MARITIME RISK

An Overview

Rolf Skjong, Dr, Chief scientist
Chalmers, April 21, 2009

N62°30'12.83" E6°06'07.94"
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, give less room for politics
- To provide a proactive, holistic approach, comprising technical as well as operational aspects
Purpose of FSA (2/2)

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

- 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

Definition of Goals, Systems, Operations

Hazard Identification
Scenario definition

Cause and Frequency Analysis
Consequence Analysis

Risk Summation

Risk Controlled? Options to decrease Frequencies
No
Yes Options to mitigate Consequences

Cost Benefit Assessment

Reporting

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
Risk Based Regulations - Status At IMO

- UK proposed FSA at IMO in 1995
  - Referred to safety case for offshore
  - Resulted in FSA as risk assessment process to justify Rules/Regulations
- FSA Interim Guidelines, v0, 1997
- FSA Guidelines, v1, 2002
- FSA Guidelines, v2, 2007
Should FSA become mandatory?

GUIDELINES ON THE ORGANIZATION AND METHOD OF WORK OF MSC AND MEPC AND THEIR SUBSIDIARY BODIES (MSC-MEPC-Circ.1)

- 2.10.5 ‘has the analysis of the issue sufficiently addressed the cost to the maritime industry as well as the relevant legislative and administrative burdens?’

- 2.14 ‘a higher priority should be assigned to items that can be shown, or estimated, to have the greatest effect on safety of life, prevention of serious injury, protection of the marine environment and the highest ratio of benefit to be gained from the implementation of the proposal compared with the cost of its implementation’

- 2.23.2.2.4 ‘do the benefits justify the proposed action?’
Risk based Rules & Risk Based Design

Risk Assessment Method

- Definition of Goals, Systems, Operations
- Hazard Identification
- Cause and Frequency Analysis
- Consequence Analysis
- Risk Summation
- Risk Controlled?
- Options to Decrease Frequencies
- Options to Mitigate Consequences
- Cost-Benefit Assessment
- Reporting

Generic Ship

Risk Based Rules

Specific Ship (in e.g. specific environment)

Risk Based Design

MSC86/5/4
Risk Based Regulation: GBS - SLA

- **Tier I**: Goals
- **Tier II**: Functional Requirements
- **Tier III**: Verification Process
- **Tier IV**: Prescriptive Regulations & Class Rules
- **Tier V**: Applicable Industry Standards & Codes of Practice

**Verification Process**
- Definition of Goals, Systems, Operations
- Hazard Identification
- Scenario definition
- Cost Benefit Assessment
- Reporting
- Systems to mitigate Consequences
- Options to decrease Frequencies
- Options to mitigate Consequences
- RA to Justify

**Risk Controlled?**
- No
- Yes
Risk Based Design (RBD)

Tier I

Goals

Tier II

Functional Requirements

Tier III

RBD Verification Process

- Definition of Goals, Systems, Operations
- Hazard Identification
- Cause and Frequency Analysis
- Consequence Analysis
- Risk Summation
- Risk Controlled?
  - Options to decrease Frequencies
  - Options to mitigate Consequences
- Cost Benefit Assessment
- Reporting

Scenario definition

RBD
FSAs

- First FSAs
  - High speed craft
  - Helicopter landing area on passenger ships
  - Bulk carrier safety

- Other FSAs
  - Navigation – Large Passenger Ships
  - Mandatory Carriage Requirements for ECDIS
  - Inert Gas System for Chemical Tankers < 20,000 dwt
FSAs by SAFEDOR

- Purpose of submitting FSAs to IMO from SAFEDOR
  - Document safety level – for reference in Risk Based Design
  - Ship types selected for FSA same as Risk Based Design projects

- Contributions from SAFEDOR
  - FSA Container ships (MSC83)-GL, AMTW, DÖHLE, SSPA
  - FSA Liquefied Natural Gas ships (MSC83)-DNV, NAVANTIA, IST, LMG
  - FSA Cruise (MSC85)-DNV, CARNIVAL
  - FSA RoPax (MSC85)-SSRC, FSG, LMG, COLOR, DNV
  - FSA Oil Tankers (MEPC58) - NTUA, GL, DNV, SSRC, DMA, ASME
  - FSA-Step 1: Container fire on deck (FP53)
  - FSA Dangerous Goods in Open-Top Container Vessels (Not Submitted yet)
FSAs by SAFEDOR

- FSAs have been carried out by different teams
- All use the IMO FSA Guidelines as basis
- FSAs are therefore quite similar, but for reuse of models more standardisation is beneficial
  - Partial models for probabilities, consequence models, reliabilities, availability, vulnerability
  - Software need clearly defined interfaces
  - Relevant both for FSA & RBD
6 accident scenarios cover 98.8% of serious ship accidents

<table>
<thead>
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<td>663</td>
<td>435</td>
<td>341</td>
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<td>3199</td>
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<td>31.5</td>
<td>24.0</td>
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6 accident scenarios cover 99.4% fatalities in ship accidents

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<td>Dry Cargo</td>
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<td>312</td>
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<td>65</td>
<td>3</td>
<td>11</td>
<td>485</td>
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<td>25</td>
</tr>
<tr>
<td>Pass./Ferry</td>
<td>657</td>
<td>553</td>
<td>221</td>
<td>260</td>
<td>8</td>
<td>1</td>
<td>1700</td>
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<td>Reefer</td>
<td>18</td>
<td>14</td>
<td>1</td>
<td>10</td>
<td></td>
<td>7</td>
<td>50</td>
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<tr>
<td>Roro</td>
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<td>2</td>
<td>4</td>
<td></td>
<td>3</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Tanker</td>
<td>333</td>
<td>16</td>
<td>36</td>
<td></td>
<td></td>
<td>14</td>
<td>402</td>
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<tr>
<td><strong>Total</strong></td>
<td>1157</td>
<td>998</td>
<td>371</td>
<td>341</td>
<td>35</td>
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<td>2950</td>
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<td>Ratio of total (%)</td>
<td>39.2</td>
<td>33.8</td>
<td>12.6</td>
<td>11.6</td>
<td>1.2</td>
<td>1</td>
<td>99.4</td>
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One clear benefit of standardization

- Decision Parameters and Risk Acceptance
- All FSAs present Individual risk, Societal Risk (FN), NCAF, GCAF, as suggested in FSA Guidelines, CATS (if relevant) – easy to read and compare results
- In [www.safedor.org](http://www.safedor.org) ‘Risk Evaluation Criteria’ a table of 50 RCO and their cost effectiveness is listed
- This report has been downloaded > 25,000 times!
FSAs by SAFEDOR

- One Standardized Vulnerability Model used
  - Probabilistic Damage Stability

![Diagram of FSAs by SAFEDOR]

- Collision frequency model
- Flooding frequency model
- Survivability model
- Time to sink model
- Evacuation model
- Environmental damage model
- Consequence

Operational state (optional)

\[
\begin{align*}
P_{\text{coll}} & \quad \text{Collision frequency model} \\
P_{\text{fl|col}} & \quad \text{Flooding frequency model} \\
P_{\text{sink|fl|col}} & \quad \text{Survivability model} \\
P_{\text{tts|sink|fl|col}} & \quad \text{Time to sink model} \\
P_{\text{ed|fl|col}} & \quad \text{Evacuation model} \\
P_{\text{col}} & \quad \text{Environmental damage model} \\
A(o, c, etc) & \quad \text{Consequence} \\
C(l_s, l_c) & \quad N(t)
\end{align*}
\]
FSA – Ship Types
Individual Risk 2007 data
Individual Risk – 2007 data

Figure 3-5 Individual risk for generic ship types broken down on accident event

* Based on vessels built 1980 and later
Loss – 2007 data

Figure 3-7 Annual accident costs as fraction of new building cost

* The costs of non-serious accidents are not included.
## Individual Risk – as reported in FSA

### Individual Risk For Crew

<table>
<thead>
<tr>
<th></th>
<th>Ship Accidents</th>
<th>Personal Accident</th>
<th>Total</th>
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<tbody>
<tr>
<td>Intolerable</td>
<td></td>
<td></td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Container</td>
<td>$2.25 \times 10^{-4}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LNG</td>
<td>$1.55 \times 10^{-4}$</td>
<td>$4.90 \times 10^{-4}$</td>
<td>$6.45 \times 10^{-4}$</td>
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<tr>
<td>Tanker</td>
<td>$2.10 \times 10^{-4}$</td>
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<td></td>
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<tr>
<td>Cruise</td>
<td>$0.80 \times 10^{-4}$</td>
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<tr>
<td>RoPax</td>
<td>$0.65 \times 10^{-4}$</td>
<td></td>
<td></td>
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<tr>
<td>Negligible</td>
<td></td>
<td></td>
<td>$10^{-6}$</td>
</tr>
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</table>
Total Risk for Container Vessels

Frequency $[F]$ of $N$ or more fatalities per ship year

Number of fatalities $[N]$

- SAFEDOR
- MSC72/16
- upper ALARP boundary
- lower ALARP boundary
## GCAF and NCAF values associated with each risk control option.

<table>
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<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3 a)</td>
<td>Increased efficiency of bilge system (conventional design)</td>
<td>143.72</td>
<td>96.69</td>
</tr>
<tr>
<td>3 b)</td>
<td>Increased efficiency of bilge system (open-top design)</td>
<td>28.67</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>4 a)</td>
<td>High bilge level alarm in cargo holds (conventional design)</td>
<td>8.64</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>4 b)</td>
<td>High bilge level alarm in cargo holds (open-top design)</td>
<td>1.72</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>4 c)</td>
<td>Second bilge alarm in cargo holds (conventional design)</td>
<td>76.83</td>
<td>25.71</td>
</tr>
<tr>
<td>4 d)</td>
<td>Second bilge alarm in cargo holds (open-top design)</td>
<td>15.32</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>5</td>
<td>Improved navigator training</td>
<td>11.66</td>
<td>5.72</td>
</tr>
<tr>
<td>10 a)</td>
<td>Bow camera system (standard)</td>
<td>109.35</td>
<td>85.34</td>
</tr>
<tr>
<td>10 b)</td>
<td>Bow camera system (including night vision)</td>
<td>407.12</td>
<td>383.23</td>
</tr>
<tr>
<td>11</td>
<td>Reduced amount of undeclared dangerous goods</td>
<td>203.02</td>
<td>189.02</td>
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<td>15</td>
<td>Improved bridge design</td>
<td>5.27</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>22</td>
<td>AIS integrated with radar</td>
<td>0.22</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>25 a)</td>
<td>Additional officer on the bridge (always)</td>
<td>197.25</td>
<td>191.45</td>
</tr>
<tr>
<td>25 b)</td>
<td>Additional officer on the bridge (on demand)</td>
<td>85.47</td>
<td>79.67</td>
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<td>30</td>
<td>ECDIS</td>
<td>12.27</td>
<td>6.62</td>
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<td>31</td>
<td>Track control system</td>
<td>1.14</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>32</td>
<td>Implementation of BRM guidelines</td>
<td>9.87</td>
<td>4.07</td>
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</table>
Risk level - LNG carriers
Broken down on accident categories

- Risk level - LNG
- Collision
- Grounding
- Contact
- Fire/Explosion
- Loading/Unloading
### Risk Control Options (RCO)

<table>
<thead>
<tr>
<th>RCO description</th>
<th>GCAF</th>
<th>NCAF</th>
</tr>
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<tr>
<td>Risk based maintenance</td>
<td></td>
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<tr>
<td>- Navigational systems</td>
<td>2.2</td>
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<tr>
<td>- Steering systems</td>
<td>7.4</td>
<td>&lt;0</td>
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<tr>
<td>- Propulsion systems</td>
<td>57</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- Cargo handling systems</td>
<td>159</td>
<td>118</td>
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<tr>
<td>Strain gauges</td>
<td>394</td>
<td>351</td>
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<tr>
<td>Increased crashworthiness</td>
<td></td>
<td></td>
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<tr>
<td>- Increase double hull width</td>
<td>74</td>
<td>71</td>
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<tr>
<td>- Increase double bottom height</td>
<td>60</td>
<td>54</td>
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<tr>
<td>- Increase hull strength</td>
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<td>55</td>
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<tr>
<td>Redundant propulsion system</td>
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<td>55</td>
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<tr>
<td>Improved navigational safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ECDIS</td>
<td>3.1</td>
<td>&lt;0</td>
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<tr>
<td>- Track control system</td>
<td>0.4</td>
<td>&lt;0</td>
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<tr>
<td>- AIS integrated with radar</td>
<td>0.06</td>
<td>&lt;0</td>
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<tr>
<td>- Improved bridge design</td>
<td>2.3</td>
<td>&lt;0</td>
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<tr>
<td>Restrictions on crew schedule</td>
<td>6.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Simulator training</td>
<td>12</td>
<td>5.8</td>
</tr>
<tr>
<td>Increased fatigue design life</td>
<td>High</td>
<td>&lt;0</td>
</tr>
<tr>
<td>Thermal image scanning</td>
<td>28</td>
<td>20</td>
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<tr>
<td>Redundant radar sounding</td>
<td>236</td>
<td>232</td>
</tr>
</tbody>
</table>

- Cost-effective RCOs exist – all related to navigational safety
  - Risk based maintenance
  - ECDIS
  - Track control system
  - AIS integrated with radar
  - Improved bridge design
Current trends that may influence future safety level of LNG shipping (not analyzed):

- Lack of qualified LNG crew
- New LNG trades – e.g. cold climate
- New LNG operators
- New trading patterns – e.g. more short-term contracts
- Bigger and faster ships
- New propulsion systems – with on-board relquefaction systems
Conclusions and recommendations

- Prior perception – LNG vessels associated with high level of safety – substantiated by the FSA:
  - Risk levels within ALARP area
  - Most RCOs not cost-effective

- However, cost-effective RCOs identified
  - All related to navigational safety
  - Should be implemented to make risk ALARP
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

- Only the six (6) events that potentially lead to LOWI (Loss Of Watertight Integrity) are taken into account.
- The full risk model should include except LOWI accidents, also "machinery failures", "failures of hull fittings" and "unknown reasons."
Risk analysis of Large Tankers
Frequency assessment

<table>
<thead>
<tr>
<th>Initial event</th>
<th>Frequency of accident</th>
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<tbody>
<tr>
<td>Collision</td>
<td>1.03E-02</td>
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<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>
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<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 by incident category, Covered period 1990-2007

Frequency of incidents, Historical Data

Source: NTUA-SDL

Oil Tankers
Historical Data, Covered Period 1990-2007

Collision, 265, 32%
Contact, 96, 11%
Grounding, 193, 23%
Fire, 95, 11%
Explosion, 49, 6%
NASF, 148, 17%

Source: NTUA-SDL Tanker casualty database
Sample data: 846 Incidents
Risk analysis of Large Tankers
Risk assessment results (2)

Potential Loss of Cargo (PLC)

![Bar chart showing potential loss of cargo for different incidents and phases of operation.]

- Oil Tankers (DWT>=60000)
- Results of Risk Analysis
- Estimated Potential Loss of Cargo, in tonnes per shipyear

- Collision-Struck ship: 1.30E+01
- Contact with fixed installation: 1.09E+00
- Contact with floating object: 3.17E-01
- Powered Grounding: 1.86E+01
- Drift Grounding: 6.16E+00
- Fire Due to internal source: 2.38E+01
- Explosion-Operational phase: 1.23E+01
- NASF: 1.44E+00
Risk analysis of Large Tankers
Risk assessment results (3)

**Individual risk for crew**

A crew of 30

Fatality rate of 1.27E-02 per ship-year

Individual risk of 4.23E-04 per year.

Three *shifts of crew alternate* -> individual risk becomes 1.41E-04.

- ALARP Area
Risk analysis of Large Tankers
Risk assessment results (4)

F-N curve for tanker crew

[Graph showing F-N curve for tanker crew]
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.
## Analysis Results (1)

<table>
<thead>
<tr>
<th>RCO 3: Active Steering Gear Redundancy</th>
<th>Risk Reduction $\Delta R_g$</th>
<th>Oil Spill Reduction $\Delta R_g$</th>
<th>Cost $\Delta C$</th>
<th>Benefit $\Delta B$</th>
<th>$\frac{\Delta C}{\Delta R_g}$</th>
<th>$\frac{\Delta B}{\Delta R_g}$</th>
<th>CATS</th>
<th>Net $\frac{\Delta C - \Delta B}{\Delta R_g}$</th>
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<tr>
<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>
</tbody>
</table>

| RCO 4: ECDIS                           | N/A                         | 170                              | 75,000         | 5,667,000        | 440                           | -4,660,000,000                |

| RCO 5: Terminal Proximity & Speed Sensors | N/A                         | 4                                | 86,000         | 119,000          | N/A                           | 21,500                       | N/A |

| RCO 6: Navigational Sonar              | N/A                         | 70                               | 196,500        | 2,361,000        | 401,000,000                   | 2,800                        | -4,417,000,000               |

| RCO 8: Hot Works Procedures Training   | 1.9E-02                     | 45                               | 28,000         | 2,200,000        | 1,450,000                     | 450                          | -111,000,000                 |

| RCO 9: Double Sheathed Low Pressure Fuel Pipes | 1.4E-02                     | 154                              | 39,000         | 5,300,000        | 2,700,000                     | 250                          | -371,000,000                 |

| RCO 11: Engine Control Room Additional Emergency Exit | 4.4E-03                     | N/A                              | 13,840         | N/A              | 3,169,000                     | N/A                          | 3,169,000                    |

| RCO 12: Hall Stress & Fatigue Monitoring System | 5.3E-04                     | 4                               | 128,000        | 134,000          | 241,000,000                   | 32,000                       | -10,200,000                  |

---

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC and PLP
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>Risk Reduction ΔRg</th>
<th>Cost ΔC</th>
<th>Benefit ΔB</th>
<th>CATS = ΔC / ΔRg</th>
</tr>
</thead>
<tbody>
<tr>
<td># tonnes of oil saved</td>
<td>$75</td>
<td>$77</td>
<td>$79</td>
</tr>
<tr>
<td>RCO 7: Enhanced Cargo Tank Subdivision</td>
<td>35.25</td>
<td>1,472,602</td>
<td>2,115,000</td>
</tr>
<tr>
<td>RCO 7: Increased Double Bottom Height</td>
<td>0.5m</td>
<td>7.5</td>
<td>0.5m</td>
</tr>
<tr>
<td>1.0m</td>
<td>13.75</td>
<td>1.0m</td>
<td>547,856</td>
</tr>
<tr>
<td>RCO 7: Increased Side Tanks Width</td>
<td>0.4m</td>
<td>7.5</td>
<td>0.4m</td>
</tr>
<tr>
<td>0.8m</td>
<td>13</td>
<td>0.8m</td>
<td>471,277</td>
</tr>
</tbody>
</table>

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only

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

<table>
<thead>
<tr>
<th>Risk Reduction ΔRg</th>
<th>Cost ΔC</th>
<th>Benefit ΔB</th>
<th>CATS = ΔC / ΔRg</th>
</tr>
</thead>
<tbody>
<tr>
<td># tonnes of oil saved</td>
<td>$65</td>
<td>$67</td>
<td>$69</td>
</tr>
<tr>
<td>RCO 7: Enhanced Cargo Tank Subdivision</td>
<td>58</td>
<td>1,723,185</td>
<td>3,480,000</td>
</tr>
<tr>
<td>RCO 7: Increased Double Bottom Height</td>
<td>0.5m</td>
<td>8.75</td>
<td>0.5m</td>
</tr>
<tr>
<td>1.0m</td>
<td>17</td>
<td>1.0m</td>
<td>587,863</td>
</tr>
<tr>
<td>RCO 7: Increased Side Tanks Width</td>
<td>0.4m</td>
<td>15</td>
<td>0.4m</td>
</tr>
<tr>
<td>0.8m</td>
<td>27.25</td>
<td>0.8m</td>
<td>500,566</td>
</tr>
</tbody>
</table>

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only

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

<table>
<thead>
<tr>
<th>Risk Reduction ΔRg</th>
<th>Cost ΔC</th>
<th>Benefit ΔB</th>
<th>CATS = ΔC / ΔRg</th>
</tr>
</thead>
<tbody>
<tr>
<td># tonnes of oil saved</td>
<td>$65</td>
<td>$67</td>
<td>$69</td>
</tr>
<tr>
<td>RCO 7: Enhanced Cargo Tank Subdivision</td>
<td>62.25</td>
<td>2,731,930</td>
<td>3,375,000</td>
</tr>
<tr>
<td>RCO 7: Increased Double Bottom Height</td>
<td>0.5m</td>
<td>8.5</td>
<td>0.5m</td>
</tr>
<tr>
<td>1.0m</td>
<td>16.5</td>
<td>1.0m</td>
<td>717,984</td>
</tr>
<tr>
<td>RCO 7: Increased Side Tanks Width</td>
<td>0.4m</td>
<td>15.35</td>
<td>0.4m</td>
</tr>
<tr>
<td>0.8m</td>
<td>27.75</td>
<td>0.8m</td>
<td>618,006</td>
</tr>
</tbody>
</table>

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only

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

<table>
<thead>
<tr>
<th>Risk Reduction ΔRg</th>
<th>Cost ΔC</th>
<th>Benefit ΔB</th>
<th>CATS = ΔC / ΔRg</th>
</tr>
</thead>
<tbody>
<tr>
<td># tonnes of oil saved</td>
<td>$65</td>
<td>$67</td>
<td>$69</td>
</tr>
<tr>
<td>RCO 7: Enhanced Cargo Tank Subdivision</td>
<td>29.25</td>
<td>956,843</td>
<td>1,755,000</td>
</tr>
<tr>
<td>RCO 7: Increased Double Bottom Height</td>
<td>0.5m</td>
<td>4</td>
<td>0.5m</td>
</tr>
<tr>
<td>1.0m</td>
<td>8.25</td>
<td>1.0m</td>
<td>982,160</td>
</tr>
<tr>
<td>RCO 7: Increased Side Tanks Width</td>
<td>0.4m</td>
<td>13.25</td>
<td>0.4m</td>
</tr>
<tr>
<td>0.8m</td>
<td>24.5</td>
<td>0.8m</td>
<td>787,337</td>
</tr>
</tbody>
</table>

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only
# Recommendations

## Table 17: RCOs recommended for further consideration at IMO due to GCAF

<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>

## Table 18: RCOs recommended for further consideration at IMO due to NCAF/CATS

<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>

## Table 19: RCOs recommended for further consideration at IMO as cost not grossly disproportionate

<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 20: RCOs not recommended for further consideration at IMO

<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>
### FSA Cruise

<table>
<thead>
<tr>
<th>Ship parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>110,000 GRT</td>
</tr>
<tr>
<td>Speed</td>
<td>22 knots</td>
</tr>
<tr>
<td>Passengers</td>
<td>2,800</td>
</tr>
<tr>
<td>Crew</td>
<td>1,200</td>
</tr>
<tr>
<td>Passengers + Crew</td>
<td>4,000</td>
</tr>
<tr>
<td>Length</td>
<td>290 m</td>
</tr>
<tr>
<td>Draft</td>
<td>8.5 m</td>
</tr>
<tr>
<td>Breadth</td>
<td>36 m</td>
</tr>
</tbody>
</table>

**High level FSA – No specific ship design**

In some cases parameters are taken to represent a more specific ship-type/size etc: Post Panamax
FRA Cruise: Individual risk

Crew
- Intolerable
- ALARP
- Negligible

Individual risk crew 8.0E-6

Passengers
- Intolerable
- ALARP
- Negligible

Individual risk passengers 6.1E-6
Cruise FN

FN Cruise ships

Frequency of N or more fatalities per ship year

Fatalities [N]

INTOLERABLE
ALARP
NEGLIGIBLE

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Cruise FN

FN Cruise ships

- Collision
- Contact
- Grounding
- Fire/Expl
- Lower
- Upper

85% from catastrophic

Frequency of N fatalities or more per ship year

Fatalities [N]
### RCO 1: Increased GM
- **ΔR**: 2.10
- **Cost**: $2,350,000
- **Benefit**: $13,400,000
- **NetCAF**: $1,120,000
- **ΔC**: $-5,260,000

### RCO 2: Increased Freeboard
- **ΔR**: 2.10
- **Cost**: $2,350,000
- **Benefit**: $8,160,000
- **NetCAF**: $1,120,000
- **ΔC**: $-2,770,000

### RCO 3: Added buoyancy
- **ΔR**: 1.35
- **Cost**: $322,800,000
- **Benefit**: $286,000
- **NetCAF**: $239,100,000
- **ΔC**: $238,900,000

### RCO 27: BRM
- **ΔR**: 0.95
- **Cost**: $344,000
- **Benefit**: $540,000
- **NetCAF**: $361,000
- **ΔC**: $-205,000

### RCO 1+3: Combined Buoyancy & GM
- **ΔR**: 2.85
- **Cost**: $12,500,000
- **Benefit**: $291,000,000
- **NetCAF**: $4,390,000
- **ΔC**: $-97,800,000

### RCO 1+2+3: Combined Buoyancy, GM and Freeboard
- **ΔR**: 3.75
- **Cost**: $12,500,000
- **Benefit**: $162,000,000
- **NetCAF**: $3,340,000
- **ΔC**: $-39,900,000

---

1) Per ship per lifetime, assumed 30 years

2) Net present value, 5% interest rate, 30 years
The following risk control options were shown to be effective in this particular design study and may warrant further investigation:

- Improved bridge design (above SOLAS)
- ECDIS - Electronic Chart Display and Information System
- Increased Simulator Training for Navigators
- Improve the damage stability
RoPax – Historic Risk

Number of Fatalities N

Frequency of N or More Fatalities (per year)

NEGLIGIBLE

ALARP

INTOLERABLE

World-Wide
1994 - 2006

NW Europe
1978 - 1994
RoPax Improvement since NWE project

- Collision. 40% frequency reduction
- Grounding. 52% frequency reduction
- Impact. 74% frequency reduction
- Flooding from other causes. Unchanged.
- Fire. 17% frequency reduction
- Overall Frequency. 57% frequency reduction
RoPax – Risk Model

![Risk Model Graph]

- **NEGLIGIBLE**
- **ALARP**
- **INTOLERABLE**

The graph illustrates the frequency of N or more fatalities per year against the number of fatalities (N), categorizing risks into NEGLIGIBLE, ALARP, and INTOLERABLE levels.
General Cargo Ships

- On-going work in IACS
- Identified serious problem of underreporting
- LRFP results is not possible to believe. Need for alternative sources of data to estimate degree of reporting
Conclusions

All SAFEDOR FSAs point at measures to improve navigational safety (preventing collisions & groundings) as cost effective measures

- Electronic Chart Display and Information System
- Agreed at MSC85, for adoption at MSC86
- Supported also by other FSA studies and ENC Coverage studies: MSC78/4/2, NAV50/11/1, NAV51/10, MSC81/24/5, NAV54/14
Conclusions

FSAs on Cruise Ships and RoPax concluded that damage stability can be improved cost-effectively.

Collision risk is dominating (small probability, potentially large consequence)

Answers from new EU Project: GOAL based Damage Stability (GOALDS).
   - Project involves yards, owners, classification societies and academia (17 partners)

FSA Tanker also demonstrate cost effective ways of reducing oil outflow
   - Final conclusion depend on criteria (CATS)
Outlook

- FSA should be made mandatory for new and major revisions of instruments (need to define criteria for use)

- Flag States need to improve accident reporting to improve quality of FSA (GISIS)

- Issues of underreporting

- Occupational risk has too low priority compared to other risk to life –often left out of the analysis

- Need for incentives to carry out FSA
  - FSAs carried out in 1+ years
  - FSA review 2-3 years?
Underreporting

- Most FSAs use LRFP (Only ship accidents)
  - Fatalities (personal) > Fatalities (Ship accidents)
- Estimated 441 accidents in NOR/NIS tanker fleet
Outlook

- Standardized risk-based tools are and will be developed
- Standardization of risk models needed
  - Reuse of information, tools etc
- Risk criteria need to be maintained, preferably by IMO
CATCH – Cost of Averting a Tonne of CO₂-eq Heating effect
## References

<table>
<thead>
<tr>
<th>FSA</th>
<th>Main Submission</th>
<th>Full FSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td>MSC83/21/1</td>
<td>MSC83/INF.3</td>
</tr>
<tr>
<td>Container</td>
<td>MSC83/21/2</td>
<td>MSC83/INF.8</td>
</tr>
<tr>
<td>Crude oil Tanker</td>
<td>MEPC58/17/2</td>
<td>MEPC58/INF.2</td>
</tr>
<tr>
<td>Cruise</td>
<td>MSC85/17/1</td>
<td>MSC85/INF.2</td>
</tr>
<tr>
<td>RoPax</td>
<td>MSC85/17/2</td>
<td>MSC85/INF.3</td>
</tr>
</tbody>
</table>

Other FSA reports at [http://research.dnv.com/skj/](http://research.dnv.com/skj/)
www.dnv.com