be about 1:4, whereas the IHS Fairplay database contains more serious than not serious casualties. This difference is caused both by the approach of collection of casualty data, as well as by the different definition of the two categories.

The number of casualty reports and representative periods used for the risk analysis will be specified in section below.

C.2. CRUISE

Collision

For Cruise ships 23 collision accidents were reported consisting of 18 serious and 5 not serious classified accidents. All except one accident (not serious) were reported for IACS class ships. The distribution of accidents over the period under consideration is shown in Fig. 2.1. As shown nearly all accidents were reported for the period 2001 to 2012[1]. Vast majority of collision accidents (75%) occurred during operation in port/harbour/dock areas. Also, close to 79% of the recorded serious collisions happened in the last 6 years of the reporting period.

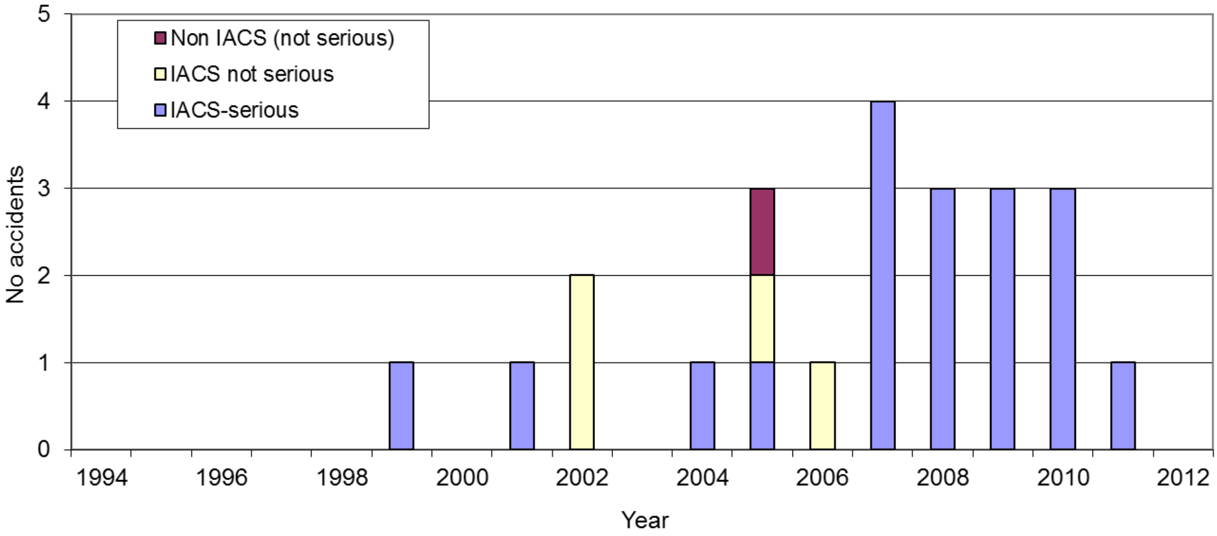

Fig. 2.1: Distribution of CN (serious and not serious collision) accidents between 1994 and 2012 distinguishing IACS and Non IACS cruise ships.

Contact

In total 33 contact accidents are considered of the IHS Fairplay database reports of which 24 were classified serious. Note that 17 (68%) of the serious contacts happened in the last 5 years of the reporting period [1]. Again the majority of accidents (24) occurred in port/harbour/dock areas. Like for the previous accident category the reports pertain to the period 2001 to 2012 (Fig. 2.2).

[1] The reasons for the recent increased number of *serious* CN and CTs may be attributed to increased traffic; however, there may be also some effect of different recording practice by the IHS Fairplay database provider, as observed in similar type of statistical analysis for other ship types (e.g. recent FSA on containerships)

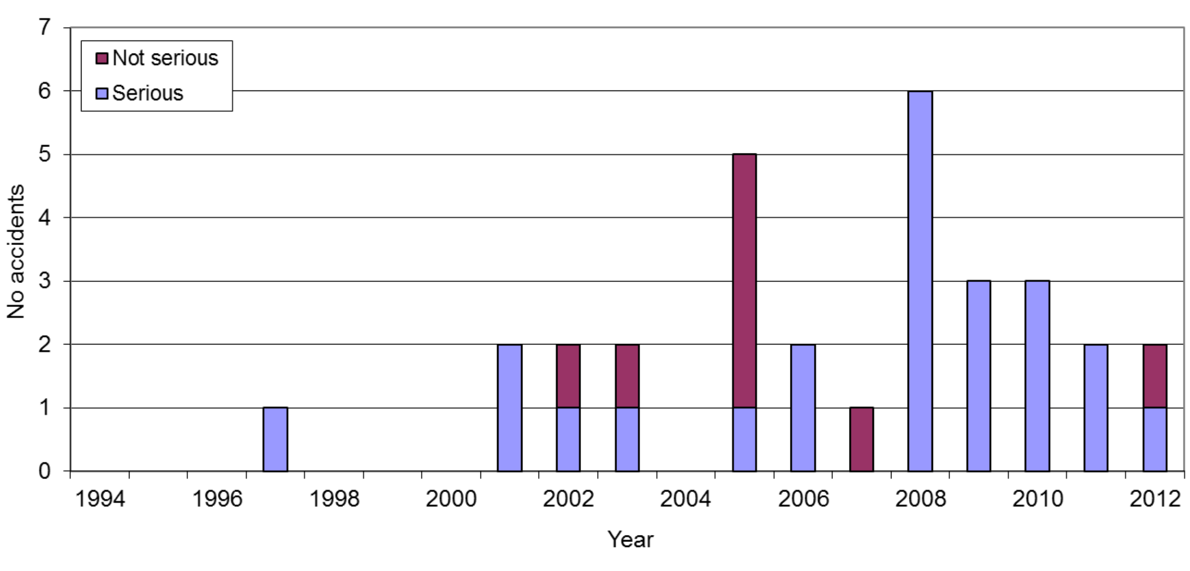

Fig. 2.2: Distribution of CT (serious and not serious contact) accidents for cruise ships between 1994 and 2012.

Grounding

For grounding IHS Fairplay database contains 30 reports of which 29 were for IACS class ships and 24 were serious (IACS 23). In contrast to collision and contact accident the accidents were more equally distributed over observation period (Fig. 2.3).

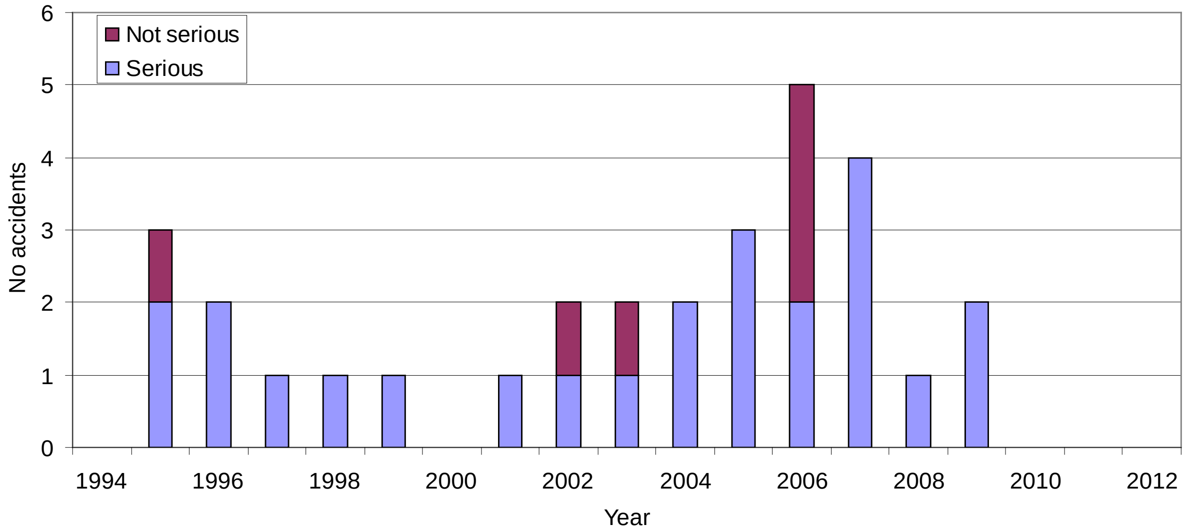

Fig. 2.3: Distribution of GR (serious and not serious grounding) accidents between 1994 and 2012 for cruise ships. One accident in 2008 was for a Non IACS ship.

Fire / Explosion

In total 36 fire/explosion accidents occurred in the period under consideration of which were 31 for IACS class ships and five for Non IACS class. The latter were all classified by IHS Fairplay as serious accidents whereas six for IACS class were in the category not serious. The detailed distribution over years is shown in Fig. 2.4. Like for groundings the accidents are mostly uniformly distributed over the whole period under consideration.

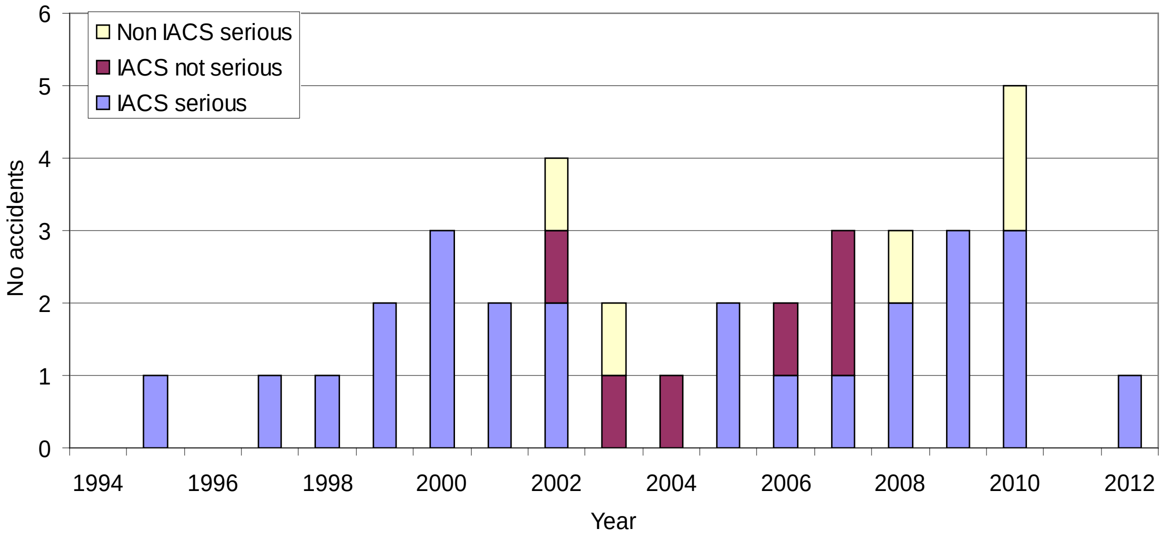

Fig. 2.4: Distribution of FX (serious and not serious) accidents between 1994 and 2012 for cruise ships.

Foundered

Only one report for a foundering accident of cruise ships in 2004 exist, which occurred in dock under construction and therefore is not considered in this investigation.

C.3. PAX

For the sample of world passenger ship fleet selected using the criteria summarised above only two collisions, one grounding and one fire/explosion were reported. Of these only one collision (1998, serious) and one fire/explosion (2012, serious) were for IACS class ships. The fire/explosion accident was during repair work and therefore is not considered further.

C.4. ROPAX

Collision

In total 92 collision accidents were reported for the period 1994 to 2012 of which 74 were of IACS class ships. As shown, the annual number of accidents significantly increased after 2002 (Fig. 4.1). 65 of all accidents were classified serious (54 “IACS”).

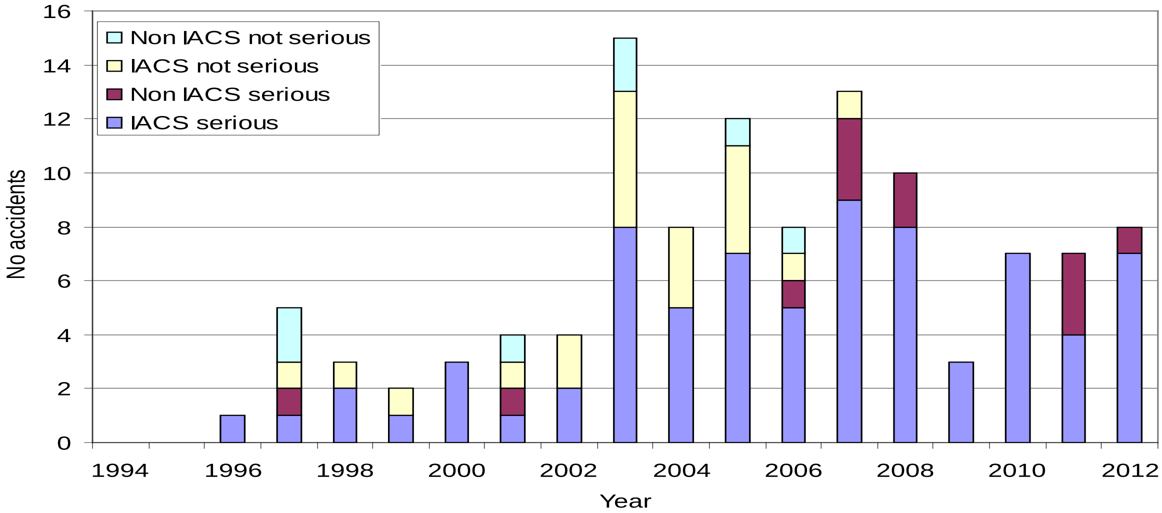

Fig. 4.1: Distribution of CN ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

Contact

IHS Fairplay reported 112 contact accidents between 1994 and 2012 ("IACS": 83) of which 102 were classified serious ("IACS": 75). The distribution over this period is shown in Fig. 4.2. Like for CN accidents significant differences between before and after the year 2000 were observed. For the period 1994 to end of 1999 IHS Fairplay reported only one contact accident, whereas for the following interval 111 were reported, thus the number had significantly increased like with the collisions[2].

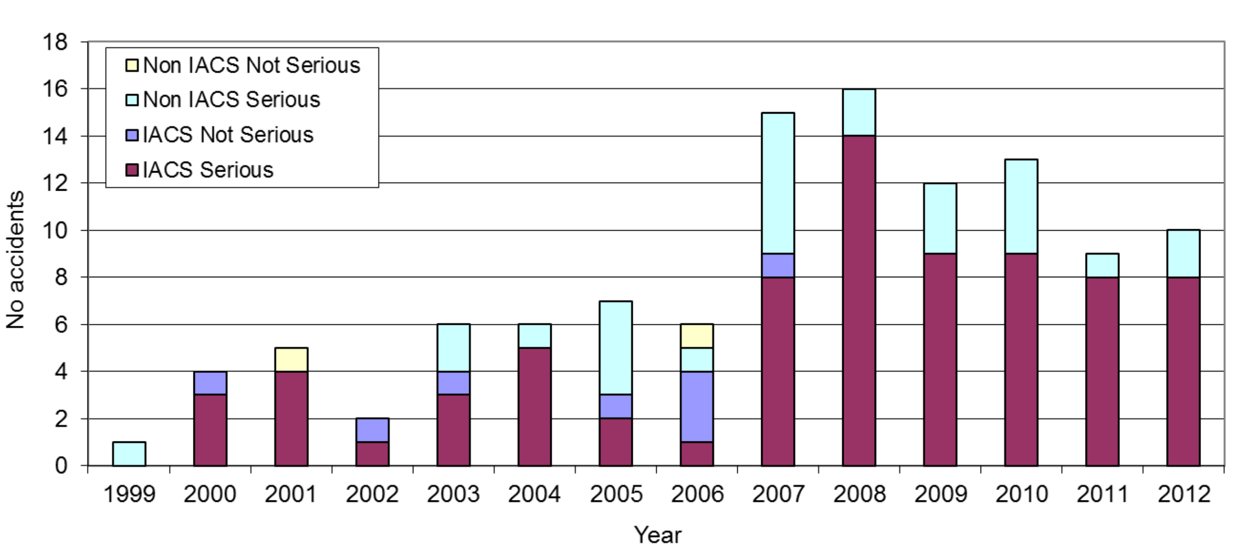

Fig. 4.2: Distribution of CT ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

[2] As mentioned before the reasons for the recent increased number of *serious* CN and CTs may be attributed to increased traffic; however, there may be also some effect of different recording practice by the IHS Fairplay database provider, as observed in similar type of statistical analysis for other ship types (e.g. recent FSA on containerships)

Grounding

55 grounding accidents were reported of which 34 were for IACS class ships (28 serious). For remaining Non IACS class ships 18 serious accidents reports were available. Of the 28 serious accidents only three were in 1990s. Again the number of reported accidents had significantly increased in the last decade.

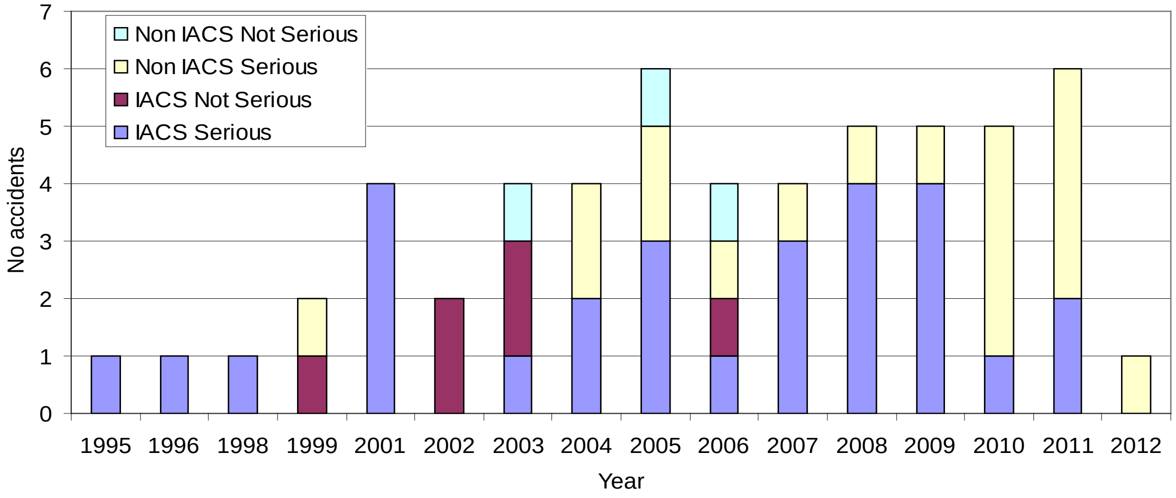

Fig. 4.3: Distribution of GR ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

Fire / Explosion

In total 62 Fire/Explosion accidents were reported for RoPax vessel (IACS and other) of which 51 were for IACS class ships. Vast majority (56) of accidents were classified "serious" by IHS Fairplay. The distribution of accidents between 1994 and 2012 is shown in Fig. 4.4.

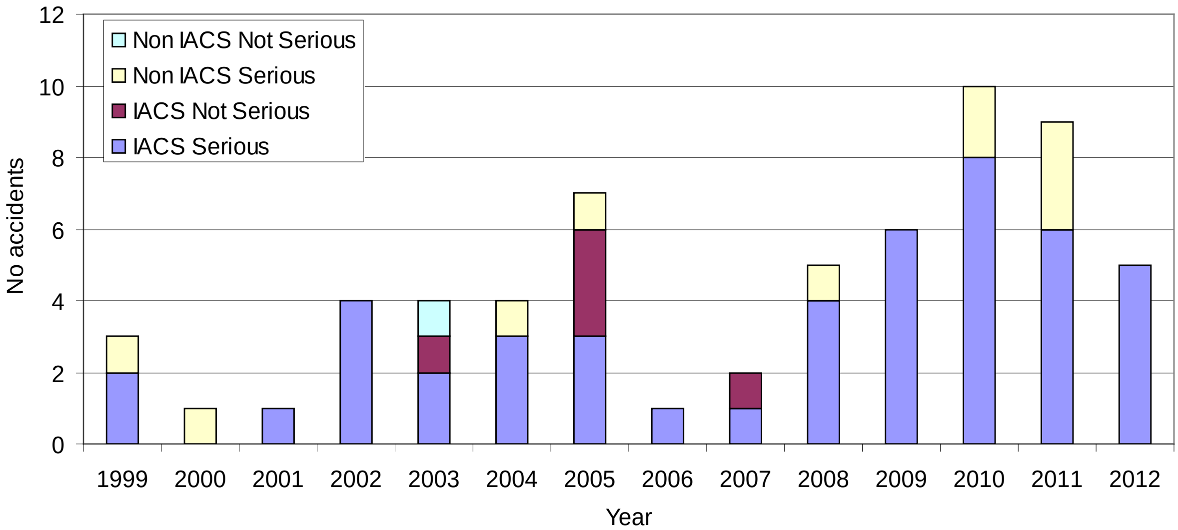

Fig. 4.4: Distribution of FX ("serious" and "not serious") accidents between 1994 and 2012 distinguishing "IACS" and "Non IACS" RoPax ships.

Foundered

For foundering of RoPax, three casualty reports were provided by IHS Fairplay with all belonging to IACS class ships (2002, 2009 and 2012). Two of the ships were relatively small with passenger capacity of 200 or less. Two of the accidents with large ships occurred in harbour, one whilst under repair and the other at anchorage.

Hull / Machinery

In the SAFEDOR FSA for RoPax, a risk model for flooding was used considering all events where ships lost water tightness, e.g. due to leaving doors open (e.g. *Herald of Free Enterprise* type of accident, in year 1987) or structural failure (e.g. *Estonia* type of accident, in year 1994). In the IHS Fairplay database, casualty reports relating to this kind of risk may be assigned to both categories foundering (see previous section) and hull/machinery. IHS Fairplay contains 164 casualty reports of IACS class ships engaged in hull and machinery incidents. Only 21 of them are clearly related to hull damage and are distributed over time, as shown in Fig. 4.5. All were reported for the period 1997 to 2012.

A more detailed analysis of damage description given by IHS Fairplay showed that five of these accidents were damages of "Ramp" or "internal Ramp" with no potential of loss of water tightness, three were damages of bridge windows, one damage occurred in dock and five collect minor cracks or blocked doors (closed).

Thus, seven casualty reports remained with potential of loss of water tightness and subsequent flooding ('06: 1, '07: 2, '09: 3; '10: 1); they refer to four door damages in heavy weather and en route, one hull damage in open sea, one heavy weather damage and one ramp/hold damage in heavy weather[3].

As earlier observed, the lack of recordings in earlier years of the reporting period and the increased data after year 2004 may be more attributed to the change of recording practice of the IHS database provider, rather than to genuine risk factors.

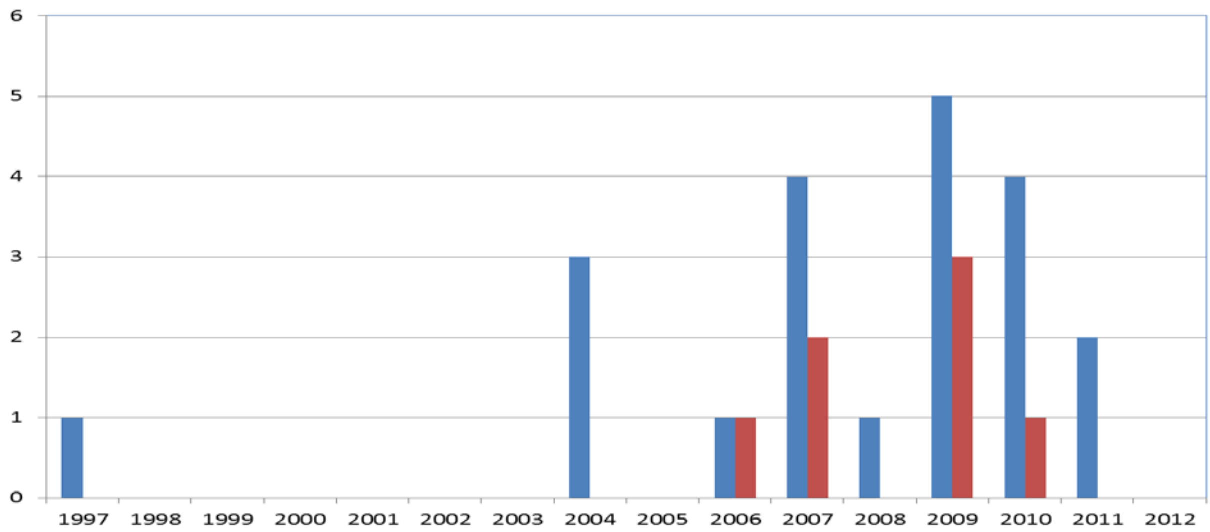

Fig. 4.5: Distribution of serious hull accidents between 1994 and 2012 for IACS class ships.

[3] In most cases, heavy weather was the initial cause of the casualty, but in none of the above cases flooding of the car deck took place (no WOD damage stability problem)

C.5. ROPAX RAIL

Collision

In total four accidents were reported for the period 1998 and 2012 (1998: two; 2009: one; 2012: one), of which one is categorised serious. All ships belong to category "IACS class".

Contact

For accident category contact ten accidents were reported, all serious and between 1997 and 2012 which were distributed over this period as shown in Fig. 5.1. All except that of 2003 are in the IHS Fairplay category "serious" and belong to category "IACS class".

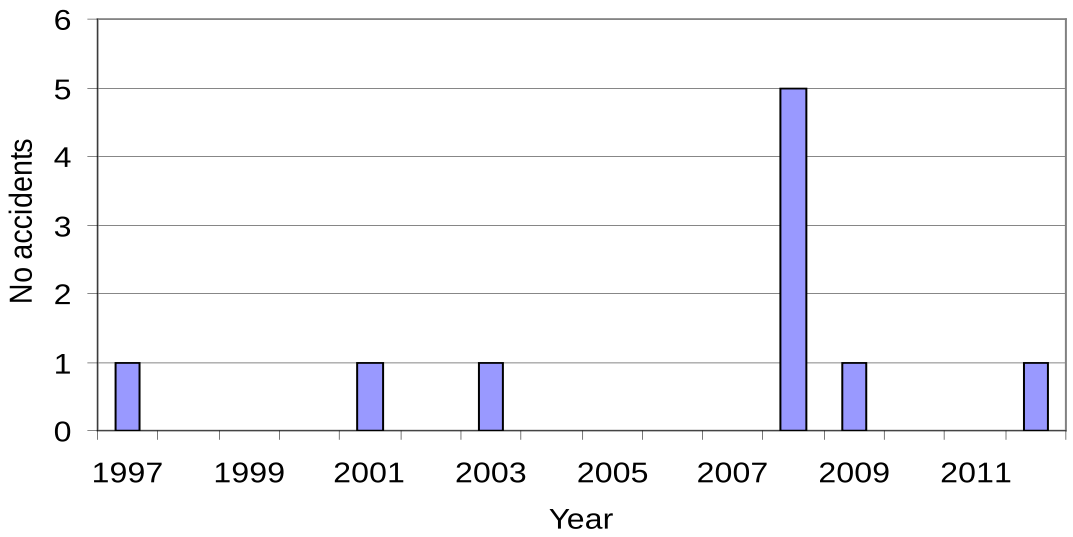

Fig. 5.1: Number of contact accidents ("serious" for RoPaxRail ships (all ships IACS class)

Grounding

Only one serious accident in 2005 is reported (IACS class).

Fire / Explosion

Between 1991 and 2012 four Fire/Explosion accidents were reported for IACS Class ships all of them classified serious.

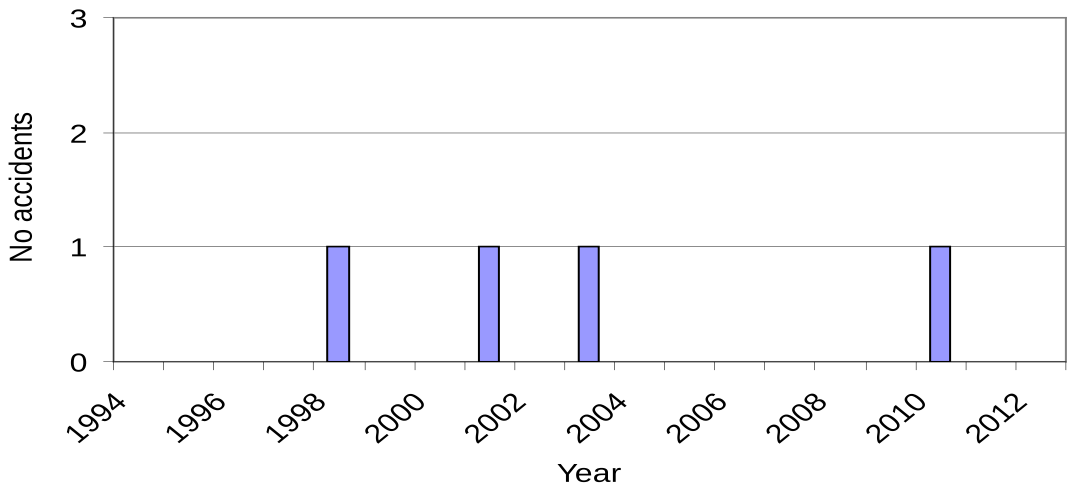

Fig. 5.2: Number of fire / explosion accidents per year for RoPaxRail ships

Foundered

No casualty reports provided by IHS-Fairplay.

Hull / Machinery

IHS Fairplay provides no hull damage related casualty reports for RoPaxRail ships.

APPENDIX D

Considering Uncertainty in Cost-Benefit Assessment

Table of contents

D.1 COLLISION

D.1.1 Initial accident frequency

Initial accident frequency was exclusively determined using the casualty reports considered in the enhanced GOALDS database and number of ship years. For the period 2000 to 2012 17 collision accidents were reported for cruise ships, respectively 53 for RoPax. The fleet at risk operating in this period corresponds to 2,673 ship years (cruise) and 5,328 for RoPax. Therefore, initial accident frequency calculated was 6.36E-03 (cruise) and 9.95E-03 (RoPax).

The confidence interval for this estimation was calculated using the approach by Engelhardt (1994) and the assumption that collision accidents are Poisson distributed. For the collision of cruise ships the respective 90% confidence interval is 4E-03 to 9.5E-03.

As shown by the characteristic values (6.36E-03 and [4E-03; 9.5E-03]) determined using the approach by Engelhardt the distribution is not symmetric to the mean value and therefore for approximation of the confidence interval the Log-Normal distribution was selected. For the Log-Normal distribution the standard deviation σ is calculated by means of the limits for the confidence interval and the mean value. However, it was not possible to meet exactly the characteristic values given above. The approximation for cruise ships is shown in Fig. 1.1. This distribution is an approximation which deviates slightly from bounds of the 90% confidence interval estimated based on Engelhardt.

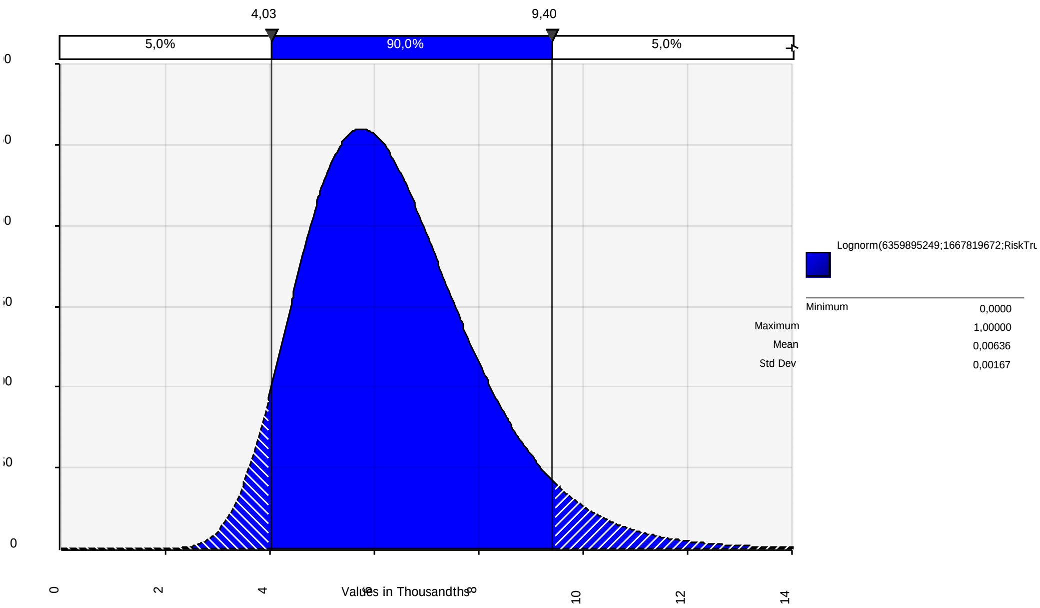

Fig. 1.1: Gauss-Normal distribution for initial accident frequency (cruise) with 90% confidence interval.

D.1.2 Struck/Striking

Similar to the approach above the distribution was estimated for the node struck/striking in the collision risk model. In this case the uncertainty was approximated by a Gauß-Normal distribution. The estimation is shown in Fig. 1.2 was based on 62 casualty reports with 32 struck ships.

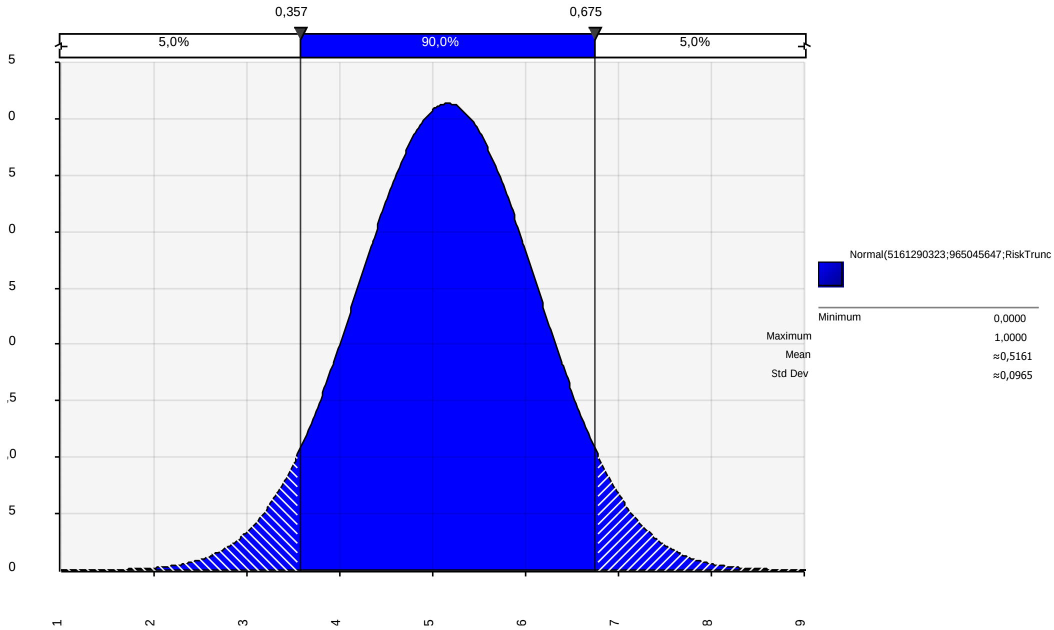

Fig. 1.2: Gauss-Normal distribution for ship being struck with 90% confidence interval.

D.1.3 Operational Status

Similar to struck/striking the probability distribution for the operational status “terminal” was estimated. The 90% confidence interval for having a collision in “terminal” area was between 1.4E-03 per ship year and 2.9E-03 per ship year. Characteristics were calculated based on 32 casualty reports. The truncated Gauss-Normal distribution is shown in Fig. 1.3. This distribution was truncated because dependent probabilities must be between 0 and 1.

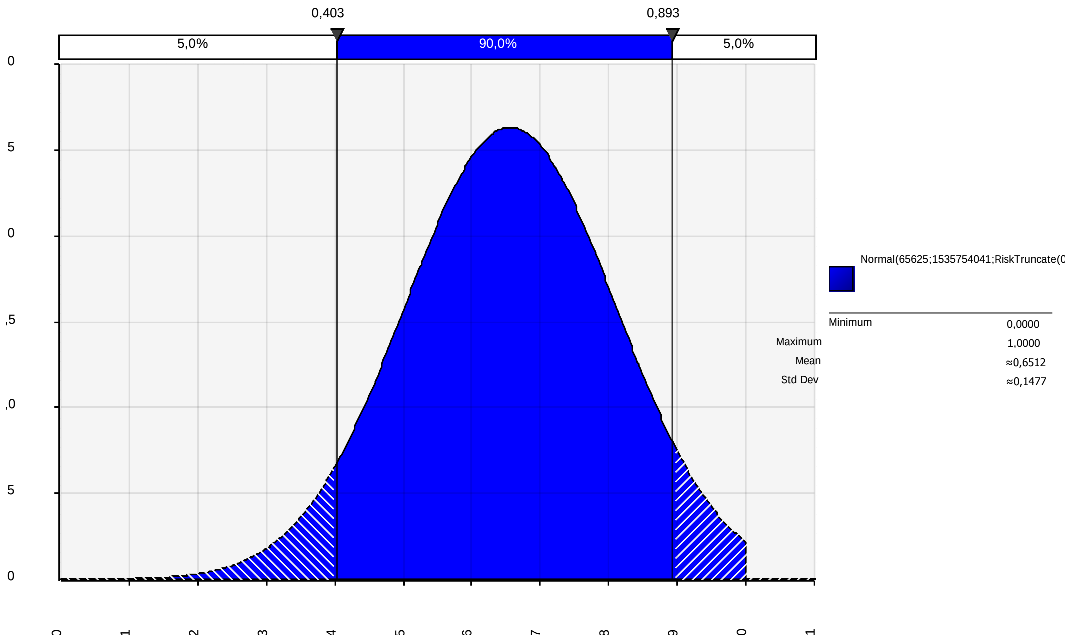

Fig. 1.3: Gauss-Normal distribution for collision in “terminal” area with 90% confidence interval.

D.1.4 Water Ingress

Two distributions for the probability of water ingress due to collision in operational areas "terminal" and "limited waters/en route" were calculated and uncertainty approximated by Gauss-Normal distributions as shown in Fig. 1.4 and Fig. 1.5. The mean values for the dependent probabilities are 7% ("terminal") and 33% ("limited waters/ en route") respectively.

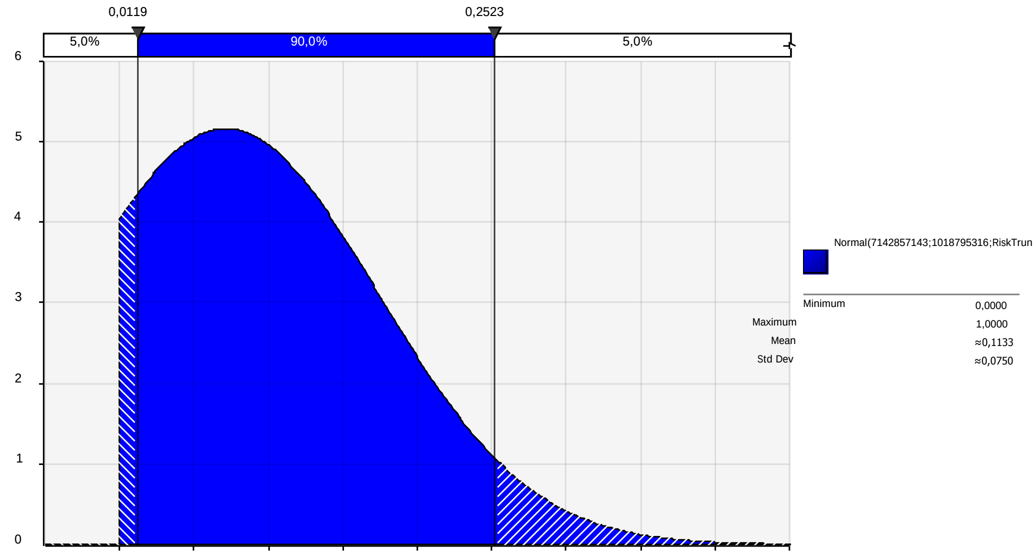

Fig. 1.4: Gauss-Normal distribution for water ingress after collision in "terminal" area.

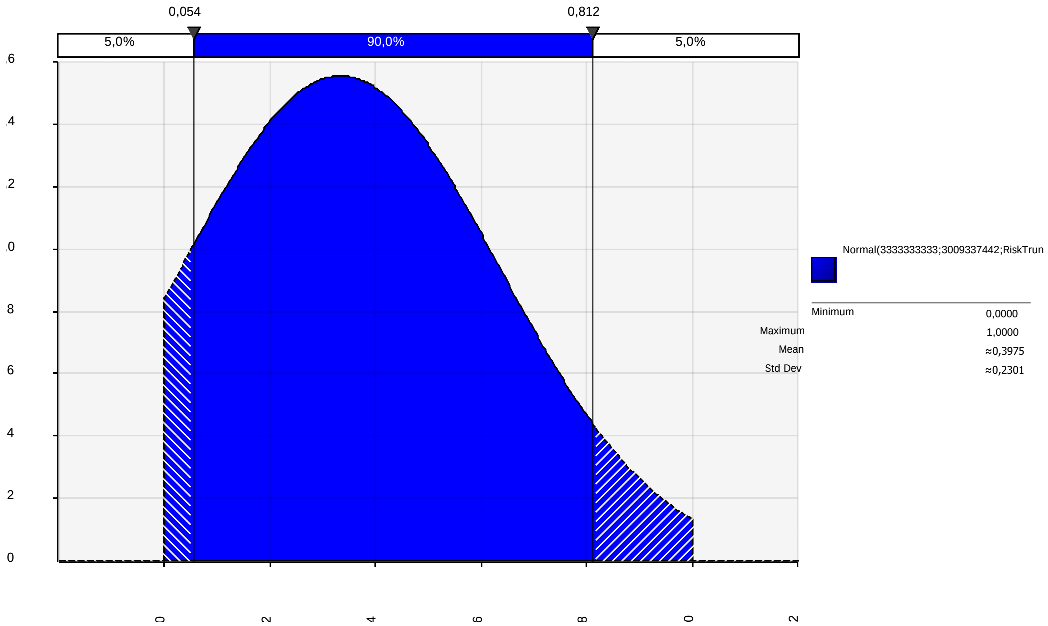

Fig. 1.5: Gauss-Normal distribution for water ingress after collision in "limited waters/en route" area.

D.1.5 Sinking

The dependent probability of sinking is estimated using the SOLAS 2009 damage stability requirement assuming that the R-Index represents the dependent probability for a ship surviving a collision damage that leads to water ingress (breach of hull).

For both dependent probabilities no uncertainty analysis was conducted.

D.1.6 Fatalities

It is obvious that the assumed fatality rate (percentage of fatalities given that a scenario occurs) has a significant influence on the collision risk of both ship types. For example, the current collision risk model leads to, for the large cruise ship with a maximum 6,730 persons (assuming year-round 90% occupancy) on board, a PLL of 5E-02 fatalities per ship year using the assumption that 5% fatalities occur in slow sinking and 80% in fast (capsizing/sinking). Reducing the fatality rate for fast sinking to 60%s would decrease the overall risk by 13%. Similar effect would be seen from changes in the year-round occupancy rates, which are highly market, seasonal and ship type/category dependent.

The fatality rates represent average (representative) consequences for the scenarios slow and fast sinking. The rates were specified in GOALDS project by expert judgement considering casualty reports, observation in model tests as well as numerical investigations (including simulations) on the stability behaviour of ships after water ingress. Representative consequences mean that all possible outcomes are merged into one, i.e. all possible fatality rates for ship sinking after collision are merged into the scenarios slow and fast sinking.

For this investigation two mean fatality rates of 5 and 80% were used. For both distributions were estimated for considering various possible consequences. These distributions are shown in Fig. 1.6 and Fig. 1.7.

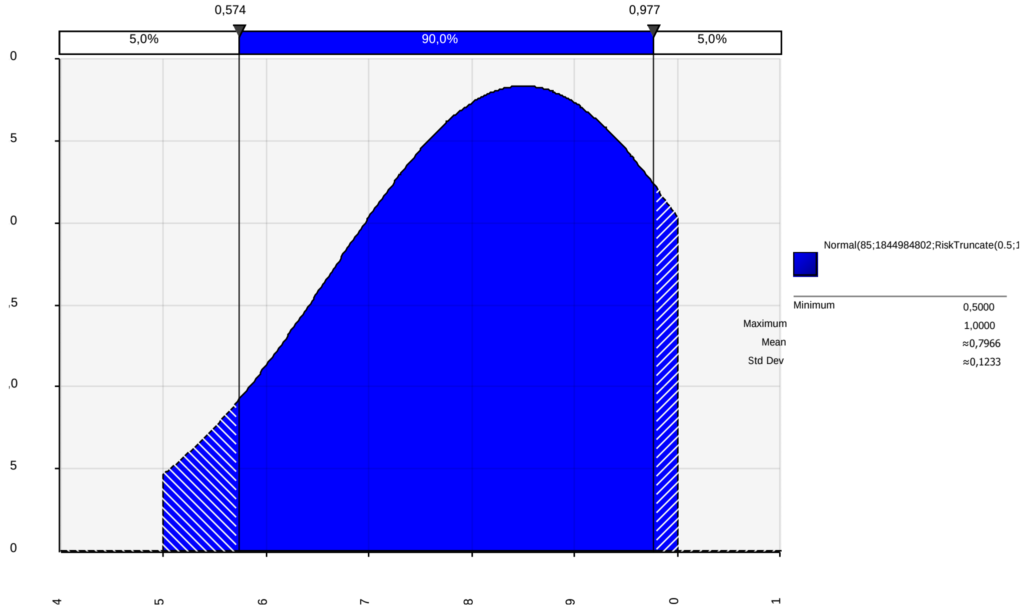

Fig. 1.6: Gauss-Normal distribution (truncated) used for the probability of fatality rate for fast sinking.

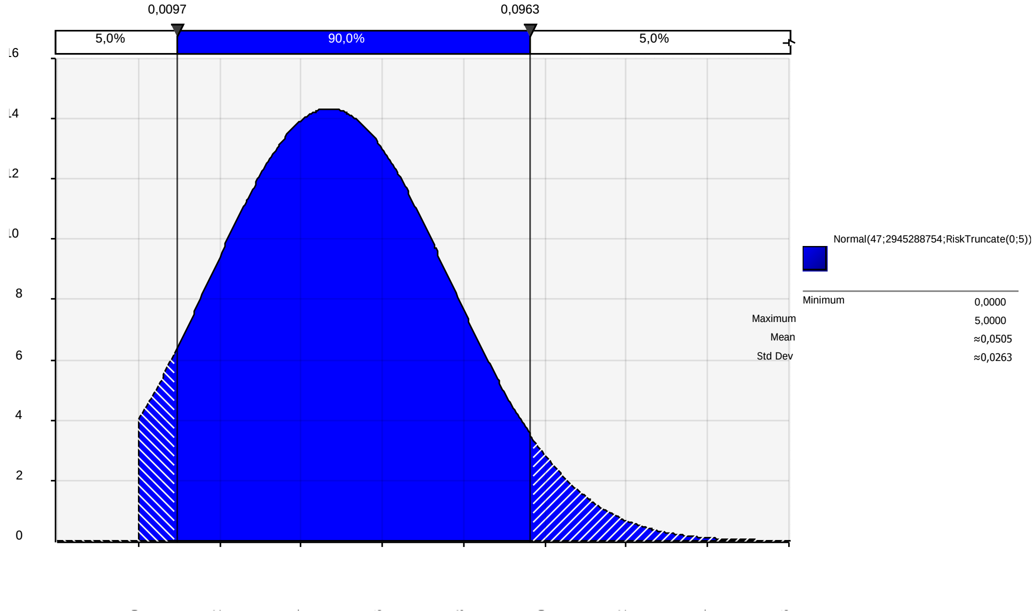

Fig. 1.7: Gauss-Normal distribution (truncated) used for the probability of fatality rate for slow sinking.

D.2 GROUNDING/CONTACT

Similar to collision uncertainty in parameters of the risk model for grounding contact were approximated by distributions. These distributions were estimated based on the casualty reports.

D.2.1 Initial accident frequency

For initial accident frequency the distribution was estimated on 42 casualty reports for Cruise ships and 113 for RoPax. The distributions are shown in Fig. 2.1 and Fig. 2.2.

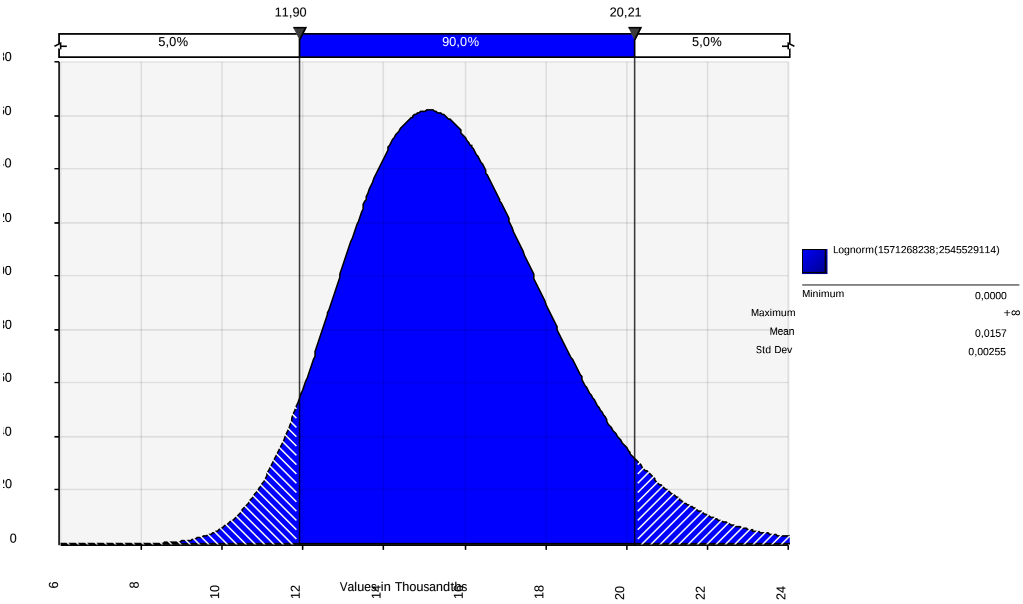

Fig. 2.1: Log-Normal distribution for initial grounding/contact accident frequency of Cruise ships

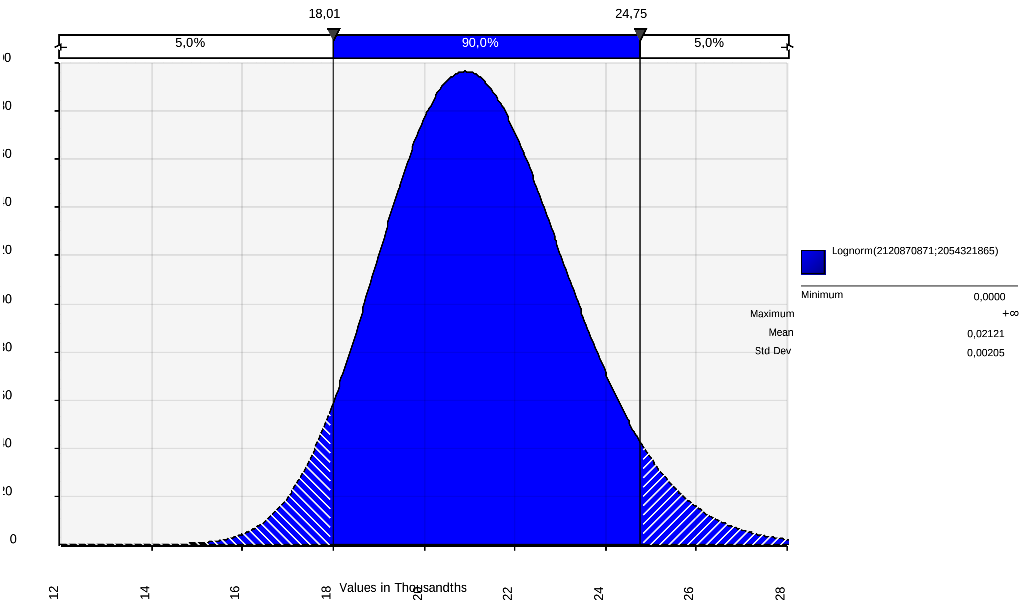

Fig. 2.2: Log-Normal distribution for initial grounding/contact accident frequency of RoPax ships

D.2.2 Operational State

The distribution for operational state was estimated on 217 casualty reports for Cruise and RoPax together, 125 for terminal and 92 limited waters and en route. The distribution for terminal area is plotted in Fig. 2.3.

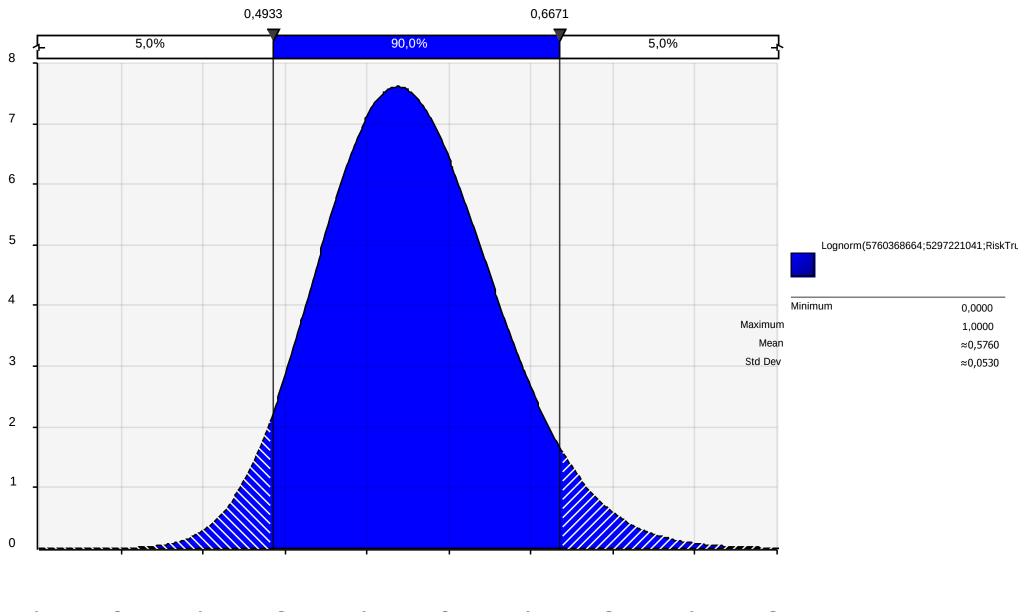

Fig. 2.3: Log-Normal distribution for grounding/contact in terminal area

D.2.3 Damage Location

The distribution for the "damage location" was estimated on 75 casualty reports for "terminal area" and 43 for "en route/limited waters" for Cruise and RoPax ships. The distributions are shown for accidents in terminal area in Fig. 2.4 and Fig. 2.5 for "en route/limited waters".

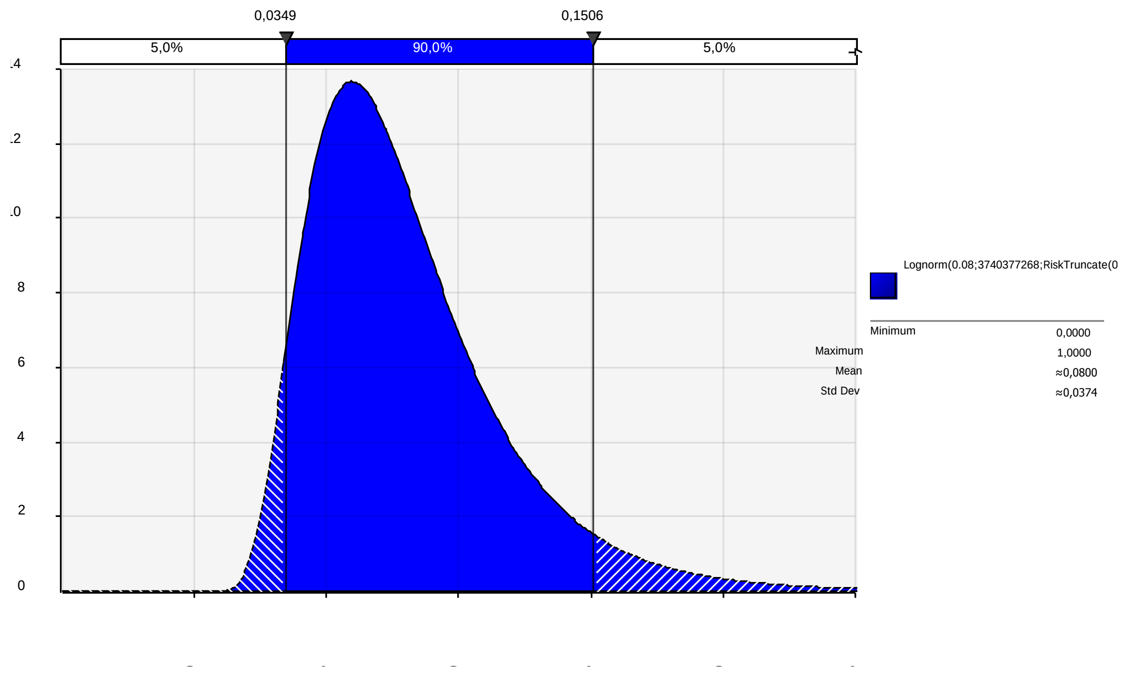

Fig. 2.4: Log-Normal distribution for contact point of accidents occurred in terminal area

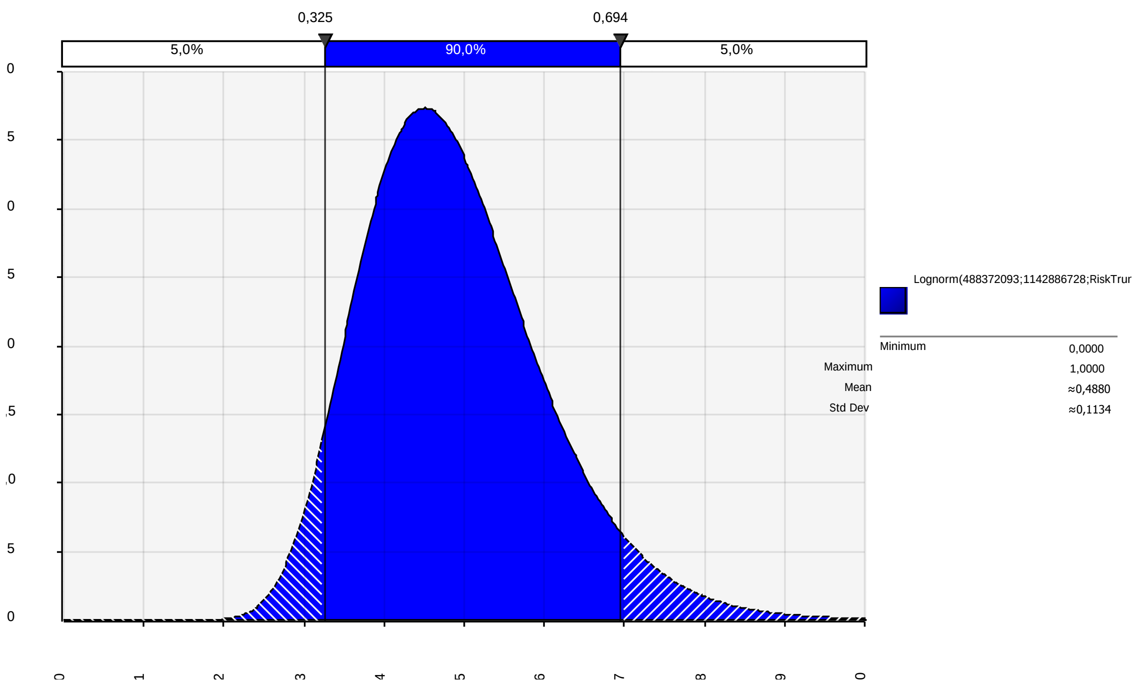

Fig. 2.5: Log-Normal distribution for contact point of accidents occurred en route and limited waters

D.2.4 Sea Bottom

In the scenarios for side damage the node "sea bottom" was not considered. For bottom damages operational area was distinguished. Only few casualty reports allowed any reasoning of sea bed conditions, i.e. five for terminal area and 21 for other areas. Based on this information distributions were estimated and plotted in Fig. 2.6 and Fig. 2.7.

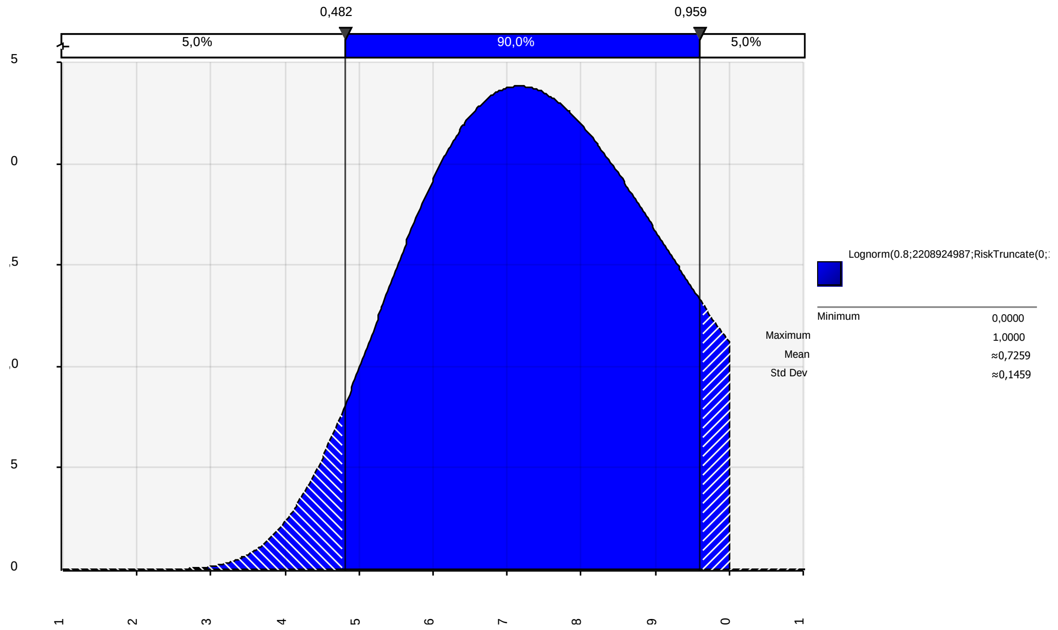

Fig. 2.6: Log-Normal distribution for sea bed and accidents in terminal waters

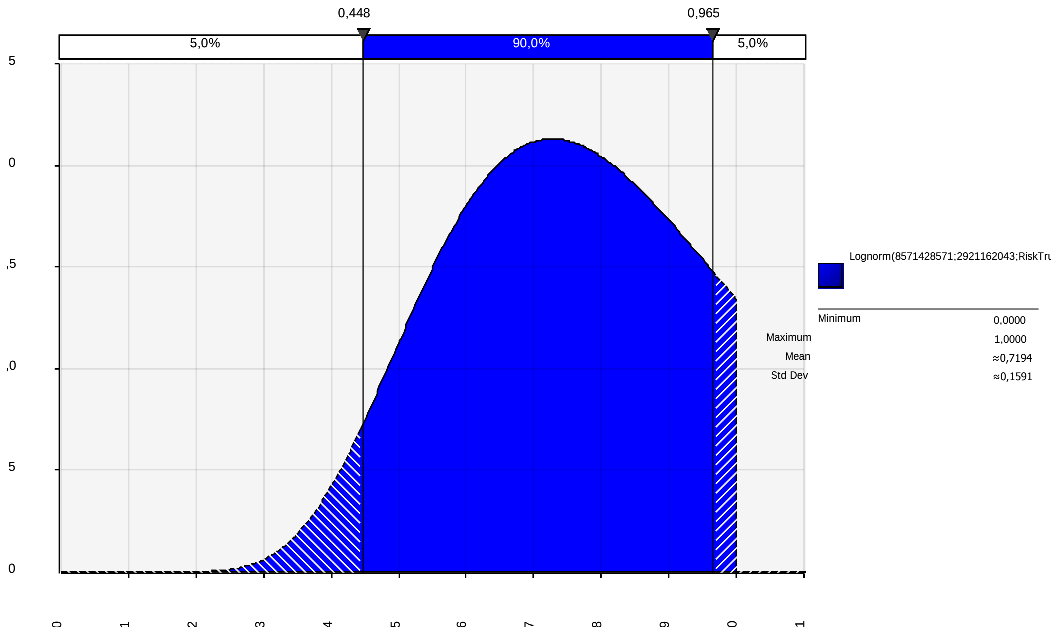

Fig. 2.7: Log-Normal distribution for sea bed of accidents occurred en route and limited waters

D.2.5 Hull Breach

Each of the branches of the Event Tree considered the node "hull breach" but with different values. Only for three of them, casualty reports were available and distributions were estimated, which are hull breach for bottom damage in terminal area and, side and bottom damages in other operational states. The estimated distributions are shown in Fig. 2.8, Fig. 2.9 and Fig. 2.10

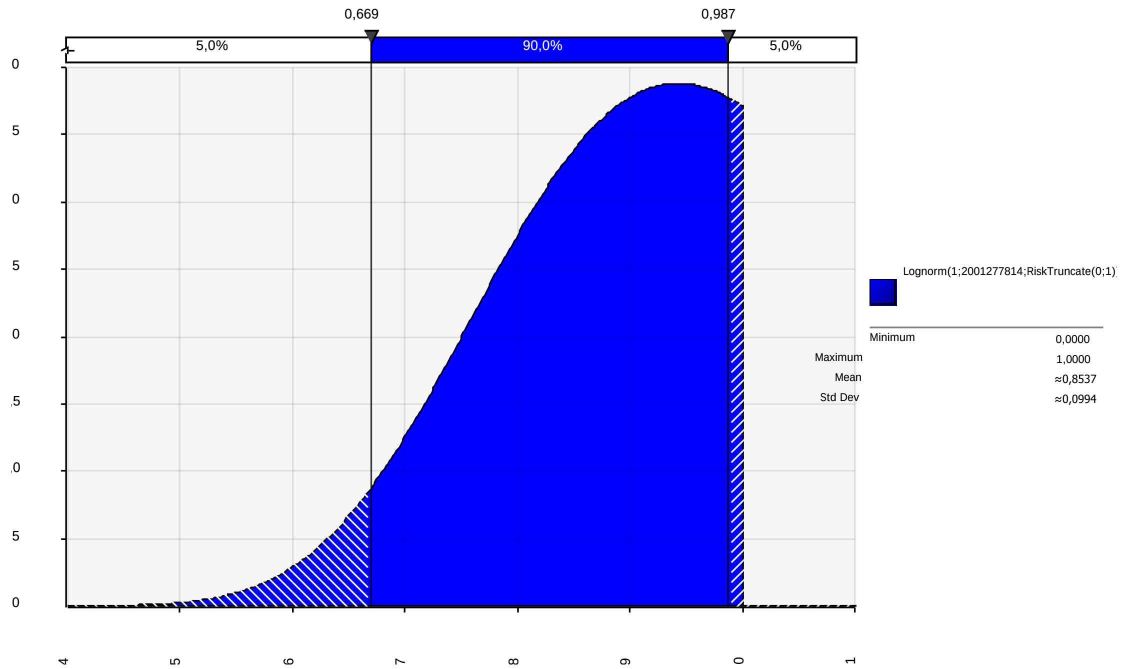

Fig. 2.8: Log-Normal distribution for hull breach after bottom damage and accidents in terminal waters

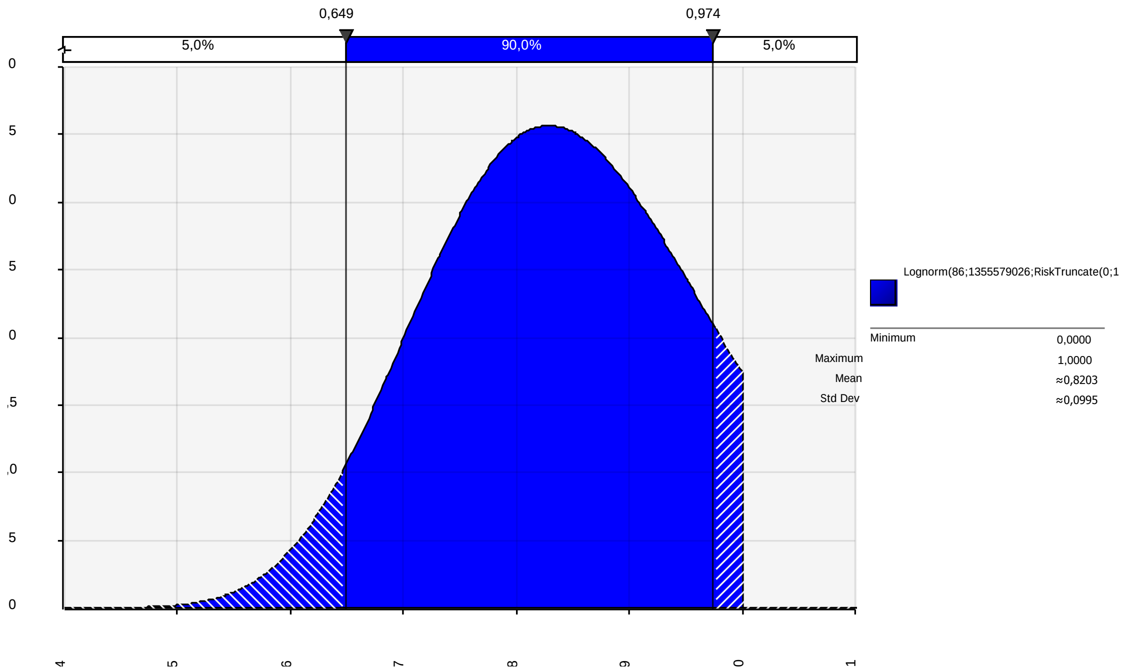

Fig. 2.9: Log-Normal distribution for hull breach after side damage and accident en route and limited waters

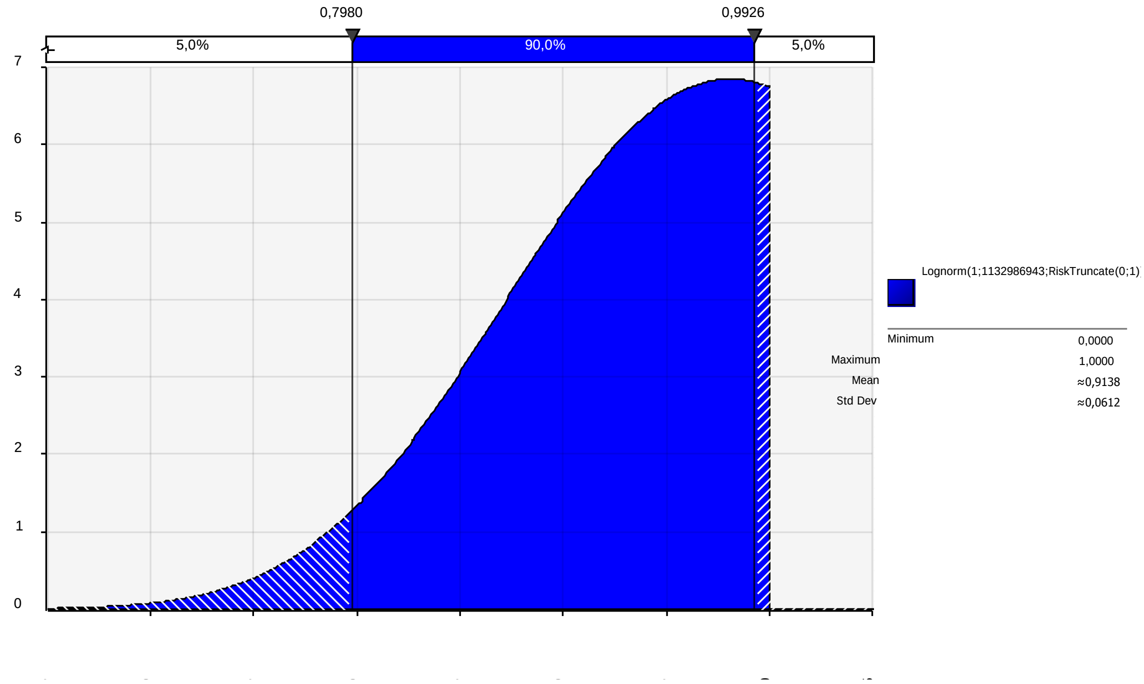

Fig. 2.10: Log-Normal distribution for hull breach after bottom damage and accident en route and limited waters

D.2.6 Water Ingress

The node "water ingress" exists only in the scenarios for side damage. The distributions were estimated on 27 casualty reports for terminal area and 13 for other operational states. Both distributions are shown in Fig. 2.11 and Fig. 2.12.

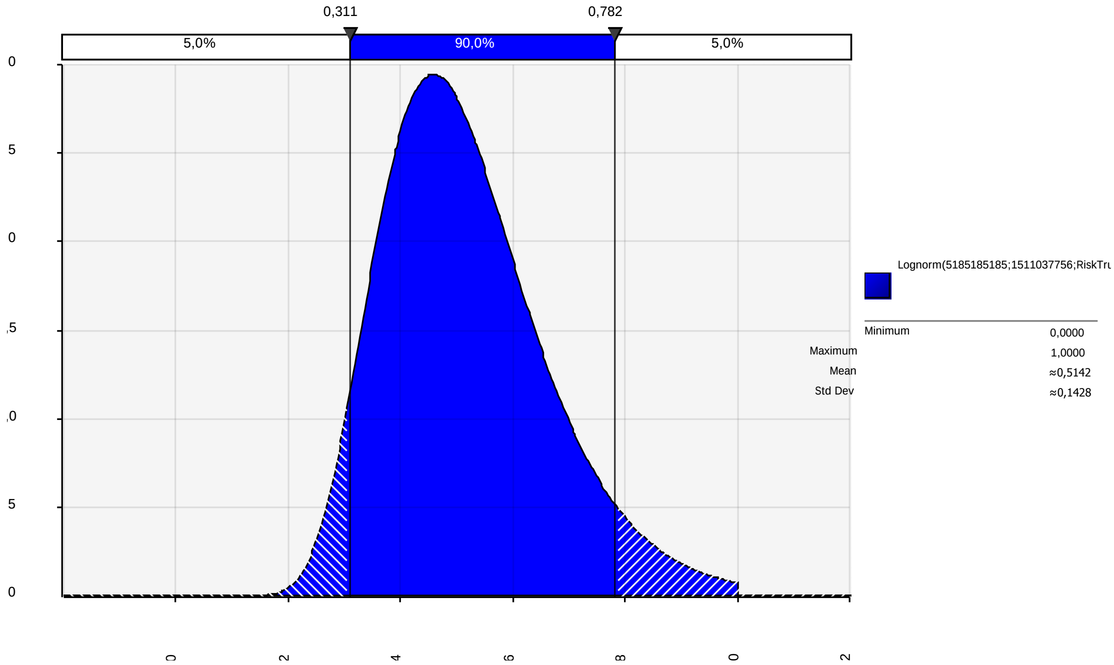

Fig. 2.11: Log-Normal distribution for water ingress after side damage and accident in terminal area

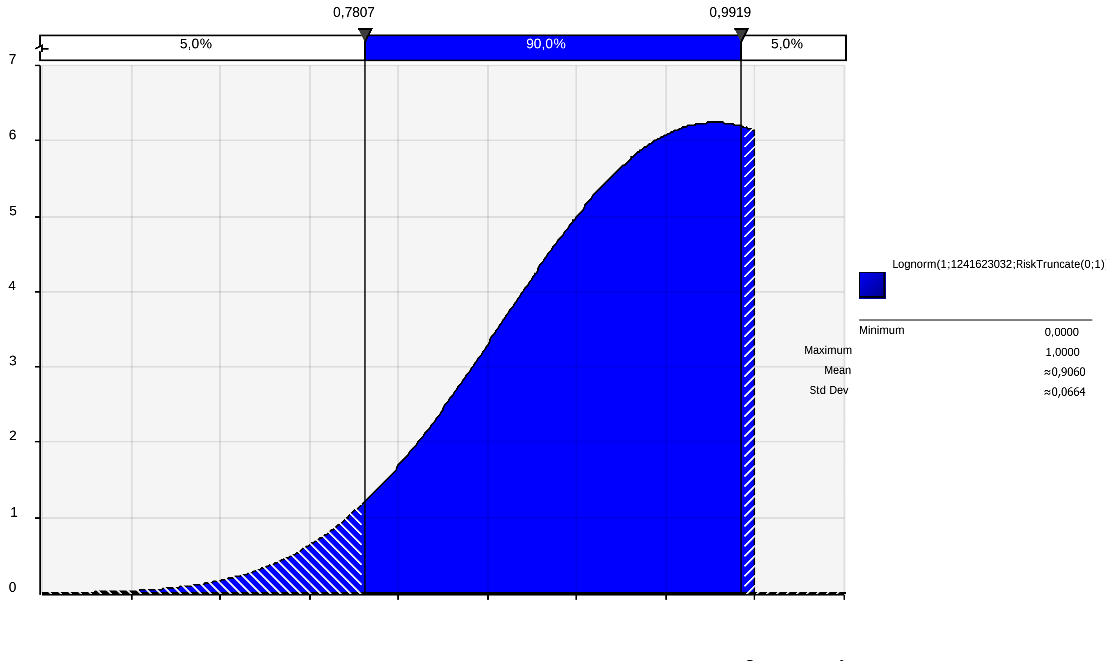

Fig. 2.12: Log-Normal distribution for water ingress after side damage and accident en route and limited waters

D.2.7 Staying Aground

For initial accident frequency the distribution was estimated on 42 casualty reports for Cruise ships and 113 for RoPax. The distributions are shown below.

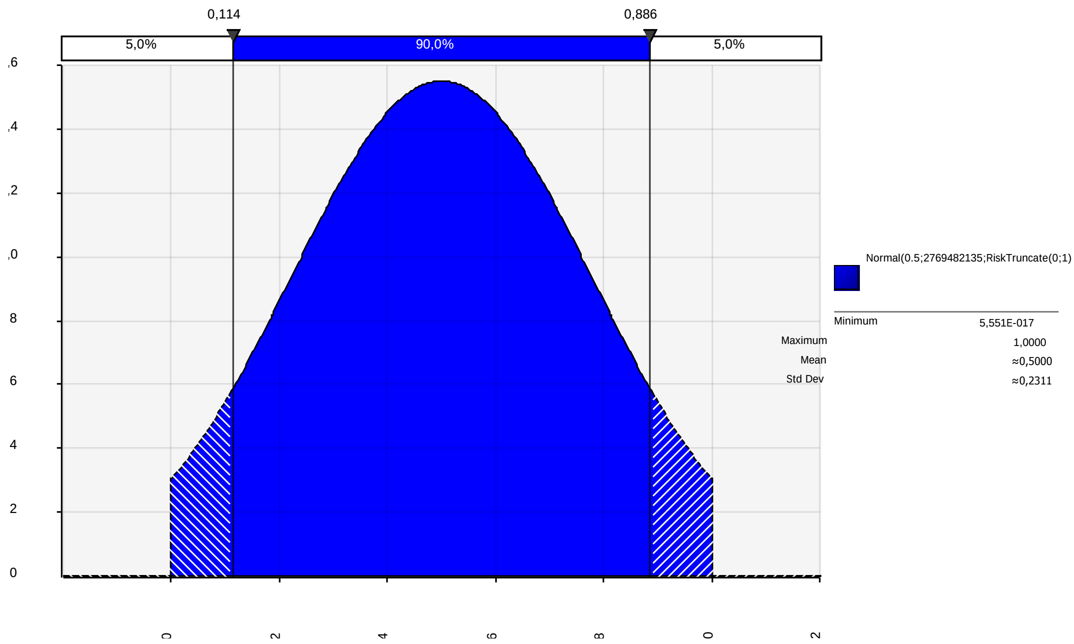

Fig. 2.13: Log-Normal distribution for staying aground for accidents with bottom damage and accident in terminal area

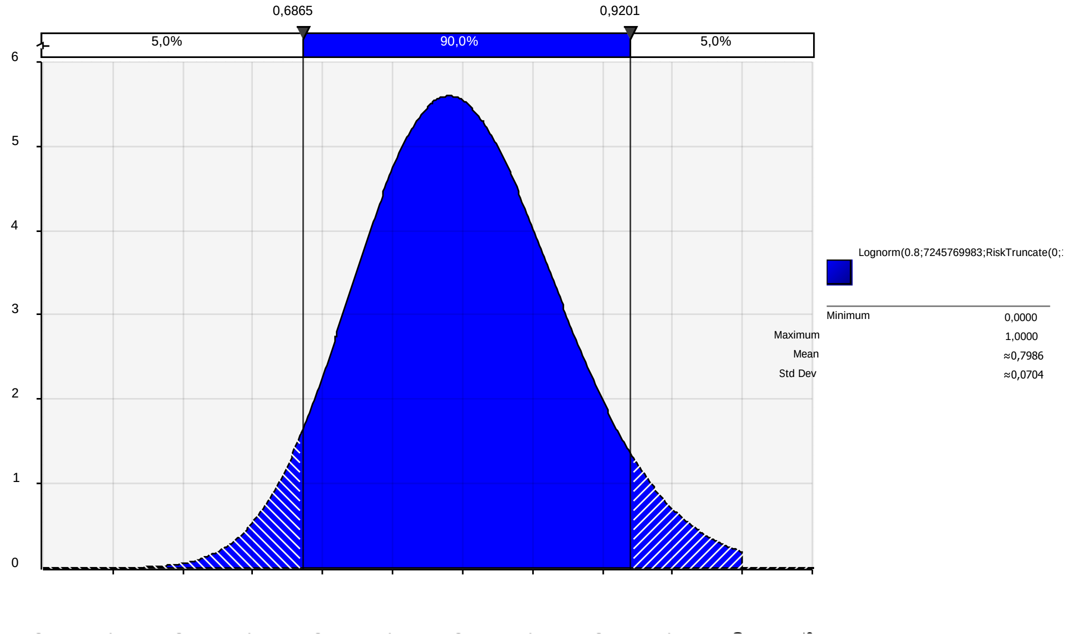

Fig. 2.14: Log-Normal distribution for staying aground for accidents with bottom damage and accident en route and limited waters

D.2.8 Sinking

The dependent probability of sinking is estimated using the SOLAS 2009 damage stability requirement assuming that the R-Index represents the dependent probability for a ship surviving a collision damage that leads to water ingress (breach of hull).

For both dependent probabilities no uncertainty analysis was conducted.

D.2.9 Fatalities

Same distributions were used as for collision described above.

APPENDIX E

Casualty database

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D.1 CASUALTY DATABASE

For the purpose of the present study, the casualty database used in the GOALDS project was updated in order to include additional casualty records (Task 1). It was also further developed in terms of structure to accommodate information relevant to Task 3 of this project.

Briefly, the update of the casualty database, with respect to Task 1 work, is focusing on the followings:

- Regarding collision and grounding events, new records were imported to the database in order to extend the time period from 2009 up to 2012.
- Contact events were inserted to the database concerning the period 1990-2012 since in GOALDS project the particular records had been excluded from the relevant work analysis.
- All records were reviewed and populated accordingly.
- Initial casualty information is coming from IHS database. This information was enhanced from other sources especially in cases where accident investigating reports were available.

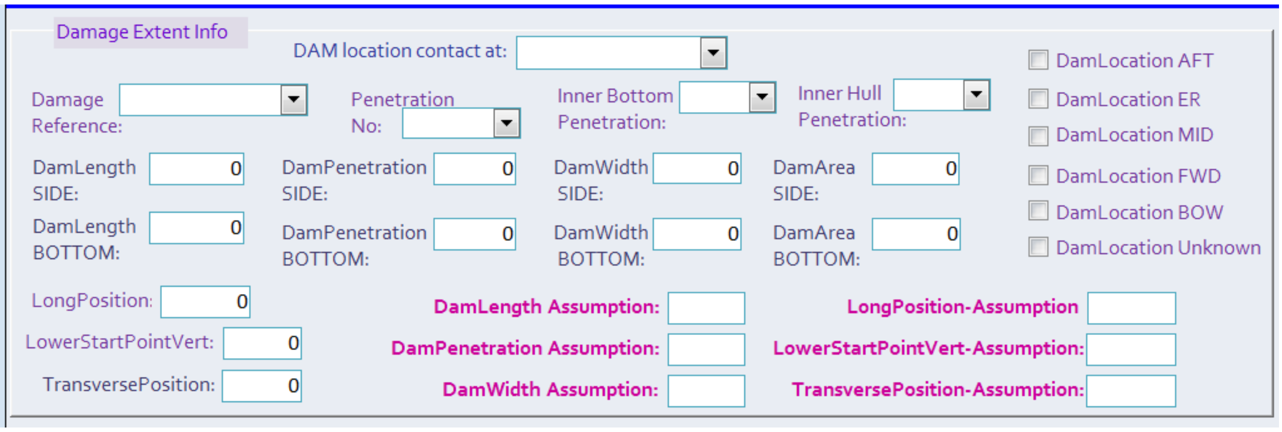
The calculation of the frequencies of initiating event is based on the reviewed data and follows the filtering described in section 10.2.

For the purpose of the project study, the following have been considered:

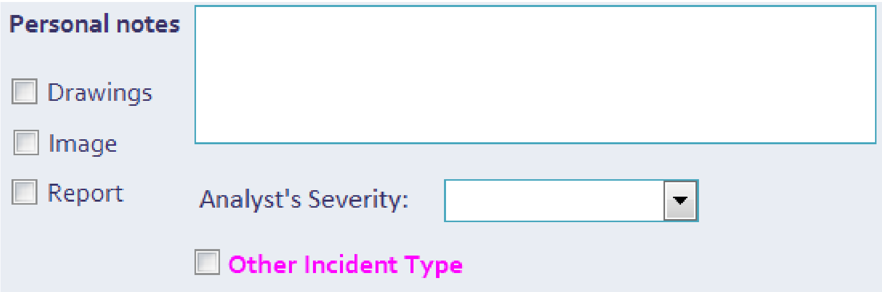
- *Collision event:* striking or being struck by another ship (regardless of whether under way, anchored or moored).
- *Grounding event:* being aground, or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.) including reefs or hitting submerged rocks.
- *Contact:* impact with fixed installation or object which extends over the surface level, or impact with a floating object.
- Captured accidents were assigned to one of the predefined main incident categories according to the last “accidental event”.

Screen Shot of SDL Casualty Database is shown on the next pages

ID 427 IMO
Vessel Name
Subtype
Source Info:
Class Info
Classed By
Class At Time Of Incident
Class
Classes IACS
Class
Classes IACS
Due or Delivered Year
Scrap or Loss Year
Status
Loa (m)
DWT:
GT
Vs (kn)
Class Society
Number of Passengers
Persons On Board
Lorries/Trailers
Crew Number
Cars
TEU
Lbp (m):
Dupd (m):
Bmld (m):
Draught (m):
Dbhd (m):
Passengers berthed
Passengers unberthed
Froude No
Incident Number
Casualty
Presic Text 1
Marsden Grid
Incident Date
Start Latitude
Incident Severity
Start Longitude
Presic Text 2
Total Loss
Location Type Info
Number of Killed
Number of Missing
Weather At Time Of Incident
Compl. text 1
Struck/Striking Info
Water Ingress Info
Sinking Info
Fire Info
Compl. text 2
Navigation Info
Sea bottom Info
Staying Aground Info
Collision
In case of collision
Fire After Collision
Collide with:
Other Ship Size:
Other Ship Operating Condition:
Contact
Contact info:
Contact Type:
Grounding
Type of Grounding
Sea Bed Info
Extent of flooding
Staying Aground:
Refloating info
Water Ingress
Damage Location
Damage WL
SIS-Zones
Ship's Operating Condition:
Status of ship after the casualty
Operational State
Ship damage extent
Sea State



Damage Extent Info
DAM location contact at:
Damage Reference:
Penetration No:
Inner Bottom Penetration:
Inner Hull Penetration:
DamLocation AFT
DamLocation ER
DamLocation MID
DamLocation FWD
DamLocation BOW
DamLocation Unknown
DamLength SIDE: 0
DamPenetration SIDE: 0
DamWidth SIDE: 0
DamArea SIDE: 0
DamLength BOTTOM: 0
DamPenetration BOTTOM: 0
DamWidth BOTTOM: 0
DamArea BOTTOM: 0
LongPosition: 0
LowerStartPointVert: 0
TransversePosition: 0
DamLength Assumption:
DamPenetration Assumption:
DamWidth Assumption:
LongPosition-Assumption
LowerStartPointVert-Assumption:
TransversePosition-Assumption:



Personal notes
Drawings
Image
Report
Analyst's Severity:
Other Incident Type

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.