Risk Based Regulation, Risk Based Design in the Maritime Industry & SAFEDOR

NTNU

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29 September 2009
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- Etymology
- Motivation
- SAFEDOR overview
- Early use
- Formal Safety Assessment
- Risk Evaluation Criteria
- Risk Based Design
ETYMOLOGY OF ‘RISK’

- Classical Greek origin, ‘root/cut from stone’
- Nautical Expression
- Metaphor for “difficulty to avoid at sea“
- From 16th century: a benefit meaning
- Middle-high-German *Rysigo* a technical term for business
- Meaning "to dare, to undertake, enterprise, hope for economic success“
- Original reference to *Grounding Risk* (Homer, Cliffs of Scylla)
Quiz

- MS Marion is a 19 years old bulk carrier owned by a Turkish ship owner, classified in Hellenic Register. She fly the flag of St. Vincent, and is operated by a Cypriote ship management company.

- Which statement about MS Marion is most likely to be true:

  1. MS Marion is larger than 70,000 gross tonne
  2. MS Marion is larger than 70,000 gross tonne, and was detained twice in Post State Controls last year

1  
2  

75% of answers
Explanation: Framing

A: Larger than 70,000 gross tonne
B: Detained twice in Post State Controls last year

Conclusion: Objective analysis – be careful with use of experts

SAFEDOR: What is risk-based ship design and approval?

- A methodology integrating probabilistic / risk-based approaches in the design and approval processes for ships and ship systems

- Safety is one additional quantified design objective along traditional objectives such as speed and cargo capacity

- Risk is used as measure to evaluate effectiveness of design changes with respect to safety

- Risk-based approval is the process of approving risk-based designed ships and their intended operation
Motivation to use risk-based approaches

- **Owners and operators benefit from improved economics of novel solutions**
  - example: more cabins with balcony on a cruise ship with fewer but larger than prescribed lifeboats
  - example: implementation of novel ship type for the first time

- **Yards and suppliers benefit from sustaining their competitive position**
  - example: offer innovative layouts for cruise ship and ferry super structures
  - example: offer new systems with better safety performance
  - example: reduce production costs with better modularisation or less installation

- **Classification societies benefit from improved client relations**
  - Risk-based approval offers planning reliability for novel concepts
  - Fast technological development: Prescriptive rules quickly outdated
The four tracks of SAFEDOR

- Enhance safety through innovation
- Strengthen the competitiveness

- Develop a risk-based design framework
- Develop a risk-based regulatory framework

- Transfer knowledge to add stimulus to maritime industry
- Apply to innovative ship and system designs
Regulatory framework – the impact of SAFEDOR

Risk-based regulatory framework

Risk-based approval processes

- High level approval process
- Ship systems’ approval process
- Requirements for documentation

- High-level acceptance criteria
- Functional acceptance criteria
- Requirements for qualification

Current level of risk

- FSA cruise vessels
- FSA RoPax vessels
- FSA oil tanker
- FSA gas tanker
- FSA container vessels
- FSA dangerous goods

MSC 86/5/3

MSC 85/17/1
MSC 85/17/2
MEPC 58/17/2
MSC 83/21/2
MSC 83/21/1
MSC87/xx/y
Approval of risk-based ships
(see guideline in MSC 86/5/3)

- An approval process to efficiently handle novel and risk-based designs
- A two-step process, integrating elements of risk assessment
- Possibly resulting in additional conditions related to in-service surveys, monitoring, testing, etc.
- Today, safety equivalence is the preferred route to demonstrate safety compliance.
- The future route to compliance is more complex and relies on risk balancing, using absolute, high-level risk acceptance criteria
Designers’ toolbox – new technology from SAFEDOR

Risk-based design framework

Integrated design platform

Collision & Grounding

Human error

Fire & explosion

Systems’ failure

Loss of stability sinking

Structural failure

Evacuation

Flooding

Systems’ availability

Loss of stability sinking

Risk-cost-earning models (per ship type)

The design process and tools are described in the published SAFEDOR handbook.
STRUCTURE OF SAFEDOR ACTIVITIES

- WP 1: design tools to assess hazards and events
- WP 2: innovative products to support safe operation
- WP 3: innovative systems to support safe operation
- WP 4: risk-based regulatory framework
- WP 5: risk-based design integration
- WP 6: validation and application for innovative ship designs
- WP 7: training and dissemination
- WP 8: project management
Ships and their systems – implementing new knowledge

**Innovative designs**

<table>
<thead>
<tr>
<th>Passenger vessels</th>
<th>Cargo ships</th>
<th>Ship systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-Panamax cruise</td>
<td>Coastal LNG tanker</td>
<td>Electrical power distribution</td>
</tr>
<tr>
<td>Cruise liner</td>
<td>Open-top container</td>
<td>Long-range LSA</td>
</tr>
<tr>
<td>Fast displacement RoPax</td>
<td>Aframax oil tanker</td>
<td>Medium-range LSA</td>
</tr>
<tr>
<td>The 13th passenger</td>
<td></td>
<td>Short-range LSA</td>
</tr>
<tr>
<td>Composite superstructure</td>
<td></td>
<td>Bridge layout</td>
</tr>
</tbody>
</table>

Details of the applications are confidential, but several concepts published.
Early Use
Intact and Damage Stability
Probabilistic Damage Stability

- Approach was invented in the 60’ties
  - (Prof Wendel)

- Relates to damage stability following a collision
  - today the dominating risk to ships

- Approach finally implemented as mandatory requirement in 2009
  - result of DNV coordinated HARDER project
Probabilistic model

The model

\[ A_i = \sum_{j=1}^{j=t} p_j \cdot v_j \cdot s_j \]

The event

Regulation:
Attained index > Required Index
The full scenario

Risk = \( P_{\text{collision}} \times P_{\text{flooding}} \times P_{\text{sink}} \times \sum_t \{P(t)_{\text{time to sink}} \times N(t)\} \)

Collision frequency model

Flooding frequency model

Survivability model

Time to sink model

Evacuation model

Consequence

A = 1 - P_{\text{sink|fl|col}}

Vulnerability

A < R

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Cruise Ship Development

Following a series of deliberations at IMO-SLF-MSC, IMO-MSC80 (2005), the finally adopted the following numerals for the Ci coefficients:

- Dry Cargo Ships (L>100m): C1=128, C2=0, C3=152.
- Passenger Ships: C1=5000, C2=2.5, C3=152.

R to be increased: GOALDS
A Risk Based Regulatory Framework

- The term regulatory framework is limited to regulations related to safety and environmental protection, and also limited to shipping activities.
- Risk based implies that regulations are justified by risk analysis, by referring to agreed risk acceptance criteria.
- The regulations themselves may be simple requirements, which do not refer to risk and may be prescriptive.
- Risk based framework: Open for risk based design
Options for approval

- To make the approval of innovative ship design as efficient as possible, three approaches are suggested:
  - Demonstration of compliance with Overall Ship Risk Acceptance Criteria
  - Demonstration of compliance with (implicit) Safety criteria found in properly reviewed FSA studies – rule commentary/justification.
  - Demonstration of compliance with Main Ship Function Risk Acceptance Criteria (when justified)
## Preliminary Findings:

<table>
<thead>
<tr>
<th>Functional Area</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural integrity</td>
<td>Hull strength, ease of construction accessibility and maintainability</td>
</tr>
<tr>
<td>Watertight/Weathertight integrity</td>
<td>Freeboard (Load Line)</td>
</tr>
<tr>
<td>Stability &amp; floatability</td>
<td>Intact and damage survivability</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Propel ship at required operating speed.</td>
</tr>
<tr>
<td>Power supply</td>
<td>Supply electrical power to all consumers.</td>
</tr>
<tr>
<td>Communication capability</td>
<td>Crew and ship to shore communication</td>
</tr>
<tr>
<td>Navigation</td>
<td>Plan route and track ship's position.</td>
</tr>
<tr>
<td>Manoeuvrability</td>
<td>Enable ship to follow planned route.</td>
</tr>
<tr>
<td>Sea-keeping performance</td>
<td>Speed and motions in rough weather.</td>
</tr>
<tr>
<td>Emergency control</td>
<td>Manage an emergency</td>
</tr>
<tr>
<td>Habitability</td>
<td>Crew and passenger accommodation,</td>
</tr>
<tr>
<td>Cargo handling capability</td>
<td>Loading, containing and discharge of cargo.</td>
</tr>
</tbody>
</table>

Not all identified Functional Areas are well suited for risk based design!

Not all identified Functional Requirements have SAFETY as dimensioning factor!
Formal Safety Assessment (ref. IMO)

1. Hazard identification

2. Risk assessment

3. Risk control option (RCO)

4. Cost benefit assessment

5. Recommendation for decision making

\[
\gamma_S M_{SW} + \gamma_W M_{WV} \leq \frac{M_U}{\gamma_R}
\]
…but some are well suited:

- Structural Integrity

“To withstand, in the intact state, the environmental conditions anticipated for the ship’s design life and the loading conditions appropriate for them, which should include full homogeneous and alternate loads, partial loads, multi-port and ballast voyage, and ballast management condition loads”

At what $P_f$?
IMO MSC81/Inf. 6 (IACS) & SP2.2

- The approach described is a perfect example of how a functional requirement, such as the above, can be translated into a technical requirement and subsequently into a risk statement, which is then evaluated based on cost-effectiveness. In essence of MSC81/Inf. 6 is an example of a cost-effectiveness assessment on the above functional requirement.
Cost Benefit Results (1)

- Including cost of property only

Cost Benefit, property

Cost (US$ Mill)

Target safety level, -log(Pf)

- Suezmax
- Product
- VLCC 1
- VLCC 2
- Aframax
- average

Including cost of property only
Cost Benefit Results (2)

- Including cost of property and life

Cost (US$ Mill) vs. Target safety level, -log(Pf)

- Suezmax
- Product
- VLCC 1
- VLCC 2
- Aframax
- average

Cost Benefit Results (2)

Including cost of property and life
Cost Benefit Results (3)

- Including cost of property, life and environment

### Including cost of property, life and environment

**Cost Benefit Results (3)**

- Including cost of property, life and environment

![Graph showing cost benefit results for different vessel types](image-url)
Risk-based Structural Design

Conclusions:

- FSA appropriate for structural rule development
- Structural Reliability Analysis
  - Quantify the probability of failure
  - Quantify effect of risk control option.
- Cost benefit to set target safety level
- Rule formulation. Calibration to SRA → partial safety factors vs. safety level
- Transparent approach, easy to quantify the effect of the various cost assumptions
- Cost of Averting a Ton of oil Spill has a significant impact on the target for tankers
The General Procedure

1. Develop risk model that include the function in question–all scenarios that are affected
2. Use the CEA criteria from IMO (SAFEDOR 4.5.2)
3. Derive the requirement (availability, target reliability etc.)
4. Use this as target in RBD
5. In practice the criteria is (4Δ- modell):
6. NCAF=(Δ Cost - Δ EconomicBenefits - CATS x Δ TonOilspillAverted )/ΔPLL
Formal Safety Assessment - FSA
Risk Assessment

- Nuclear Industry in 60s: Probabilistic Safety Assessments
- Chemical Industry in 70s: QRA, Seveso Directive I and II
- Offshore Industry in 80s:
  - QRA, Industrial Self Regulation Regime in Norway
  - Safety Case Regimes in UK
- Shipping Industry since mid 90s: Formal Safety Assessment (FSA)

- 92: UK House of Lords, Lord Carver Report
- 93, MSC 62: UK proposes FSA concept at IMO
- 97, FSA Interim Guidelines
- 01, FSA Guidelines
- 07, FSA Guidelines Version II
Purpose of FSA (1/2)

- FSA is intended to be a tool for rule-making at IMO:
  - To make the decision process at IMO more rational, reduce ad-hoc proposals/implementation
  - To provide a proactive, holistic approach, comprising technical as well as operational aspects
  - Give less room for politics
Purpose of FSA (2/2)

- To generate information achieved in a way which is structured, systematic, comprehensive, objective, rational, documented and auditable

- To demonstrate that suitable techniques have been applied and sufficient efforts have been made to identify hazards and to manage the associated risk
FSA – A risk Based Approach

Preparatory Step

Step 1
Hazard Identification

Step 2
Risk Analysis

Step 3
Risk Control Options

Step 4
Cost Benefit Assessment

Step 5
Recommendations for Decision Making

Definition of Goals, Systems, Operations

Hazard Identification

Scenario definition

Cause and Frequency Analysis

Consequence Analysis

Risk Summation

Risk Controlled?

Options to decrease Frequencies

Options to mitigate Consequences

Cost Benefit Assessment

Reporting
## FSA – Compared to traditional approach

<table>
<thead>
<tr>
<th>Step</th>
<th>Formal Safety Assessment</th>
<th>Current Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td><em>(What might go wrong?)</em></td>
<td>Hazard identification</td>
</tr>
<tr>
<td>Step 2</td>
<td><em>(How often, how likely? How bad?)</em></td>
<td>Risk analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequencies, probabilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consequences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk = probability x consequence</td>
</tr>
<tr>
<td>Step 3</td>
<td><em>(How can matters be improved?)</em></td>
<td>Risk control options</td>
</tr>
<tr>
<td></td>
<td></td>
<td>identification</td>
</tr>
<tr>
<td>Step 4</td>
<td><em>(How much? How much better?)</em></td>
<td>Cost benefit evaluation</td>
</tr>
<tr>
<td>Step 5</td>
<td><em>(What actions are worthwhile to take?)</em></td>
<td>Recommendation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What actions are worthwhile to take?</td>
</tr>
</tbody>
</table>
Risk Acceptance

High Risk

Intolerable

Not acceptable

ALARP

Acceptable if made ALARP

Negligible

Acceptable

Low Risk
Individual Risk

![Graph showing individual risk levels for different types of vessels]

- Oil Tanker
- Chemical Tanker
- Gas Tanker
- Bulk/Oil Carrier
- Bulk Carrier (incl. Ore)
- Container Vessel
- General Cargo Carrier
- Ro/Ro Cargo Carrier

Categories:
- Intolerable Risk
- ALARP
- Negligible Risk
Societal Risk - FN Diagrams

The diagram illustrates the frequency of N or more fatalities (per ship year) versus the number of fatalities (N) for different types of vessels: Oil tankers, Chemical tankers, Oil/Chemical tankers, and Gas tankers. The horizontal lines represent the levels of Intolerable and Negligible risks, while the ALARP (As Low As Reasonably Practicable) line indicates the balance between risk and cost.

- **Oil tankers** are represented by circles.
- **Chem. tankers** are shown with triangles.
- **Oil/Chemical tankers** are depicted using squares.
- **Gas tanker** is indicated with crosses.

The y-axis shows the frequency of N or more fatalities on a logarithmic scale, ranging from 1.0E-06 to 1.0E-02, while the x-axis represents the number of fatalities (N) ranging from 1 to 100.
Societal Risk - FN Diagrams

![FN Diagram](image-url)

- **Fatalities (N)**: X-axis
- **Frequency of N or more fatalities (per ship year)**: Y-axis

- **Negligible**
- **ALARP**
- **Intolerable**

- **Bulk and ore**
- **Container**
Methods for deriving criteria

- Human capital approach
- Willingness to pay
- Comparing to well informed (risk informed) decisions in democratic institutions
- Comparing to previous decision
- Societal Indicators
- Individual decisions
- Etc.

- All methods give similar results
## Cost Effectiveness Criteria

<table>
<thead>
<tr>
<th>Decision</th>
<th>Decision Maker</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthening Bulkheads on Existing Bulk Carriers</td>
<td>IACS and IMO (1)</td>
<td>&gt; $ 1.5 million</td>
</tr>
<tr>
<td>Helicopter Landing Area on non-Ro/Ro Passenger Ships</td>
<td>IMO(2)</td>
<td>&lt; $ 37 million</td>
</tr>
<tr>
<td>3 bulkheads on car deck Passenger Ro/Ro</td>
<td>IMO(3)</td>
<td>&lt; $ 5 million</td>
</tr>
<tr>
<td>3 bulkheads + sponsons</td>
<td>IMO(3)</td>
<td>&lt; 7.8 million</td>
</tr>
<tr>
<td>Extended sponsons only</td>
<td>IMO(3)</td>
<td>&lt; $ 11 million</td>
</tr>
<tr>
<td>Extra Deck Officer</td>
<td>IMO(3)</td>
<td>&lt; $ 5.5 million</td>
</tr>
<tr>
<td>Two conventional lifeboats BC</td>
<td>IMO(4)</td>
<td>&gt; $ 1 million</td>
</tr>
<tr>
<td>Throw overboard life-raft on BC</td>
<td>IMO (4)</td>
<td>&gt; $ 3 million</td>
</tr>
</tbody>
</table>

Re: (1) Mathisen et al.(1997), (2) Skjong et al.(1997), (3) DNV(1997), (4) Skjong and Wenthworth,

Much longer and more updated list: [http://www.safedor.org/resources/](http://www.safedor.org/resources/)
Previous decision

<table>
<thead>
<tr>
<th>Results from Tengs et al. (1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Five Hundred Life-Saving Interventions and their Cost Effectiveness”</td>
</tr>
<tr>
<td>Number of measures studied</td>
</tr>
<tr>
<td>Range of cost effectiveness</td>
</tr>
<tr>
<td>Median Value</td>
</tr>
<tr>
<td>Median for Medical Interventions</td>
</tr>
<tr>
<td>Median for Injury Prevention</td>
</tr>
<tr>
<td>Median for toxic control</td>
</tr>
</tbody>
</table>

• By reallocation 40,000 lives could be saved annually in the US
Societal Indicators

CAF for OECD Countries ( $ million )

<table>
<thead>
<tr>
<th>Country</th>
<th>CAF (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>3.5</td>
</tr>
<tr>
<td>Austria</td>
<td>3.0</td>
</tr>
<tr>
<td>Belgium</td>
<td>2.5</td>
</tr>
<tr>
<td>Canada</td>
<td>2.0</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2.5</td>
</tr>
<tr>
<td>Denmark</td>
<td>3.0</td>
</tr>
<tr>
<td>Finland</td>
<td>2.5</td>
</tr>
<tr>
<td>France</td>
<td>2.0</td>
</tr>
<tr>
<td>Germany</td>
<td>2.5</td>
</tr>
<tr>
<td>Greece</td>
<td>3.0</td>
</tr>
<tr>
<td>Hungary</td>
<td>2.0</td>
</tr>
<tr>
<td>Iceland</td>
<td>2.5</td>
</tr>
<tr>
<td>Ireland</td>
<td>3.0</td>
</tr>
<tr>
<td>Italy</td>
<td>2.0</td>
</tr>
<tr>
<td>Japan</td>
<td>4.5</td>
</tr>
<tr>
<td>Korea</td>
<td>3.0</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>2.5</td>
</tr>
<tr>
<td>Mexico</td>
<td>1.5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2.0</td>
</tr>
<tr>
<td>New Zealand</td>
<td>2.5</td>
</tr>
<tr>
<td>Norway</td>
<td>1.5</td>
</tr>
<tr>
<td>Poland</td>
<td>2.0</td>
</tr>
<tr>
<td>Portugal</td>
<td>2.5</td>
</tr>
<tr>
<td>Spain</td>
<td>1.0</td>
</tr>
<tr>
<td>Sweden</td>
<td>2.5</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1.5</td>
</tr>
<tr>
<td>Turkey</td>
<td>2.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>2.5</td>
</tr>
<tr>
<td>United States</td>
<td>3.0</td>
</tr>
<tr>
<td>Average OECD</td>
<td>2.25</td>
</tr>
</tbody>
</table>

IMO
Human Capital, Societal Indicators & Upper limit
Updated results: 2007 data
Concept and Criteria used

- GCAF = $\Delta$Cost/$\Delta$PLL < $3m$
- NCAF = $(\Delta$Cost - $\Delta$Benefits)/$\Delta$PLL <$3m$
- CATS = $(\Delta$Cost/$\Delta$Spill) < $60,000$
- Cost of averting the loss of a QALY < $3m/35$
- Note: IPCC defines Cost of Averting a Ton of CO$_2$-eq Heating effect: CATCH < $50$
Energy Efficiency Index (CO₂)

Cost of Averting a Tonne of CO₂-eq Heating effect, CATCH = $50
Example: Formal Safety Assessment
Example: FSA Tanker for Oil

Major oil trade movements

The present analysis covers crude oil tankers of the following types:

- **PANAMAX** (60,000 DWT – 79,999 DWT)
- **AFRAMAX** (80,000 DWT - 119,999 DWT)
- **SUEZMAX** (120,000 DWT - 199,999 DWT)
- **Very Large Crude Carriers** (VLCC; 200,000 DWT - 320,000 DWT)
- **Ultra-Large Crude Carriers** (ULCC; more than 320,000 DWT).
Risk analysis of Large Tankers

Frequency assessment

- The full risk model should include except LOWI accidents, also "machinery failures", "failures of hull fittings" and "unknown reasons. In the scope of the present study, however herein only the six (6) events that potentially lead to LOWI (Loss Of Watertight Integrity) are taken into account.

- These generic accident scenarios have been selected based on a balanced consideration of the hazard identification process and following a historical accident analysis for tanker ships of capacity greater than 60,000 DWT.
Variation of sample ship years and age – Single and Double Hull ships

Development of ship years for SH and DH between 1990 and 2007
Risk analysis of Large Tankers
Frequency assessment

Frequency of the 6 major incident categories in terms of accidents per shipyear

<table>
<thead>
<tr>
<th>Initial event</th>
<th>Frequency of accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>1.03E-02</td>
</tr>
<tr>
<td>Contact</td>
<td>3.72E-03</td>
</tr>
<tr>
<td>Grounding</td>
<td>7.49E-03</td>
</tr>
<tr>
<td>Fire</td>
<td>3.68E-03</td>
</tr>
<tr>
<td>Explosion</td>
<td>1.90E-03</td>
</tr>
<tr>
<td>NASF</td>
<td>DH ships: 1.93E-03</td>
</tr>
<tr>
<td></td>
<td>All ships: 5.74E-03</td>
</tr>
</tbody>
</table>

Frequency of incidents, Historical Data

Source: NTUA-SDL

Oil Tankers
Historical Data, Covered Period 1990-2007

Source: NTUA-SDL Tanker casualty database
Sample data: 846 Incidents
Risk analysis of Large Tankers

Consequence assessment (1)

**Consequences on crews’ life**

The expected number of fatalities for each identified scenario is presented as the Potential Loss of Life, PLL, per shipyear. The related estimation of PLL is derived from historical data on the basis of a typical crew number of 30 persons.

**Environmental impact**

The consequences to the environment for each identified scenario are presented as the expected cargo oil tonnes released to the sea. To account for the variation of ship sizes within the large tanker sample, an average generic large tanker and probable average oil spill was defined.

<table>
<thead>
<tr>
<th>Oil release in case of 1 tank breaching</th>
<th>Oil release in case of ship’s total loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH ships</td>
<td>DH ships</td>
</tr>
<tr>
<td>Mean (t)</td>
<td>Stdw(t)</td>
</tr>
<tr>
<td>PANAMAX</td>
<td>6450.9</td>
</tr>
<tr>
<td></td>
<td>1813.5</td>
</tr>
<tr>
<td>AFRAMAX</td>
<td>9298.5</td>
</tr>
<tr>
<td></td>
<td>2424.5</td>
</tr>
<tr>
<td>SUEZMAX</td>
<td>10947.9</td>
</tr>
<tr>
<td></td>
<td>2622.3</td>
</tr>
<tr>
<td>VLCC &amp; ULCC</td>
<td>19828.4</td>
</tr>
<tr>
<td></td>
<td>2443.2</td>
</tr>
<tr>
<td>Assumed average for generic large tanker</td>
<td>10,726</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference Vessel</th>
<th>100% Volume (m³)</th>
<th>Oil cargo (in tonnes) (98% full, 0.85 t/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANAMAX</td>
<td>80,659</td>
<td>67,189</td>
</tr>
<tr>
<td>AFRAMAX</td>
<td>125,203</td>
<td>104,294</td>
</tr>
<tr>
<td>SUEZMAX</td>
<td>174,846</td>
<td>145,647</td>
</tr>
<tr>
<td>VLCC</td>
<td>350,100</td>
<td>291,633</td>
</tr>
<tr>
<td>Assumed average for generic large tanker</td>
<td>182,702</td>
<td>152,191</td>
</tr>
</tbody>
</table>
Risk analysis of Large Tankers
Consequence assessment (2)

Environmental impact based on a weighted Fleet at Risk basis

A second alternative for the definition of the generic large tanker and oil spill was explored, which is based on the weighted Fleet at Risk, accounting for the number of accidents (historical data) of the Fleet at Risk.

<table>
<thead>
<tr>
<th>DH ships</th>
<th>wt</th>
<th>Mean tank size (t)</th>
<th>Oil release in case of 1 tank breaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANAMAX</td>
<td>0.16</td>
<td>5285.8</td>
<td>845.7</td>
</tr>
<tr>
<td>AFRAMAX</td>
<td>0.36</td>
<td>8145.8</td>
<td>2932.5</td>
</tr>
<tr>
<td>SUEZMAX</td>
<td>0.19</td>
<td>11365.7</td>
<td>2159.5</td>
</tr>
<tr>
<td>VLCC&amp;ULCC</td>
<td>0.29</td>
<td>18106.5</td>
<td>5250.9</td>
</tr>
</tbody>
</table>

Weighted average value based on Fleet at Risk basis: 11,189

<table>
<thead>
<tr>
<th>Reference Vessel</th>
<th>Oil cargo (in tonnes) (98% full, 0.85 t/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANAMAX</td>
<td>67,189</td>
</tr>
<tr>
<td>AFRAMAX</td>
<td>104,294</td>
</tr>
<tr>
<td>SUEZMAX</td>
<td>145,647</td>
</tr>
<tr>
<td>VLCC</td>
<td>291,633</td>
</tr>
</tbody>
</table>

Weighted average value based on Fleet at Risk basis: 160,543
Risk analysis of Large Tankers
Consequence assessment (3)

**Economic impact**

Next Table presents the assumed economic impact values, accounting for the total loss of ship and cargo.

<table>
<thead>
<tr>
<th>Ship &amp; oil cargo typical values</th>
<th>Ship value(^1) in $</th>
<th>Oil cargo ($/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANAMAX</td>
<td>50,000,000</td>
<td></td>
</tr>
<tr>
<td>AFRAMAX</td>
<td>65,000,000</td>
<td></td>
</tr>
<tr>
<td>SUEZMAX</td>
<td>85,000,000</td>
<td>923(^2)</td>
</tr>
<tr>
<td>VLCC</td>
<td>130,000,000</td>
<td></td>
</tr>
<tr>
<td><strong>Average value</strong></td>
<td><strong>82,500,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Based on an assumed age of about 5 years.

\(^2\) Assumed $/tonne oil value as of March, 2008
Risk analysis of Large Tankers
Employed Risk models

For each studied event, the sequence in the particular event risk model was generated. Based on this, the Event Trees were constructed and relevant risks calculated. As an example, the figure below presents the event sequence of the collision risk model.
Risk analysis of Large Tankers
Risk assessment results (1)

Based on the developed risk modelling, the contributions from the various scenarios to the total Potential Loss of Lives (PLL) from large oil tanker shipping operations are presented. Relatively high PLL values are noted for explosion and collision events.
Risk analysis of Large Tankers
Risk assessment results (2)

Based on the present risk modelling, the contributions from the various scenarios to the total Potential Loss of Cargo (PLC) from large oil tanker shipping operations are presented.

Relatively high PLC values are noted for fire, powered grounding, collision and explosion events, in that order.
Risk analysis of Large Tankers
Risk assessment results (3)

**Individual risk for crew**
Individual risks for 3rd parties were not an issue in the context of this study, as only the individual risk for the tanker crew was considered.

It is assumed that all members of the tanker crew are equally exposed to the risk.

Assuming a crew of 30 on a typical large oil tanker, a fatality rate of 1.27E-02 per shipyear was estimated, leading to a **corresponding individual risk of 4.23E-04 per year**.

Given the fact that *three shifts of crew alternate* are needed for a continuous ship operation, **the individual risk becomes 1.41E-04**.

Compared to the risk acceptance criteria for individual risk for crew that were established in other SAFEDOR FSA studies (D4.5.2), the resulting individual risk level for large oil tankers **proves lower than the generally accepted maximum tolerable risk for crew member and lies within the defined ALARP region**.
Risk analysis of Large Tankers
Risk assessment results (4)

F-N curve for tanker crew
Based on the available historical data, for the period 1990-2007, the F-N curve for the overall risk to crew is generated.

Compared to the established criteria in SAFEDOR SP4.5.2, it is clearly indicated that the presently calculated societal risk for large tankers lies within the defined ALARP region.
Risk analysis of Large Tankers
Main Conclusions - Identified high risk areas

- In terms of potential loss of crew life, three areas of main concern or generic accident scenarios were identified:
  - Collision scenarios of the struck ship
  - Fire scenarios due to internal source initiation
  - Explosion scenarios.

- In terms of potential loss of oil cargo, four areas of main concern or generic accident scenarios were identified:
  - Collision scenarios of the struck ship
  - Powered grounding
  - Fire scenarios due to internal source initiation
  - Explosion scenarios.
Cost Benefit analysis
RCO Screening

- Screened from 79, to:
  - No 3: Active Steering Gear Redundancy
  - No 4: Electronic Chart Display and Information System (ECDIS)
  - No 5: Terminal Proximity and Speed Sensors (Docking Aid)
  - No 6: Navigational Sonar
  - No 7: Ship Design Modifications to reduce grounding and oil pollution risks
    - No 7.1: Panamax, Aframax and Suezmax from 6x2 to 6x3, VLCC from 5x3 to 6x3
    - No 7.1: Increased DB height
    - No 7.3: Increased DS width
  - No 8: Hot Work Procedures Training
  - No 9: Double Sheathed Fuel oil pipes within the engine room
  - No 11: Engine control room additional emergency exit
  - No 12: Hull stress and fatigue monitoring system
### Cost Benefit Analysis Results(1)

**Table 12: Results**

<table>
<thead>
<tr>
<th>Risk Reduction $\Delta R_d$</th>
<th>Oil Spill Reduction $\Delta R_g$</th>
<th>Cost $\Delta C$</th>
<th>Benefit $\Delta B$</th>
<th>$G_{R}\Delta C$</th>
<th>$C_{ATS}$</th>
<th>$\Delta C$</th>
<th>$\Delta R_g$</th>
<th>$\Delta C - \Delta R_g$</th>
<th>NetCAF</th>
</tr>
</thead>
<tbody>
<tr>
<td># of saved lives&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>Tonnes&lt;sup&gt;2)&lt;/sup&gt;</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
<td>$^3)&lt;sup&gt;3)&lt;/sup&gt;$</td>
</tr>
<tr>
<td>RCO 3: Active Steering Gear Redundancy</td>
<td>1.2E-4</td>
<td>16</td>
<td>4,800</td>
<td>530,000</td>
<td>40,000,000</td>
<td>300</td>
<td>-4,377,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 4: ECDIS</td>
<td>1.2E-3</td>
<td>170</td>
<td>75,000</td>
<td>5,667,000</td>
<td>62,500,000</td>
<td>440</td>
<td>-4,660,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 5: Terminal Proximity &amp; Speed Sensors</td>
<td>N/A</td>
<td>4</td>
<td>86,000</td>
<td>119,000</td>
<td>N/A</td>
<td>21,500</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 6: Navigational Sonar</td>
<td>4.9E-4</td>
<td>70</td>
<td>196,500</td>
<td>2,361,000</td>
<td>401,000,000</td>
<td>2,800</td>
<td>-4,417,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 8: Hot Works Procedures Training</td>
<td>1.9E-02</td>
<td>45</td>
<td>28,000</td>
<td>2,200,000</td>
<td>1,450,000</td>
<td>450</td>
<td>-111,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 9: Double Sheathed Low Pressure Fuel Pipes</td>
<td>1.4E-02</td>
<td>154</td>
<td>39,000</td>
<td>5,300,000</td>
<td>2,700,000</td>
<td>250</td>
<td>-371,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 11: Engine Control Room Additional Emergency Exit</td>
<td>4.4E-03</td>
<td>N/A</td>
<td>13,840</td>
<td>N/A</td>
<td>3,169,000</td>
<td>N/A</td>
<td>3,169,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCO 12: Hall Stress &amp; Fatigue Monitoring System</td>
<td>5.3E-04</td>
<td>4</td>
<td>128,000</td>
<td>134,000</td>
<td>241,000,000</td>
<td>32,000</td>
<td>-10,200,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

<sup>1)</sup> Per ship lifetime, assumed to be 25 years
<sup>2)</sup> Includes NPV at 5% per year where relevant
<sup>3)</sup> Reduced PLC and PLP
Cost Benefit analysis  
Results (2) – RCO 7

- RCO 7: Ship Design Modifications were analyzed for every ship type and as such the results are presented in separate tables

### Table 13: Panamax Results for RCO 7: Ship Design Modifications

<table>
<thead>
<tr>
<th>RCO 7: Enhanced Cargo Tank Subdivision</th>
<th>Risk Reduction $\Delta R$</th>
<th>Cost $\Delta C$</th>
<th>Benefit $\Delta B$</th>
<th>CATS $= \frac{\Delta C}{\Delta R}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.25</td>
<td>1,472,602</td>
<td>2,115,000</td>
<td>41,736</td>
<td></td>
</tr>
</tbody>
</table>

Note:
- $\#$ tonnes of oil saved
- $^a$: Per ship lifetime, assumed to be 25 years
- $^b$: Includes NPV at 5% per year where relevant
- $^c$: Reduced PLC only

### Table 14: Aframax Results for RCO 7: Ship Design Modifications

<table>
<thead>
<tr>
<th>RCO 7: Enhanced Cargo Tank Subdivision</th>
<th>Risk Reduction $\Delta R$</th>
<th>Cost $\Delta C$</th>
<th>Benefit $\Delta B$</th>
<th>CATS $= \frac{\Delta C}{\Delta R}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>1,723,185</td>
<td>3,480,000</td>
<td>20,710</td>
<td></td>
</tr>
</tbody>
</table>

Note:
- $\#$ tonnes of oil saved
- $^a$: Per ship lifetime, assumed to be 25 years
- $^b$: Includes NPV at 5% per year where relevant
- $^c$: Reduced PLC only

### Table 15: Suezmax Results for RCO 7: Ship Design Modifications

<table>
<thead>
<tr>
<th>RCO 7: Enhanced Cargo Tank Subdivision</th>
<th>Risk Reduction $\Delta R$</th>
<th>Cost $\Delta C$</th>
<th>Benefit $\Delta B$</th>
<th>CATS $= \frac{\Delta C}{\Delta R}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.25</td>
<td>2,731,930</td>
<td>3,735,000</td>
<td>43,886</td>
<td></td>
</tr>
</tbody>
</table>

Note:
- $\#$ tonnes of oil saved
- $^a$: Per ship lifetime, assumed to be 25 years
- $^b$: Includes NPV at 5% per year where relevant
- $^c$: Reduced PLC only

### Table 16: VLCC Results for RCO 7: Ship Design Modifications

<table>
<thead>
<tr>
<th>RCO 7: Enhanced Cargo Tank Subdivision</th>
<th>Risk Reduction $\Delta R$</th>
<th>Cost $\Delta C$</th>
<th>Benefit $\Delta B$</th>
<th>CATS $= \frac{\Delta C}{\Delta R}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.25</td>
<td>956,843</td>
<td>1,755,000</td>
<td>32,713</td>
<td></td>
</tr>
</tbody>
</table>

Note:
- $\#$ tonnes of oil saved
- $^a$: Per ship lifetime, assumed to be 25 years
- $^b$: Includes NPV at 5% per year where relevant
- $^c$: Reduced PLC only
Cost Benefit analysis
Recommendations (1)

- This study demonstrates that one RCO detailed in Table 17 below is cost-effective purely from a GCAF point of view according to the IMO criteria and the information available.

<table>
<thead>
<tr>
<th>No.</th>
<th>RCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Hot Works Procedures Training</td>
</tr>
</tbody>
</table>

- On the other hand the RCOs listed in Table 18 can be recommended from a NCAF and CATS perspective only, indicating that they are not cost-effective in terms of preventing fatalities but are cost-effective in reducing oil spilled and property damage.

<table>
<thead>
<tr>
<th>No.</th>
<th>RCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Active Steering Gear Redundancy</td>
</tr>
<tr>
<td>4</td>
<td>ECDIS – Electronic Chart Display Information System</td>
</tr>
<tr>
<td>6</td>
<td>Navigational Sonar</td>
</tr>
<tr>
<td>7</td>
<td>Ship Design Modifications (in certain instances; see discussion below)</td>
</tr>
</tbody>
</table>

- As Table 18 illustrates four of the selected RCOs recommended for further consideration by the IMO are significant due to their potential for reduced risk with regards to PLC and PLP rather than PLL. Thus, RCOs 3, 4, 6 and 7 should be considered further by the IMO by virtue of their economic benefit.

<table>
<thead>
<tr>
<th>No.</th>
<th>RCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Double Sheathed Low Pressure Fuel Pipes</td>
</tr>
<tr>
<td>11</td>
<td>Engine Control Room Additional Emergency Exit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>RCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Terminal Proximity and Speed Sensors</td>
</tr>
<tr>
<td>12</td>
<td>Hull Stress and Fatigue Monitoring System</td>
</tr>
</tbody>
</table>
Cost Benefit analysis
Recommendations (2)

- Specifically with regards to RCO 7 Ship Design Modifications the following recommendations can be made:

- For all design modifications described in sub-RCOs 7.1 (enhanced cargo tank subdivision), 7.2 (increased double bottom height) and 7.3 (increased side tank width) all CATS values (max. $43,500) are within the $60,000 threshold recommended by SAFEDOR, thus can be considered cost-effective, with the exception of RCO 7.2 for VLCCs, which can be disregarded as not economically viable.

- However, particular RCOs outcomes are more cost-effective than others, namely RCO 7.1 and RCO 7.3 (0.4m) for Aframax size tankers (Table 14) and RCO 7.3 (0.4m) for Suezmax size tankers (Table 15), thus should be recommended for implementation ahead of the other RCOs which have higher CATS values and are hence less cost effective.
A comment on data
Comparing LRFP & Norwegian NOR/NIS – all accidents

- NMD (N) - 40.5%
- Common (Rc) - 12%
- LRFP (L) - 30%
- Not reported - 41.5%
Risk Based Design

- Provisions in International trade regulations (WTO, EU, etc) prevent other regulations (safety, environment) used as trade barriers – need for allowing ‘equivalent solutions’

- SOLAS Regulation 5 in Chapter 1
  - Regulation 17-II in Chapter II-2 (Fire)
  - machinery and electrical installations (new regulation II-1/55)
  - life-saving appliances and arrangements (new regulation III/38).
  - II-1/8-1, II-2/21.4, II-2/21.5.1.2 and II-2/22.3.1 – related to the safe return to port agenda item – as adopted by resolution MSC.216(82).

- MARPOL Regulation I/5’
  - I/19(5) provides for the acceptance of alternative oil tanker design provided that at least the same level of protection against oil pollution in the event of collision and stranding compared to prescriptive design is ensured

- The International Convention on Load Lines (LL) contains provisions on equivalents
  - (article 8).

- Etc.
Safety Impact

Quantitative risk assessment:

- Risks modelled by event tree:
  - Superstructure design fire scenarios
  - Local fires (only those nearby at risk)
  - Escalating fires where ship is abandoned

- Probabilities estimated from service experience, simulations and tests

- Consequences judged based on simulations, tests and experience

- Expected number of fatalities estimated for all phases of the fires

- Estimated effects of human decisions included
Conclusion

- A novel design case has been studied that challenges SOLAS II-2 Regulation 11.

- The base design showed
  - About 60% weight saving at moderate cost
  - Acceptable individual and societal risk

- A risk based design process was adopted.
  - MSC/Circ. 1002 guided the risk assessment
  - Risks were reduced by adopting cost effective risk control options
  - Adequate safety of final design was documented by a quantitative fire risk assessment.

- Such designs may in the future be approved according to SOLAS II-2 Reg 17

Alternative designs and arrangements
Risk Based Design Tools

- Integrated RBD tool?
- PERC models
  - Performance
  - Earning
  - Risk
  - Cost
- Tool that control all dependencies
RBD GUI
Probabilistic tools

- FT, ET
- Bayesian Networks
- System Optimization (Hip-Hop)
Outlook

- The value of the new approach demonstrated.
- Risk-based design and approval in use by the maritime industry today.
- We expect
  - more frequent risk-based designs
  - increased application of risk-based approaches in rule development
  - linking with risk-based approaches during operation
Safeguarding life, property and the environment

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