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EMSA European Maritime Safety Agency

# EMSA OP/10/2013

## A STUDY ASSESSING THE ACCEPTABLE AND PRACTICABLE RISK LEVEL OF PASSENGER SHIPS RELATED TO DAMAGE STABILITY

10 November 2015

Università degli Studi di Trieste · Meyer Werft · Fincantieri S.p.A. · Safety at Sea · Stena Teknik · NTUA · Knud E. Hansen A/S · Meyer Turku · Color Line · Royal Caribbean International · University of Strathclyde Glasgow · STX France · Euroyards · Carnival Corporation & PLC · NAPA

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# Content

- Introduction and overview of the EMSA III studies (Odd Olufsen)
- Formal Safety Assessment, Risk Models for collision and grounding (Rainer Hamann)
- Sample ships; design and risk control options (Odd Olufsen)
- Sensitivity Analysis (Rainer Hamann)
- Summary of results, recommendations for decision making (Odd Olufsen)

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# Members of the consortium

- Shipyards:
  – EUROYARDS, representing: Meyer Werft, Fincantieri, Meyer Turku, STX-France
- Designers/Consultants:
  – Knud E. Hansen AS & Safety at Sea
- Operators:
  – Carnival Cruise, Color Line, Royal Caribbean & Stena Line
- Universities:
  – National Technical University of Athens, University of Strathclyde & University of Trieste
- Software developer:
  – Napa OY
- Classification Society:
  – DNV GL

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# Background

- Passenger ships transport significant numbers of persons compared to cargo ships
- Therefore, safety of persons on board is in focus in passenger ship design
- The main risk contributors for passenger ships are accidents leading to loss of water tightness, i.e. collision, contact and grounding
- Currently designed ships need to comply with SOLAS 2009 probabilistic damage stability requirements
- SOLAS 2009, to a great extent, was based on research work of the HARDER project
- When introducing SOLAS 2009, the level of R was based on the safety level of the current fleet.

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# Overview of completed tasks in the EMSA III project

- Risk acceptance criteria and risk based damage stability
- Evaluation of risk from watertight doors
- Evaluation of risk from grounding
- Damage stability calculations of GOALDS design
- Combined assessments

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# Defined tasks and their main elements

Task 1:

**Acceptable and practicable risk level of passenger ships**

-risk level in comparison with other transport modes

-updated collision risk model

-risk control options(rco) and cost benefit assessment(cba)

-recommending level of the required index R

Task 2:

**Evaluation of risk from watertight doors**

-collecting records; onboard monitoring cruise and RoPax

-parametric model reflecting number, categorisation and closing time of wtd

-parametric model developed and used to assess risk on the sample ships

-rco and cba carried out for some sample ships

Task 3:

**Evaluation of risk from grounding**

-updated damage statistics and grounding risk model including contact damages

-side and bottom grounding damage statistics

-NAPA software developed for direct generation of hull breaches from statistics

-attained index for grounding damages

-calculations of A carried out on all sample ships

-rco and cba carried out for some sample ships

Task 4: Combined assessment of cost effectiveness of previous parts, FSA compilation and overall recommendation for decision making.

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# EMSA III

- Main contributors to passenger ship risk are collision and grounding accidents
- In order to reduce the risk, RCOs can address
  - Measures to reduce the probability of accident:
    - to large extent CN and GR are human error related
  - Measures to reduce the consequences of accident:
    - Two main areas: increase survivability of vessel – life-saving appliances
    - Best: survive with the ship
- EMSA III focused on main risk contributors and measures to increase the damage stability of ships

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# EMSA III

- Study needs to be regarded in context of previous work of GOALDS
  - Risk models for CN and GR
  - Reviewed casualty reports
  - Specify representative sample
  - New casualty database providing more detailed access to casualty characteristics
- In EMSA III
  - Extend the period under consideration until 2012 and amend database by reviewed casualty reports
  - Select a period for determining initial accident frequencies
  - Assess overall risk for passenger ships -> in the area of so-called “ALARP”
  - Review and update HazIds of previous FSAs (MSC 85/INF.2 and INF.3)
  - Apply ALARP process for RCOs increasing damage stability

# EMSA III

- Focus:
  - Passenger ships, i.e. cruise, passenger, RoPax and RoPax-Rail
  - Ships in compliance with current damage stability requirements (reference)
  - Consider only damage stability of ships
  - Optimise designs with respect to damage stability
  - Evaluate the designs with respect to cost-benefit

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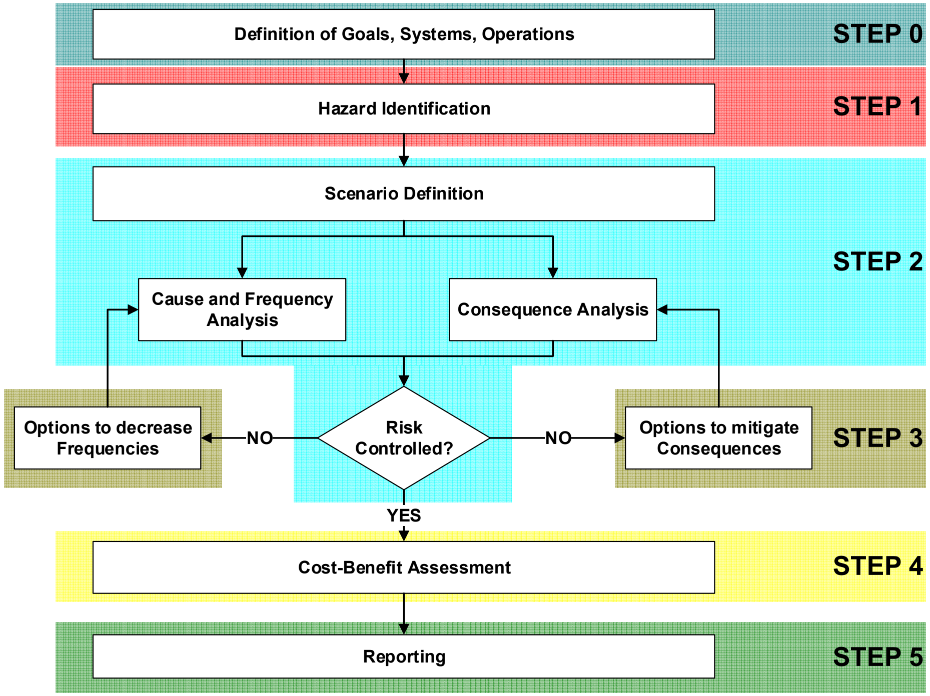
# Hazard Identification

- Work carried out:
  - Review of SAFEDOR HAZIDS for Cruise and RoPax ships
  - Review of NAV49/INF.2
  - Review of causality reports from accidents that have occurred since these reports were completed (2005)

- Conclusions:
  - Causes included in HAZIDs, as the result of brainstorming, cover a much wider range of possibilities when compared with the causes of accidents occurred
  - 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.

# Risk Analysis I

- Following FSA Guidelines in step 2 the current risk level has to be evaluated
- The current risk level determined based on updated risk models from previous FSAs and GOALDS project (FSAs reviewed by IMO EG/FSA in Nov. 2009)
- Evaluation criterion, i.e. FN-diagram, was updated for 2014 (update led to significantly lower limits)
- Risk of ship types under consideration can be regarded as tolerable -> ALARP principle should be applied

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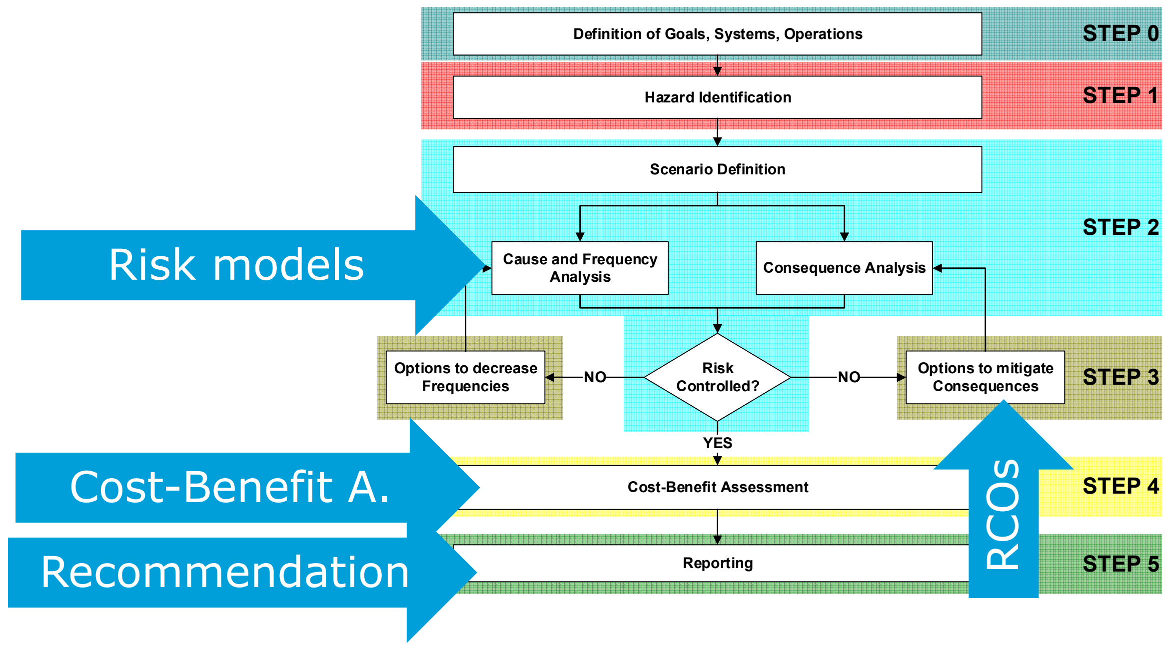
# Risk Analysis II

- Focus only on damage stability
- Update of collision risk model
- Development of new grounding/contact risk model

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# Development of risk models

- Analysis of casualty reports to determine main events characterising risk
  - → Develop high-level event sequence
- Analysis of accident statistics to specify representative sample
  - → Development of annual accident frequencies
- Select/review casualty reports
- Develop risk model, e.g. in form of event tree
- Quantify risk model
  - Initial accident frequency
  - Dependent probabilities
    - Numerical model
    - Historical data
    - Expert judgement

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# Definition of sample

- Basis:
  - IHS Fairplay casualty database and ship register (commercial)
  - Lloyds Maritime Investigation Unit database (LMIU) (commercial)
  - Global Integrated Ship Information System (GISIS)
- Sample characteristics of ships
  - Built after 1981
  - ≥ 1000 GT
  - ≥ 80 m
  - IACS class at time of accident/today
  - No High Speed Crafts

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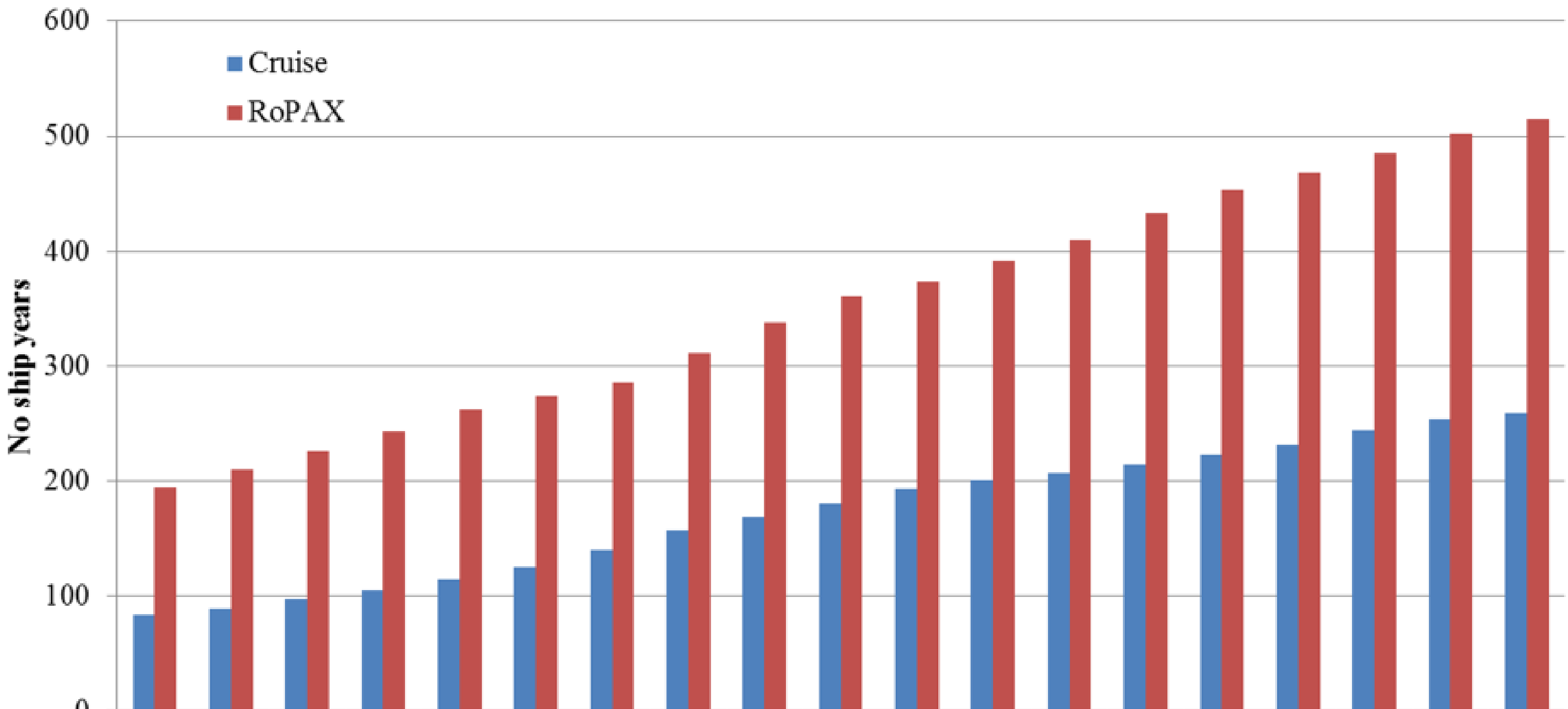
# Fleet size




| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cruise | 84 | 89 | 98 | 105 | 115 | 126 | 140 | 157 | 169 | 181 | 193 | 201 | 207 | 215 | 223 | 232 | 244 | 253 | 259 |
| RoPAX | 195 | 210 | 227 | 243 | 262 | 274 | 285 | 311 | 338 | 361 | 373 | 392 | 410 | 433 | 453 | 468 | 485 | 503 | 515 |

Year

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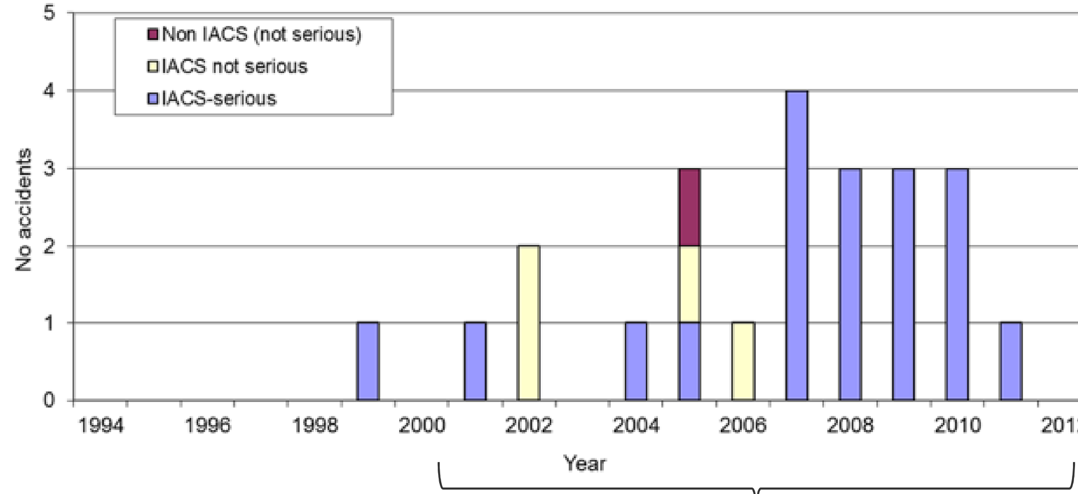
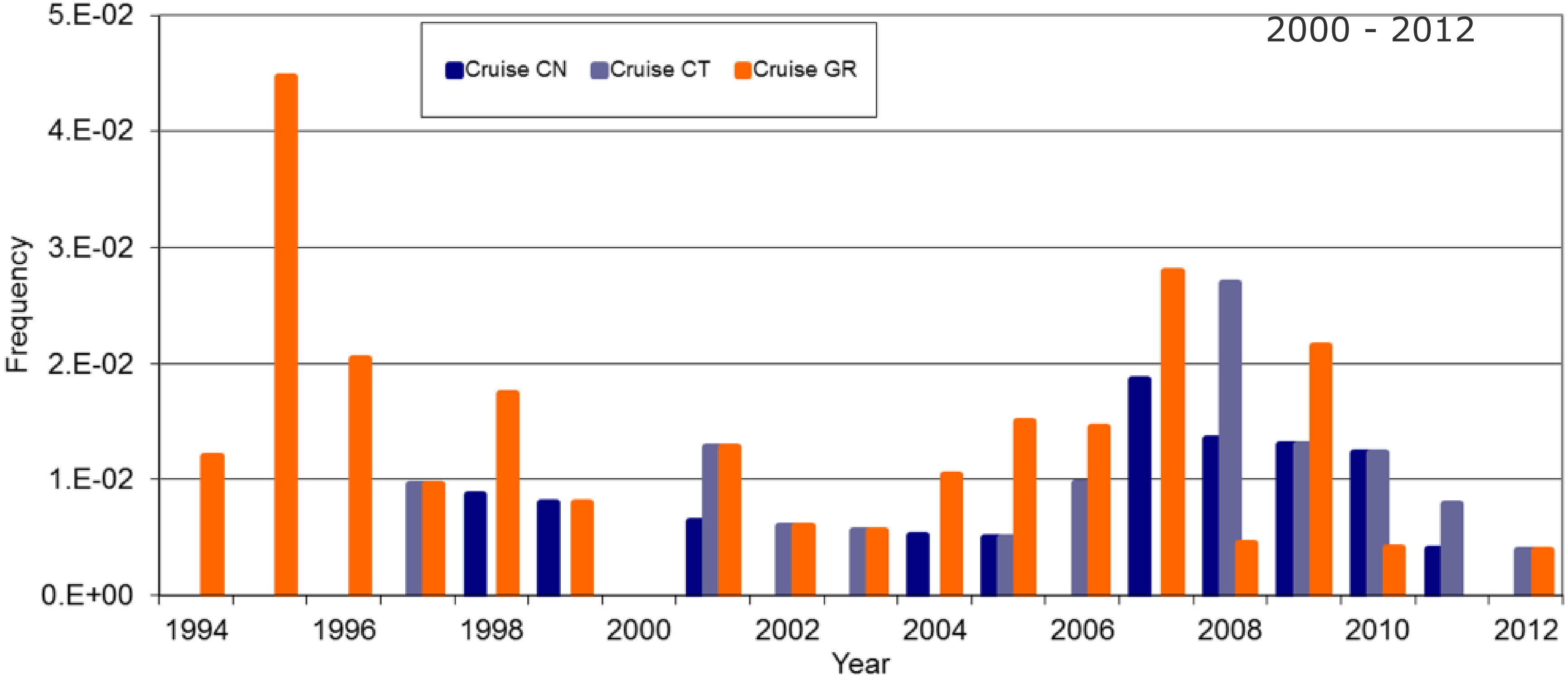
# Casualties cruise

CN (serious and not serious collision) accidents between 1994 and 2012 distinguishing IACS and Non IACS cruise ships.




2000 - 2012

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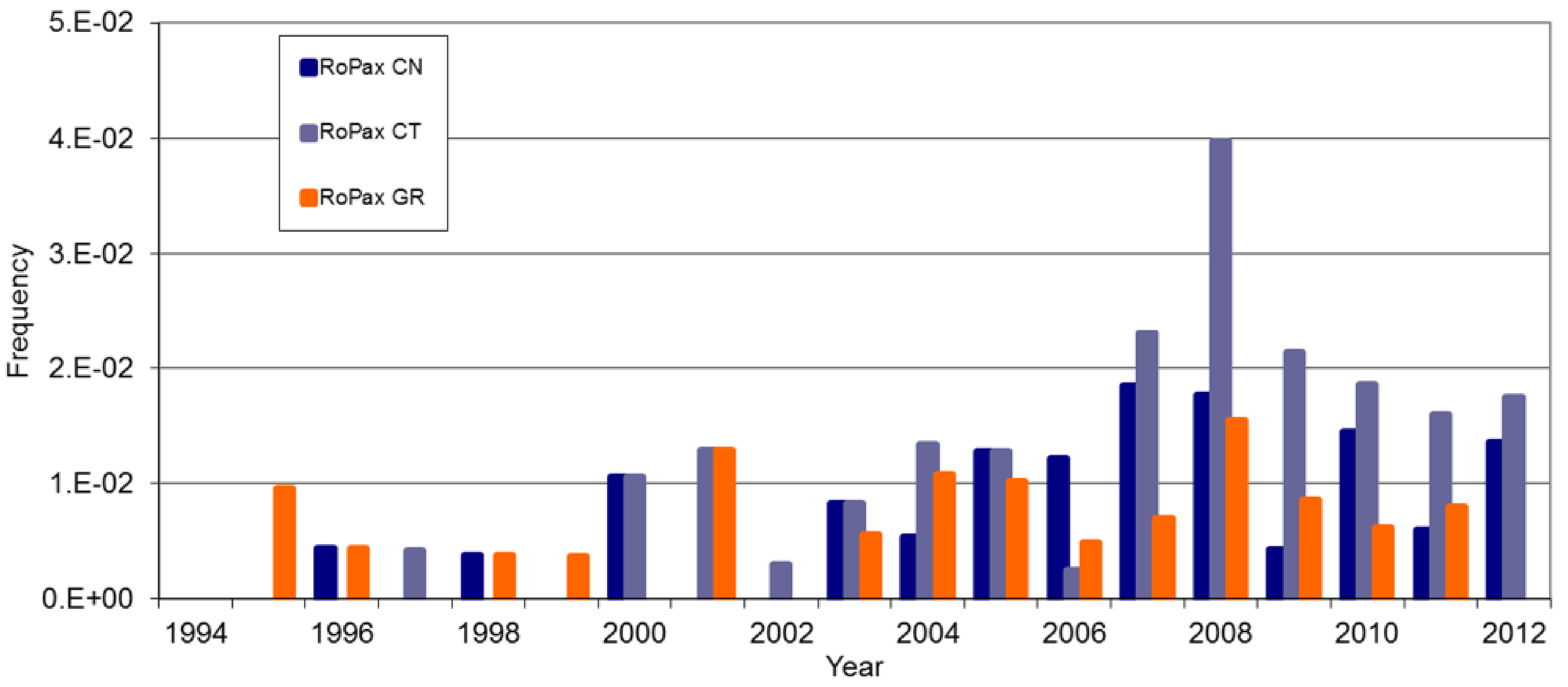
# Casualties RoPax

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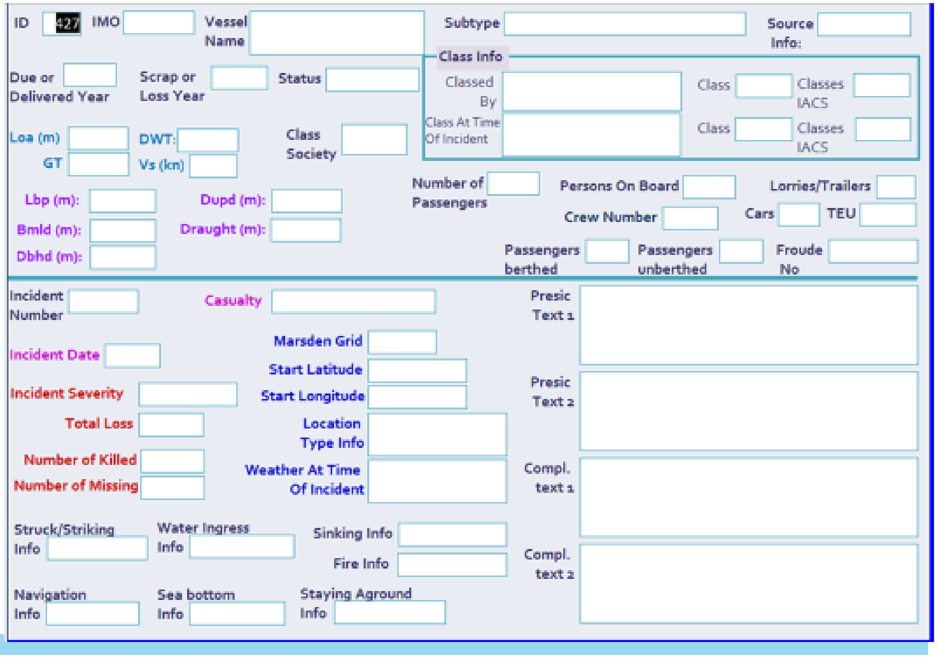
# Casualty database

- Basis for this study formed the casualty database developed in GOALDS project extended by reports after 2009
- All records were reviewed when transferred to the new database
- By review process casualty reports not relevant for this study were identified and not further considered
- Initial casualty information is coming from IHS database. This information was enhanced from other sources especially in cases where accident investigating reports were available (e.g. GISIS)
- Only casualties considered complying with filtering criteria (ship size, year built etc.)

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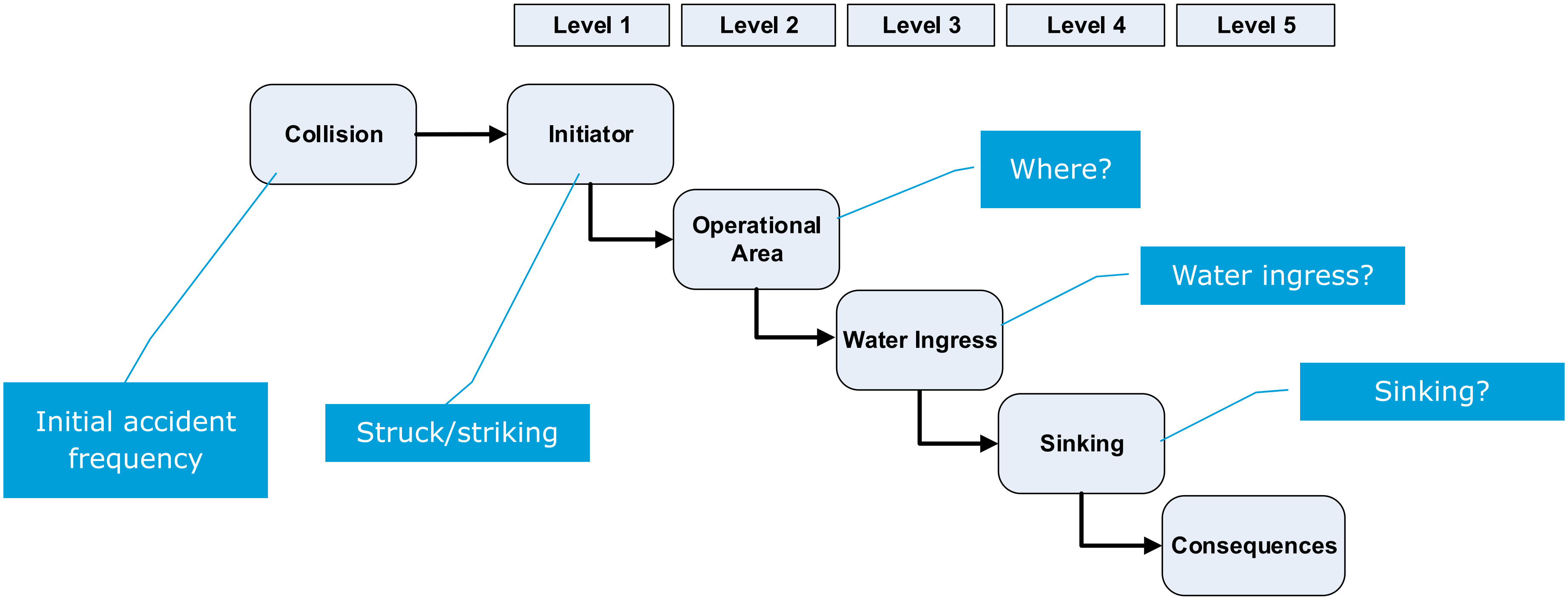
# Risk Model

- For the purpose of this study two risk models were developed for accident categories
  - Collision
  - Grounding (+ contact)
- Only consequences with respect to persons on board are in focus
- Quantitative risk model developed using Event Tree method
- Ship type dependent risk models were developed separately for cruise and RoPax, in order to considering particularities, e.g. for
  - Initial accident frequencies
  - Fatality rates
- Risk models are ship size dependent, with respect to
  - Number of person on board
  - Probability of sinking

# Risk Model: Collision




- High-level event sequence for collision casualties of passenger ship
  - Considers main factors influencing the risk to persons on board

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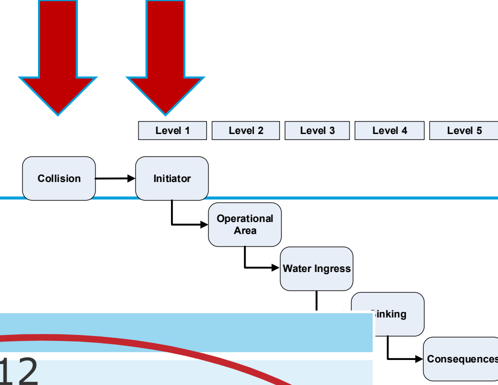
# Risk Model: Quantification




- Initial accident frequency

| Time Period | | | |
|---|---|---|---|
| 1994 - 2012 | | 2000 - 2012 | |
| **No of casualties** | 1/ship year | No of casualties | 1/ship year |
| **Cruise** | | | |
| **19** | 5.78E-03 | 17 | 6.36E-03 |
| **RoPax** | | | |
| **52** | 7.72E-03 | ~~50~~ 49 | ~~9.38E-03~~ 9.19 E-03 |

- Initiator: Struck/striking
  – Small number of casualty reports providing sufficient information for quantifying nodes of risk model
  – Therefore, in the view of reducing uncertainty, casualty reports for cruise and RoPax were merged
  – On average struck/striking probability is about 50% (struck: 43% cruise, 58% RoPax)
  – Analysis of casualty reports showed that collision accident damages are only relevant for ship stability when ship is struck

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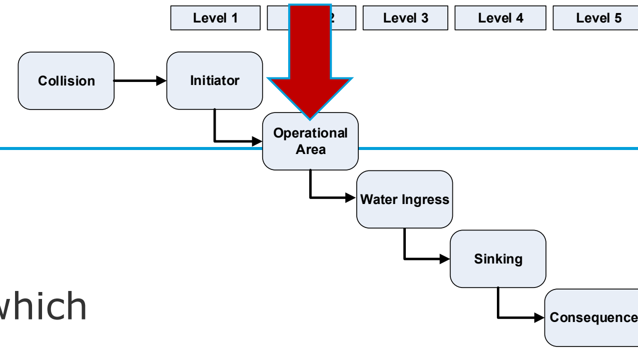
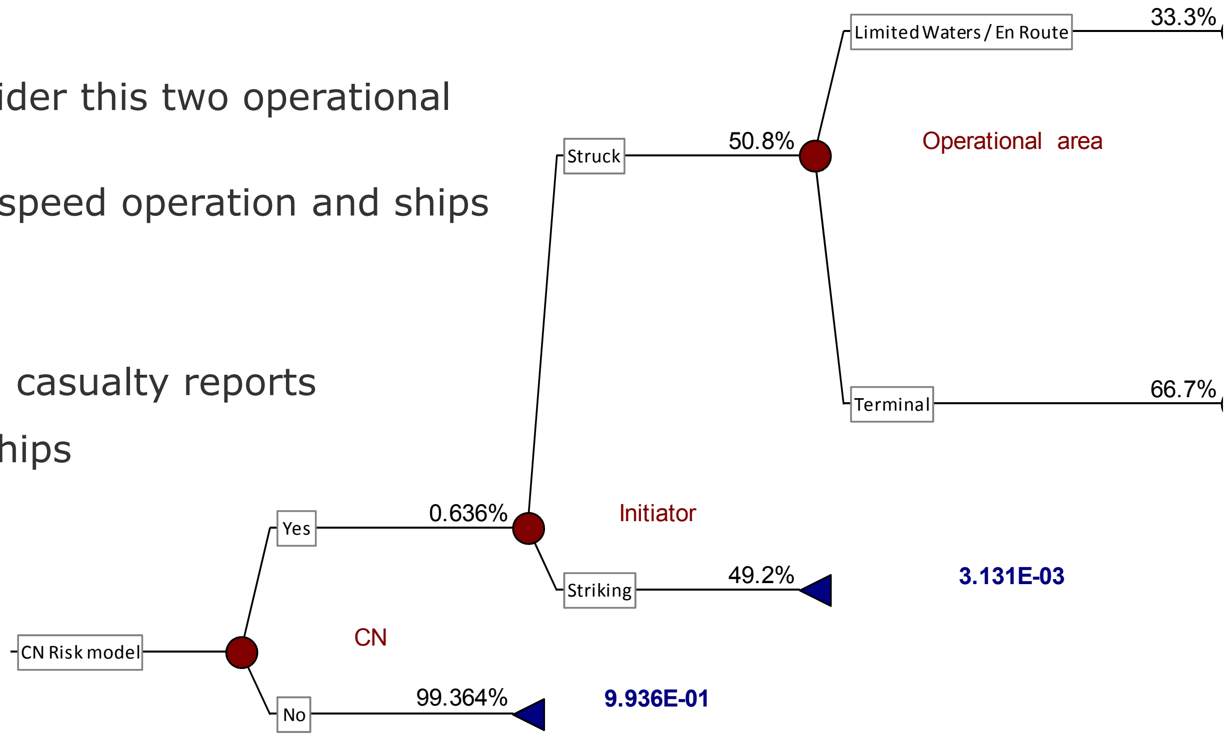
# Risk Model: Quantification




- Operational area
  - Extent of hull damage heavily relates to impact energy which depends on ship speed and mass
  - In terminal area extent of hull damage is smaller than for collision in open sea or coastal waters
  - In order to adequately consider this two operational areas were distinguished
    - Terminal with typical low speed operation and ships berthed
    - All other areas
  - Quantification was based on casualty reports merging cruise and RoPax ships (33 reports)

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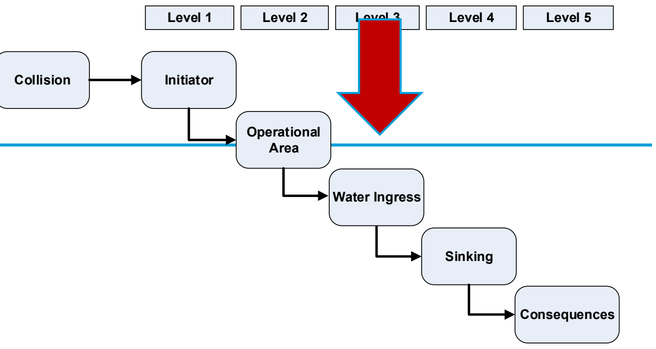
# Risk Model: Quantification




- Water ingress
  - Depends on
    - Whether hull is penetrated in collision
    - Location of the breach, i.e. is water ingress possible

- By distinguishing two operational areas the model considers the differences between operation in terminal areas and others:
  - Probability of water ingress in terminal areas is about 7% (based on 14 casualty reports)
  - Probability of water ingress in other areas is about one third (based on six reports)
  - Quantification was based on casualty reports merging cruise and RoPax ships

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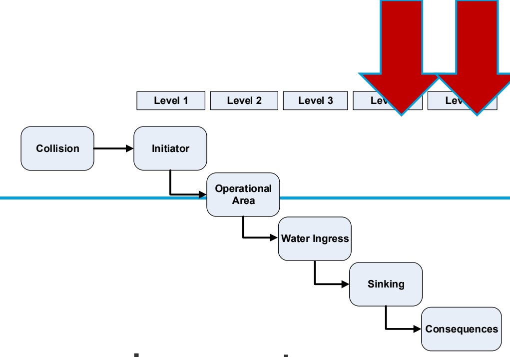
# Risk Model: Quantification



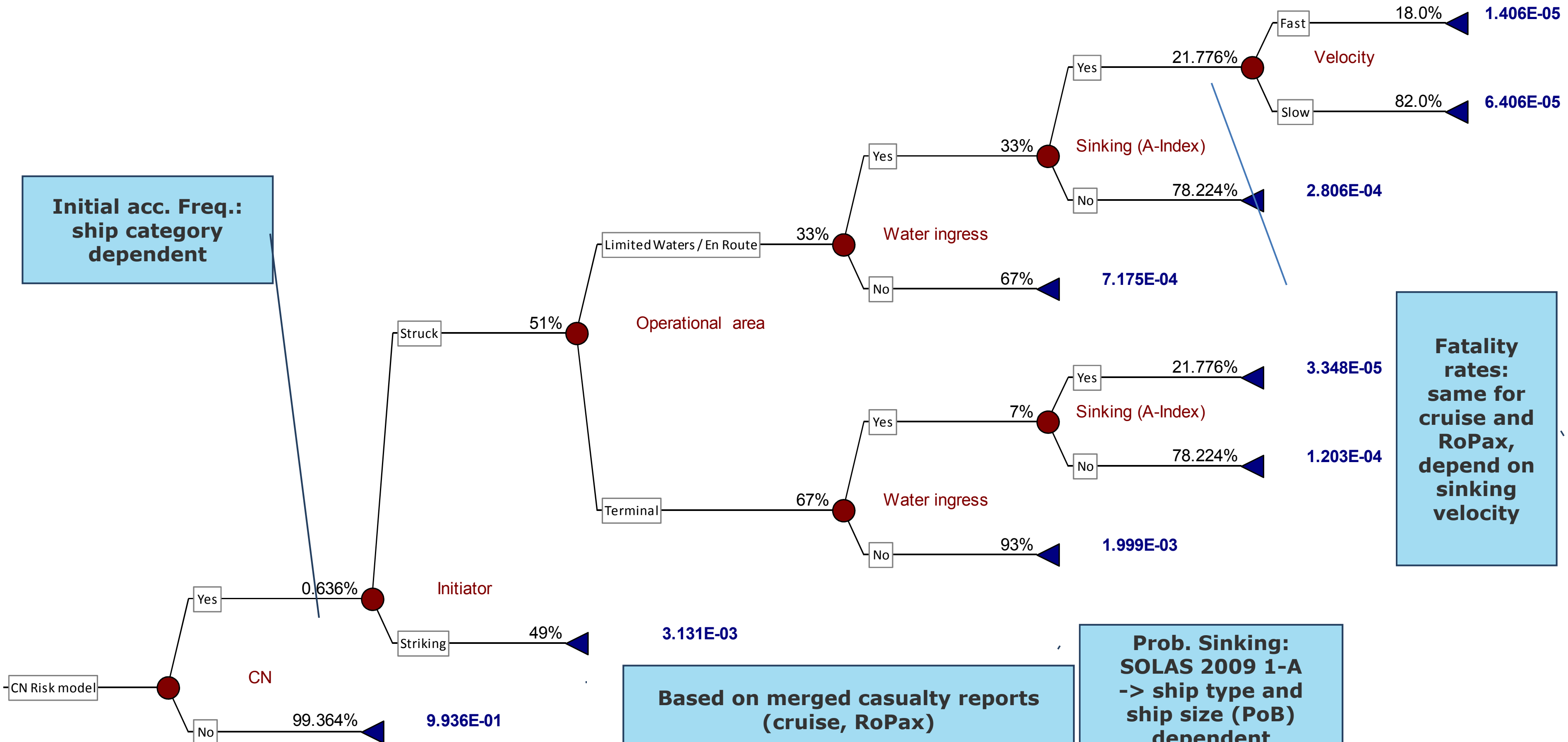

- Probability of sinking
  - Is determined on basis of SOLAS 2009 damage stability requirements
  - Probability of sinking equal to 1 minus attained index (A-Index)

- Consequences
  - Related to persons on board (crew + passengers)
  - Considering occupancy of 90% for cruise, respectively seasonal occupancy for RoPax (100% for 12.5% of the year, 75% for 25% of the year and 50% for remaining time)
  - Two representative fatality rates used for the scenarios
    - Fast sinking/capsizing 80% of persons on board
    - Slow sinking 5% of persons on board
    - For sinking in terminal areas 5% fatality rate used for all scenarios
  - Probability of fast sinking depends on ship type (18% for cruise, 50% for RoPax)

# Collision risk model

**Prob. Fast sinking: Ship type dependent (18% cruise, 50% RoPax)**

**Initial acc. Freq.: ship category dependent**




**Fatality rates: same for cruise and RoPax, depend on sinking velocity**

**Based on merged casualty reports (cruise, RoPax)**

**Prob. Sinking: SOLAS 2009 1-A -> ship type and ship size (PoB) dependent**

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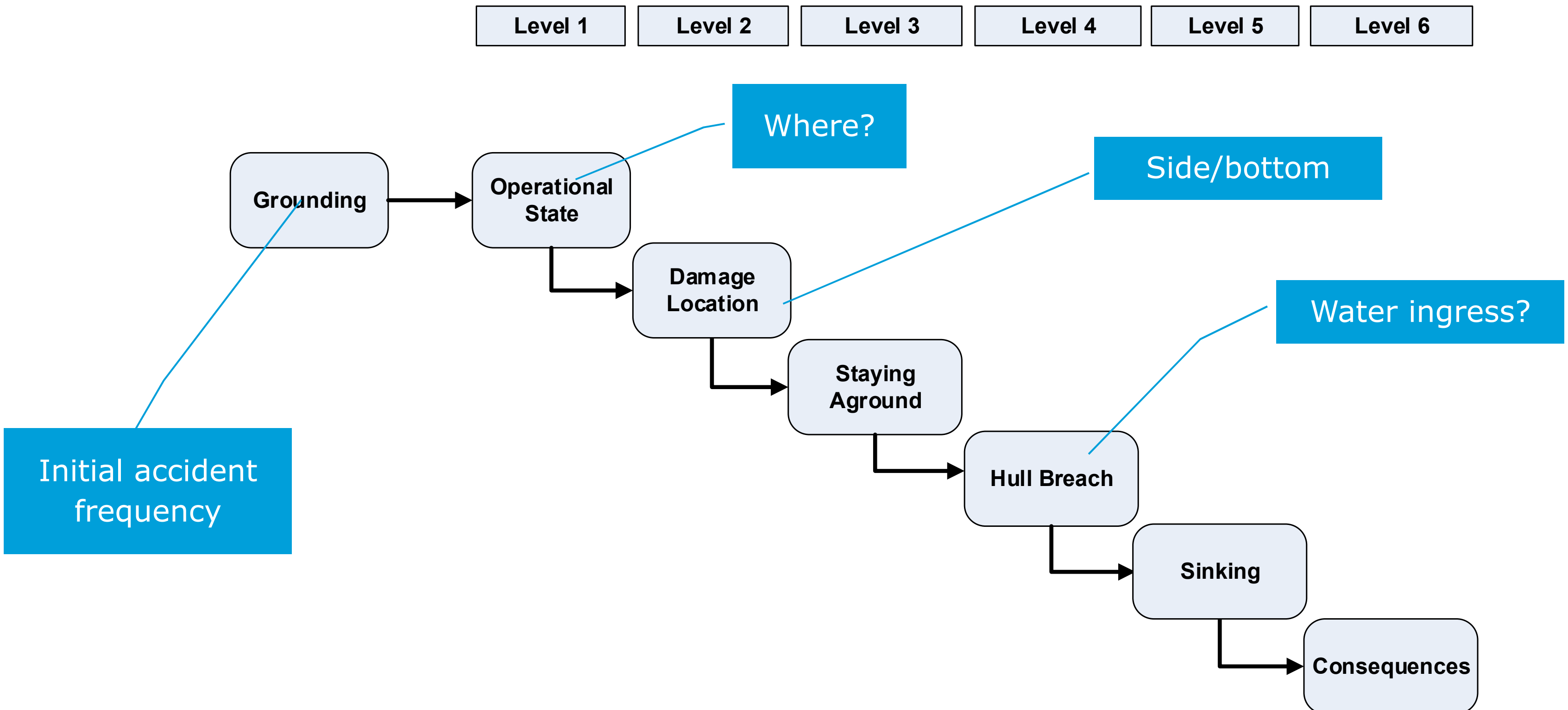
# Risk Model: Grounding




- High-level event sequence for grounding and contact casualties of passenger ship
- Contact casualties with potential of penetrating hull and subsequent water ingress
- Only consequences with respect to persons on board are in focus

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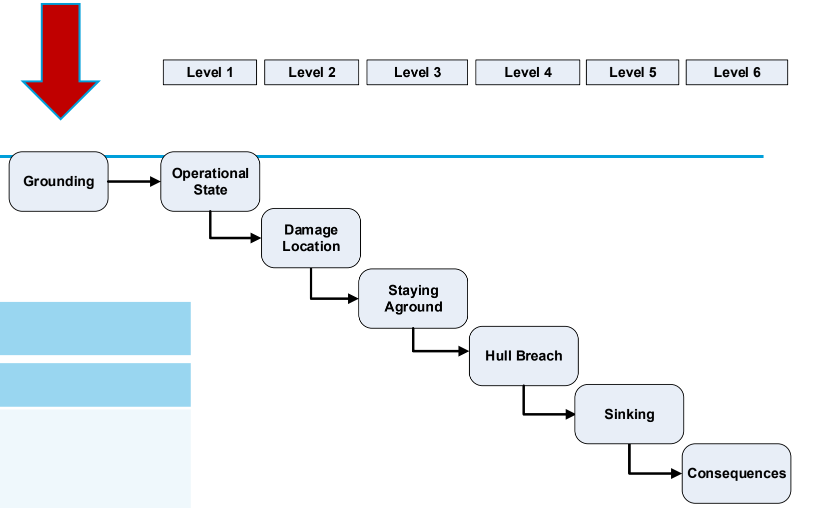
# Risk Model: Quantification




- Initial accident frequency

| Time Period | |
|---|---|
| 2000 - 2012 | |
| casualties | 1/ship year |
| Cruise | |
| 20 + 22 | 1.57E-02 |
| RoPax | |
| 27 + 86 | 2.12E-02 |

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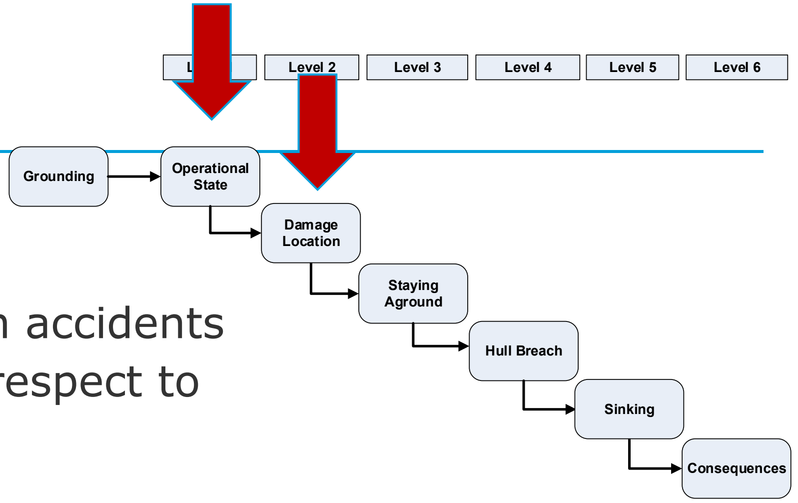
# Risk Model: Quantification




- Operational state
  - Considering that scenarios will differ between accidents in terminal areas and other areas, e.g. with respect to possibility of rescue but also water depth
  - About 57% of accidents occurred in terminal areas (217 reports for period 1990 to 2012)
- Damage location
  - Distinguishing between side and bottom damage
  - For terminal areas about 92% are side damages (75 casualty reports)
  - For other areas about 51% are bottom damages (43 casualty reports)

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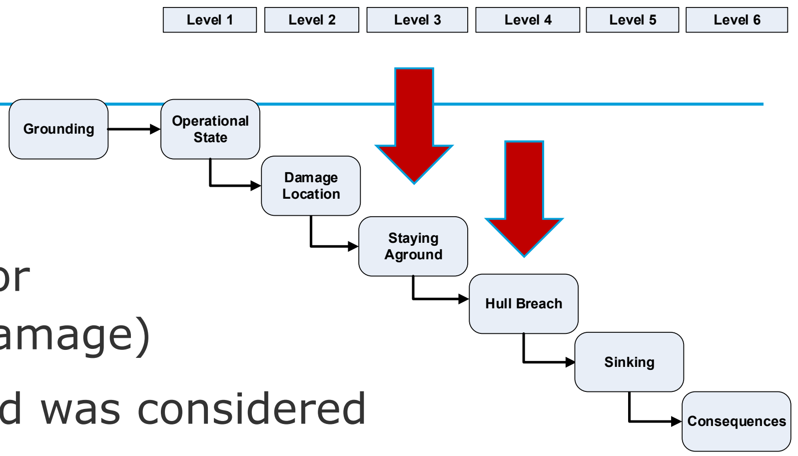
# Risk Model: Quantification




- Nodes *staying aground* and *hull breach*
  - Consider influences like sea bed (soft/hard) or the general probability of hull breach (side damage)
  - Additionally, the possibility of staying aground was considered (= no possibility of sinking)

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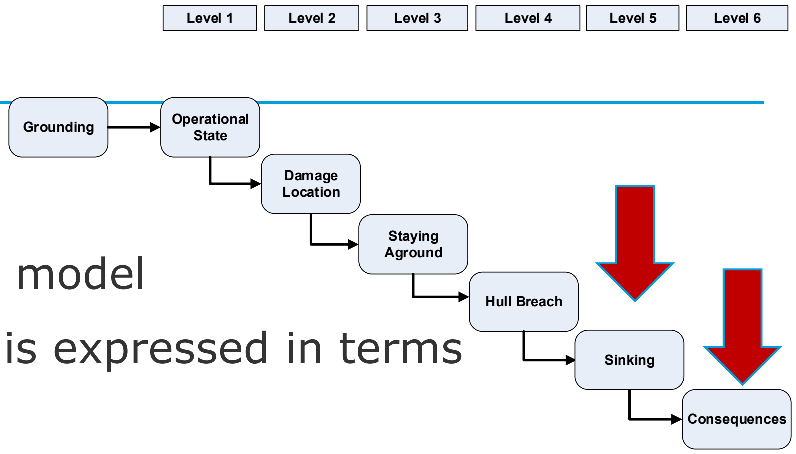
# Risk Model: Quantification




- Probability of sinking
  - Is determined on basis of the new developed model
  - Similar to collision the probability of survival is expressed in terms of an index ($A_{GR}$-Index)
- Consequences
  - Related to persons on board (crew + passengers)
  - Considering occupancy of 90% for cruise, respectively seasonal occupancy for RoPax (100% for 12.5% of the year, 75% for 25% of the year and 50% for remaining time)
  - Two representative fatality rates used for the scenarios
    - Fast sinking/capsizing 80% of persons on board
    - Slow sinking 5% of persons on board
    - For sinking in terminal areas 5% fatality rate used for all scenarios
  - Probability of fast sinking depends on ship type (18% for cruise, 50% for RoPax)

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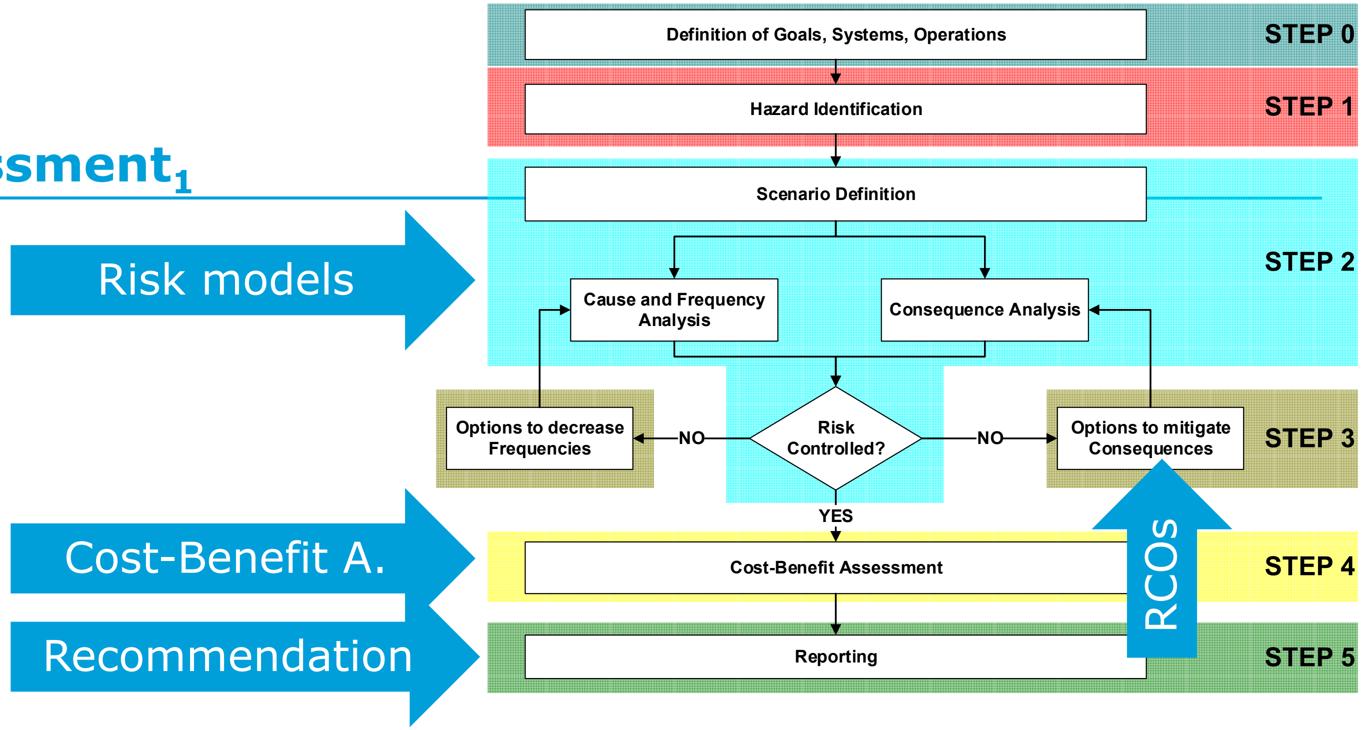
# Cost-benefit assessment$_1$




- Risk models are used to determine risk reduction by increased damage stability
- Risk models are based on experience and numerical models
- For cost-benefit assessment so-called cost thresholds were calculated by means of risk models, i.e. calculating risk reduction (difference between A-Indices of reference and novel design) and monetary value per avoided fatality

# Cost-benefit assessment$_2$

- FSA guidelines provide criteria for cost-benefit assessment
  - Gross cost of averting a fatality (GCAF) $GCAF = \frac{\Delta Cost}{\Delta Risk}$
  - Net cost of averting a fatality (NCAF) $NCAF = \frac{\Delta Cost - \Delta Benefit}{\Delta Risk}$
  - An RCO is cost beneficial if GCAF/NCAF are equal to or lower than threshold
- Threshold for GCAF and NCAF provided by FSA Guidelines ($3 million)
- Threshold were determined by means of specified process using social indicators (not static, follows general development)
- The value given in FSA Guidelines was suggested in 1999 (MSC 72/16) considering social indicators until 1988
- In GOALDS project threshold was updated to $7.45 million

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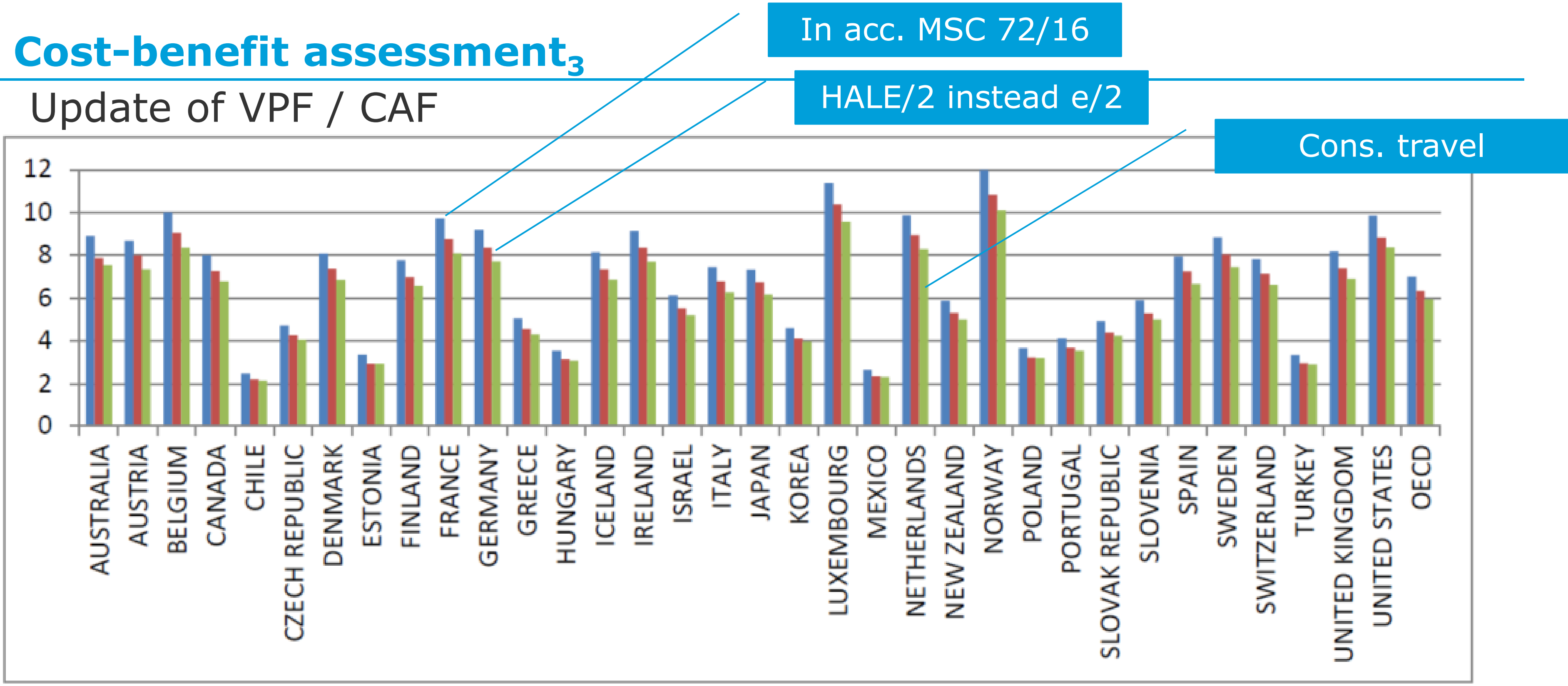
# Cost-benefit assessment$_3$

## Update of VPF / CAF




Based on parameters:

GDP

e: life expectancy at birth

w: portion of life spent in economic production

HALE: Health Adjusted Life Expectancy

Two values recommended used in EMSA III:

**4 mill USD and 8 mill USD**

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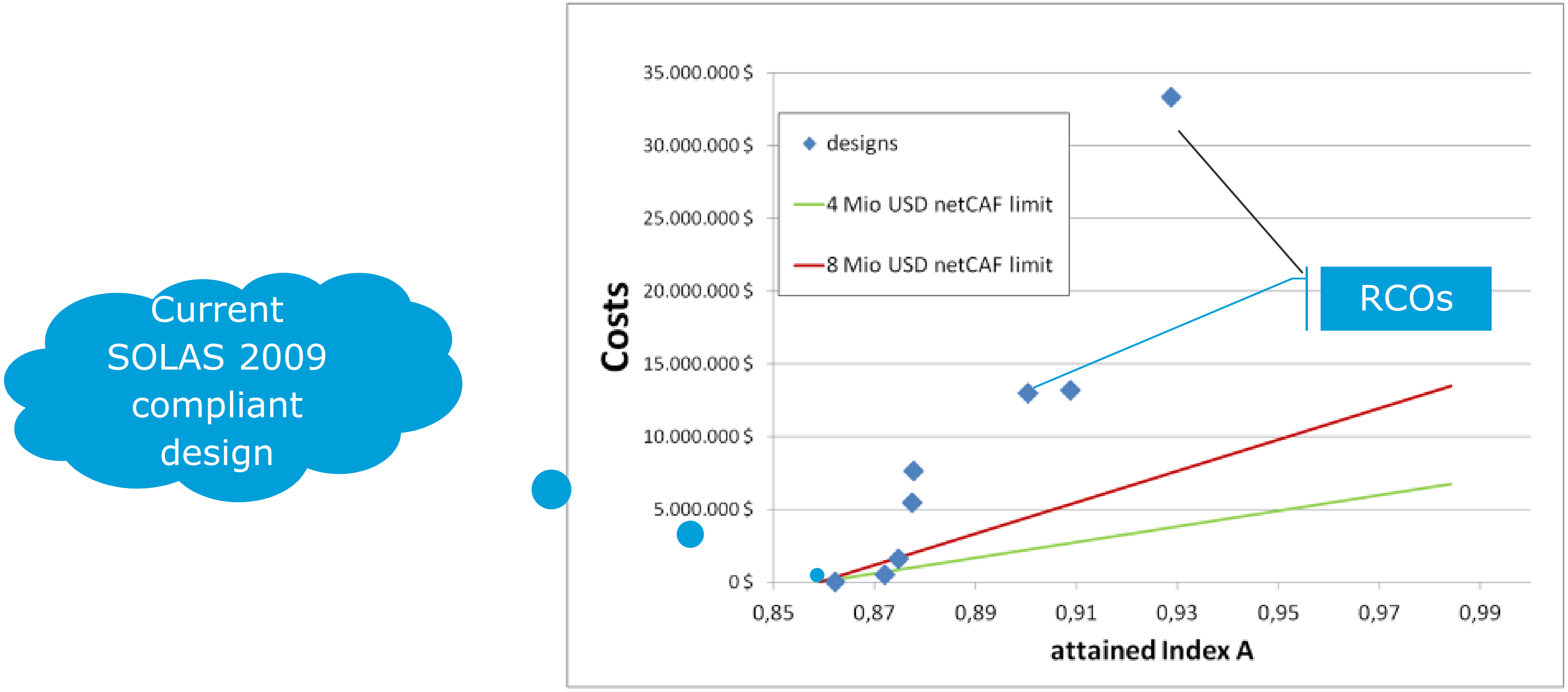
# Cost-benefit assessment$_4$

- In this study US$4 and US$8 million per avoided fatality has been used for cost-benefit assessment
- For facilitating the assessment of designs for each ship the relation between ΔA and ΔCost were calculated
- This allows a simple check, if an RCO meets the criteria for cost effectiveness

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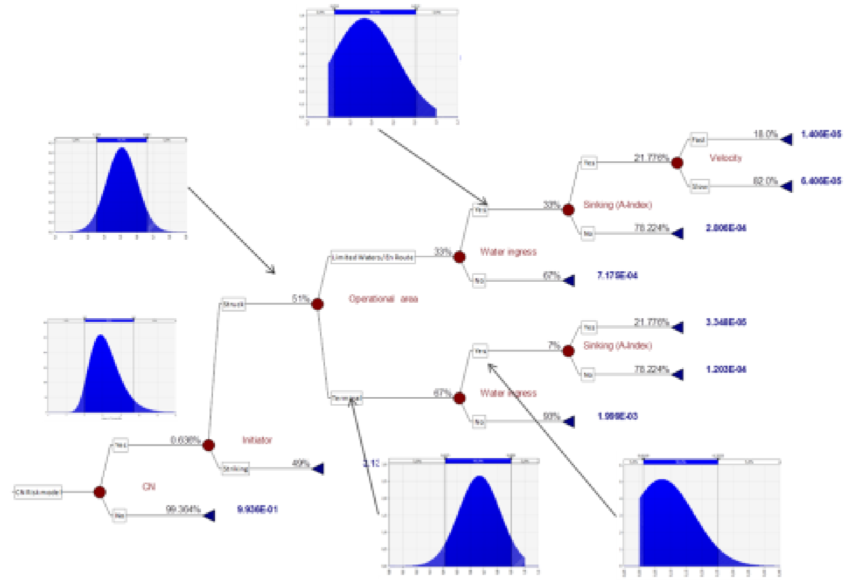
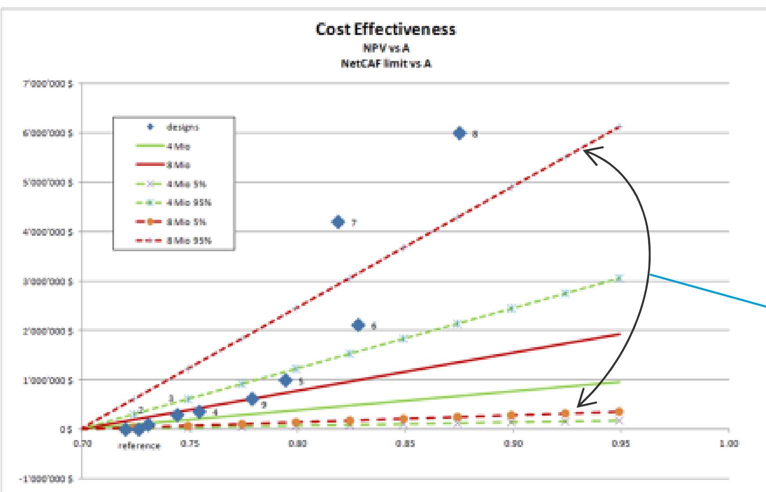
# Cost-benefit assessment$_5$

- Risk model use “mean” values for calculating risk, e.g. representative fatality rates of 5% and 80%
- In order to demonstrate the effect of changes in the parameter distributions for risk model parameter were estimated
- By means of Monte Carlo simulation the effect of these “distributions” on the cost-benefit assessment was determined






90% interval

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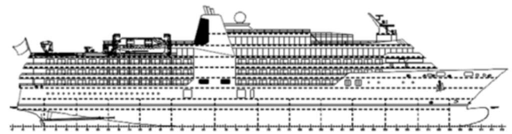
# EMSA3 Sample ships and design teams

MEYER WERFT PAPENBURG 1795

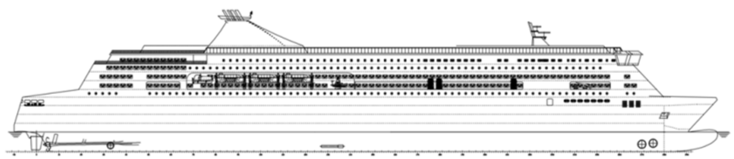
CARNIVAL CORPORATION&PLC

FINCANTIERI S.p.A.



RoyalCaribbean INTERNATIONAL

MEYER TURKU SHIPYARD 1737



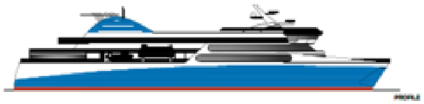
ColorLine

stx France

Stena Teknik CARE, INNOVATION & PERFORMANCE

ColorLine

KNUD E. HANSEN A/S NAVAL ARCHITECTS DESIGNERS MARINE ENGINEERS ~ Since 1937 ~



Stena Teknik CARE, INNOVATION & PERFORMANCE

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# Overview EMSA III  Sample ships

| Yard/Designer | Type | Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|---|---|
| MW | Large cruise | 294.6 | 40.8 | 8.75 | 153400 | 6730 |
| Fincantieri | Small cruise | 113.7 | 20.0 | 5.30 | 11800 | 478 |
| Meyer Turku | Baltic RoPax | 232.0 | 29.0 | 7.20 | 60000 | 3280 |
| STX-France | Med RoPax | 172.4 | 31.0 | 6.60 | 43000 | 1700 |
| KEH | Small RoPax | 95.5 | 20.2 | 4.90 | 7900 | 625 |
| KEH | Double ender | 96.8 | 17.6 | 4.30 | 6245 | 610 |

- Sample ships are suitable examples for state-of-the-art designs
- Basic design level
  - feasible realistic design to meet business model
  - No detailed layout of structure, architectual layout, piping and ducting

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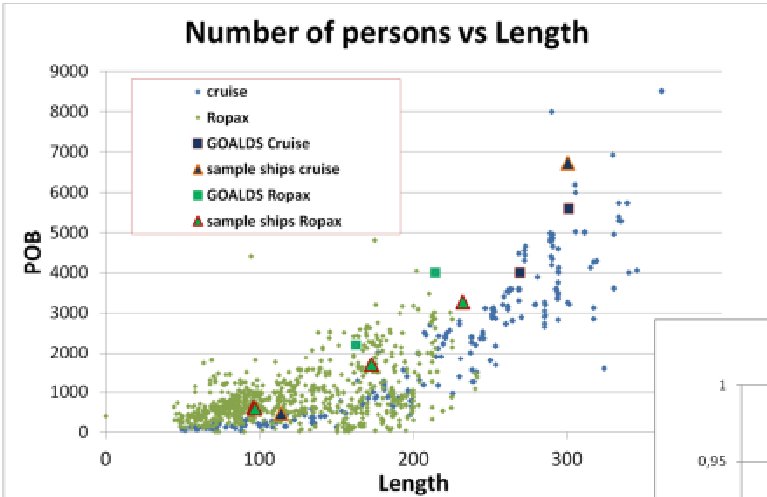
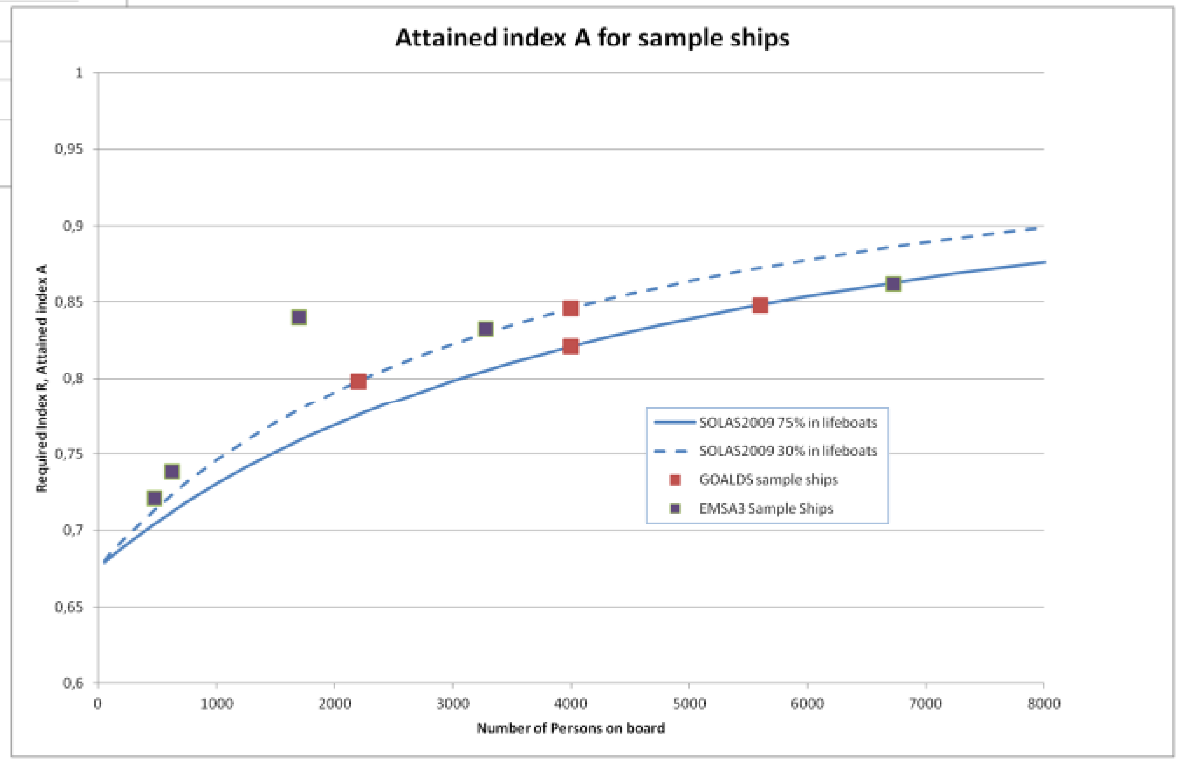
# Overview EMSA III  Sample ships




**Attained index for Ropax based on SOLAS2009, impact of S-wod (SLF55) not shown**

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# Design variations

- For each sample ship design variations (RCOs) have been developed
- Following modifications have been applied in different combinations
  - Change of breadth and freeboard
  - Improvement of watertight subdivision
  - Different hull form
  - Buoyancy boxes on the car deck
  - Subdivided LLH
- For each RCO the change of A and costs have been calculated

# Calculation assumptions

- SOLAS2009 is used as calculation base
  - Assumptions as in Explanatory Notes
  - For RoPax additional new S-wod according SLF55 calculated
  - Draught range based on loading conditions
  - A-class boundaries considered in flooding stages
- Assumptions:
  - The business model is kept constant
    - No significant change of capacity (cargo, cabins)
    - Operational profile kept the same (distance, turn around time)
  - Same methodology to calculate weight and stability
  - Simplified but realistic cost estimations
  - GM limit curve defined based on loading conditions
  - Margins to GM curve are kept constant
- No detailed internal watertight integrity considered
  - Projects are on basic design level
  - No detailed routing of pipes and ducts

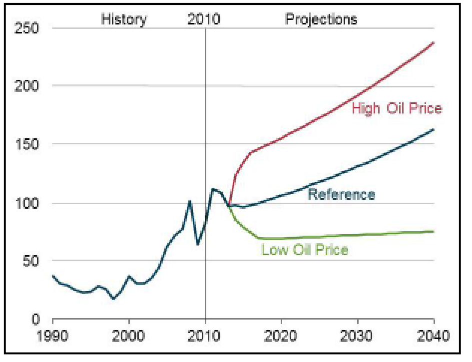
# Cost-Benefit Assessment

- Cost Benefit Assessments for sample ships are based on:
  - **Investment Costs**
    - Building costs due to enlarged ship (steel, interior systems)
    - Cost impact due to changed equipment (engines, propulsion, thrusters etc)
    - Financing costs
  - **Operational costs**
    - Mainly fuel costs
    - Increased time in port may cause increased speed → higher fuel costs
    - Increased maintenance costs
  - **Revenue**
    - Small adjustments of income
    - Reduced probability of total loss results in less costs for scrap
- All costs are calculated in Euro and converted in USD based on exchange rate of 1.35 USD/Euro
- Changes of costs to the society or industry in general due to changed probability of large accidents have not been accounted for
- The assessments have been carried out for :
  - Mean values,
  - all costs reduced by 20 % and
  - all costs increased by 20 %

Ungraded

# Fuel oil price development

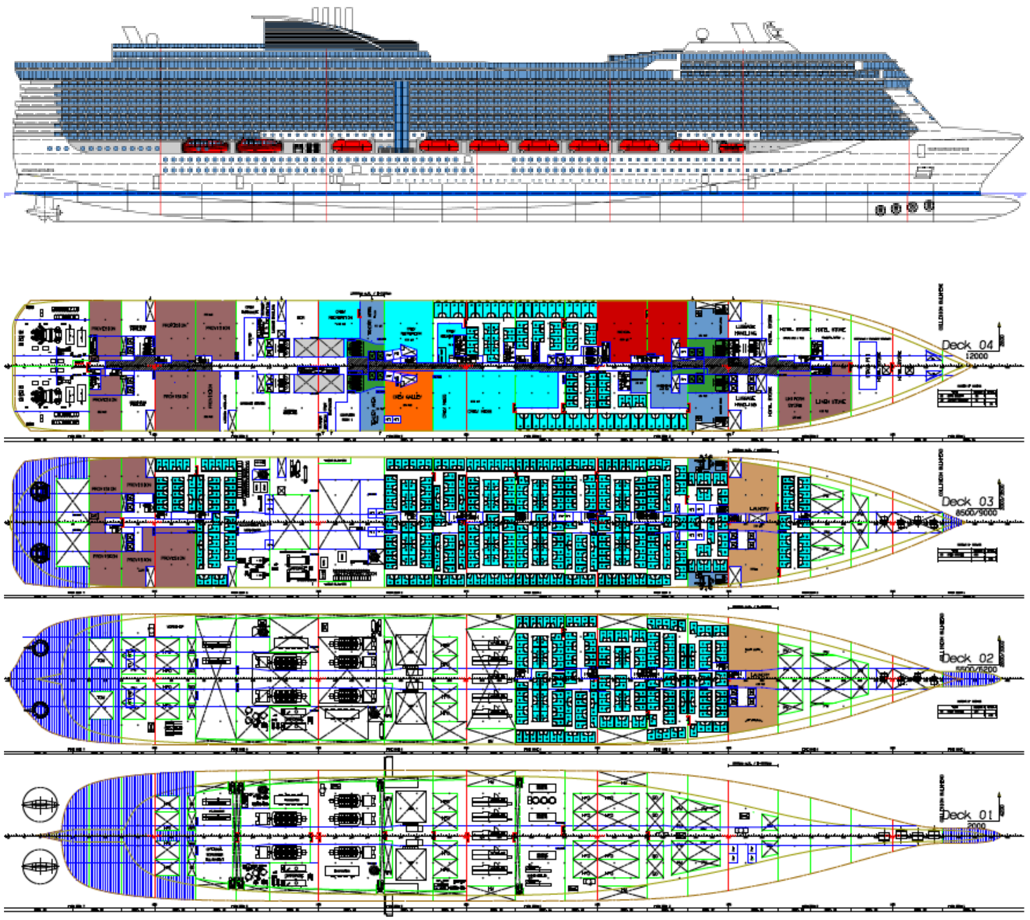
- Data published by EIA energy outlook have been used as basis for estimating the future trends.

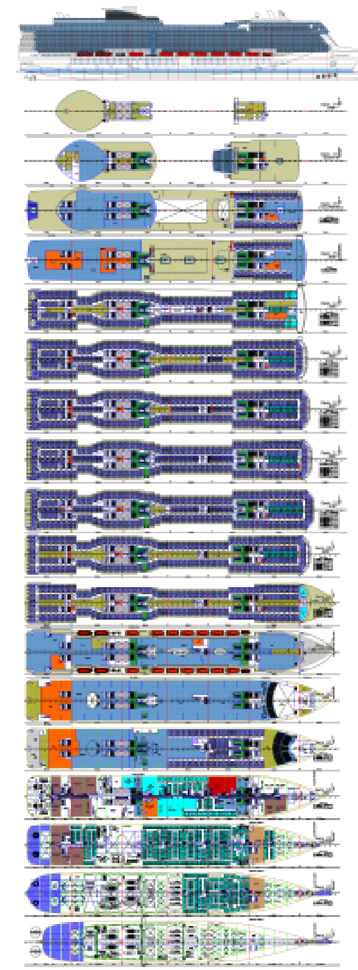



- The current prices for HFO and MGO; 600 USD/t and 900 USD/t, have been obtained using the average reported prices for 2013 and 2014 in Rotterdam using Clarkson Intelligence as a source.
- The price of LSHFO is obtained based on a 20/80 distribution of the HFO and MGO price. This is the distribution 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.
- The latest reduction of fuel prices (MGO 540 USD/t, HFO 300 USD/t) has not been accounted for.

**Ungraded**

# Large cruise vessel – Meyer Werft & Carnival



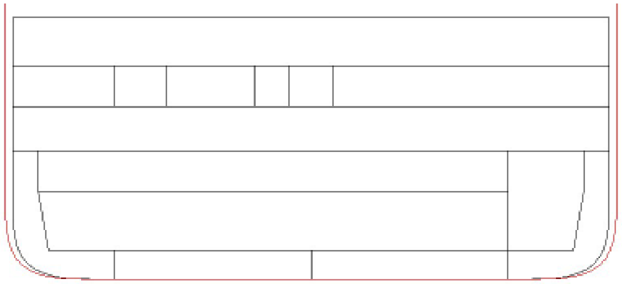



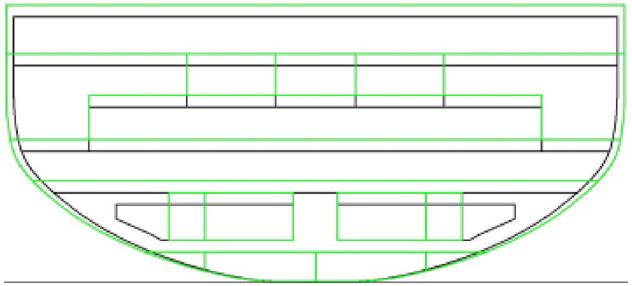
| | Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|---|
| Ungraded | 294.6 | 40.8 | 8.75 | 153400 | 6730 |

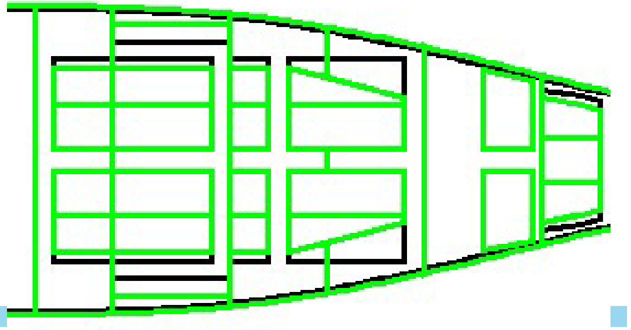
# Large cruise vessel – Meyer Werft & Carnival

- Global changes (beam, freeboard)
- Local changes (internal subdivision)

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

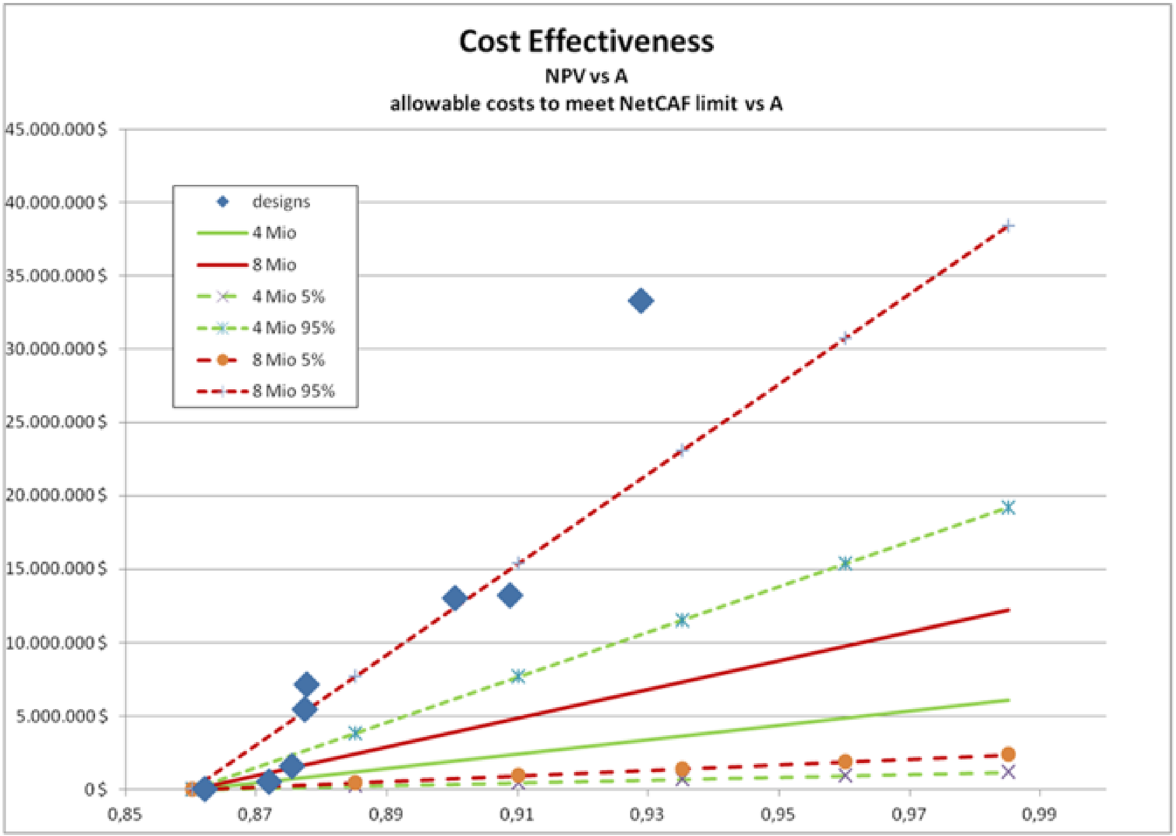






Ungraded

# Large cruise vessel – Meyer Werft & Carnival

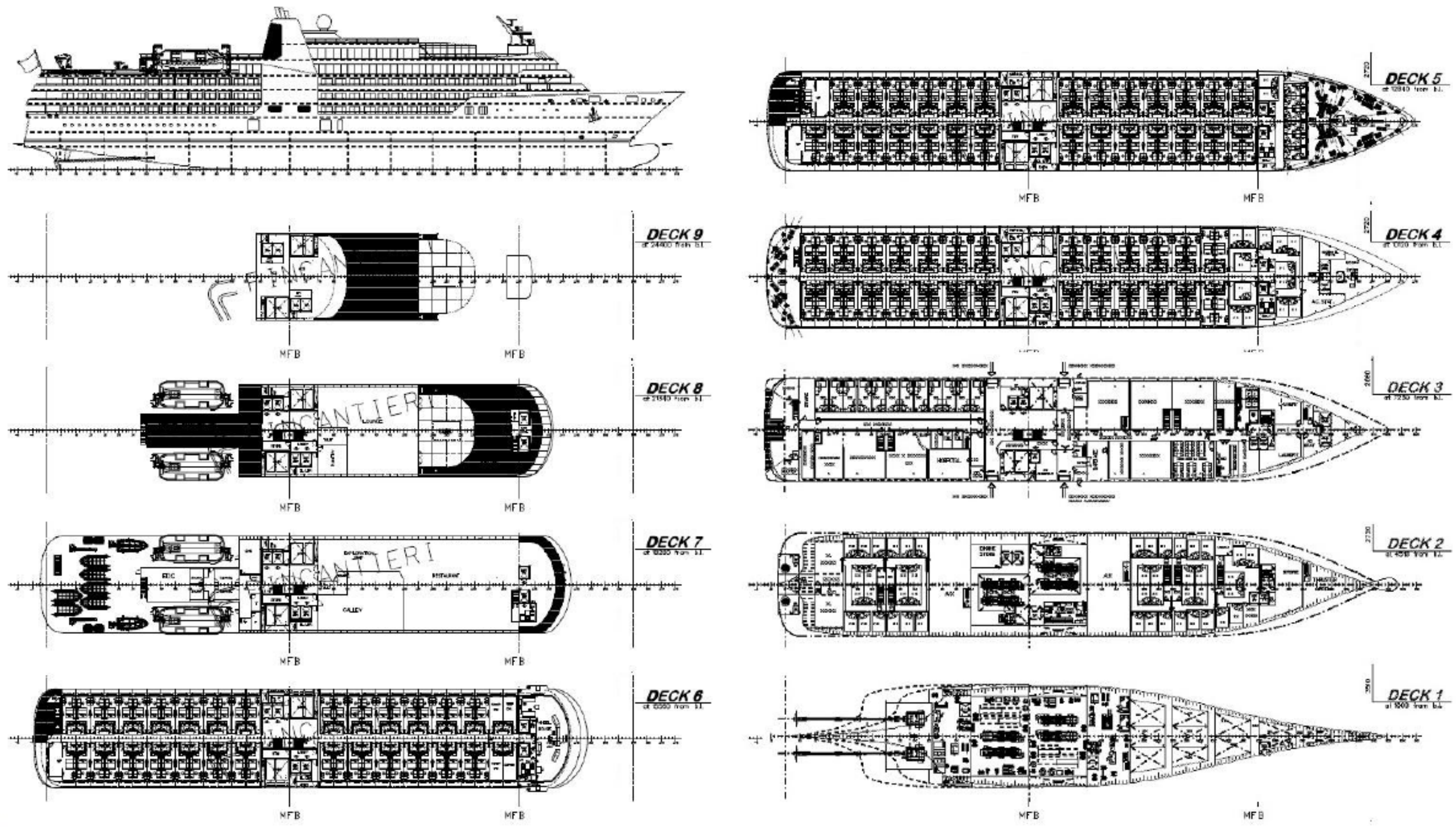



| Version | Description |
|---|---|
| G2 | Reference design |
| H4 | Breadth increased by 1.0m |
| I3 | Breadth increased by 1.0m<br>Freeboard increased by 0.8m |
| J1 | Breadth increased by 0.6m<br>Freeboard increased by 0.2m |
| K1 | change internal subdivision |
| K2 | change internal subdivision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

| 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 in A | 0.0000 | 0.0466 | 0.0667 | 0.0383 | 0.0098 | 0.0156 | 0.0133 | 0.0153 |

**Ungraded**

# Small Cruise – Fincantieri & RCCL

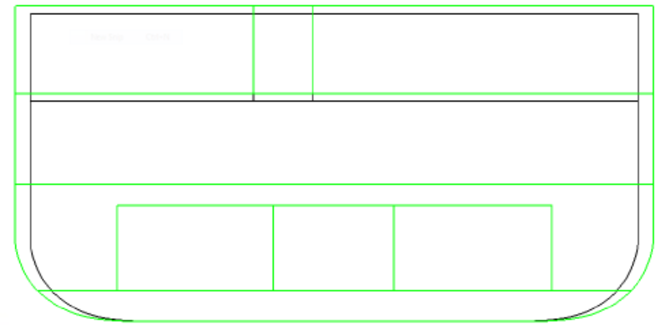


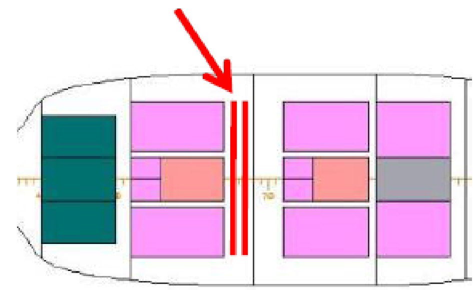

| | Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|---|
| Ungraded | 113.7 | 20.0 | 5.30 | 11800 | 478 |

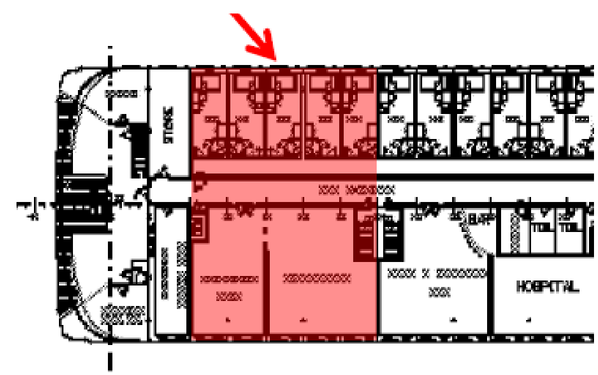
# Small Cruise – Fincantieri & RCCL

- Global changes (beam, freeboard)
- Local changes (internal subdivision, watertight decks)

| 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) |

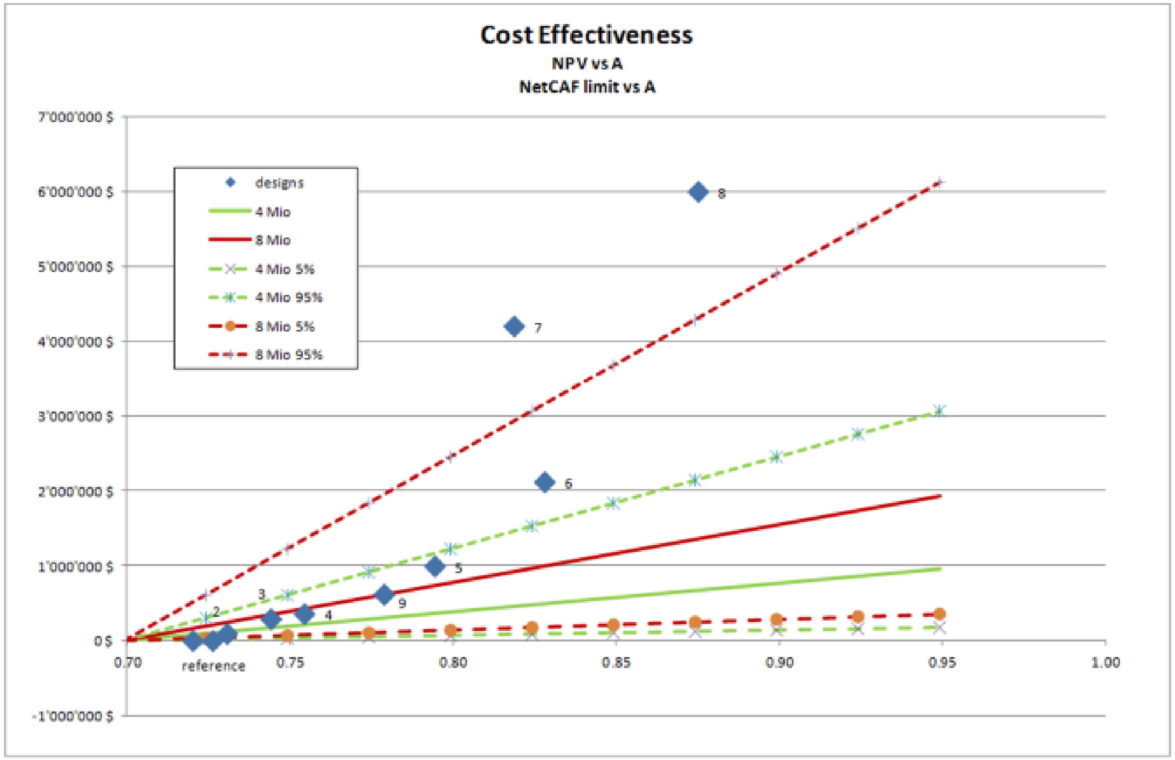






**Ungraded**

# Small Cruise – Fincantieri & RCCL

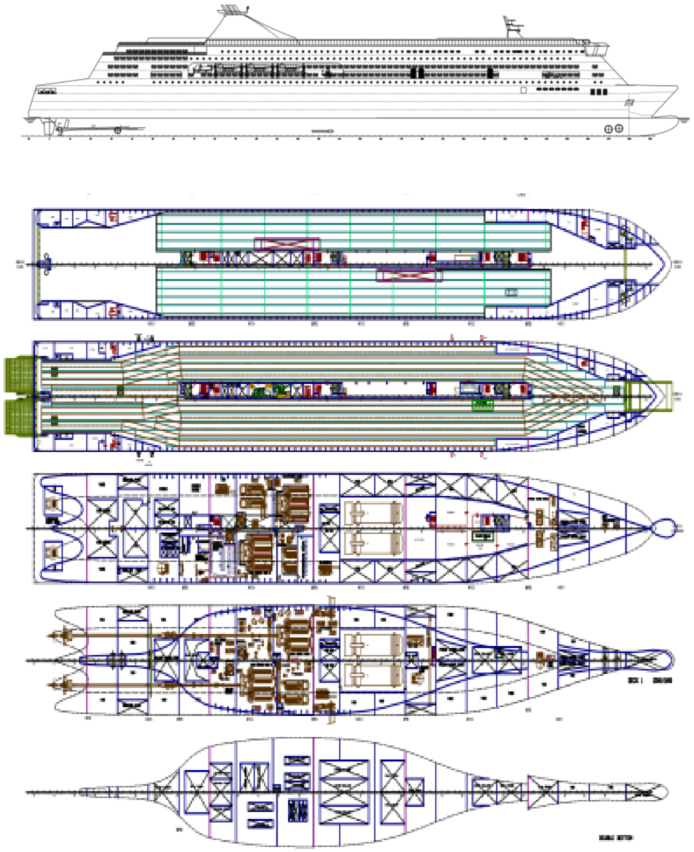


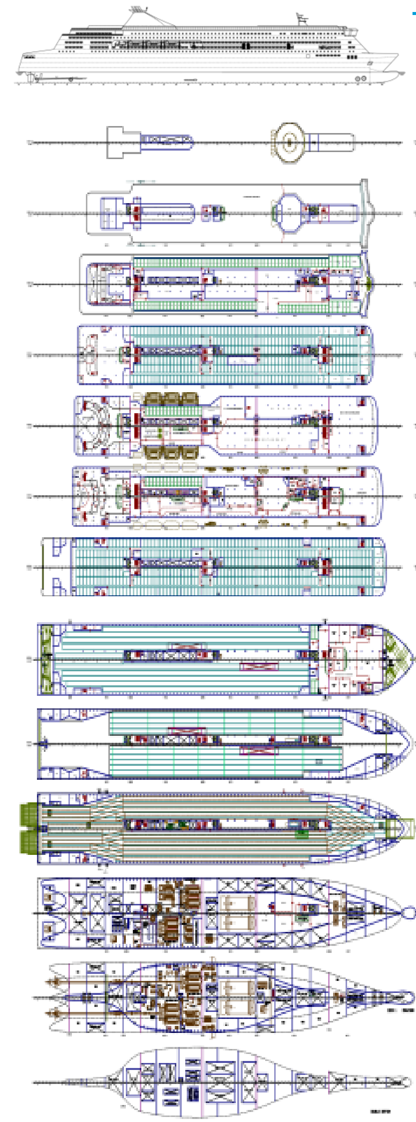

| Version | Description |
|---|---|
| 00 | Reference design |
| 01 | Sill increased on external weathertight aft doors |
| 02 | Vs.01 + Deck 3 made wathertight for comp n.2 and n.3 |
| 03 | Vs.02 + Cross flooding section within DB void spaces improved adding pipes |
| 04 | Vs.03 + Two weathertight door 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) |

| 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 in A | 0.0000 | 0.0061 | 0.0105 | 0.0240 | 0.0342 | 0.0742 | 0.1079 | 0.0985 | 0.1550 | 0.0587 |

**Ungraded**

# Baltic RoPax – Meyer Turku & Color Line





Ungraded

| Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|
| 232.0 | 29.0 | 7.20 | 60000 | 3280 |

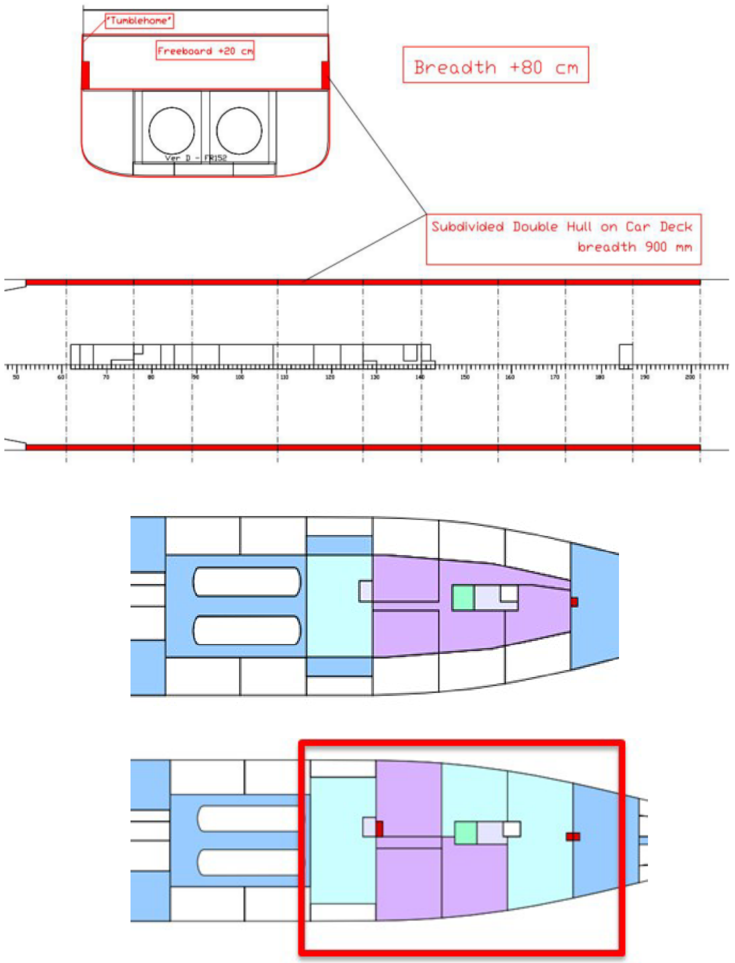


DNV·GL

# Baltic RoPax – Meyer Turku & Color Line

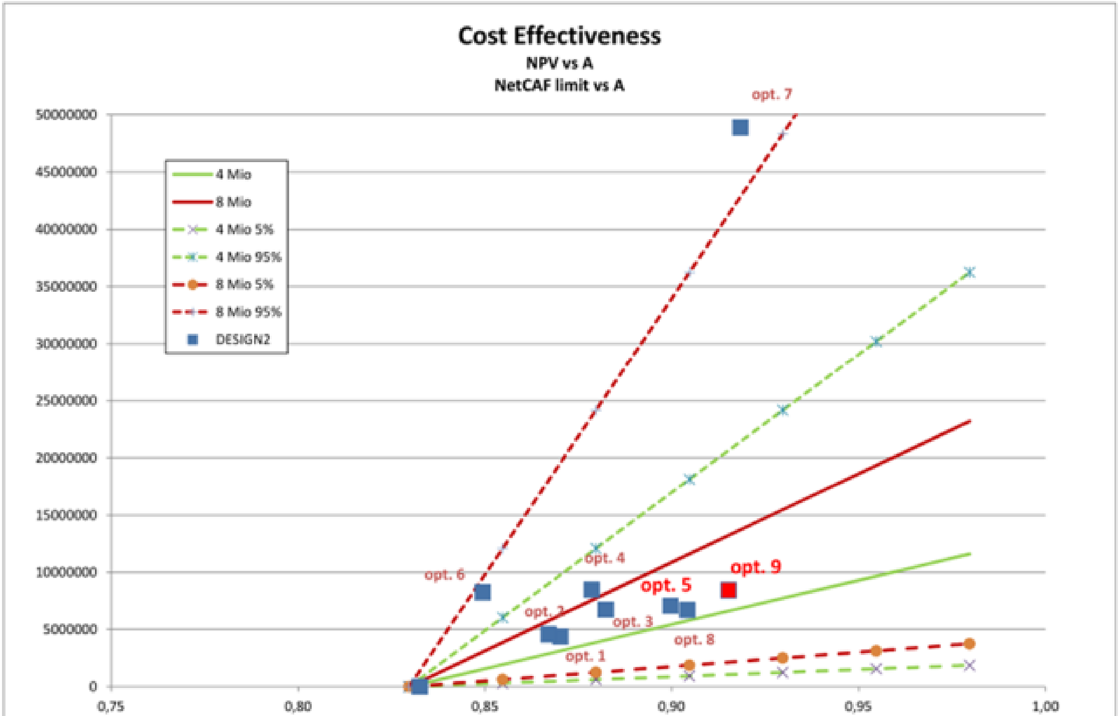
- Global changes (beam, new hullform subdivided double hull on bulkhead deck)
- Effect of LLH

| 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<br>Freeboard increased by 20 cm |
| **Phase 1** | D (Option 3) | Breadth increased by 40 cm<br>Freeboard increased by 20 cm |
| **Phase 1** | E (Option 4) | Breadth increased by 40 cm<br>Freeboard increased by 40 cm |
| **Phase 2** | F (Option 5) | As version D (opt. 3)<br>subdivided double hull on bulkhead deck |
| **Phase 3** | I (Option 6) | As version F (opt. 5)<br>impact of LLH |
| **Phase 3** | J (Option 7) | As version F (opt. 5)<br>Subdivided Car Deck |
| **Phase 3** | K2 (Option 8) | As version F (opt. 5)<br>No Lower Hold |
| **Phase 4** | L (Option 9) | As version F (opt. 5) + 40 cm more breadth =<br>Breadth increased by 80 cm<br>Freeboard increased by 20 cm<br>subdivided double hull on bulkhead deck |




**Ungraded**

# Baltic RoPax – Meyer Turku & Color Line

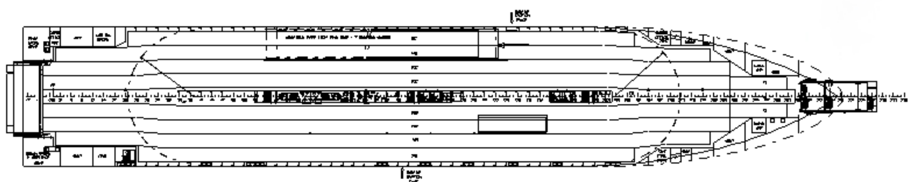



| Phase | Version | Description |
|---|---|---|
| | A | Reference design |
| Phase 1 | B (Option 1) | Breadth increased by 40 cm |
| Phase 1 | C (Option 2) | Breadth increased by 20 cm<br>Freeboard increased by 20 cm |
| Phase 1 | D (Option 3) | Breadth increased by 40 cm<br>Freeboard increased by 20 cm |
| Phase 1 | E (Option 4) | Breadth increased by 40 cm<br>Freeboard increased by 40 cm |
| Phase 2 | F (Option 5) | As version D (opt. 3)<br>subdivided double hull on bulkhead deck |
| Phase 3 | I (Option 6) | As version F (opt. 5)<br>impact of LLH |
| Phase 3 | J (Option 7) | As version F (opt. 5)<br>Subdivided Car Deck |
| Phase 3 | K2 (Option 8) | As version F (opt. 5)<br>No Lower Hold |
| Phase 4 | L (Option 9) | As version F (opt. 5) + 40 cm more breadth =<br>Breadth increased by 80 cm<br>Freeboard increased by 20 cm<br>subdivided double hull on bulkhead deck |

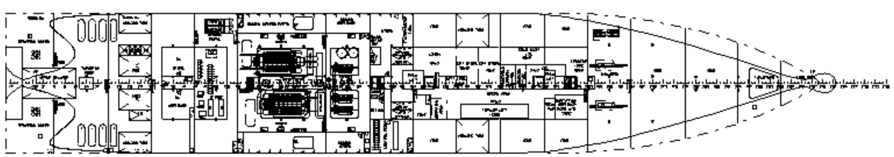
| Version | A | B opt 1 | C opt 2 | D opt 3 | E opt 4 | F opt 5 | I opt 6 | J opt 7 | K2 opt 8 | L opt 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| required index R | 0.8300 | 0.8300 | 0.8300 | 0.8300 | 0.8300 | 0.8300 | 0.8300 | 0.8300 | 0.8300 | 0.8300 |
| attained index $A_{SLF55}$ | 0.8326 | 0.8703 | 0.8670 | 0.8824 | 0.8786 | **0.8997** | 0.8494 | 0,.184 | 0.9042 | **0.9152** |
| Change in A | 0.0000 | 0.0377 | 0.0344 | 0.0498 | 0.0460 | **0.0671** | 0.0168 | 0.0858 | 0.0716 | **0.0826** |

**Ungraded**

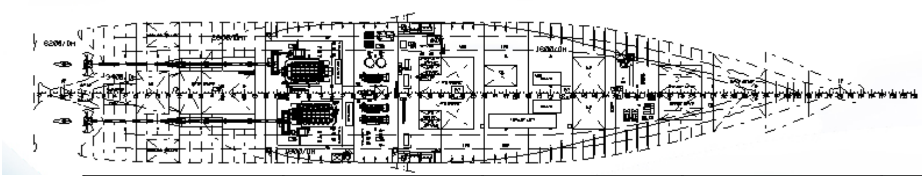
# Mediterranean Ropax – STX-France & Stena Line/Color Line



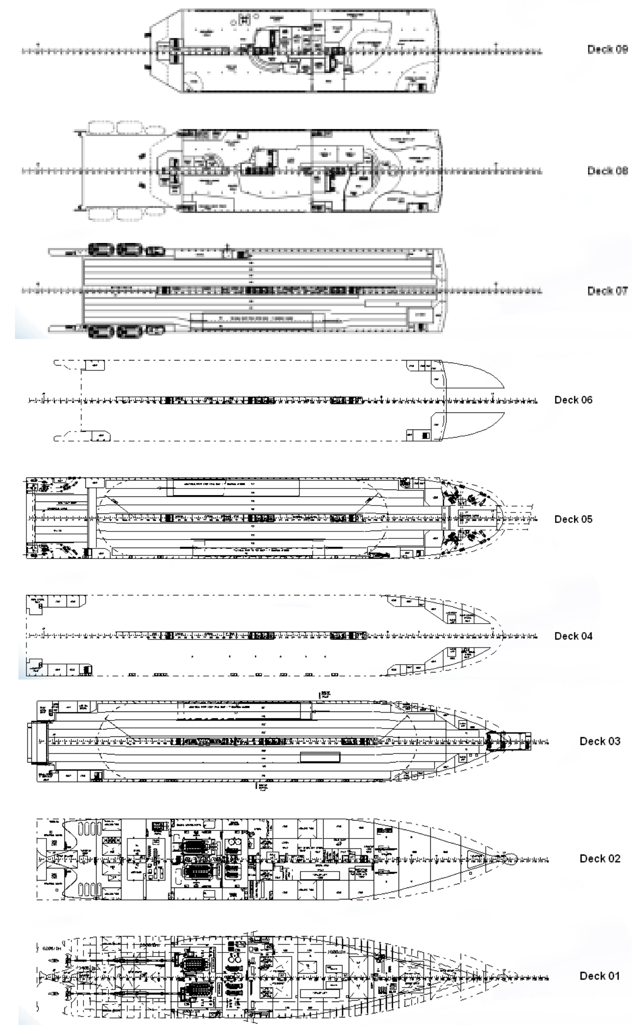
Deck 03



Deck 02



Deck 01




| | Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|---|
| Ungraded | 172.4 | 31.0 | 6.60 | 43000 | 1700 |

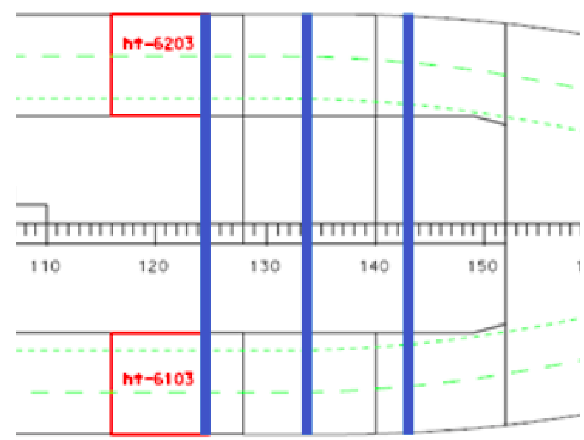


DNV·GL

# Mediterranean Ropax – STX-France & Stena Line/Color Line

- Internal subdivion
- Subdivided car deck
- Effect of LLH

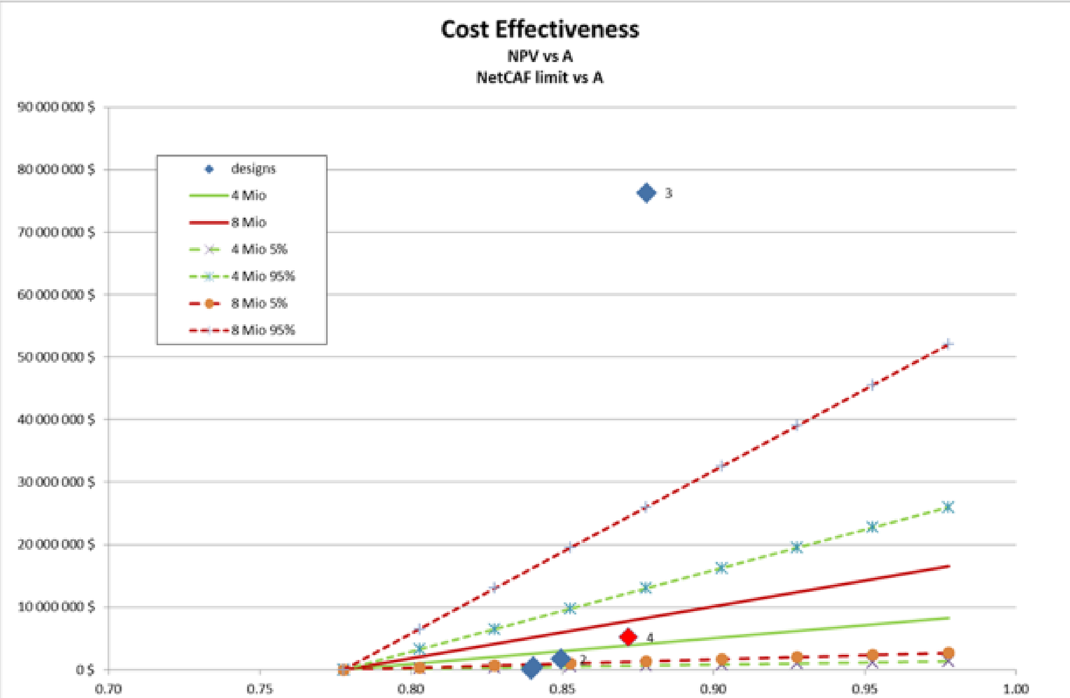
| Version | Description |
|---|---|
| **Initial design** | |
| **V0** | New S Ropax (SLF55 formulation) |
| **V1** | Depth + 10cm |
| **V12** | Additional WT bulkheads below bulkhead deck |
| **V21** | Additional WT subdivisions above bulkhead deck |
| **V13** | Side casing based on V12* |
| **V14** | Increase in breadth + 20cm based on V12 |




*studied but not found to contribute significantly to raise A

**Ungraded**

# Mediterranean Ropax – STX-France & Stena Line/Color Line



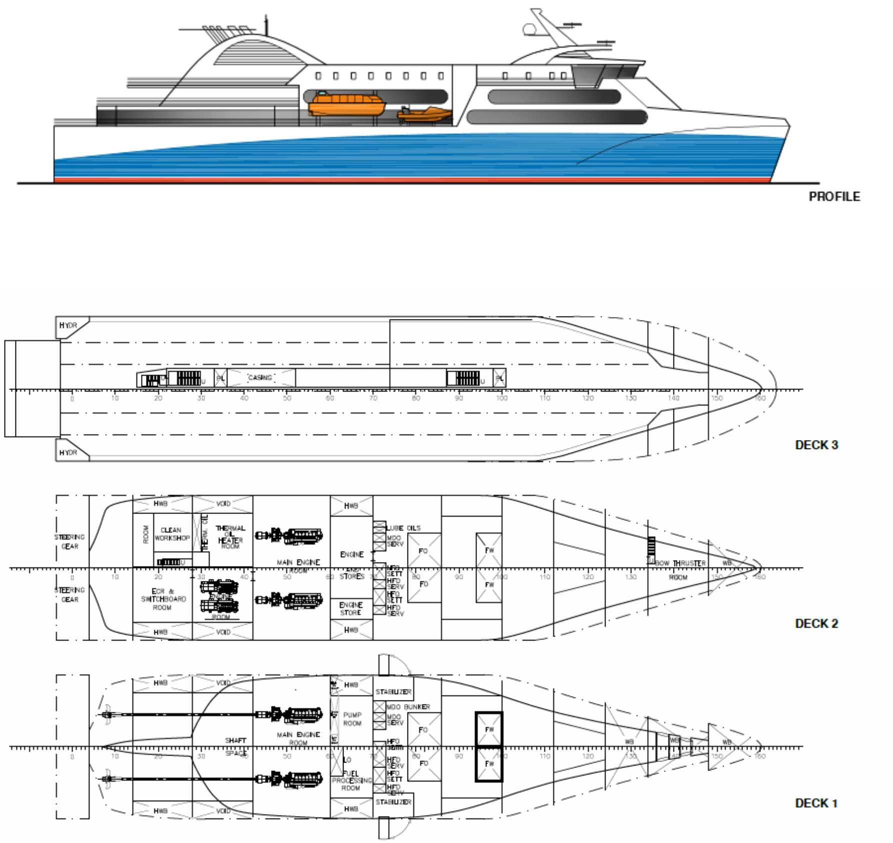

| Version | Description |
|---|---|
| Initial design | |
| V0 | New S  Ropax (SLF55 formulation) |
| V1 | Depth + 10cm |
| V12 | Additional WT bulkheads below bulkhead deck |
| V21 | Additional WT subdivisions above bulkhead deck |
| V13 | Side casing based on V12* |
| V14 | Increase in breadth + 20cm based on V12 |

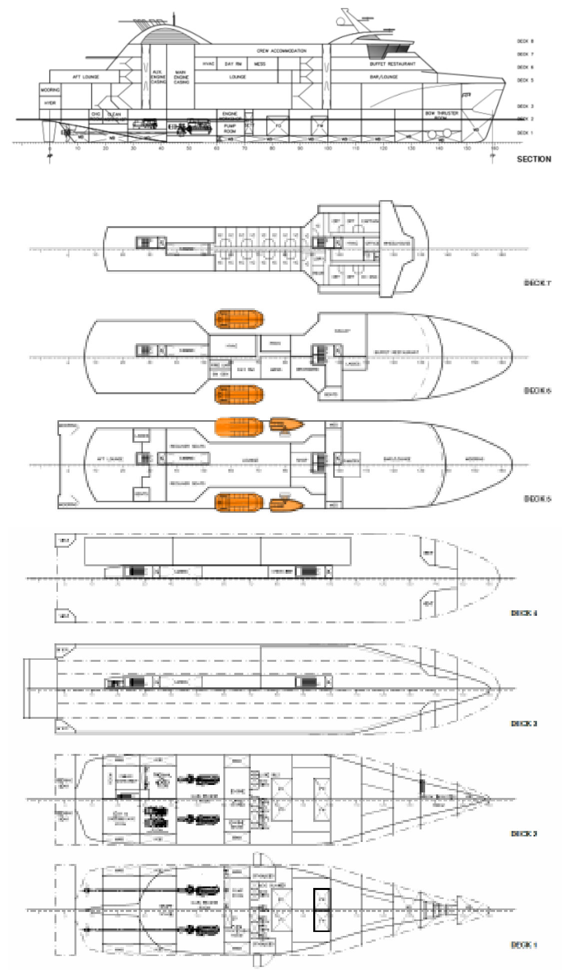
*studied but not found to contribute significantly to raise A

| 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 in A | 0.0000 | 0.0005 | 0.0097 | 0.0380 | 0.0319 |

Ungraded

# Small RoPax – KEH & Stena Line




| | Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|---|
| Ungraded | 95.5 | 20.2 | 4.90 | 7900 | 625 |

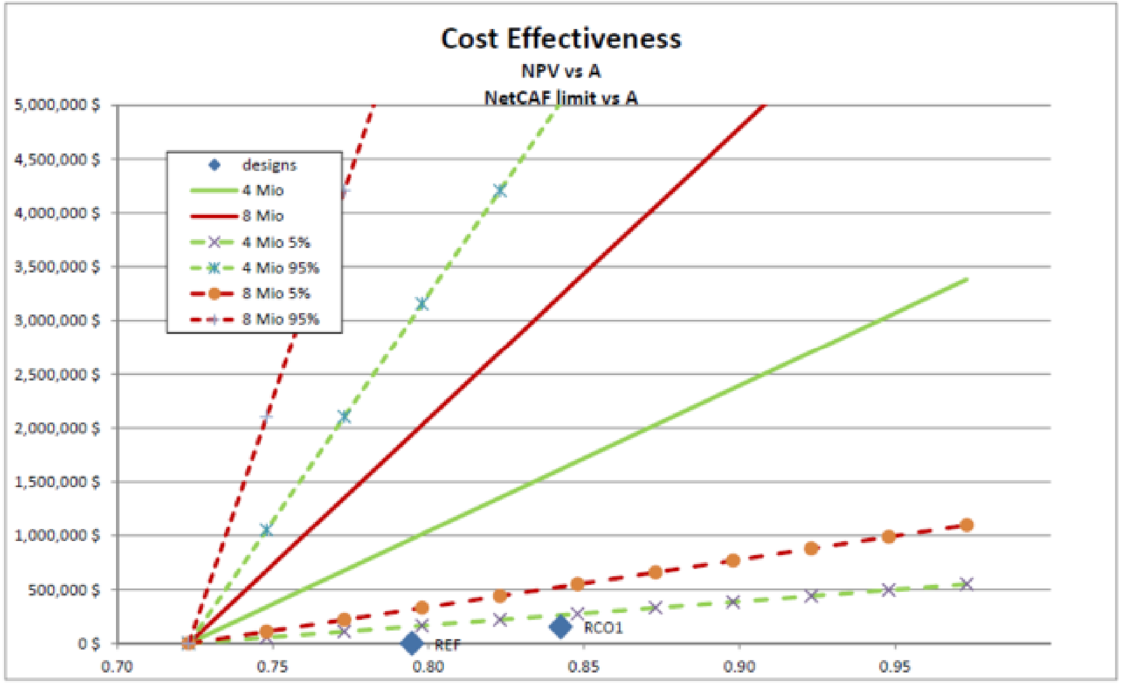

DNV·GL

# Small RoPax – KEH & Stena Line

- Change of freeboard

| Version | Initial | RCO 1 |
|---|---|---|
| **Required index R** | 0.7214 | 0.7214 |
| **Attained index A** | 0.7947 | 0.8426 |
| **change A** | 0.0000 | 0.0479 |

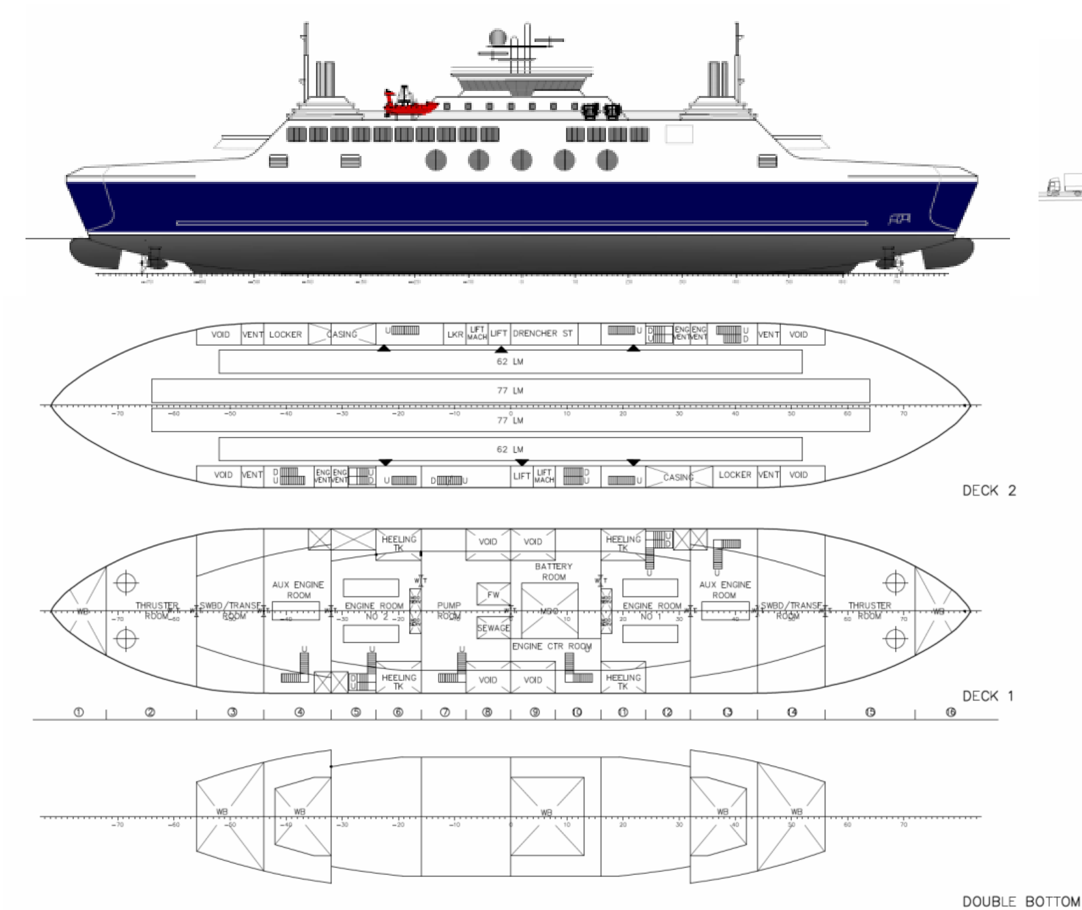
| Version | Description |
|---|---|
| **Initial design** | |
| **RCO1** | Raise main deck + 30 cm |

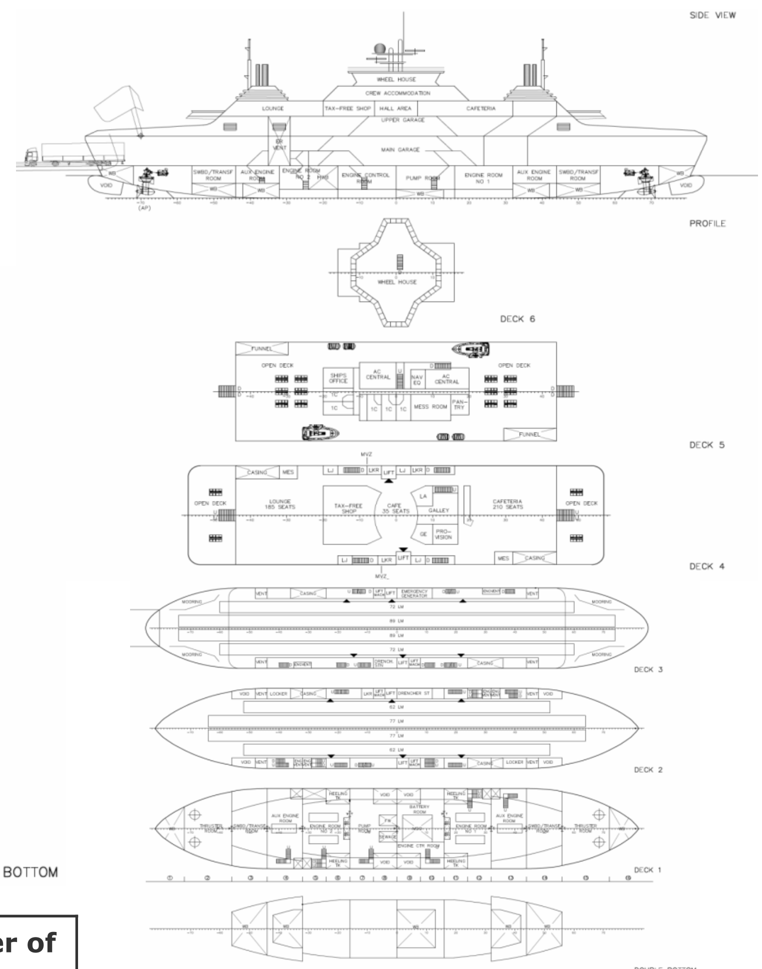



**Ungraded**


DNV·GL

# Double  ender ferry – KEH & Stena Line



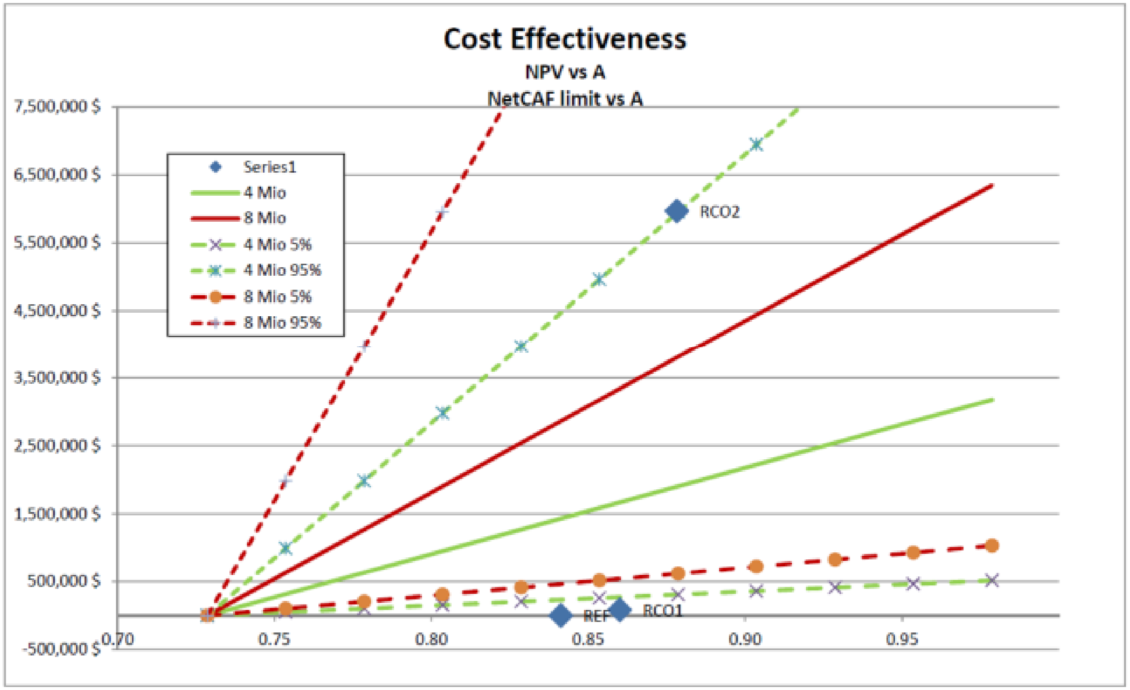

| | Length bp (m) | B (m) | T (m) | GT | Number of persons |
|---|---|---|---|---|---|
| **Ungraded** | **96.8** | **17.6** | **4.30** | **6245** | **610** |

# Double  ender ferry – KEH & Stena Line

- Change of freeboard

| Version | Initial | RCO 1 | RCO 2 |
|---|---|---|---|
| **Required index R** | 0.7279 | 0.7279 | 0.7279 |
| **Attained index A** | 0.8412 | 0.8601 | 0.8782 |
| **change A** | 0.0000 | 0.0189 | 0.037 |

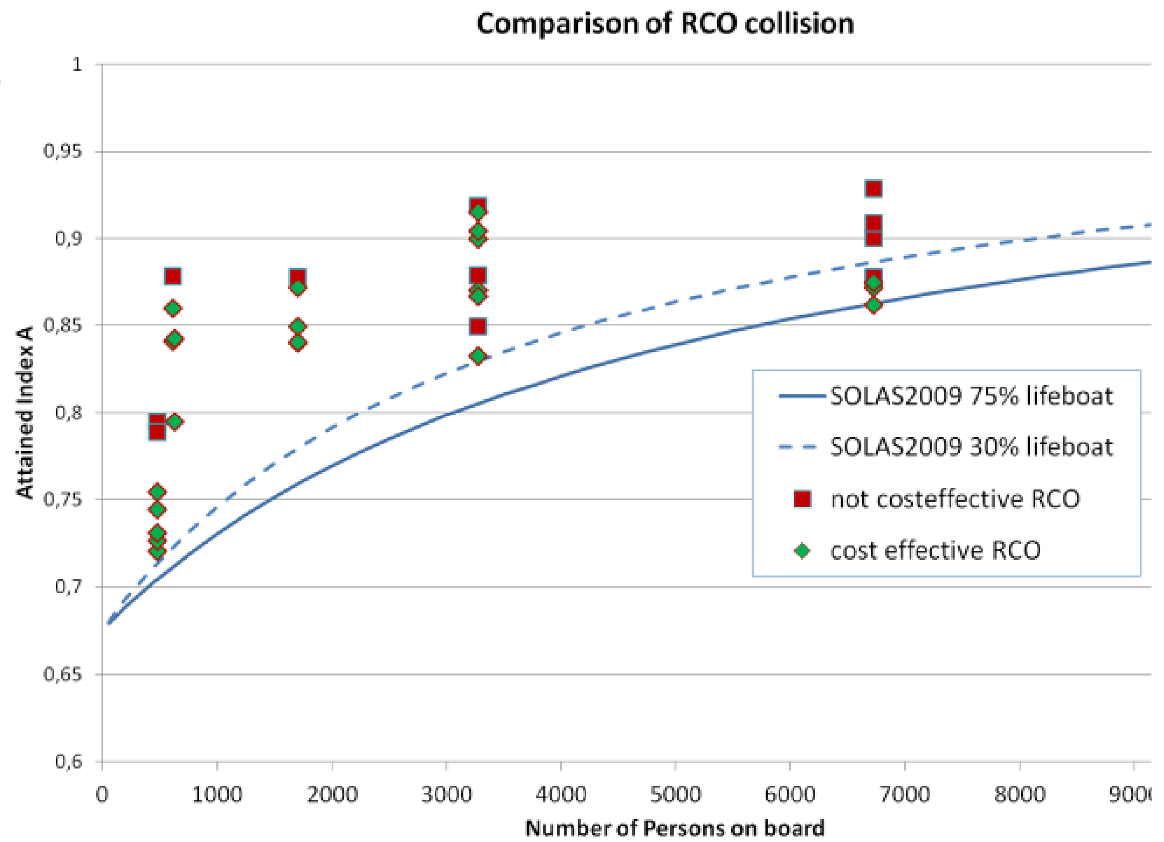
| Version | Description |
|---|---|
| **Initial design** | |
| **RCO1** | Raise main deck + 30 cm |
| **RCO2** | Increase Beam +40 cm |




**Ungraded**

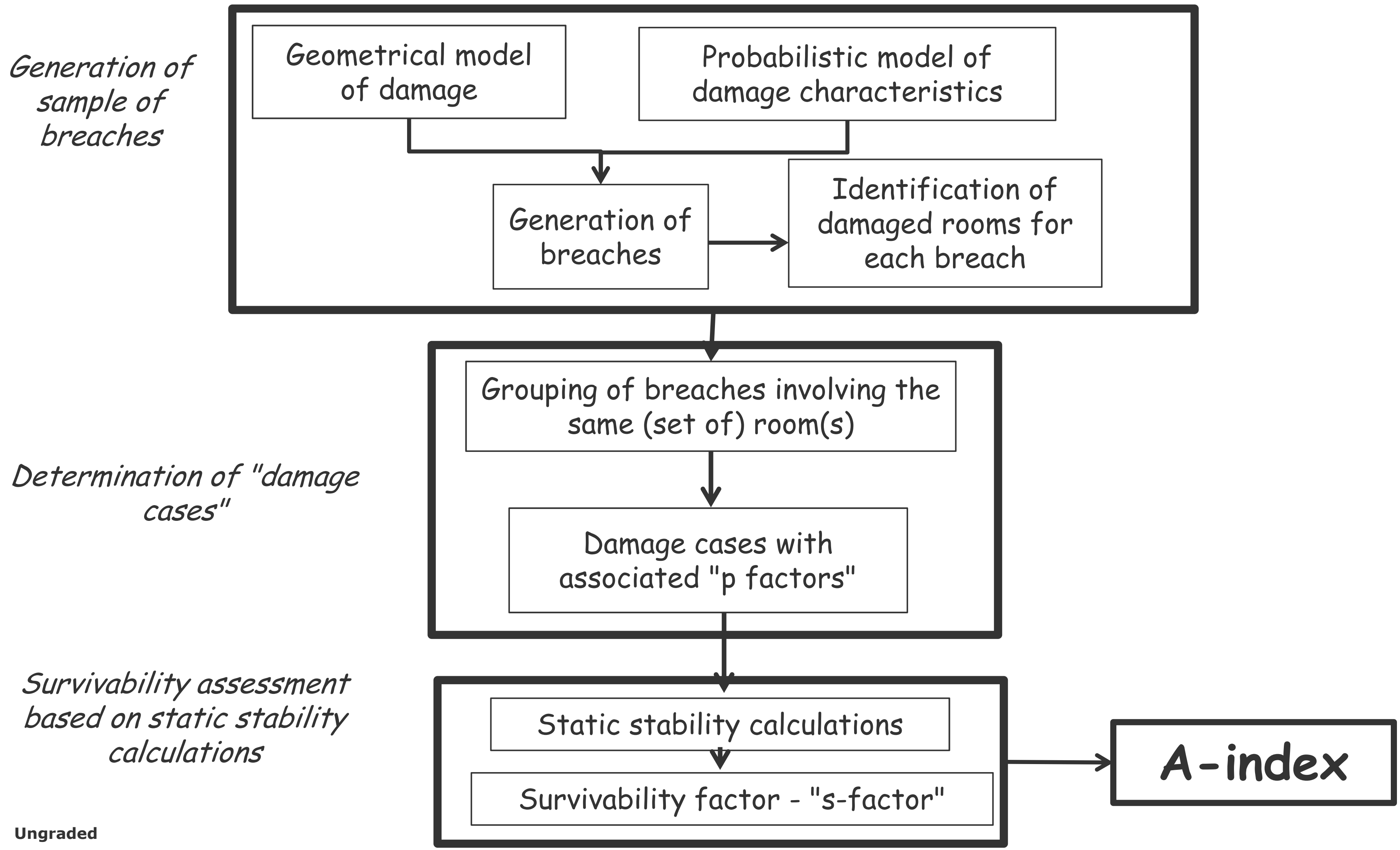
# Summary RCOs collision

- High attained index possible
- For RoPax higher cost-effective RCOs can be found
- Large difference between RoPax and cruise




Ungraded

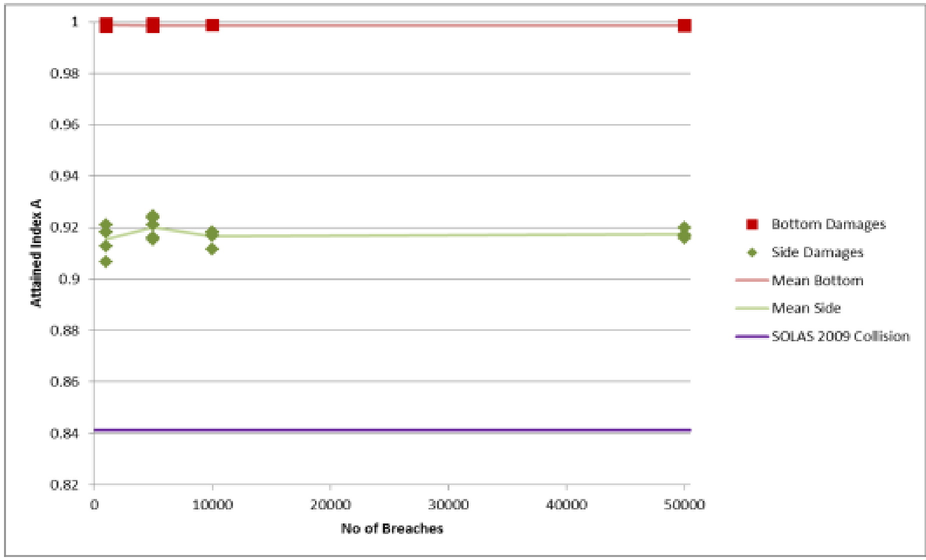
# Approach for determination of A-index for Grounding

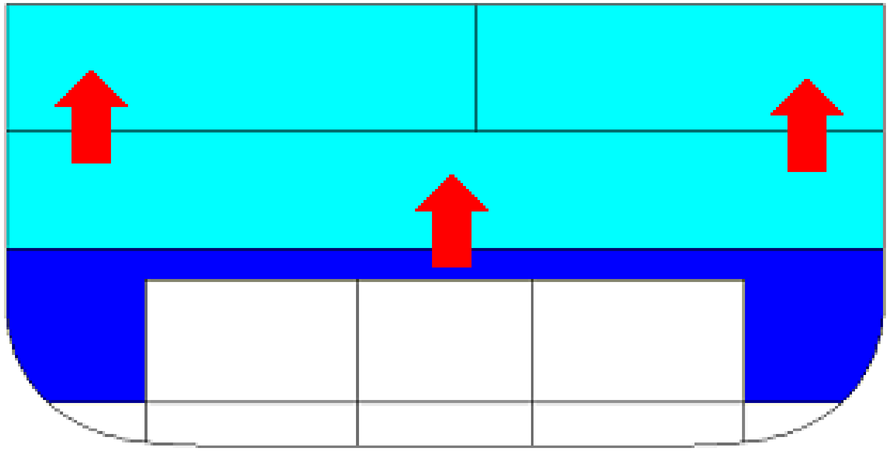



Ungraded

# GROUNDING
## Methodology

- Direct approach used
  - Bottom and side groundings
  - 5 repititions with 10000 breaches each
  - Good approximation of A
- Internal watertight integrity not fully considered
- Explicit RCOs investigated for large cruise and mediterranean ropax only
- For remaining sample ships only recalculation of reference version and one collision RCO.



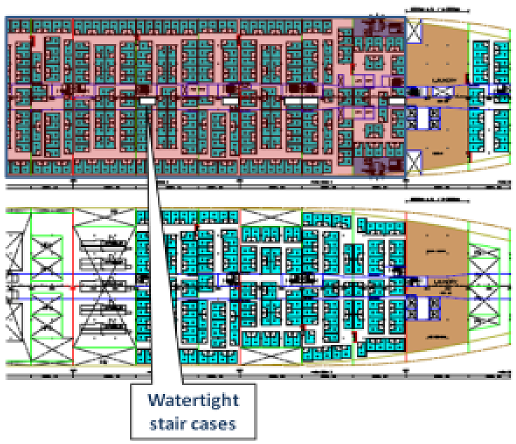



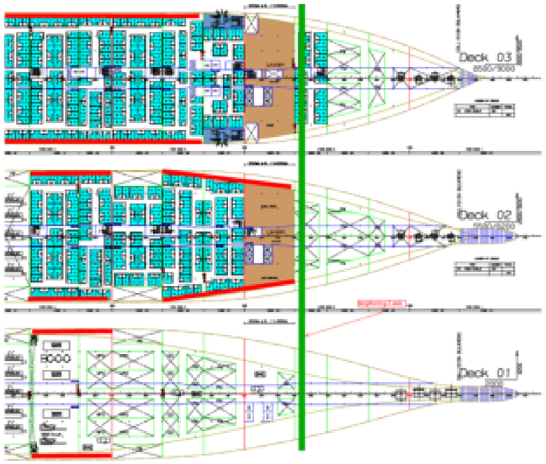
**Ungraded**

# GROUNDING
## Large cruise vessel – Meyer Werft & Carnival

- Global changes (beam, freeboard)
- Local changes (double hull, WT decks)

| Version | Description |
|---|---|
| **G2** | Reference design |
| **G3** | as G2<br>with deck 3 made watertight as far as possible |
| **K3** | Selected optimized version for collision<br>change internal subdivision as K1<br>Freeboard increased by 0.4m |
| **K4** | as K3<br>with deck 3 made watertight as far as possible |
| **M1** | double hull<br>increased DB height<br>lengthened by 1 web frame |
| **M2** | as M1<br>with deck 3 made watertight as far as possible |
| **I3** | Breadth increased by 1.0m<br>Freeboard increased by 0.8m |



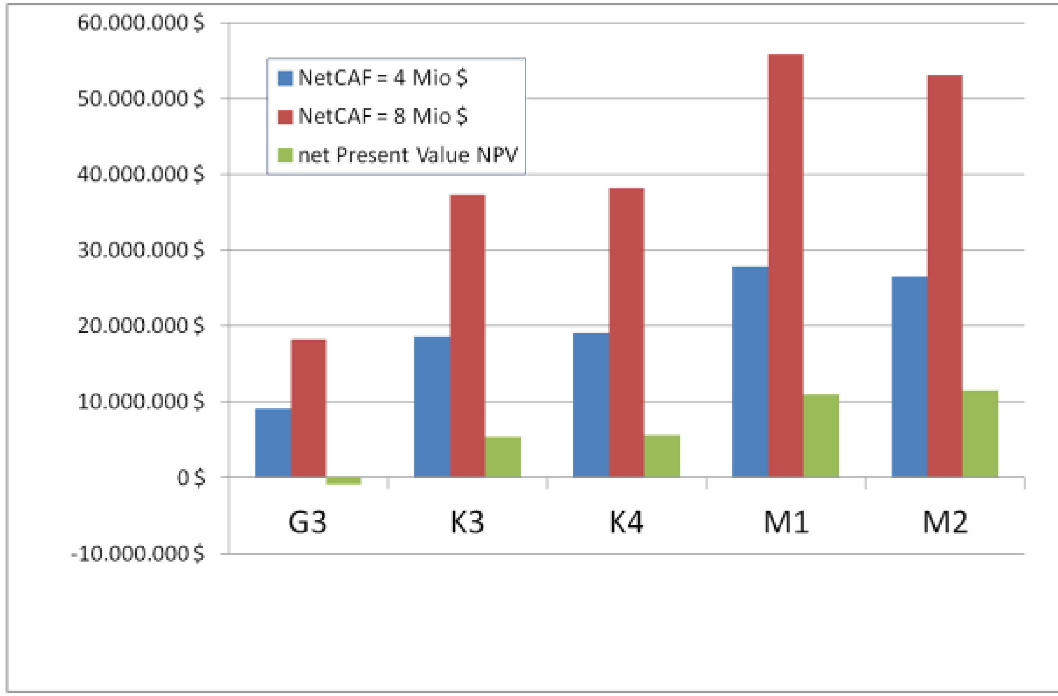




**Ungraded**


DNV·GL

# GROUNDING
# Large cruise vessel – Meyer Werft & Carnival

- All grounding RCOs are cost effective
- some RCO do not comply with SOLAS2009 anymore




| Version | G2 | G3 | K3 | K4 | M1 | M2 | I3 |
|---|---|---|---|---|---|---|---|
| **Description** | reference version | as G2 with wt decks | opt. Version for collision | as K3 with wt decks | double hull increased DB height | as M1 with wt decks | Increased beam, increased freeboard |
| SOLAS2009 | 0.8626 | 0.8643 | 0.8754 | 0.8792 | 0.8529 | 0.8747 | 0.9288 |
| A Grounding | 0.9142 | 0.9336 | 0.9543 | 0.9551 | 0.9736 | 0.9707 | 0.9513 |

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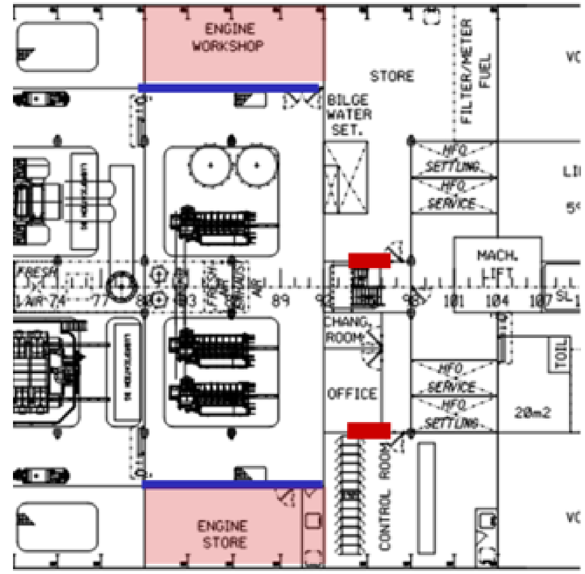
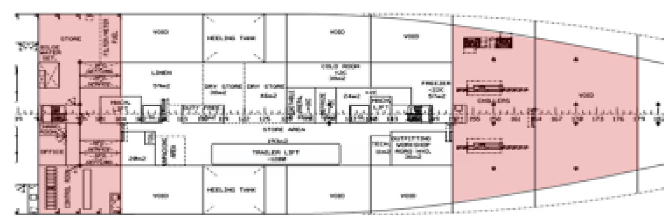
# GROUNDING
## Mediterranean RoPax – STX-France & Stena Line/Color Line

- Internal subdivision + beam increased
- WT decks + crossflooding




| Version | Description |
|---|---|
| **V0** | original design |
| **V14** | Optimized for collision: Internal subdivision + Breadth increased |
| **V15** | Cross flooding devices + watertightness of longitudinal bulkheads |
| **V16** | Additional watertight parts of decks |



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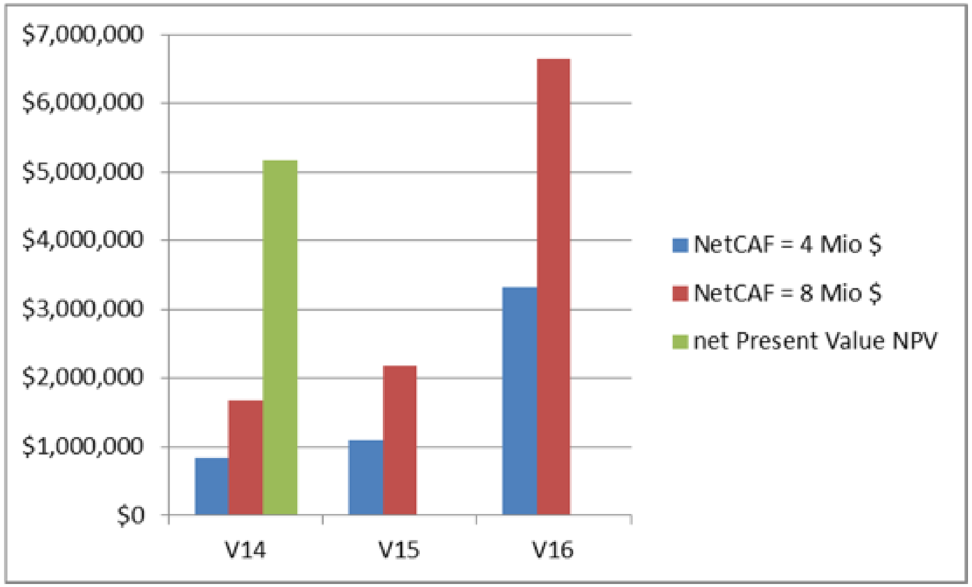
# GROUNDING
# Mediterranean RoPax – STX-France & Stena Line/Color Line

- Internal changes are cost effective
- Change of main parameters are not cost-effective




| Version | V00 | V14 | V15 | V16 |
|---|---|---|---|---|
| | original design | Optimized for collision: Internal subdivision + Breadth increased | Cross flooding devices + watertightness of longitudinal bulkheads | Additional watertight parts of decks |
| Collision SOLAS2009 +SLF55 | 0.8398 | 0.8718 | 0.8717 | 0.880855 |
| Mean attained index A grounding $A_{GR}$ | 0.954 | 0.958 | 0.963 | 0.973 |

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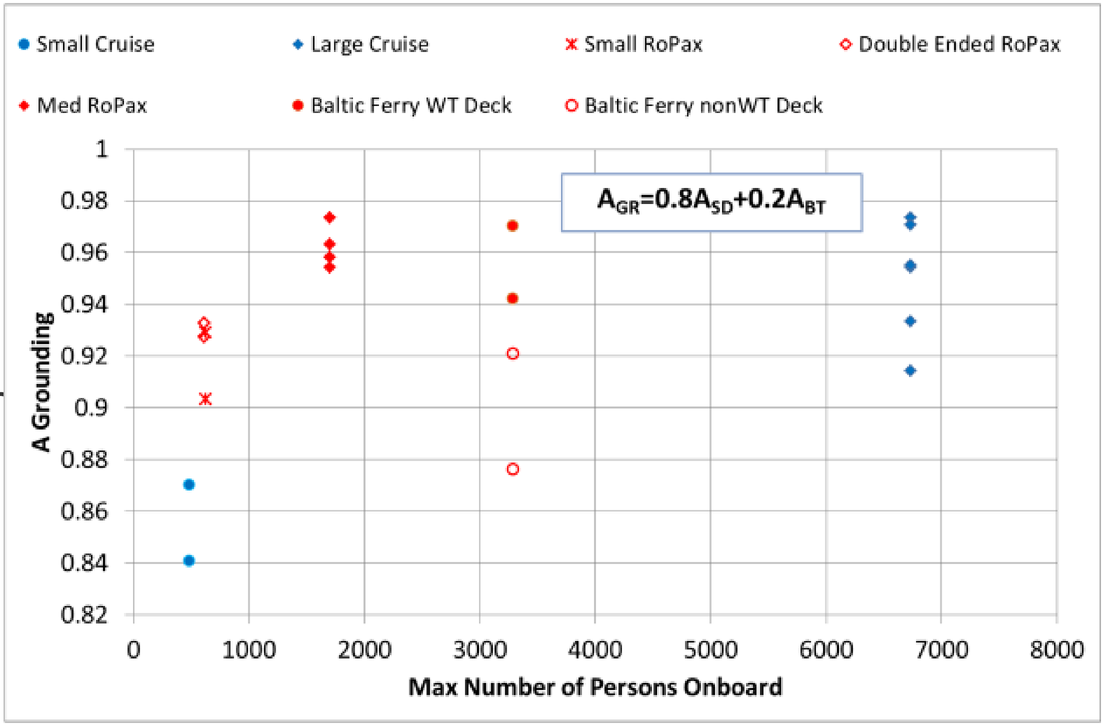
# GROUNDING
## Summary

- High index for grounding can be attained
- Direct approach is very time consuming but offers great potential to be used also for collision
- Methodology requires further validation and confirmation by IMO
- Some RCOs improve collision and grounding, other RCOs have adverse effects on collision or grounding
- Effect on detailed design and internal watertight integrity to be further analysed

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# Content

- Introduction and overview of the EMSA III studies (Odd Olufsen)
- Formal Safety Assessment, Risk Models for collision and grounding (Rainer Hamann)
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- Sensitivity analysis (Rainer Hamann)
- Summary of results, recommendations for decision making (Odd Olufsen)

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# Sensitivity of CBA Results for CN

- In CBA RCOs are evaluated related to

$$GCAF = \frac{\Delta Cost}{\Delta Risk}$$

$$NCAF = \frac{\Delta Cost - \Delta Benefit}{\Delta Risk}$$

- Sensitivity of the results was analysed with respect to
  - Initial accident frequency
  - Number of accidents in terminal area/open sea
  - Probability of water ingress in open sea
  - Percentage of fast sinking
  - High-low fuel price scenario

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# Sensitivity of CBA Results for CN

- Fuel price:
  - Main influence on Δcost
  - Specific cost per tonne (fuel mix) and 30 years

| Low | Mean | High |
| --- | --- | --- |
| 9791 $/t | 140934 $/t | 16205 $/t |

  - For large cruise fuel costs are between 0% (no add. fuel consumption) and 50% of Δcost

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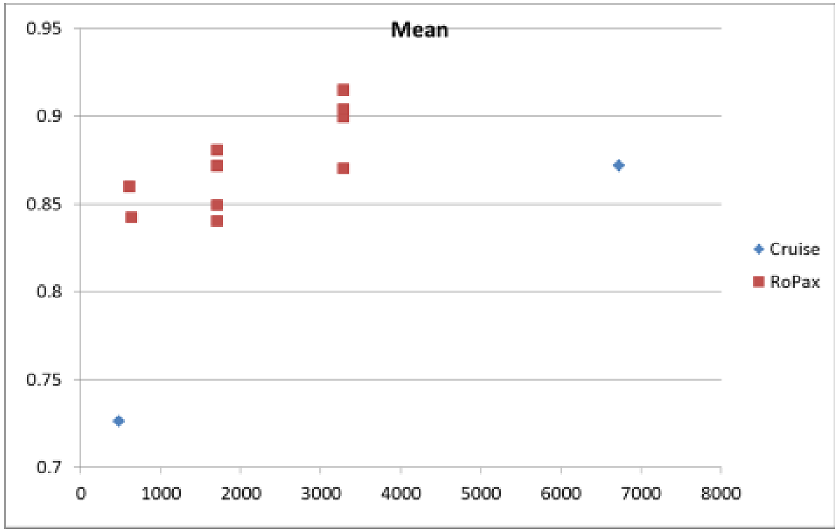
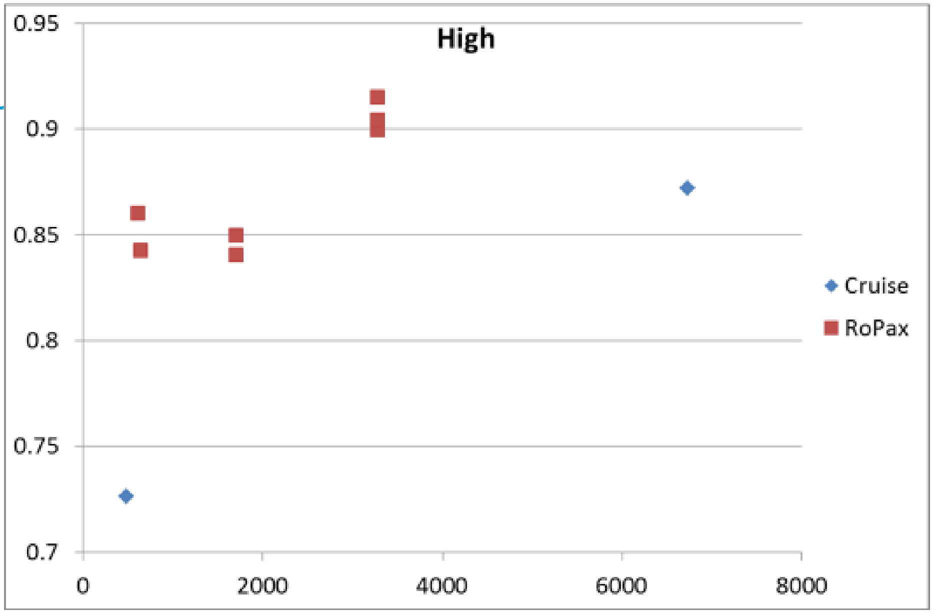
# Sensitivity of CBA Results for CN

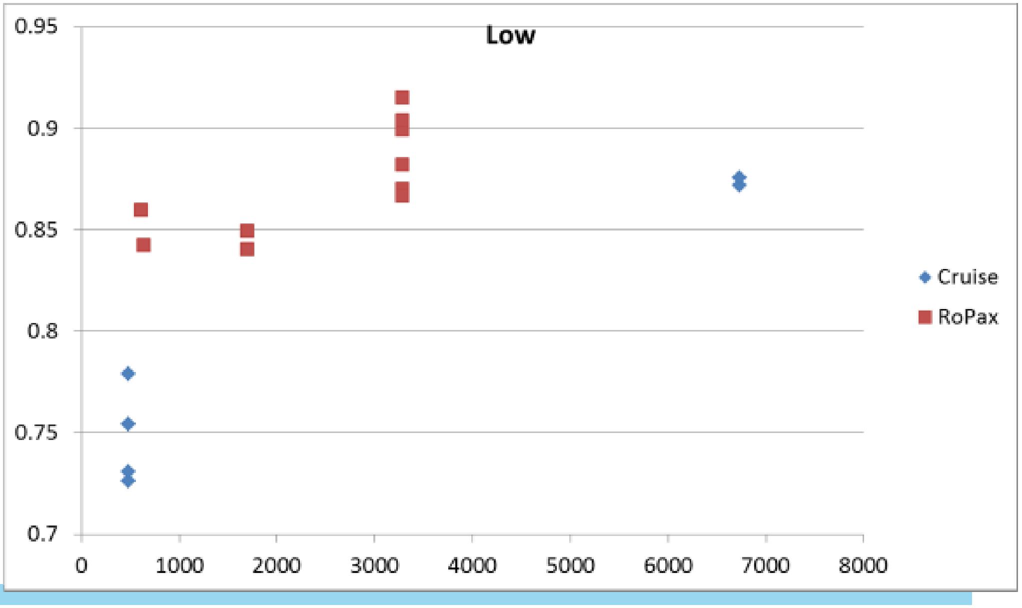



- Lower fuel price scenario delivered more cost beneficial RCOs for small and large cruise

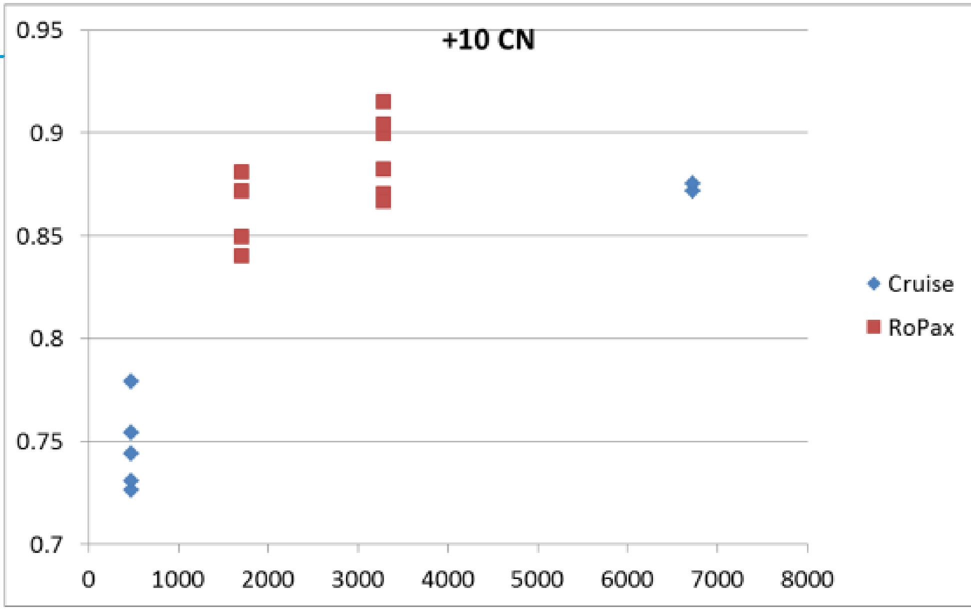
| Cruise | Low | Med | High |
|---|---|---|---|
| Large | 0.8754 | 0.8719 | 0.8719 |
| Small | 0.7789 | 0.7263 | 0.7263 |

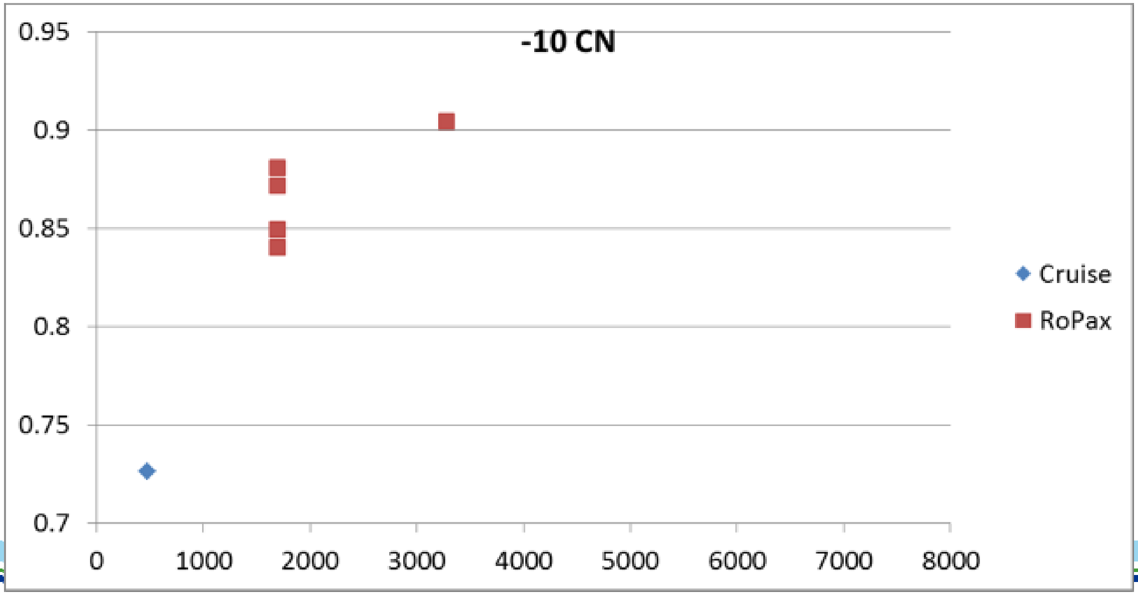
| RoPax | Low | Med | High |
|---|---|---|---|
| Large | 0.9152 | 0.9152 | 0.9152 |
| Med | | 0.8809 | |
| Small | 0.8601 | 0.8601 | 0.8601 |



# Sensitivity of CBA Results for CN

| | CN +10 | -10 |
|---|---|---|
| **Cruise** | | |
| large | 0.8754 | |
| small | 0.7789 | 0.7263 |
| **RoPax** | | |
| large | 0.9152 | 0.9042 |
| Med | 0.8809 | 0.8809 |
| small | | |

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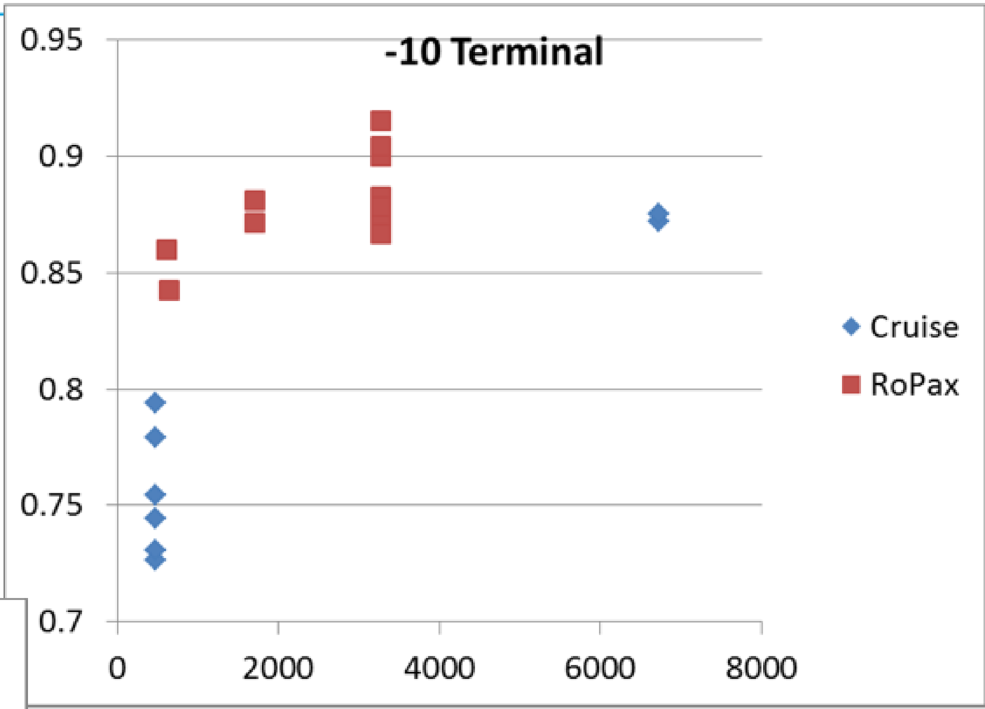
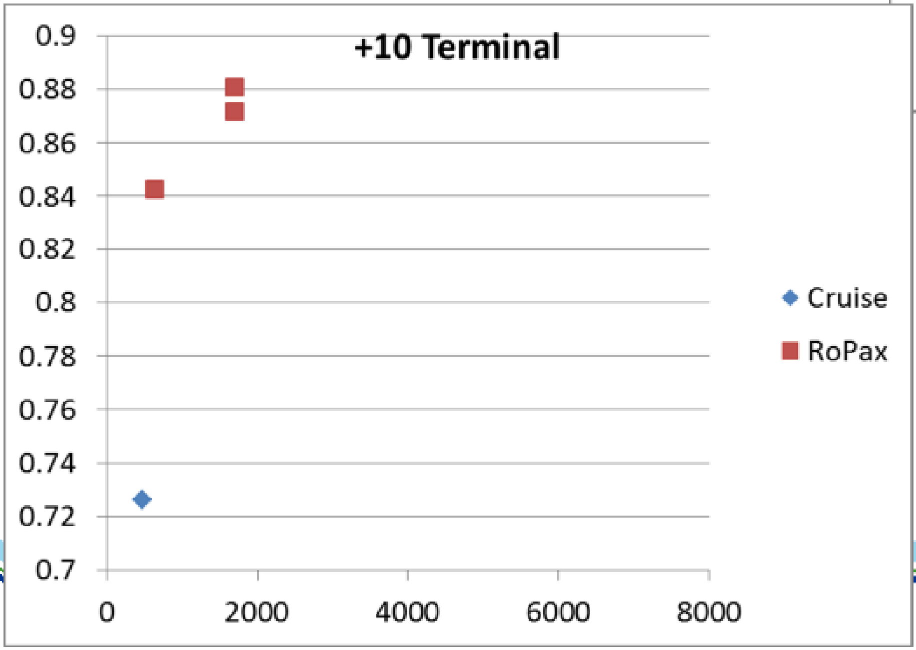
# Sensitivity of CBA Results for CN

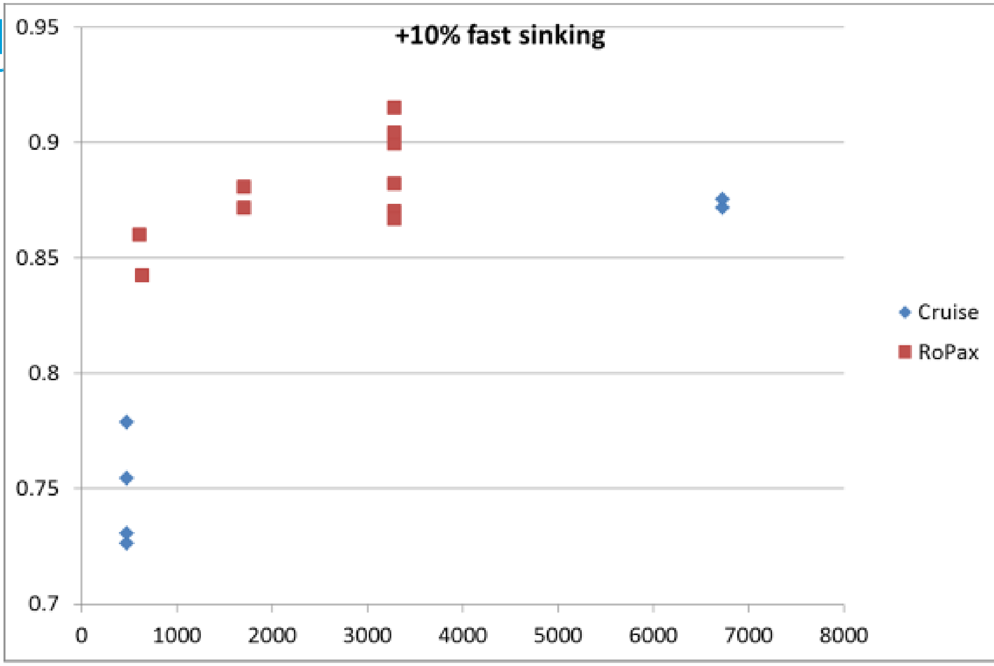
| | Terminal +10 | -10 |
|---|---|---|
| **Cruise** | | |
| Large | | 0.8754 |
| Small | 0.7263 | 0.7944 |
| **RoPax** | | |
| Large | | 0.9152 |
| Med | 0.8809 | 0.8809 |
| Small | 0.8426 | 0.8601 |

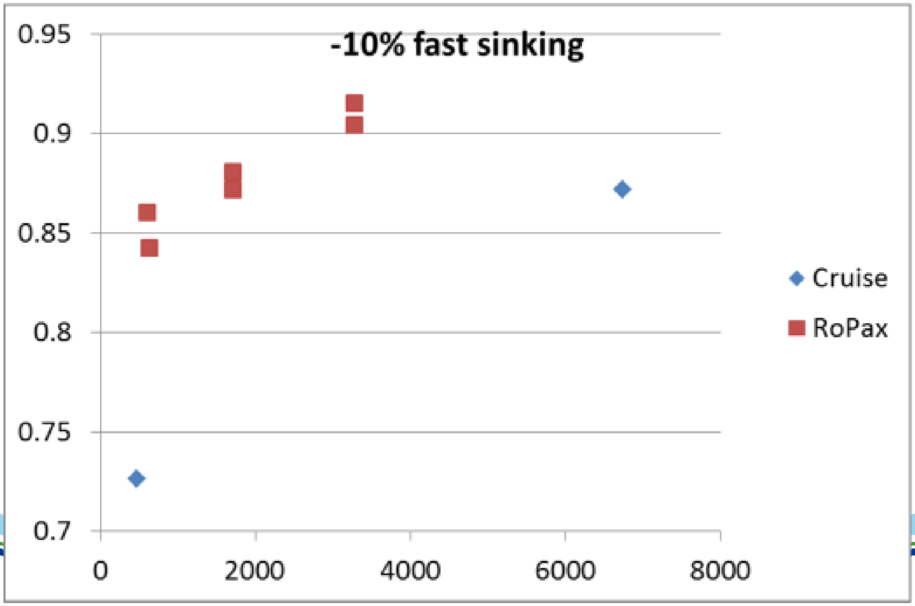


# Sensitivity of CBA Results for CN

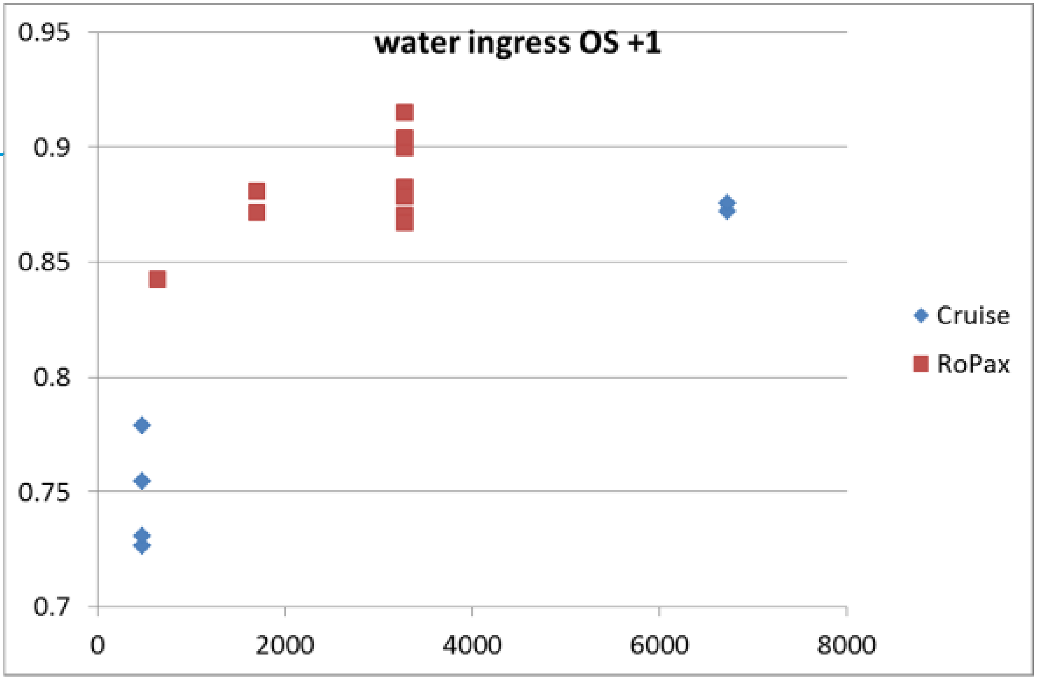
| | Sinking, fast +10% | -10 |
|---|---|---|
| **Cruise** | | |
| Large | 0.8754 | 0.8719 |
| Small | 0.7789 | 0.7263 |
| **RoPax** | | |
| Large | 0.9152 | 0.9152 |
| Med | 0.8809 | 0.8809 |
| Small | 0.8601 | 0.8601 |

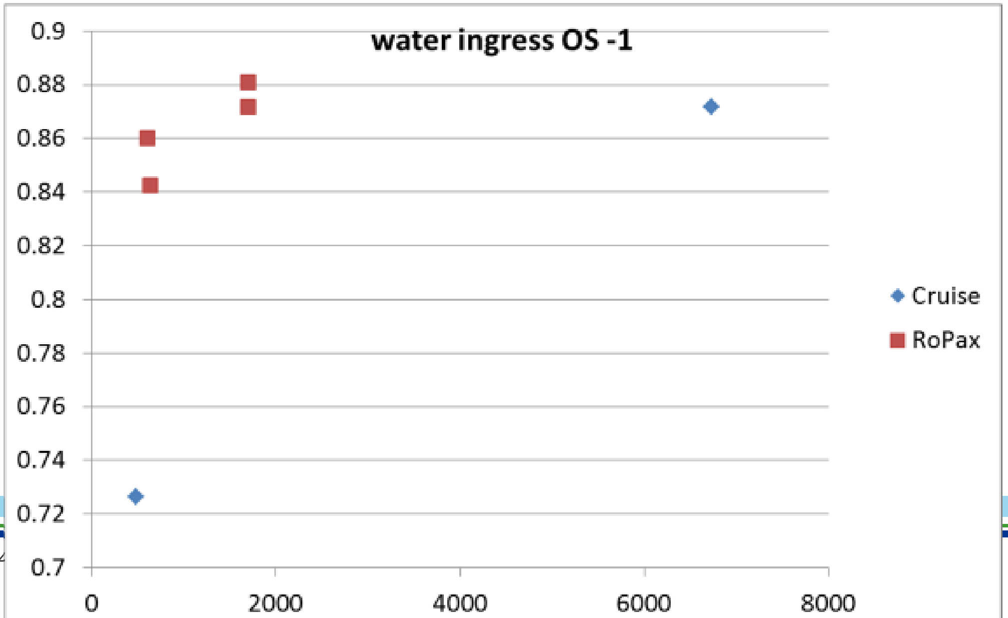


# Results of CBA for CN

| | Water ingress +1 | Water ingress -1 |
|---|---|---|
| **Cruise** | | |
| Large | 0.8754 | 0.8719 |
| Small | 0.7789 | 0.7263 |
| **RoPax** | | |
| Large | 0.9152 | |
| Med | 0.8809 | 0.8809 |
| Small | 0.8601 | 0.8601 |

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# Combining collision and grounding

| Ship type | Design ident | Collision A | Grounding Abottom | Grounding Aside | Grounding Agr | DPLL GR+CN | NPV Mean | NPV taking into account revenue (loss of ship) Mean | CAF Mean | CAF revenue from loss of ship Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| Large cruise | Ref G2 | 0,8621 | 0,9171 | 0,9135 | 0,9142 | | | | | |
| | I3 | 0,9288 | 0,9483 | 0,952 | 0,9513 | 5,27 | 33,31 | 17,33 | 6,32 | 3,29 |
| | K3 | 0,8754 | 0,9625 | 0,9522 | 0,9543 | 4,86 | 1,59 | | 0,33 | |
| | G3 | 0,8643 | 0,9264 | 0,9354 | 0,9336 | 2,31 | | -0,88 | | -0,38 |
| | K4 | 0,8792 | 0,9621 | 0,9534 | 0,9551 | 5,01 | | 5,61 | | 1,12 |
| | M1 | 0,8529 | 0,9406 | 0,9818 | 0,9736 | 6,85 | | 10,98 | | 1,60 |
| | M2 | 0,8747 | 0,9416 | 0,978 | 0,9707 | 6,82 | | 11,51 | | 1,69 |
| Small Cruise | Ref 00 | 0,7202 | 0,8799 | 0,8312 | 0,8409 | | | | | |
| | 06 | 0,8281 | 0,9192 | 0,8897 | 0,8956 | 0,57 | 2,11 | | 3,72 | |
| | 09 | 0,7789 | 0,9159 | 0,8589 | 0,8703 | 0,30 | 0,62 | | 2,03 | |
| Baltic RoPax | Ref A | 0,8326 | 0,9707 | 0,9351 | 0,9422 | | | | | |
| | L | 0,9152 | 0,9737 | 0,9697 | 0,9705 | 4,27 | 8,44 | | 1,98 | |
| Mediterannean RoPax | Ref 1 | 0,8398 | 0,9811 | 0,9475 | 0,9542 | | | | | |
| | 5(V14) | 0,8718 | 0,9829 | 0,9519 | 0,9581 | 1,26 | 5,23 | 5,17 | 4,16 | 4,11 |
| | V15 | 0,8717 | 0,9823 | 0,9584 | 0,9632 | 0,74 | 0,04 | -0,12 | 0,06 | -0,16 |
| | V16 | 0,8809 | 0,9948 | 0,9680 | 0,9734 | 1,38 | 0,28 | -0,04 | 0,21 | -0,03 |
| Small RoPax | Ref SRoPax1 | 0,7947 | 0,9789 | 0,9171 | 0,9295 | | | | | |
| | SRoPax2 | 0,8426 | 0,9767 | 0,8852 | 0,9035 | -0,37 | 0,15 | | 1,08 | |
| De Ferry | Ref 0 | 0,8412 | 0,9987 | 0,9165 | 0,9329 | | | | | |
| | De1 | 0,8601 | 0,9982 | 0,9098 | 0,9275 | -0,05 | 0,08 | | 1,56 | |

RCOs for grounding investigated

RCOs for grounding investigated

Separate data for grounding not available

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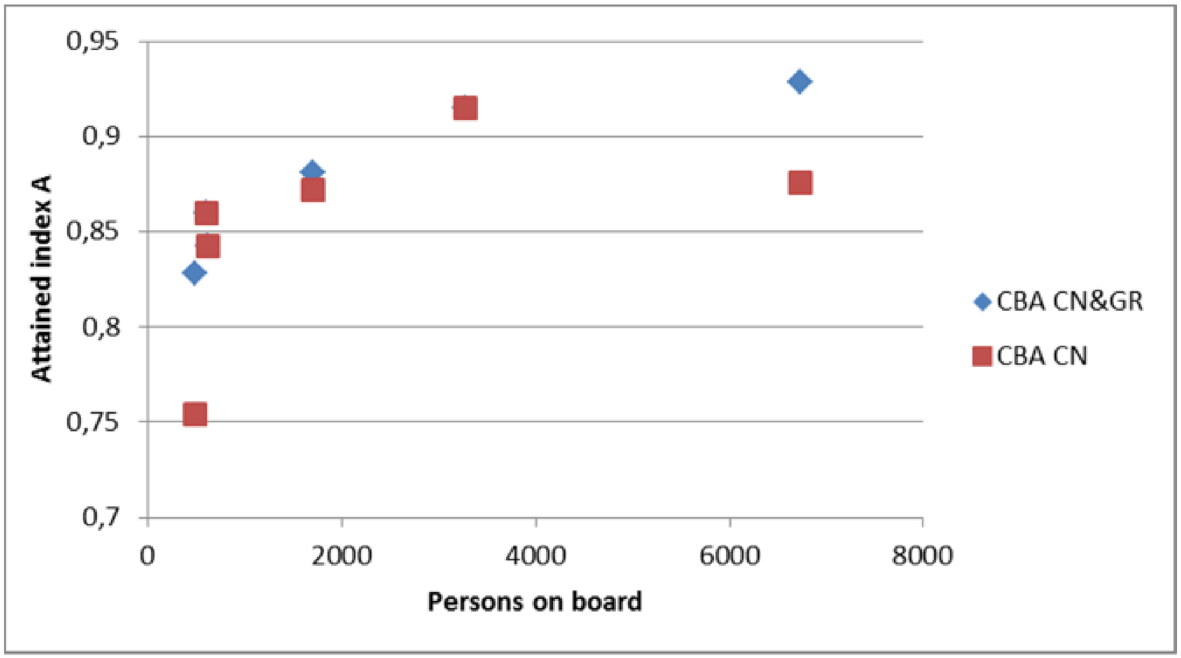
# Effects of taking grounding into account in the CBA

Attained Index A (collision) for Risk control Options meeting the CAF criteria with and without including the effect from grounding.

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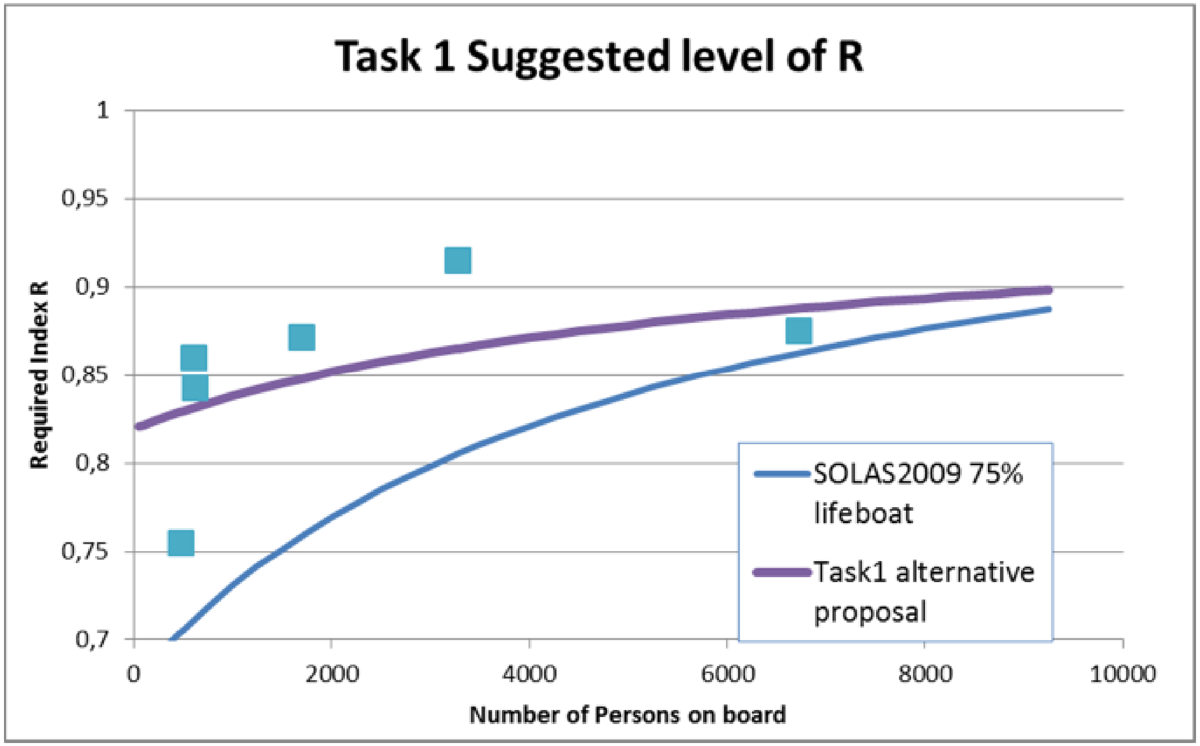
# Suggested level of R if considering collision only




$$R = 1 - C1 * \frac{5000}{2{,}5 * N + 15225}$$

$$C1 = 0.8 - \frac{0.25}{10{,}000} * (10{,}000 - N)$$

N is the number of persons onboard without consideration of type of LSA

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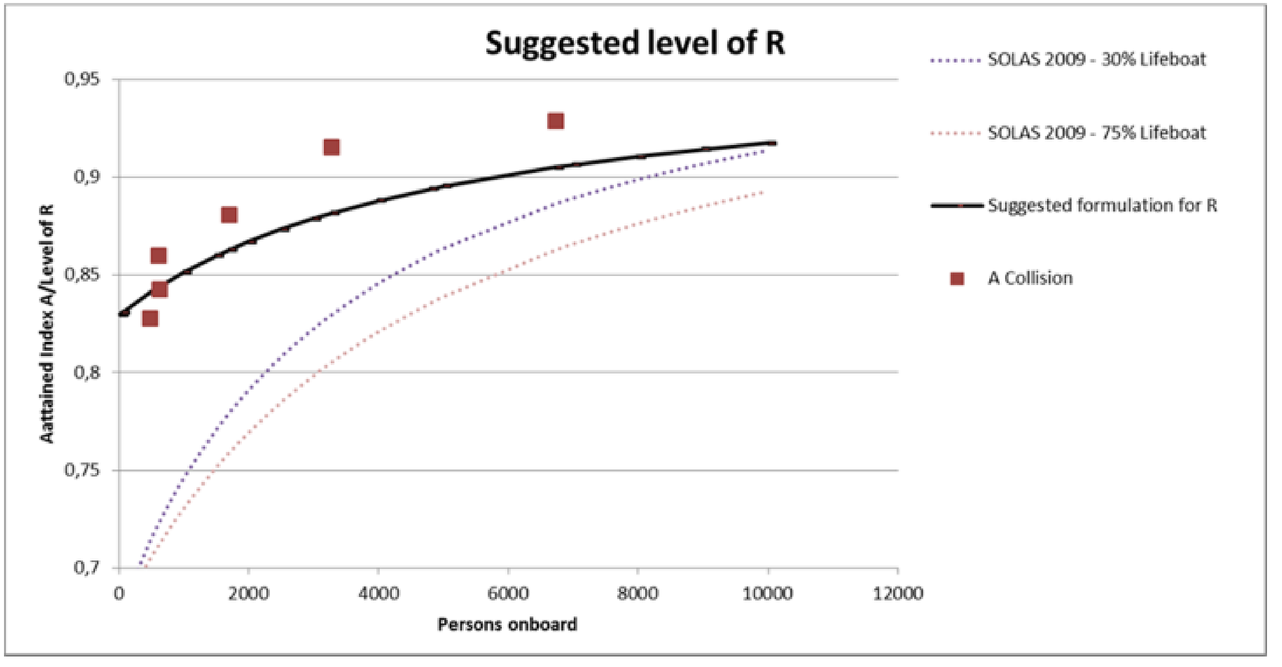
# Alternative when grounding is accounted for in the CBA




$$R = 1 - \frac{C1 * 6200}{4 * N + 20000}$$

$$C1 = 0.8 - \frac{0.25}{10000} * (10000 - N)$$

N is the number of persons onboard without consideration of type of LSA

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# Conclusions

- The project does not provide any data for RoPax and passenger ships carrying less than 400 persons onboard.
- There is no data available for RoPax having more than 3280 persons onboard.
- The Cost-Effectiveness Analysis performed in the project, supports raising the level of R for collision.
- For cruise ships, a number of RCOs have been investigated on 2 sample ships. When the assessment is based on benefits from collision only, the RCOs found to be cost effective show only limited improvement. Grounding represents a significantly higher risk than collision based on the calculations carried out in the project. There is a clear trend that RCOs improving the attained index A for collision would also improve the attained index A for grounding. When grounding is included in the risk assessment the CAF values are generally reduced and additional RCOs become cost-effective.
- Suggested levels of R are shown in two different formulations. Both formulations show a significant increase of safety level for small and medium sized ships and a moderate increase for very large ships. However, accounting for the additional cost-effective RCOs deriving from consideration of grounding (as explained above), it is concluded that the formulation with the higher level of R is deemed more appropriate, following closely the FSA process and methodology. *

* Some members of the consortium have expressed their reservation wrt. use of grounding in the CBA before the methods and assumptions have been further tested and validated.

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## Discussion points

- These include recommendations by the Project Partners as a Group of Experts and as Stakeholders of the maritime/marine industry beyond the EMSA III framework.
  - For large cruise ships, there is limited amount of information/data concerning their survivability in damaged conditions due to relatively small fleet and (luckily) small number of casualties, thus not attracting research focus. The limited amount that does exist indicates that the current formulation of the s-factor in SOLAS 2009 tends to underestimate the survivability of cruise ships.  This, in turn, influences ΔPLL and cost-effectiveness.
  - By contrast, there are significantly more published validation results available for damage stability of RoPax ships (s-factor) than for cruise ships, e.g., North-West European Project for Damage Stability of Ro-Ro Passenger Ships (the basis for Stockholm Agreement) and the EC-funded projects HARDER and GOALDS.
  - The results of EMSA III show that grounding is the dominant risk. It certainly represents a significantly higher risk than collision. However, further validation and testing is required in order to develop specific proposals.
  - Presentation to and familiarisation by industry outside the consortium is also recommended before suggesting requirements such as combined collision and grounding to IMO.
  - Method and software for calculation of A for collision should be developed based on the non-zonal approach as was done in the EMSA III project for grounding.

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# Thank you for your kind attention

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