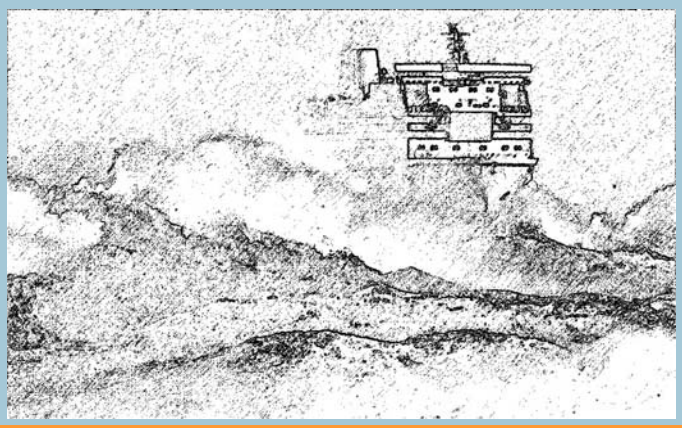
Risk-Based Design

Overview



Presentation Outline

- Maritime Risk and Risk Management
- Design Today: Rules-Based Design
- Developing a New Design Methodology: Risk-Based Design
- RBD Implementation – Passenger Ships
- Concluding Remarks

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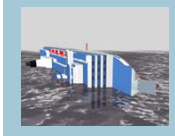
Historical Risk (Maritime Accidents)

Risk to Human Life

				No. Fatalities
	*Herald of Free Enterprise*	*March 1987*	*Rapid Capsize, high list*	***193***
	*Scandinavian Star*	*April 1990*	*Fire, Toxic Smoke*	***158***
	*Moby Prince*	*April 1991*	*Fire*	***140***
	*Estonia*	*Sept 1994*	*Rapid Capsize, high list*	***852***
	*Samina Express*	*Sept 2000*	*Collision, Flooding, Sinking*	***82***
	Al Salam 98	*Feb 2006*	*Fire, Flooding, Capsize*	***1,002***

Containing Risk Today (HLR)

SAFEDOR

SOLAS

⬇

Minimum standards

Statistical average

Historical risk

⬇

Compliance with Rules/regulations

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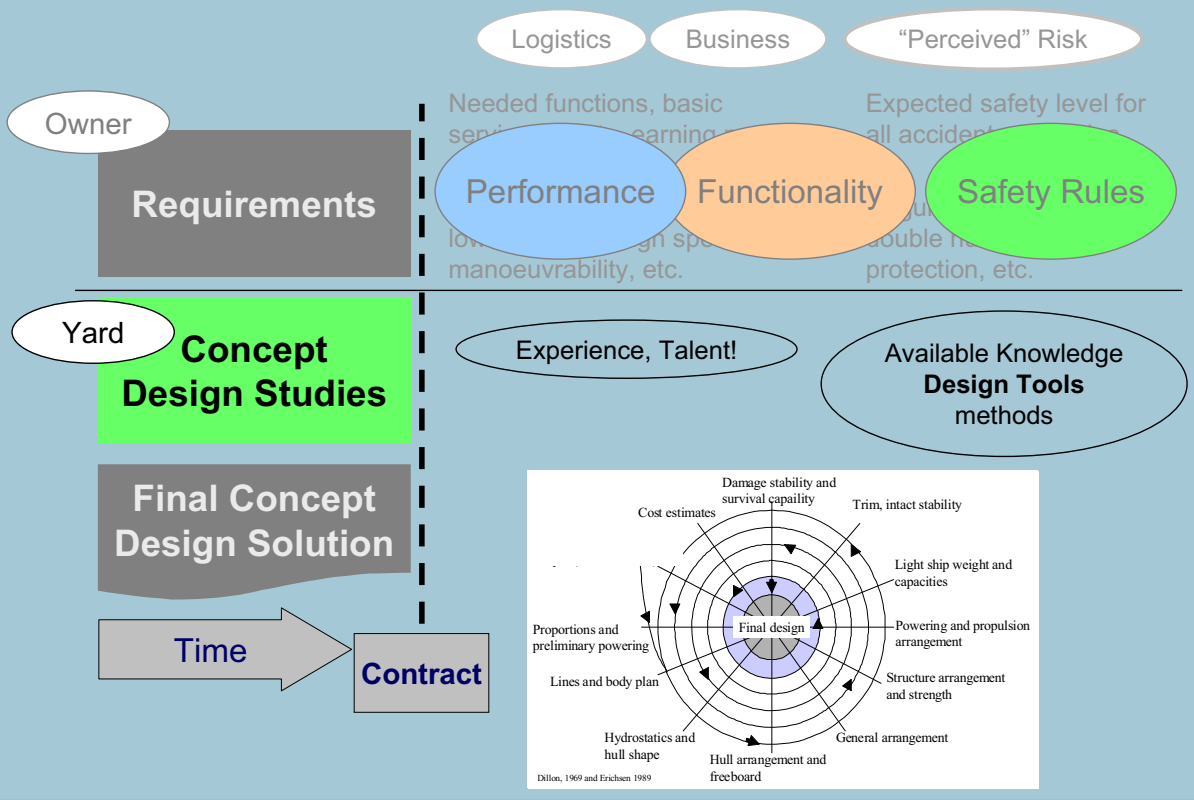
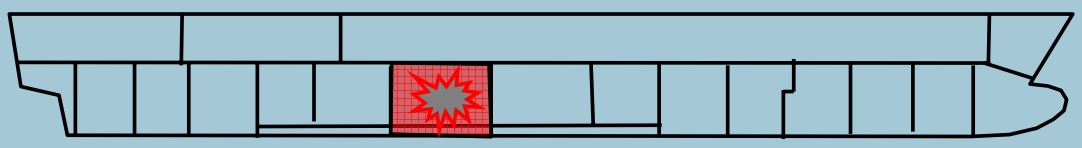
Design Today: Rules-Based Design



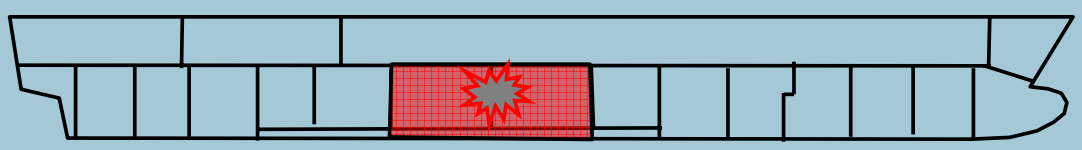
Design Today: Rules-Based Design

Does it work?

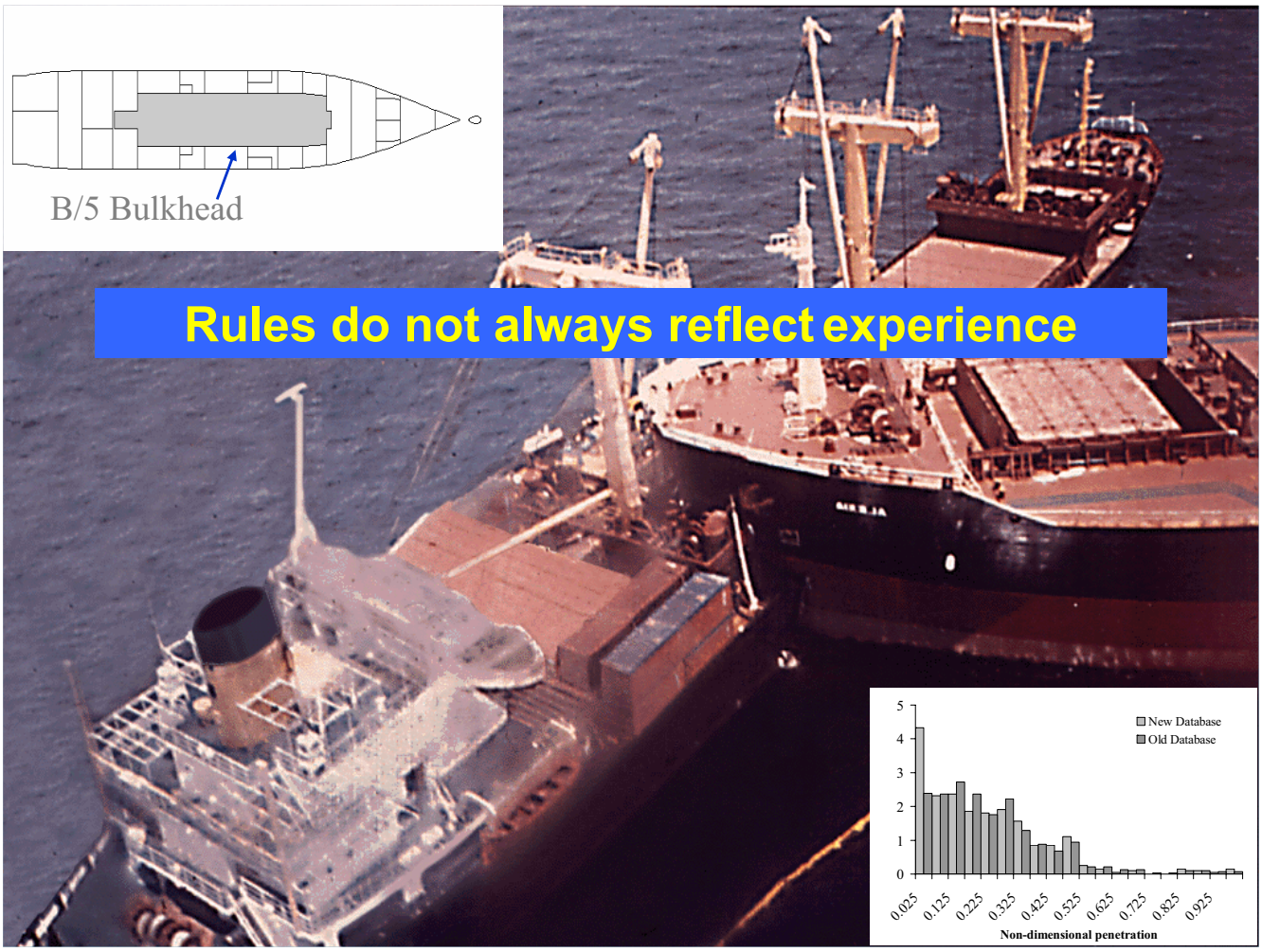
Safety Level in Rules is Unknown!



1-Comp standard: High likelihood x Severity??



2-Comp standard: Lower Likelihood x Severity??



Pitfalls of Rules-Based Design

- Treating safety as a constraint (rule compliance) implies that meeting safety expectations cost-effectively is left to chance.
- Incompatibility of design and performance evaluation tools, time limitations, lack of an integrated design environment; all hinder design optimisation in the design process.
- Lack of a formal optimisation process also implies that life-cycle issues (future costs / earning potential) are not being taken “explicitly” into account in design decision-making.

Can we do better??

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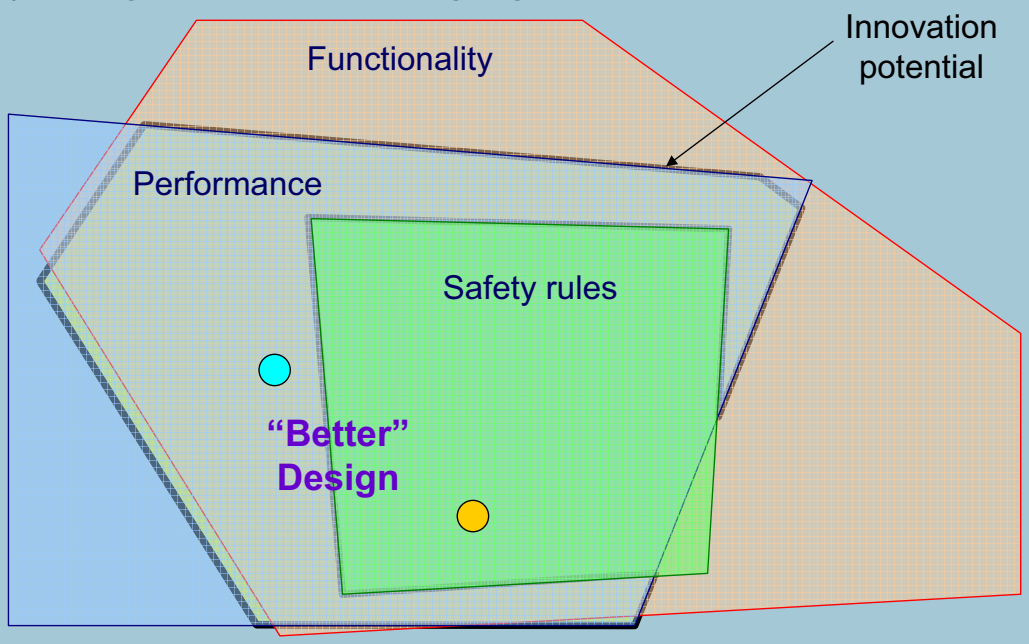
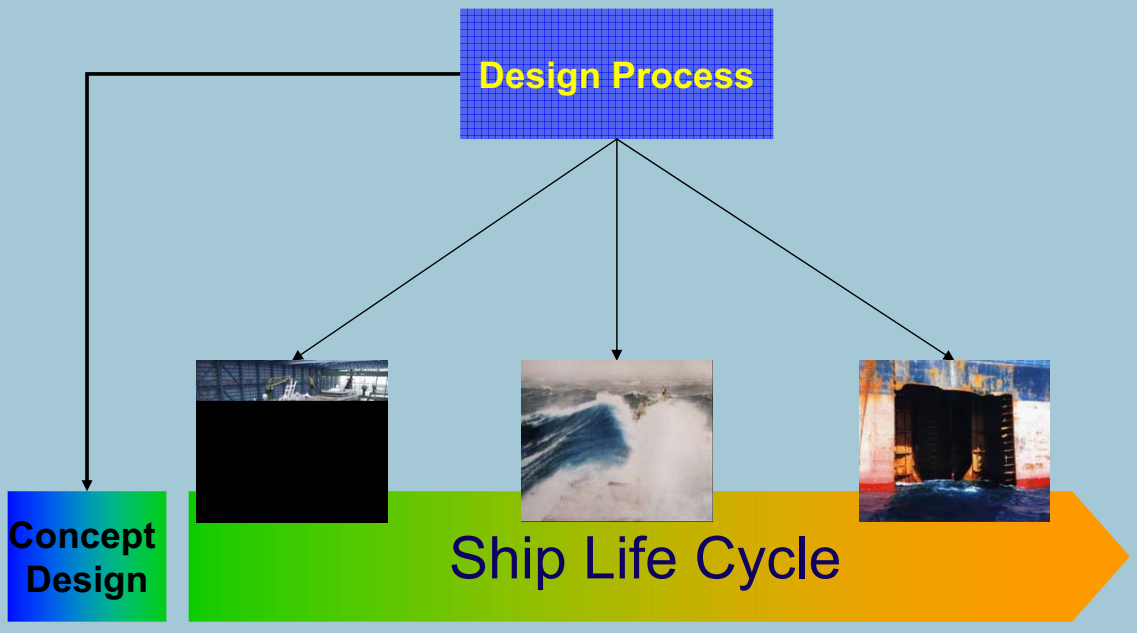
Use a Goal-setting Approach

Design solutions developed to meet “safety goals” (beyond rules) along side other design goals

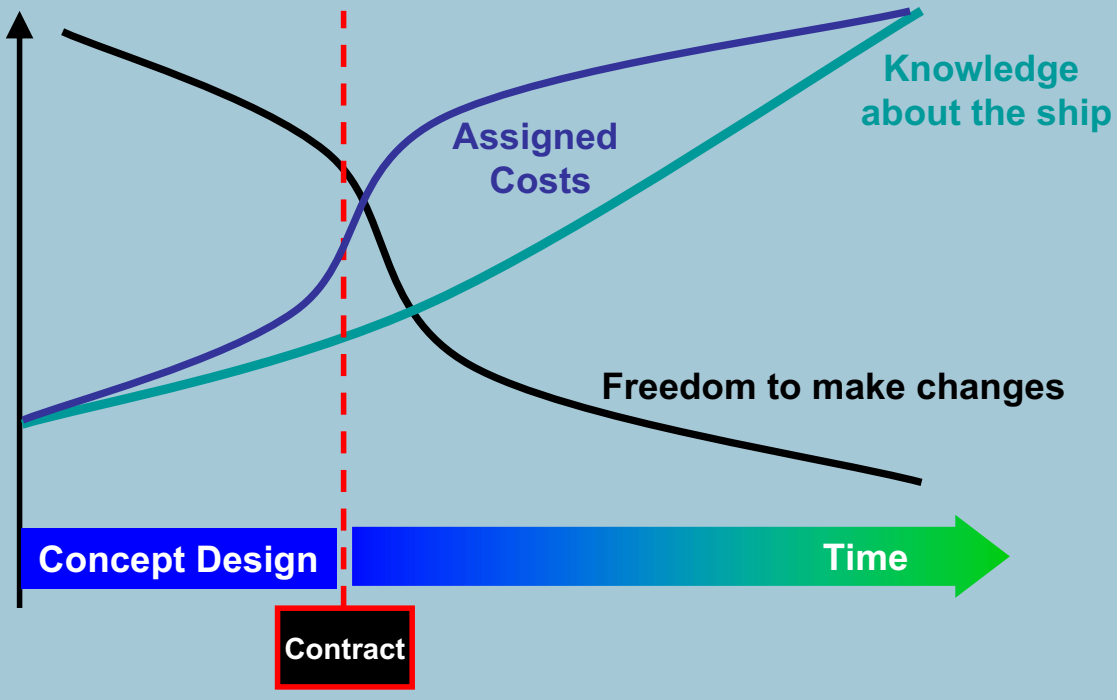


Design Solutions Space

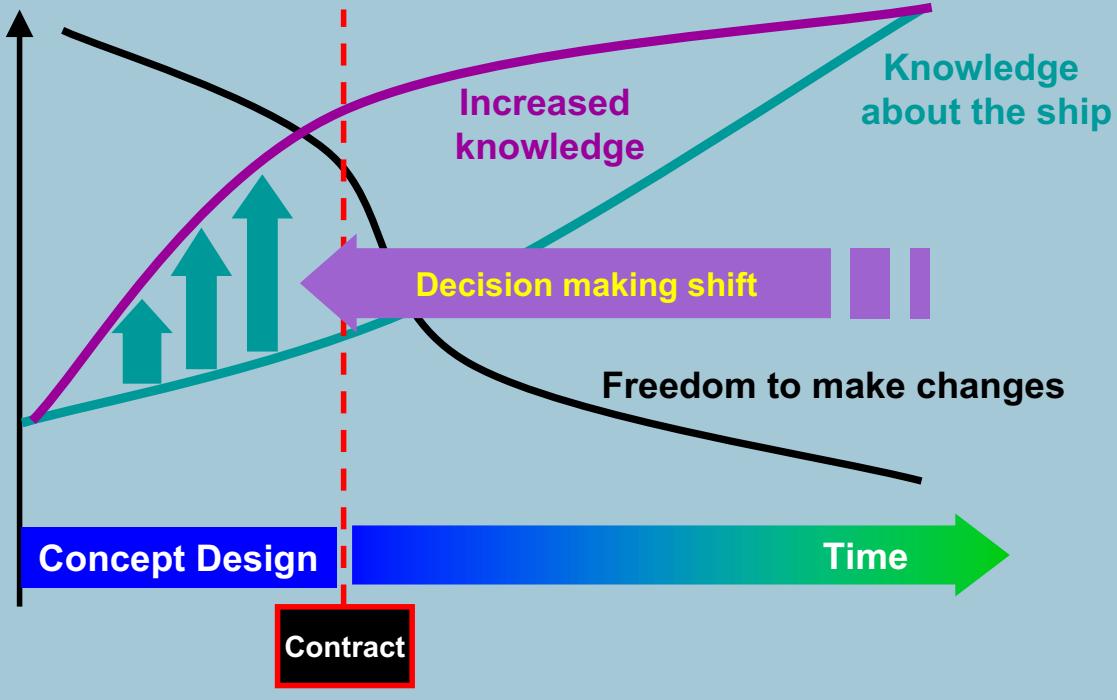
Provide Feedback on Life-Cycle Issues



Routine Use of First-Principles Tools



Routine Use of First-Principles Tools



Risk-Based Design

Logistics

Business

"Perceived" Risk

Owner

Requirements

Performance

Functionality

Safety Objectives

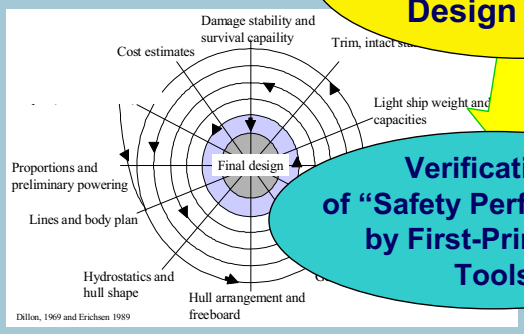
Yard

Concept Design Studies

Experience, Talent!

Additional Functional Requirements Design Criteria

Final Concept Design Solution



Verification of "Safety Performance" by First-Principles Tools

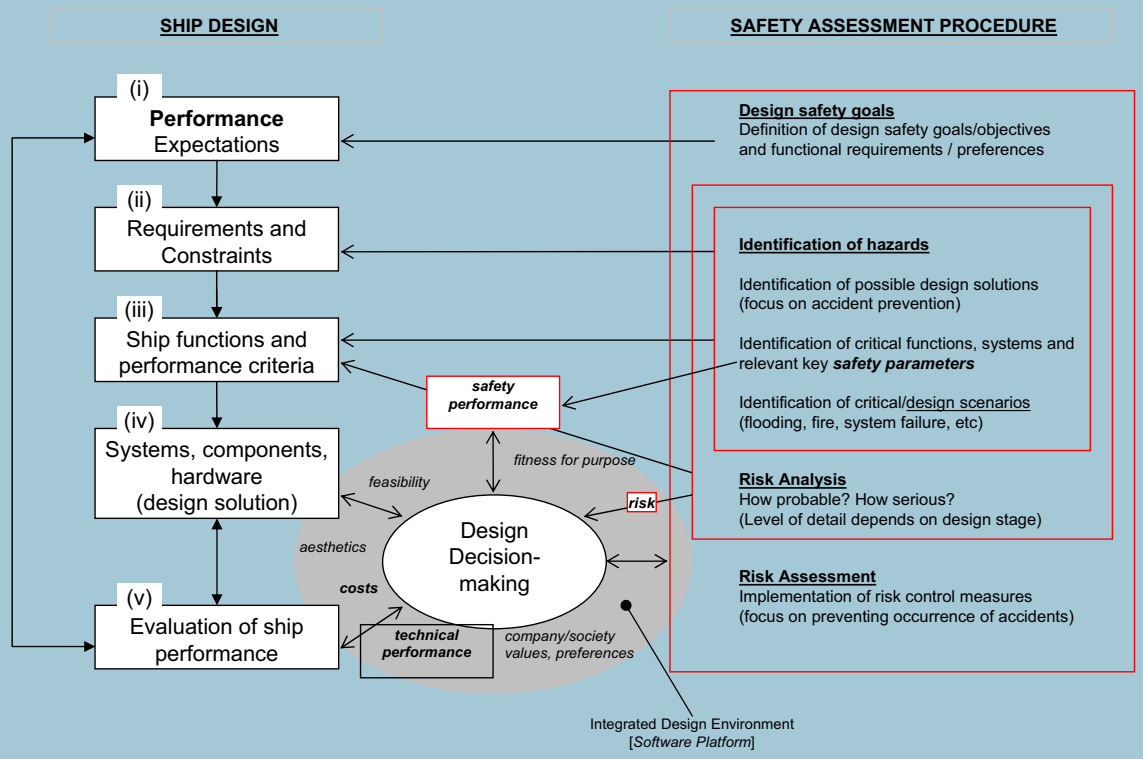
Time

Contract

Risk-Based Ship Design Principles

- Adoption of a formalised procedure to measure safety consistently (risk analysis / risk assessment / risk management)
- Integration of such procedure in the design process (integrated design environment)
- Flexibility to allow trade-offs between Costs, Earnings, Performance and Safety (Risk)

RBD High-Level Framework



RBD and Innovation

Low

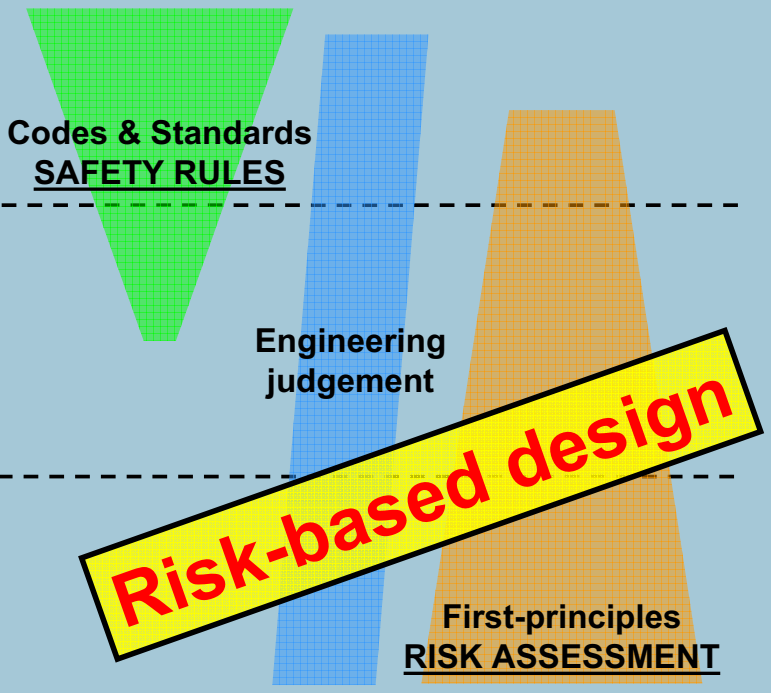
Nothing new or unusual
Well understood issues
Established practice

Medium

Uncertainty/deviation from standard practice. Possible safety trade-offs. Economic and lifecycle implications.

High

Novel or/challenging concepts. Large uncertainties. Significant safety trade-offs.



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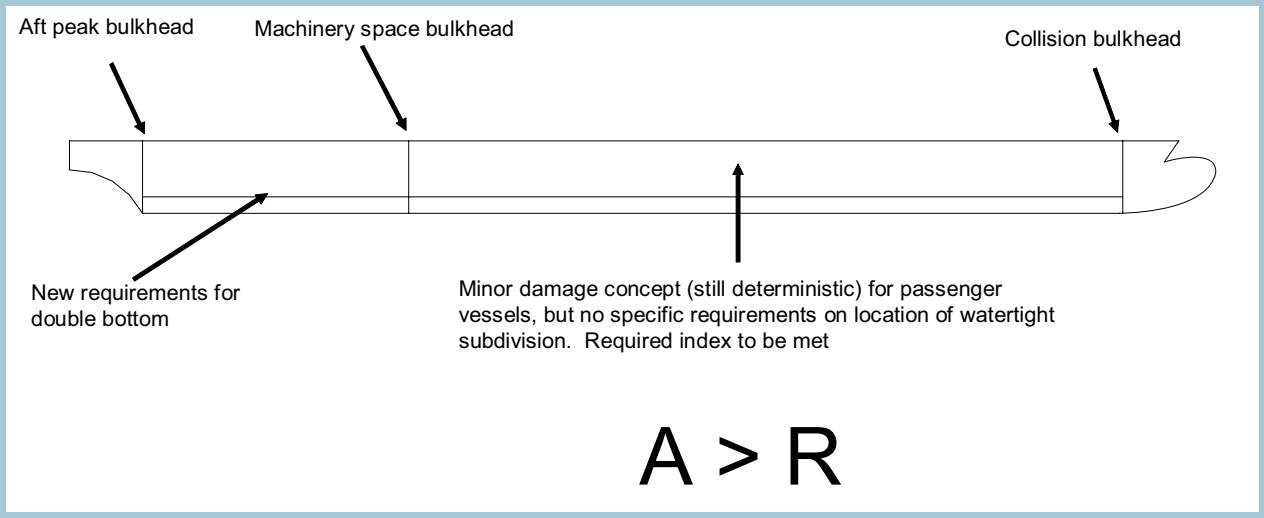
Hypothetical Cruise Ship

Principal Particulars

Length	270 m
Breadth	35.5 m
Draught	8.3 m
Displacement	56,500 tonnes
Metacentric Height	2.35 m
Number of persons	2,300
Required Index of Subdivision, R	0.8

Design for Survivability

Statutory Assessment – Probabilistic Rules

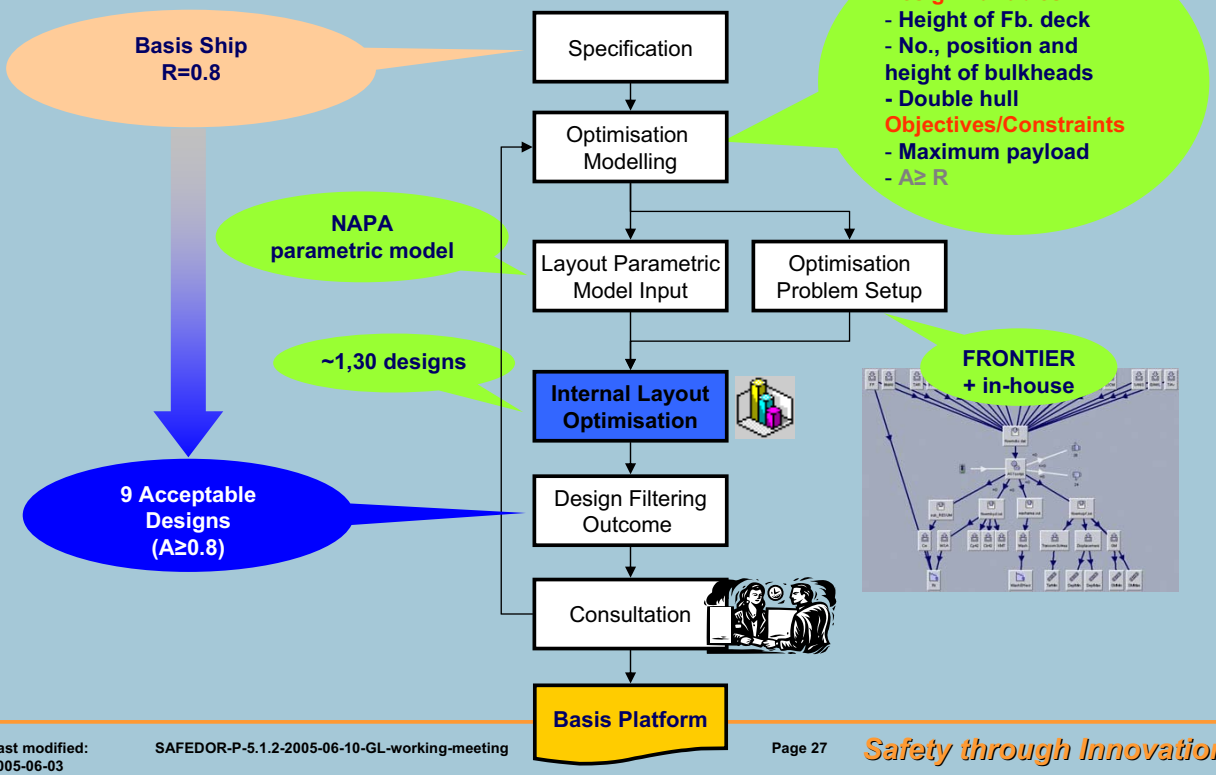


Platform Optimisation

Probabilistic subdivision optimisation procedure :

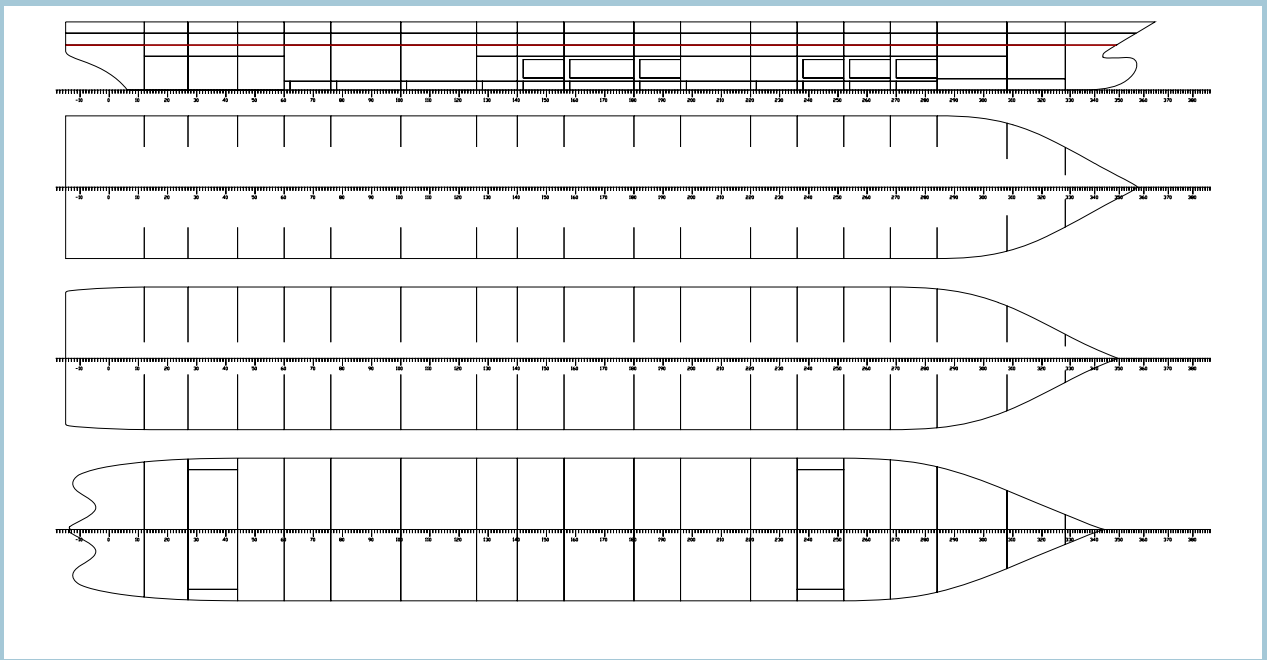
- Concept development
- Layout optimisation
- Tank arrangement optimisation
- Systems location optimisation

Platform Optimisation



Platform Optimisation

Version 1: A=0.8



Ship Safety Level (Total Risk)

Risk is a chance of loss of life

The chance is measured by statistics

loss scenarios:

- flooding
- fire

~90% of the risk

- intact stability loss
- other

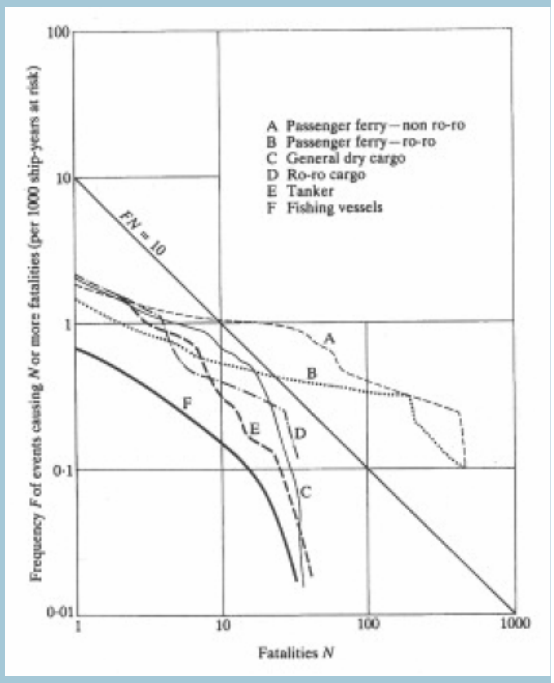
loss of **life**

(expected number of fatalities per year)

Risk Model

$$Risk_{PLL} \equiv E(N) \equiv \sum_{i=1}^{N_{\max}} F_N(i)$$

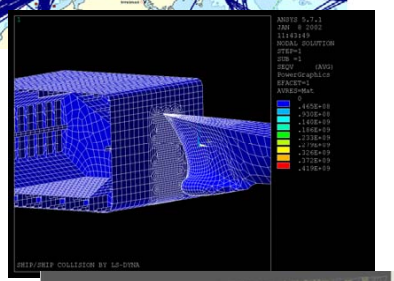
$$F_N(N) = \sum_{i=N}^{N_{\max}} fr_N(i)$$

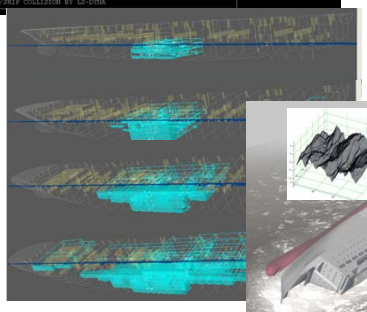


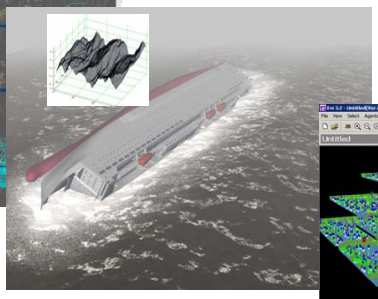
Risk Model

$$fr_N(N) = \sum_{j=1}^{n_{hz}} fr_{hz}(hz_j) \cdot pr_N(N \mid hz_j)$$

j	Principal hazards, hz_j	$fr_{hz}(hz_j)$
1	Collision and flooding	2.58 E-3 1/sy
2	Fire	1.20 E-2 1/sy
3	Intact Stability Loss	
4	Systems Failure	
	… etc	







Loss Scenario:

flooding

Collision

- Route
- Crew
- Navigation
- Bridge

Hull breach

- Crashworthiness

Stability failure

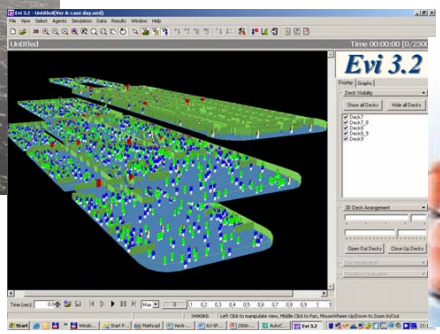
- Geometry (hull & GA)
- Loading
- Sea State

Muster failure

- Crew procedures
- Layout

Abandon failure

- LSA



Risk model

Flooding

$$Risk_{PLL} = \sum_{i=1}^{N_{max}} F_N(i) \qquad F_N(N) = \sum_{i=N}^{N_{max}} fr_N(i)$$

2.58e-3 [1/sy]

$$fr_N(N) = \sum_{j=1}^{n_{hz}} fr_{hz}(hz_j) \cdot pr_N(N|hz_j) = fr_{hz}(hz_1) \cdot pr_N(N|hz_1)$$

$$pr_N(N|hz_1) = \sum_{i}^{3} \sum_{j}^{n_{flood}} w_i \cdot p_j \cdot \sum_{k}^{n_{Hs}} e_k \cdot c_{i,j,k}(N)$$

$$c_{i,j,k}(N) = \left(-\ln(\varepsilon_{i,j,k}) \cdot (\varepsilon_{i,j,k})^{\frac{t_{fail}(N)}{30}} \right) \cdot \frac{|\partial t_{fail}(N)|}{30}$$

Assembly

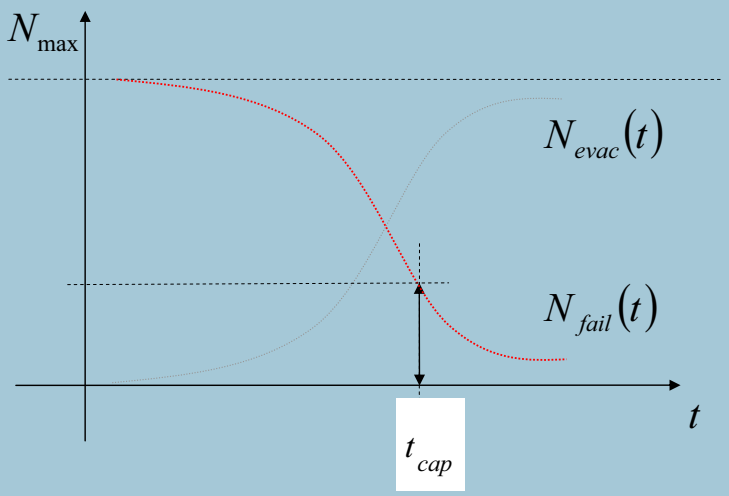
Abandonment

- Geometry
- Loading
- Sea State
- Flooding extent

Risk model

Flooding

$$c_{i,j,k}(N) = \left(-\ln(\varepsilon_{i,j,k}) \cdot (\varepsilon_{i,j,k})^{\frac{t_{fail}(N)}{30}} \right) \cdot \frac{|\partial t_{fail}(N)|}{30}$$



Prediction of Time to Capsize

A relationship between governing parameters and the time is required:

→ **Time-domain simulation**

→ **Inference models (UGD™)**

$$p(t_{cap}) = \sum_{i}^{3} \sum_{j}^{n_{flood}} w_i \cdot p_j \cdot \sum_{k}^{n_{Hs}} e_k \cdot c_{i,j,k}(t_{cap})$$

$$c_{i,j,k}(t_{cap}) = -\ln(\varepsilon_{i,j,k}) \cdot (\varepsilon_{i,j,k})^{\frac{t_{cap}}{30}} / 30$$

UK MCA (1996, 1999, 2002)

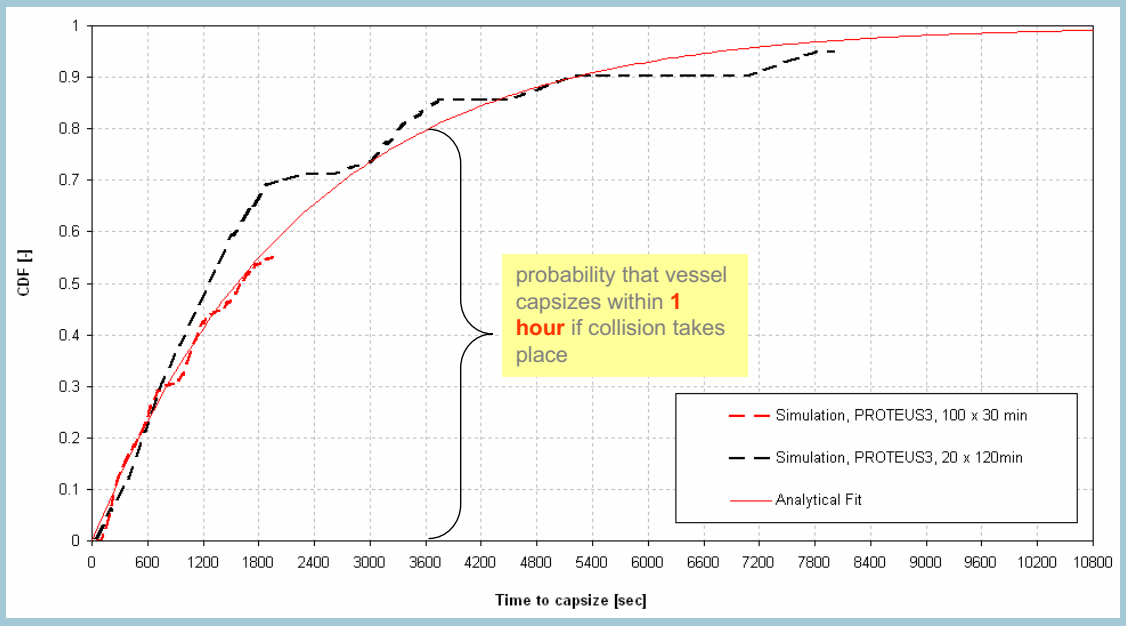
NEREUS (1999-2003) / HARDER (1999-2003)

SAFEDOR (2005-2007)

Prediction of Time to Capsize

Inference at Scenario Level

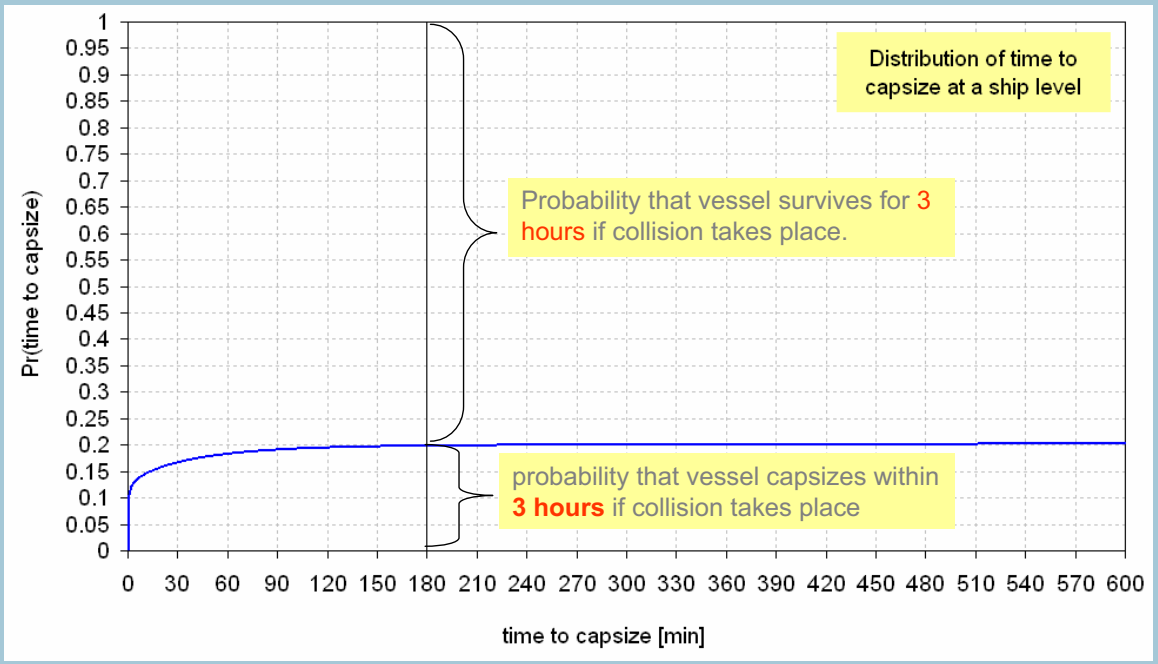
Scenario={displ, KG, damage, Hs}



Prediction of Time to Capsize

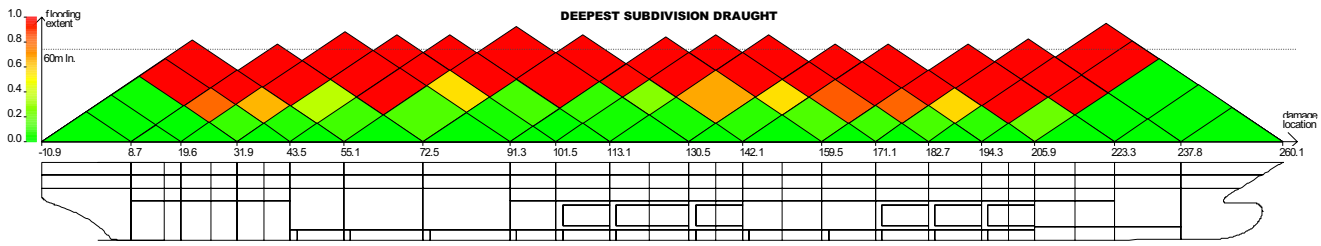
Inference at Ship Level (Version 1)

40,000 scenarios



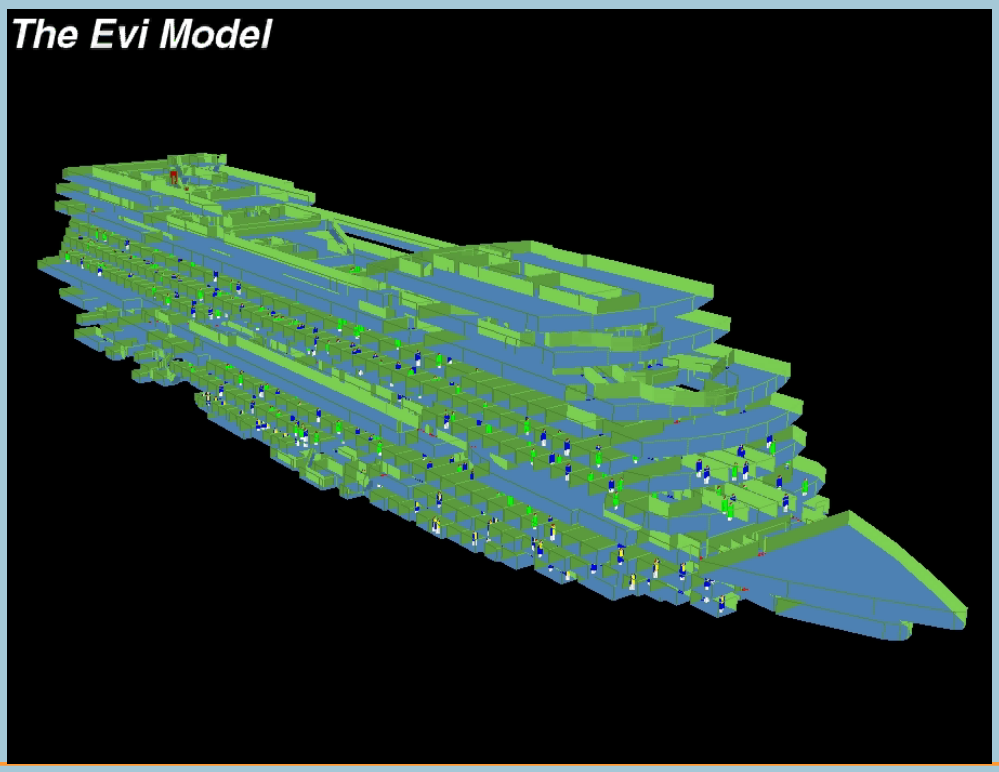
$P[t_c<3$ hours$\}$; conditional on loading and damage characteristics

Version 1



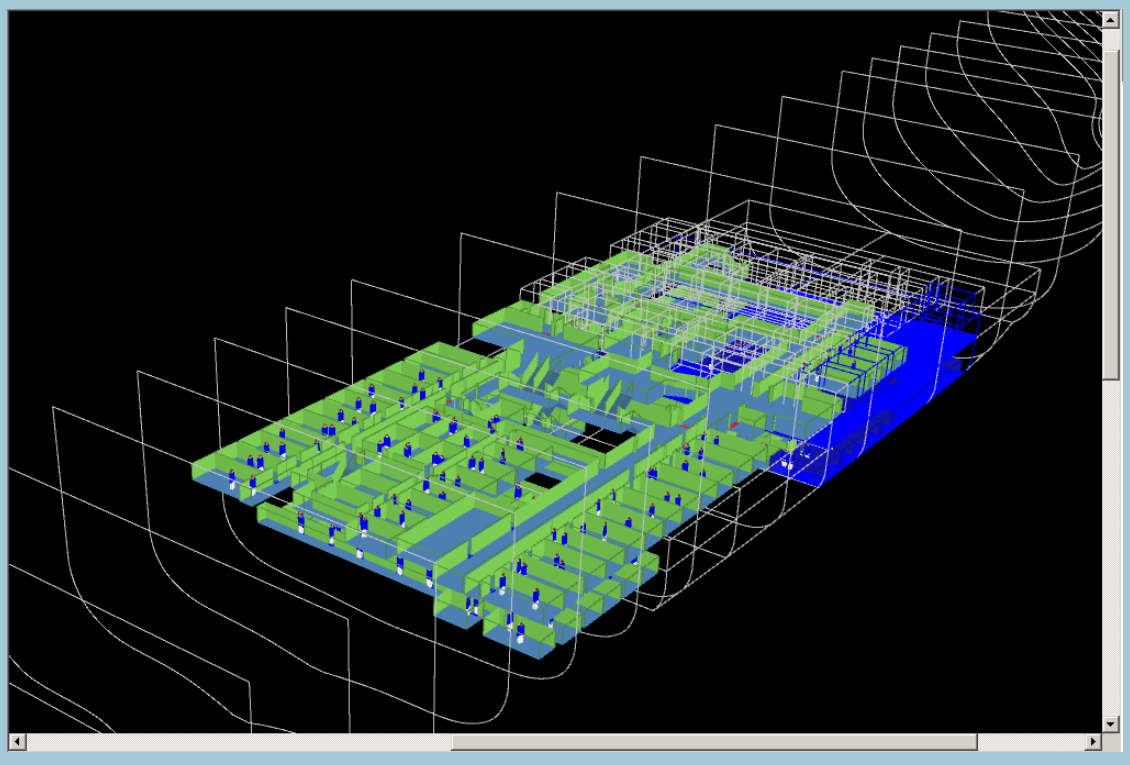
Evacuation Analysis

Ship Muster List



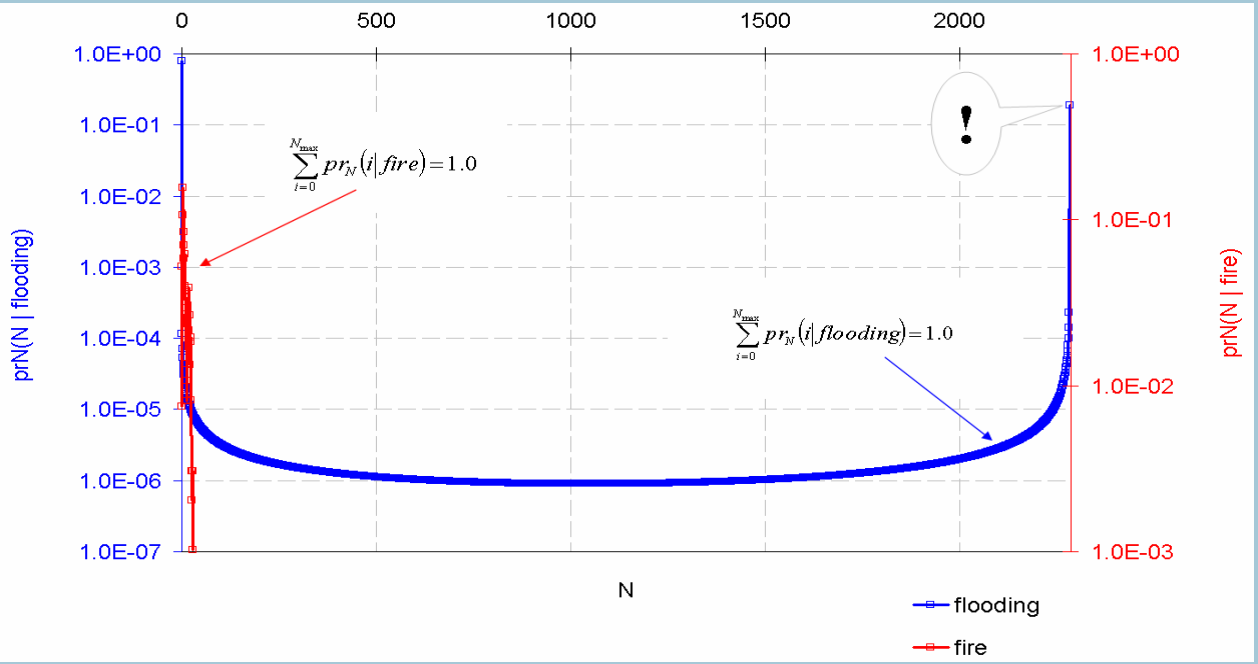
Evacuation Analysis

Coupled Flooding-Evacuation Model



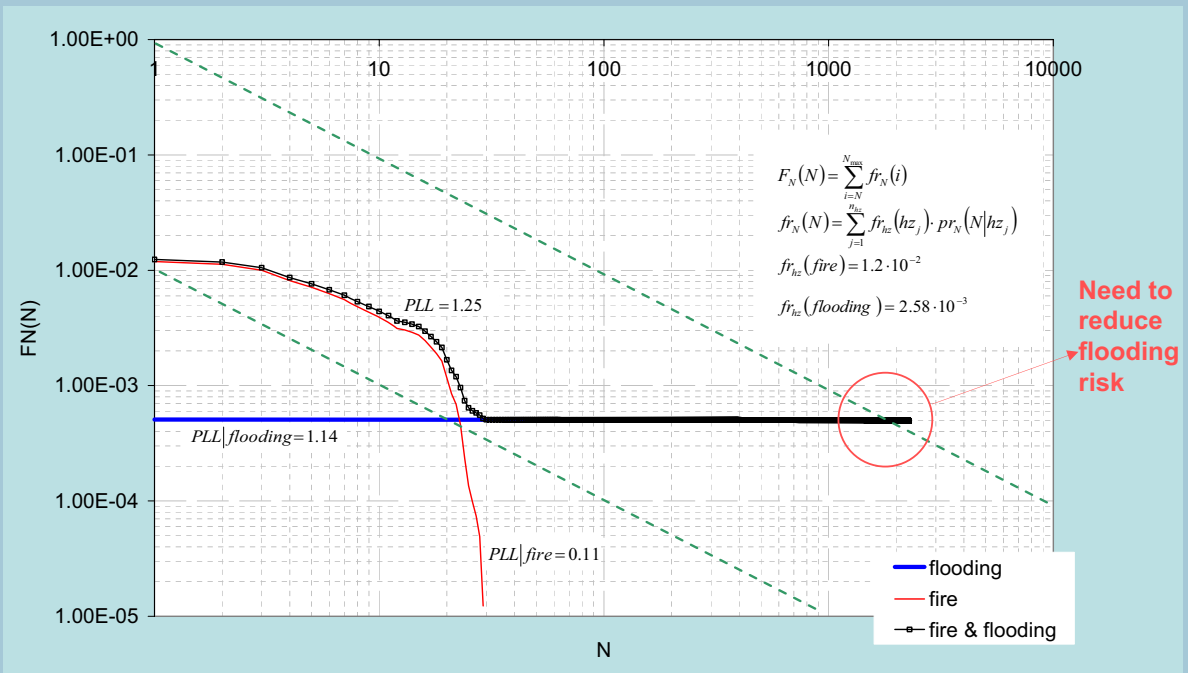
Probability Distribution of N Fatalities

Flooding and Fire (Version 1)



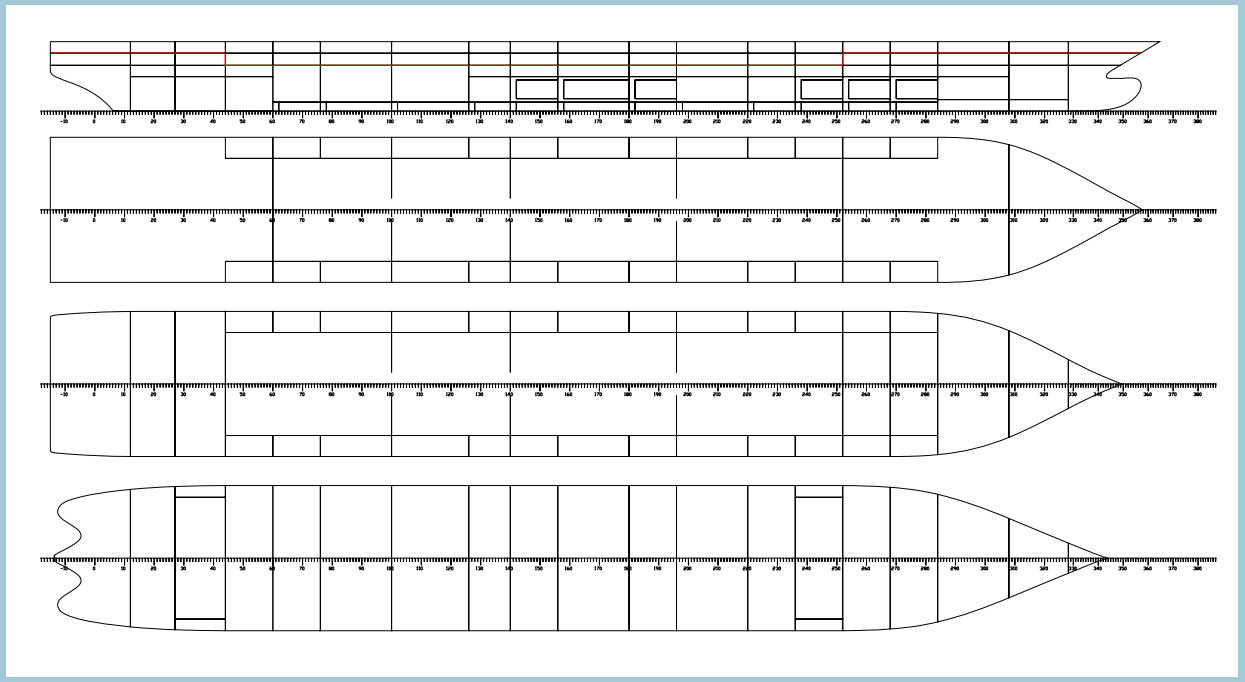
Annual Frequency of N or more Fatalities

Flooding and Fire (Version 1)



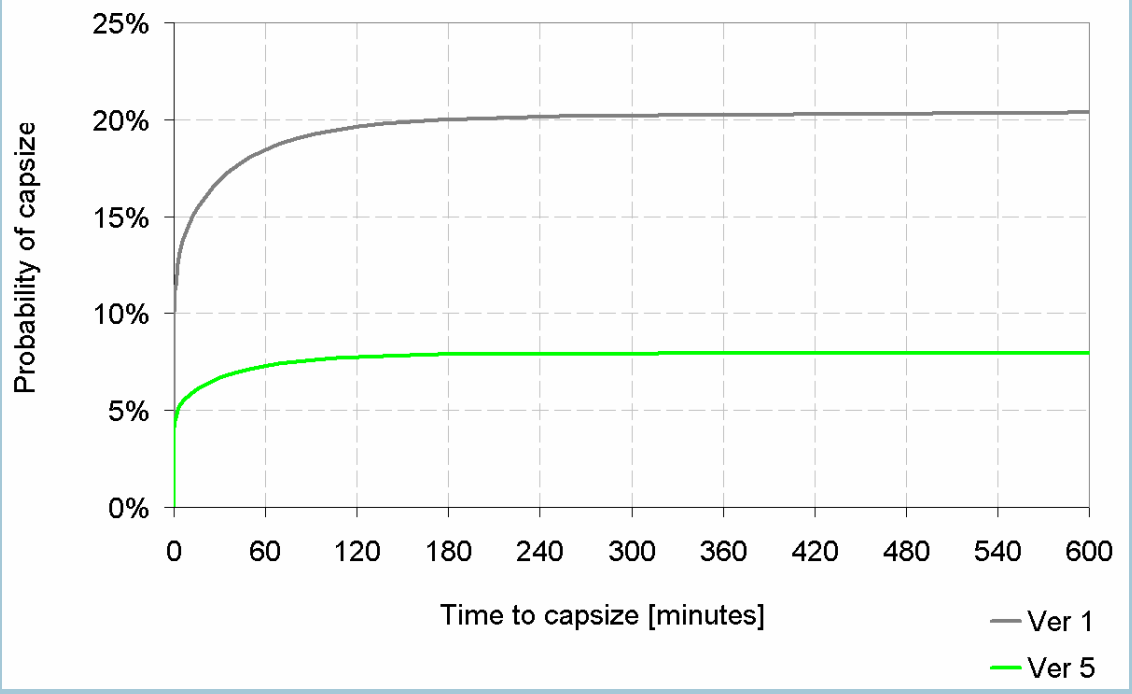
Platform Optimisation

Version 5: A=0.92



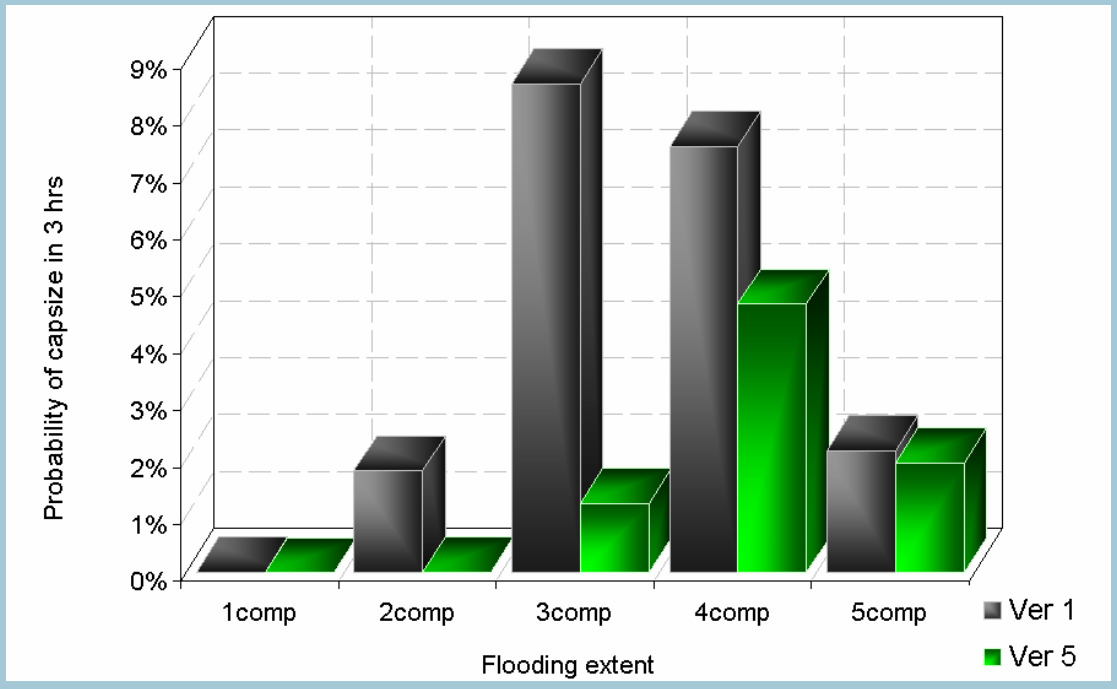
Prediction of Time to Capsize

Effect of A-Index – Version 5



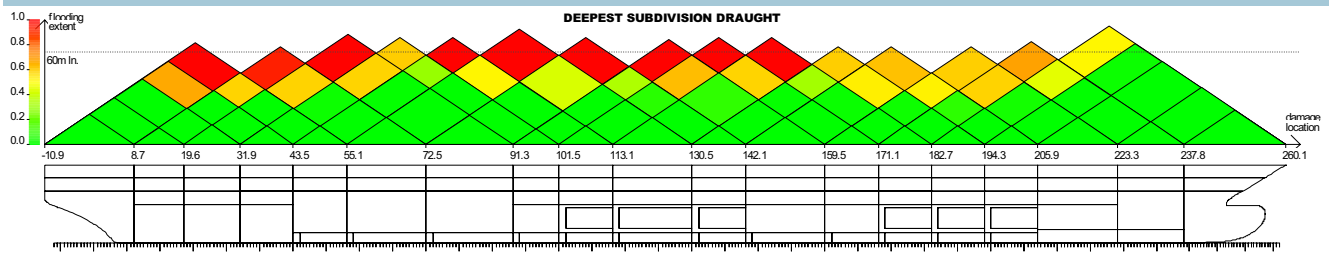
Prediction of Time to Capsize

Effect of Damage Extent – Version 5



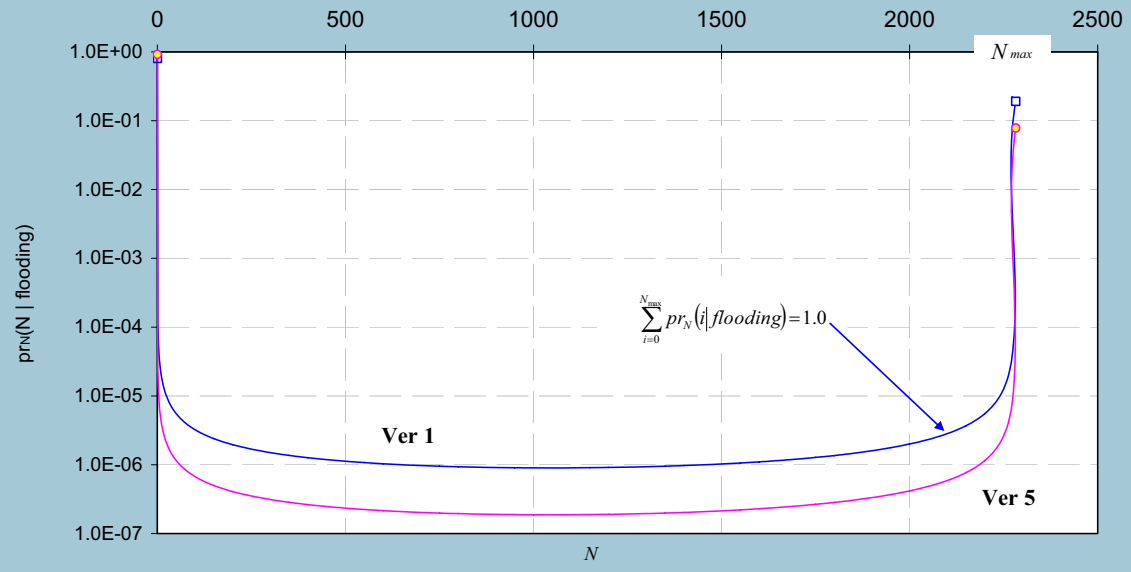
P[t_c<3 hours}; conditional on loading and damage characteristics

Version 5



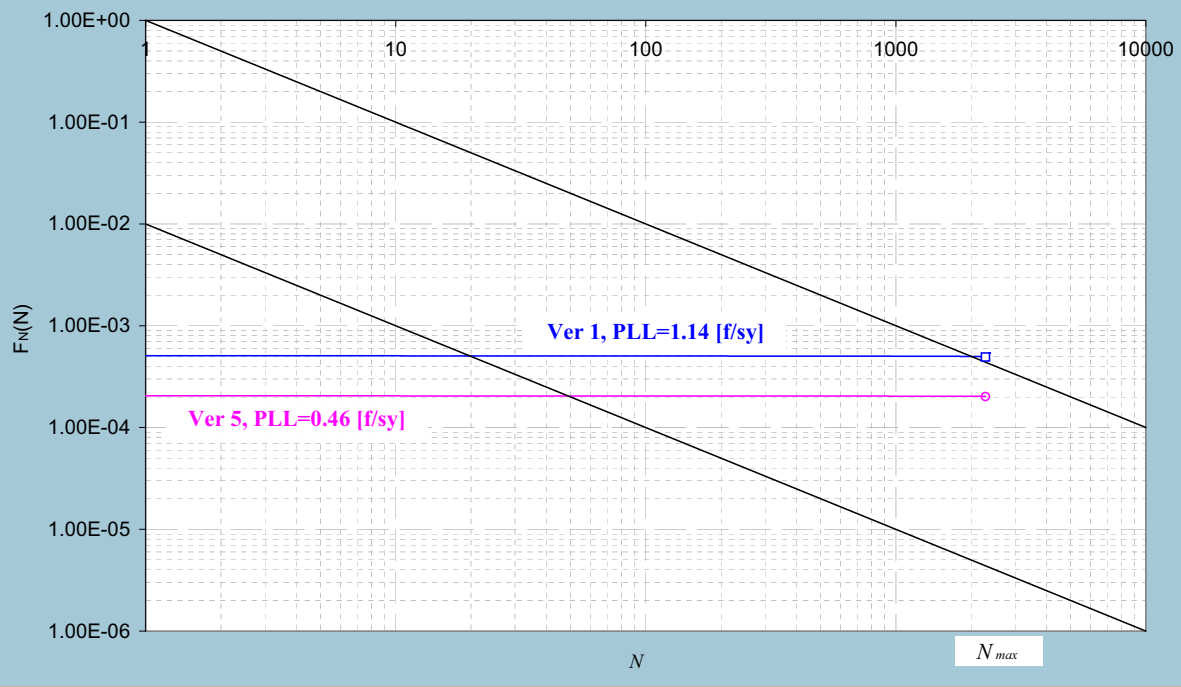
Probability Distribution of N Fatalities

Flooding and Fire (Version 5)



Annual Frequency of N or more Fatalities

Flooding and Fire (Version 5)



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Concluding Remarks

General

- A new philosophy on “Design for Safety” and the development of a Risk-Based Design (RBD) methodology enable ship safety to be dealt with in a systematic and all embracing way by treating safety as a objective in the design process.
- RBD opens the door to innovation and offers competitive advantage to the maritime industry by facilitating cost-effective safety; without RBD optimal design solutions are not possible!
- Adopting a risk-based framework is synonymous with promoting rational decision making; in this respect, such an approach can support and guide contemporary regulatory developments at IMO, e.g., on Goal-Based Standards.

Concluding Remarks

Specific

SAFEDOR developed competence in assessing the damage survivability of passenger ships

This can be used to respond to a wide range of merging industry needs:

- Design of safer ships cost-effectively
- Decision support in crisis management
- Training
- Support the regulatory process:
  - Casualty threshold
  - Return to port
  - Safety level