PASSENGER SHIP SAFETY: EFFECTIVE VOYAGE PLANNING FOR PASSENGER SHIPS

FSA - Large Passenger Ships - Navigational Safety

Submitted by Norway

SUMMARY

Executive summary: This document reports on the Norwegian FSA study on Navigational Safety of Large Passenger Ships

Action to be taken: Paragraph 6

Related documents: NAV 49/INF.2, MSC 72/21, MSC 72/16, MSC 78/4/2, NAV 50/11/1, MSC/Circ.1023/MEPC/Circ.392 and SLF 47/17

1 When the Secretary-General initiated the work on Large Passenger Ship Safety at MSC 72 in May 2000, it was emphasized that a holistic approach should be chosen and that potential measures should focus on the prevention of accidents from happening in the first place.

2 As stated on previous occasions, Norway would have preferred that a broad study to identify and evaluate potential risk reducing measures in a holistic way was carried out. However, this was not the view of the majority of the member States. The second best option, in our opinion, is to conduct part analysis on important areas of the construction and operation of large passenger ships which, to some extent, can replace the broad analysis in providing a decision-making platform.

3 Following up on this second option, with focus on prevention of accidents, Norway decided to undertake an FSA-study on navigational safety of large passenger ships. Navigational safety was chosen due to the fact that relevant statistics show that collision and grounding account for a substantial part of the losses due to ship accidents.

4 Trying to identify measures to reduce the frequency of collisions and groundings is, in our opinion, important in order to increase the overall safety of large passenger ships in a cost-effective way. It should be noted that in documenting the cost efficiency of the different risk control options, it is assumed that required index R for the ships in question is 0.90. If the required index is kept on today’s level, or somewhere in between these two figures, all the risk control options will be even more cost-effective.
In section D.5 of the attached annex, Step 5 – “Recommendations”, the following risk control options have been documented to be cost effective and representing a considerable potential for reducing the frequency of collision and grounding:

.1 ECDIS (Electronic Chart Display and Information System)
.2 TCS (Track Control System)
.3 AIS (Automatic Identification System) integration with radar
.4 Improved bridge design
.5 Improved navigator training.

In addition, the following risk control options are cost efficient, but with limited risk reduction effects:

.1 Automatic logging of information
.2 Implementation of guidelines for BRM
.3 Improved navigation system reliability.

All but the last of the recommended risk control options have net economic benefits. This implies that the reduction in economic consequence exceeds the investment. Viewed this way, the safety benefits are additional benefits.

All recommendations can also be made based on safety considerations alone, as the gross cost of averting a fatality (GCAF) is lower than the decision criteria used for safety interventions.

An abridged version of the full FSA report is attached in the annex. All RCOs are described in appendix II to the annex.

Action requested of the Sub-Committee

The Sub-Committee is invited to consider the information provided and take action as appropriate.

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ANNEX

FORMAL SAFETY ASSESSMENT
OF CRUISE SHIP NAVIGATION
A Summary

A full Formal Safety Assessment (FSA) is performed to assess risk control options (RCOs) for cruise navigation, and the methodology, results and conclusions are presented in this report.

The basis for the recommendations given in this study is the following:

- An RCO is considered cost-effective if the GrossCAF (Cost of Averting a Fatality) is less than $3M. This is the value used in all decisions made following the FSA studies submitted under agenda item 5, Bulk Carrier Safety, at MSC 76, December 2002 and suggested in MSC 72/16.

- Accident avoidance is important as the consequences of navigational errors can be catastrophic.

- One single catastrophic accident may damage the reputation of the whole cruise industry.

- It is of outmost importance to control both the likelihood of occurrence and the consequences; however, this study focuses on measures for avoiding accidents, not mitigating the consequences of accidents.

- As cost effectiveness is used as the decision criterion, it is implicitly assumed that large passenger ship risks are in the ALARP (As Low As Reasonably Practicable) area. As total risks are not estimated in this report, this assumption has not been verified.

- It has been demonstrated by the HARDER project, that large passenger ships has somewhat poorer damage survivability than smaller passenger ships, whilst the opposite effect would be expected in practice and as a requirement. In SLF 6/INF.5 it is suggested to require a damage survivability of 0.9. This represents the probability of surviving a collision resulting in water ingress. In this analysis it has been assumed that this requirement is enforced. If a less strict requirement is enforced, more preventive measures may become cost effective.

- Recent development within IMO indicates that a required damage survivability of 0.8 will most likely be enforced. The effect of this on the cost-effectiveness assessment of the RCOs has been considered, and even though new calculations have not been carried out, the conclusions and hence the recommendations are somewhat modified.

To avoid collisions and groundings, this study demonstrates that the following RCOs are providing considerable improved cruise navigation safety in a cost-effective manner:

- ECDIS (Electronic Chart Display and Information System)
- Track control
- AIS (Automatic Identification System) integration with radar
- Improved bridge design
- Improved navigator training.
These five cost-effective RCOs with significant potential to reduce loss of lives are strongly recommended as IMO requirements. Some of these RCOs are already implemented on most cruise vessels. The measures are not, however, required by IMO. The cost benefit assessment is based on the introduction of one RCO at a time.

Some other RCOs were also concluded cost effective. However, both their costs and their contribution to saving lives are rather small:

- Automatic logging of information
- Implementation of guidelines for BRM
- Improved navigation system reliability.

Furthermore, the following RCOs have been evaluated.

- Onboard Safety and Security Centre
- Two officers on the bridge.

Given a required index $R=0.9$, those RCO’s shown not to be cost-effective. However, according to the recommendation from the SLF-sub-committee, the new required index $R$ for large passenger ships will be lower than 0.9, hence more scrutiny is needed in order to conclude whether they are cost-effective or not.

The possible lack of cost-effectiveness for these two RCOs is a result of large implementation costs; their contributions to improving safety are significant. Especially the Onboard Safety & Security Centre has high costs as the operation of such a centre would require additional space onboard and one additional officer on watch, which would be expensive. However, if the vessel already is planning to install a Security Centre to follow up security issues, the marginal cost of this RCO may be significantly reduced.

## B Background information

Statistics and experience indicate that collision, contact and grounding are important accident scenarios both with respect to accident frequency, severity and claim costs. About 50% of all serious accidents with cruise vessels are related to navigation. The risk related to navigation therefore needs a special focus when considering the safety on cruise vessels.

This was the background for a planning a joint industry project involving Det Norske Veritas, The Norwegian Maritime Directorate, Kongsberg Maritime and The Norwegian Shipowners’ Association using the IMO Formal Safety Assessment (FSA) methodology. The FSA methodology is illustrated in Figure 1.

In the period 1990 to 2001, 86 serious accident entries have been reported and registered in the Lloyd’s Register/Fairplay’s accident database for cruise vessels above 4,000 GT.
Table 1: Annual property damage frequency for cruise vessels

<table>
<thead>
<tr>
<th>Accident type</th>
<th>Serious casualty (excl. total loss)</th>
<th>Total loss</th>
<th>All incidents*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>4.5E-03</td>
<td>3.4E-04</td>
<td>4.9E-03</td>
</tr>
<tr>
<td>Contact</td>
<td>3.2E-03</td>
<td></td>
<td>3.2E-03</td>
</tr>
<tr>
<td>Foundering</td>
<td>1.4E-03</td>
<td>1.4E-03</td>
<td>1.4E-03</td>
</tr>
<tr>
<td>Fire/explosion</td>
<td>8.8E-03</td>
<td>2.4E-03</td>
<td>1.1E-02</td>
</tr>
<tr>
<td>Hull/Machinery/Equipment</td>
<td>7.2E-03</td>
<td></td>
<td>7.2E-03</td>
</tr>
<tr>
<td>War loss/Hostilities</td>
<td>0.0E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrecked/Stranded</td>
<td>9.1E-03</td>
<td>6.8E-04</td>
<td>9.7E-03</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.0E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3.3E-02</td>
<td>4.8E-03</td>
<td>3.8E-02</td>
</tr>
</tbody>
</table>

* Non-serious incidents have not been reported to LRFP for Cruise Vessels

Figure 1: The five steps of FSA

B.1 Objective and scope of work

The objective of the FSA of cruise navigation is to:

Identify risk control options to be implemented for large passenger ships, related to safe navigation
This project consisted of the following activities:

**STEP 1: HAZARD IDENTIFICATION**
- Hazard identification have been carried out and provided input to the risk assessment (NAV 49/INF.2).

**STEP 2: RISK ANALYSIS**
- Risk screening – identification of available statistics and the accidents that have happened. This information serves as input to the risk modelling. Some relevant accident cases have also been further studied to reveal causes of the accidents.
- Risk assessment - Design risk models that quantify failure probabilities and consequence of grounding and collision for cruise operations. The models include human factors, technical factors, geographical and other external factors, chosen with the aim to reflect important risk contributors and to be able to evaluate the effect of RCOs. The models are designed by use of Bayesian network technique.

**STEP 3: RISK CONTROL OPTIONS**
- Identification of risk control options – based on the HAZID, risk modelling and expert input, 11 risk control options were identified and described.

**STEP 4: COST BENEFIT ASSESSMENT**
- Each of the identified RCOs has been evaluated through a cost benefit assessment, indicating their cost effectiveness by Gross Cost of Averting a Fatality (GrossCAF) and Net Cost of Averting a Fatality (NetCAF).

**STEP 5: RECOMMENDATIONS FOR DECISION MAKING**
- Recommendations are included at the end of this annex.

### B.2 Limitations

The FSA concentrates on risk to personnel, not on environmental or property risk.

The models are intended to represent large cruise vessels only, i.e. carrying more than some 2,000 passengers. The project focuses on frequency reduction, i.e. accident avoidance, and is not intended to cover recommendations for consequence reduction.

Historically, few accidents have occurred with cruise vessels. Statistics have been used to coarsely calibrate the results from the modelling, however, statistics are not considered to be the correct answer. The observation that there is no record of a certain type of accidents in the database does not necessarily mean that the certain event can not happen. The result from the modelling is therefore the best estimate on what is the actual risk level for collision and grounding of cruise vessels.

The personnel risk includes only fatalities on own vessel, i.e. the cruise vessel, and not fatalities at the other vessel in case of collision. A cruise vessel may also pose risk to others in the event of collision. Therefore, accidents at e.g. leisure crafts are not included in the study, as they represent a negligible hazard for cruise vessels.
B.3 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS</td>
<td>Automatic Identification System</td>
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<tr>
<td>ARPA</td>
<td>Automatic Radar Plotting Aid</td>
</tr>
<tr>
<td>BRM</td>
<td>Bridge Resource Management</td>
</tr>
<tr>
<td>ECDIS</td>
<td>Electronic Chart Display and Information System</td>
</tr>
<tr>
<td>ELB</td>
<td>Electronic Log Book</td>
</tr>
<tr>
<td>GrossCAF</td>
<td>Gross Cost of Averting a Fatality</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>FSA</td>
<td>Formal Safety Assessment</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GT</td>
<td>Gross Ton</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>LRFP</td>
<td>Lloyd’s Register/Fairplay</td>
</tr>
<tr>
<td>NetCAF</td>
<td>Net Cost of Averting a Fatality</td>
</tr>
<tr>
<td>OOW</td>
<td>Officer on Watch</td>
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<tr>
<td>RCO</td>
<td>Risk Control Option</td>
</tr>
<tr>
<td>ROT</td>
<td>Rate of Turn</td>
</tr>
<tr>
<td>SOLAS</td>
<td>Safety of Life at Sea</td>
</tr>
<tr>
<td>STCW</td>
<td>Standards of Training, Certification and Watchkeeping for seafarers</td>
</tr>
<tr>
<td>VTS</td>
<td>Vessel Traffic Service</td>
</tr>
</tbody>
</table>

C Method of work

The 5 step FSA methodology used in the study is briefly described in section B above.

The main work in the project has been carried out by risk analysts. The work with the risk assessment and the cost effectiveness assessment was done consecutively. This approach has the advantage that the risk models were reviewed in detail when the cost effectiveness assessment was carried out (repetitive use of the models).

The risk model is based on Bayesian theory and network models were made for the accident scenarios collision and powered grounding. A team of risk analysts developed the models, and the result was reviewed by navigational experts.

The cost estimation has been done primarily by contacting suppliers of navigational equipment, training centres, yards and ship owners. This is necessary to be able to estimate all relevant costs for equipment, installation, maintenance, replacement, training, etc.

There have been four major meetings during the project: The HAZID Meeting, and three expert workshops in relation to quantification of important probabilities in the risk models. In addition, a brainstorming meeting for identifying/agreeing on which risk control options to be analysed has been arranged. Furthermore, navigation experts have been involved during the whole project, and also other relevant personnel have been conferred with when found necessary.

The project started in January 2003 and was finished in October 2003.
D  Description of the results achieved in each step

D.1  STEP 1 – Hazard Identification

The results from the HAZID have already been submitted to IMO and can be found in NAV 49/INF.2.

D.2  STEP 2 – Risk Analysis

First, a risk screening of the historic risk level for cruise vessels was carried out, (see Annex I of the full FSA report). The objective of this work is to present the generic risk related to navigation of cruise vessels based on as much information as possible from available historic data. This provides the necessary foundation for focusing the risk assessment, and to concentrate the effort on effective RCOs.

There are two ways to quantify risk, through statistics and through models. The disadvantage of using statistics is that statistics will only represent the past, and not take into account recent developments or new requirements. Risk modelling is the proactive approach, where risks are assessed before the accident take place.

The modern vessels are less likely to ground or collide due to technical failure than older, conventional vessels are. This will again put more focus on human and organizational factors in general, and the navigators’ attention, competence and performance in particular. The importance of human elements can be well reflected in a model, however, difficult to reveal through statistics. Due to the above, risk models for collision and powered grounding were established, see appendix I of this annex for an overview or Annex II of the full FSA report for a detailed description.

The most valuable output from a risk model is not the overall risk level that are predicted by the model, but the structure itself and all the contributing factors that enables an understanding of the failure mechanisms and gives a quantified result whenever one of the input parameters is altered. Bayesian reliability theory and Bayesian networks were assessed to be ideal for this purpose.

It is quite easy to present an opinion on risk; the challenge is to quantify and document the basis for a risk prediction. In the work process to establish probabilistic input to the models, various experts and data sources were used to ensure a solid foundation for the dependencies and figures entered into the model. Statistical data were used where available. If statistical data were not available, experts were interviewed or directly involved in the modelling process.

The failure mechanisms for grounding and collisions are quite similar, and the accident models have most of the structure and nodes (contributors) in common. The results from the grounding and collision model when using input that are representative for large cruise vessels world wide are presented in Table 2 and Table 3. Note that pr nm in the tables refer to total nautical miles sailed for all passengers, i.e. the distance sailed multiplied by number of passengers.
The predicted accident frequencies are somewhat lower than the figures in the accident statistics. This is reasonable due to the fact that the statistics show a continuously declining accident trend. The main reasons are the improved vessel manoeuvrability and modern navigational equipment, which will ensure reduced accident frequency. However, the poor damage stability makes the cruise vessel vulnerable to hull damage, and therefore the consequences of both collision and grounding are considered to be severe. This is taken into account in the risk model.

The model results show that powered grounding represents 40% higher risk for loss of lives than collision. This is due to a higher accident frequency for grounding than for collision. Due to the high proportion of non-serious groundings, a collision is nine times as dangerous for people onboard compared to a grounding accident (Compare third line of Table 2 with third line in Table 3.)

In order to convert the fatality rates in the table [pr nm] to the more commonly used [per person year] or [per ship year], the following average exposure is assumed: 7.5E+4 nm per person year and 1.5E+08 nm per shipyear. This is based on a typical cruise trade of 1,500 nm, an average of 50 trades per year and an average of 2,000 people on board for each trade.

No fatal grounding accidents have occurred so far for cruise vessels according to the available statistics. However, the individual risk in this model shows a fatality frequency of 2.2E-05 per person year, i.e. with 2,000 people on board, this means a fatality frequency of 4.4E-02 per ship year (1 fatality every 23 years per ship). The model also shows that the potential risk for a catastrophic grounding accident with more than 100 people killed is 2.4E-04 per ship year, i.e. every 3,900 years per vessel in the fleet.

The corresponding figure for collision is an individual risk of 1.6E-05 per person year, which is in the same order of magnitude as what the statistics show. A vessel in a typical trade with 2,000 people on board has then a fatality frequency of 3.1E-02 per ship year due to collision (1 fatality every 32 years per ship). The potential risk for a catastrophic collision accident
(i.e. more than 100 fatalities) is $3.9E-05$ per ship year, i.e. every 25,000 years per vessel in the fleet.

The most important learning from the project is the understanding of the relation between the influencing factors that contribute to grounding and collision. The most important use of the models will be as a tool to evaluate the effect of risk control options or new regulations. The models will thus be used in subsequent steps of the FSA, which is the cost-benefit analysis of identified risk control options.

**D.3 STEP 3 – Identification of Risk Control Options**

The descriptions of the major hazards and corresponding risk control options from the hazard identification and the risk assessment were summarized and presented to navigational experts, as well as to a group of ship operators and the Norwegian steering committee for the FSA project. The list of RCOs was discussed and prioritized in each of these forums. This resulted in the following list of RCOs:

**RCOs to reduce the distraction level for the navigators**
- Onboard Safety and Security Center
- Automatic logging of information
- Two officers on the bridge

**RCOs to liberate more time to observations**
- Electronic Chart Display and Information System (ECDIS)
- Automatic Identification System (AIS)
  - Integration with ARPA radar
- Track Control

**RCOs for improved human performance**
- Improved bridge design
  - user interface
  - the design of the work station (ergonomic conditions)
  - bridge layout
- Improved navigator training
  - Simulator training
- Implementation of guidelines for Bridge Resource Management (BRM)

**RCOs for improved technical performance**
- Navigation system reliability

The focus has been kept on identifying RCOs for future cruise ships that are expected to be larger than most vessels today. It was decided that these RCOs were to be assessed by cost benefit assessment. The RCOs are thoroughly described in appendix II of this annex.

**D.4 STEP 4 – Cost Benefit Assessment**

The objective for the cost benefit assessment is to evaluate the cost effectiveness of implementing the suggested risk control options. The aim of performing such an analysis is to establish a list of recommendations on cost effective risk control options that will reduce the
frequency of incidences and accidents on large cruise vessels as a result of navigational errors. Step 4 is described in further detail in appendix III of this annex.

As a basis for the cost benefit calculations, the following important assumptions are made:

- The total number of persons onboard: 5,000
- The average lifetime of the cruise vessel: 30 years

The GrossCAF and NetCAF values are presented in Table 4.

<table>
<thead>
<tr>
<th>No</th>
<th>Risk Control Option</th>
<th>Gross CAF [$]</th>
<th>NetCAF [$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Onboard Safety and Security Centre</td>
<td>$9,200,000</td>
<td>$7,200,000</td>
</tr>
<tr>
<td>2</td>
<td>Automatic logging of information&lt;br&gt;(Electronic logbook)</td>
<td>$2,000,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>3</td>
<td>Two officers on the bridge</td>
<td>$9,400,000</td>
<td>$7,600,000</td>
</tr>
<tr>
<td>4a</td>
<td>ECDIS</td>
<td>$2,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>4b</td>
<td>ECDIS (no track control)</td>
<td>$3,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>5</td>
<td>AIS integration with radar</td>
<td>$5,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>6</td>
<td>Track control system</td>
<td>$1,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>7a</td>
<td>Improved bridge design (above SOLAS)</td>
<td>$340,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>7b</td>
<td>Improved bridge design (above average)</td>
<td>$350,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>8</td>
<td>Improved Navigator Training</td>
<td>$350,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>9</td>
<td>Implementation of guidelines for BRM&lt;br&gt;(Bridge Resource Management)</td>
<td>$870,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>10</td>
<td>Navigation system reliability</td>
<td>$7,100,000</td>
<td>$4,800,000</td>
</tr>
</tbody>
</table>

All numbers are based on introduction of one RCO at the time only. Introduction of one RCO will lead to higher NetCAF/GrossCAFs for all other RCOs as the remaining risk is less.

The results show that RCO1 Onboard Safety and Security Centre, RCO3 Two officers on the bridge and RCO10 Navigation System Reliability have high values for both GrossCAF and NetCAF compared to the other RCOs. The GrossCAFs are above $7M and NetCAFs above $4.8M. All other RCOs have GrossCAF below $3M and negative NetCAFs.

A negative NetCAF indicates that the RCO is economically beneficial in itself, i.e. the costs of implementing the RCO is less than the economical benefit of implementing it due to the monetary gain of the risk reduction. Life saving would represent an additional benefit. Such RCOs should therefore be implemented. The economical benefit is in this assessment only measured in terms of reduced accident costs. Other economical benefits, e.g. fewer business interruptions, are not considered. If all benefits were included, this would make the RCOs more cost-effective. The results presented therefore seem to be robust.

Some of these RCOs are already implemented on most cruise vessels. For example, RCO4 ECDIS (Electronic Chart Display and Information System) is installed on practically every vessel in the cruise fleet and proves in this assessment to be very cost effective. This measure is not, however, a requirement in SOLAS.
In addition, **RCO5 AIS integration with radar** and **RCO6 Track control** are among the most cost effective measures in this evaluation. Both the GrossCAF and the NetCAF values are low. **RCO7 Improved bridge design** and **RCO8 Improved navigator training** are also areas for improvement, and the assessment indicates high cost-effectiveness.

It is also noted that if a required index of \( R = 0.8 \) were assumed in the cost-effectiveness assessment, **RCO10 Navigation System Reliability** would most probably prove to be cost effective (although with limited risk reduction effect). Furthermore, GrossCAF and NetCAF values for **RCO1 Onboard Safety and Security Centre** and **RCO3 Two officers on the bridge** would be significantly reduced.

### D.5 STEP 5 – Recommendations

As basis for the recommendations it is observed that:

- An RCO is considered cost-effective if the GrossCAF (Cost of Averting a Fatality) is less than $3M. This is the value used in all decisions made following the FSA studies submitted under agenda item 5, Bulk Carrier Safety, at MSC 76, December 2002 and suggested in MSC 72/16.

- Accident avoidance is important as the consequences of navigational errors can be catastrophic.

- It is of utmost importance to control both the likelihood of occurrence and the consequences; however, this study focuses on measures for avoiding accidents, not mitigating accidents.

- As cost effectiveness is used as the decision criterion, it is implicitly assumed that large passenger ship risks are in the ALARP (As Low As Reasonably Practicable) area. As total risks are not estimated in this report, this assumption has not been verified.

- It has been demonstrated by the HARDER project, that large passenger ships has somewhat poorer damage survivability than smaller passenger ships, whilst the opposite effect would be expected in practice and as a requirement. In SLF 46/INF.5 it is suggested to require a damage survivability of 0.9. This represents the probability of surviving a collision resulting in water ingress. In this analysis it has been assumed that this requirement is enforced. If a less strict requirement is enforced, more preventive measures may become cost effective.

- Recent development within IMO indicates that a required damage survivability of 0.8 will most likely be enforced. The effect of this on the cost-effectiveness assessment of the RCOs has been considered, and even though new calculations have not been carried out, the conclusions and hence the recommendations are somewhat modified.

To avoid collision and grounding, this study demonstrates that the following RCOs are providing considerable improved cruise navigation safety in a cost-effective manner (see appendix III of this annex for a detailed description):
• ECDIS
• Track control
• AIS integration with radar
• Improved bridge design
• Improved navigator training.

These five cost-effective RCOs with significant potential to reduce loss of lives are strongly recommended as IMO requirements. Some of these RCOs are already implemented on most cruise vessels. The measures are not, however, required by IMO. The cost benefit assessment is based on introduction of one RCO at a time only. However, the conclusions are robust in any case.

Some other RCOs were also concluded cost effective. However, both their costs and their contribution to saving lives are rather small:

• Automatic logging of information
• Implementation of guidelines for BRM
• Improved navigation system reliability.

Furthermore, the following RCOs have been evaluated:

• Onboard Safety and Security Centre
• Two officers on the bridge

Given a required index R = 0.9, those RCO’s shown not to be cost-effective. However, according to the recommendation from the SLF Sub-Committee, the new required index R for large passenger ships will be lower than 0.9, hence more scrutiny is needed in order to conclude whether they are cost-effective or not:

The possible lack of cost-effectiveness for these two is a result of large implementation costs; their contributions to improving safety are significant. Especially the Onboard Safety & Security Centre has high costs as the operation of such a centre would require additional space onboard and one additional officer on watch. This is expensive; however, if the vessel already is planning to install a Security Centre to follow up security issues, the marginal cost of this RCO may be significantly reduced.
APPENDIX I – The risk models

I.1 General

The accident scenarios collision and grounding have been modelled. Because the available statistical foundation is weak for cruise ships, relying on accident statistics is not possible. Statistics represent events in the past and may exclude severe scenarios that have not yet happened, especially if the data foundation is poor. In addition, the quality and sensitivity of the results are quite dependent on the extent of data. If accident statistics only are including few cases representing an accident scenario, one additional serious accident can dramatically change the results. For cruise vessels, the statistical foundation is limited compared to most other vessel types, due to relatively small fleet.

When modelling a scenario, all important parameters that influence the frequency and the consequence of the event are included, regardless of whether similar accidents have happened. This cause analysis enables an effective evaluation of introducing risk control options (RCOs).

The model is based on the need to be able to analyse and evaluate the effect of RCOs, both those that are already implemented and those that will be implemented shortly. The models are, however, not intended to cover RCOs for consequence reduction.

I.2 Trade and waters sailed by cruise ships

The cruise industry is dominated by some specific trades. To be able to estimate the frequency of critical situations, i.e. exposure to grounding and collisions, the characteristics and the traffic intensity of the generic cruise routes were identified. A generic route is a cruise route representative for the different cruise routes in the trade.

The cruise trades were divided into five main trades based on market information and expert judgement. Further, the passage was divided into three water types: Open waters, Coastal waters and Narrow waters. This division was done by expert judgements. The results are given in Table 5.

<table>
<thead>
<tr>
<th>Trading area</th>
<th>Percentage of cruise ships in trade</th>
<th>Type of water [% of time]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Open</td>
</tr>
<tr>
<td>Caribbean</td>
<td>55%</td>
<td>70%</td>
</tr>
<tr>
<td>Alaska/Canada</td>
<td>13%</td>
<td>10%</td>
</tr>
<tr>
<td>Europe</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Asia</td>
<td>15%</td>
<td>70%</td>
</tr>
<tr>
<td>Other</td>
<td>7%</td>
<td>70%</td>
</tr>
</tbody>
</table>

The types of waters are defined as:

- Open waters: No obstacles within 5 nautical miles in all directions
- Coastal waters: No obstacles within 2 nautical miles in all directions
- Narrow waters: No obstacles within 0.5 nautical miles in any direction.
The division into water types enable a calculation of the frequency of critical courses towards shore and the number of collision courses a cruise vessel is likely to encounter, e.g. a cruise vessel will have more critical courses in coastal waters and a meeting situation in narrow waters is more likely to give a collision course than a meeting situation in open waters.

I.3 The grounding scenario

It is distinguished between powered grounding and drift grounding, defined as follows:

- **Powered grounding** – An event in which grounding occurs because a vessel proceeds down an unsafe track, even though it is able to follow a safe track, due to errors related to human or technical failure.
- **Drift grounding** – An event in which grounding occurs because the vessel is unable to follow a safe track due to mechanical failure, adverse environmental conditions, anchor failure, and assistance failure.

Only powered grounding is considered to be navigation related. Drift grounding is therefore not considered in this study. ‘Grounding’ in this study is thus equivalent to ‘Powered grounding’.

Figure 2 gives a brief overview of the risk model developed by Bayesian network for grounding. The nodes are only illustrative and are not the nodes used in the actual model, which has a far higher level of detail. The full model is enclosed in Appendix A of Annex II of the full FSA report.

![Figure 2: Overview of Bayesian grounding model](image)

Briefly explained, the left side of the figure illustrates the level of grounding risk that the vessel is exposed to, while the right side indicates how well the ship handles this risk. The lower part of the diagram illustrates the consequences.
The left side of the figure (‘Course towards shore’) is the frequency of critical situations where loss of control is critical and grounding may happen. The number of courses towards shore is modelled in Excel. The Excel model contains five scenarios that may lead to grounding:

1. Course towards shore, supposed to change course - does not turn
2. Course along shore, not supposed to change course - turns towards shore
3. Course along shore, drift-off, should correct course - does not correct course
4. Wrong position, should steer away from object - does not steer away
5. Meeting/crossing traffic, supposed to give way - gives way, steers towards shore

The five scenarios are illustrated in Figure 3.

Figure 3: The five grounding scenarios

The frequencies of “course towards shore” for each of the five scenarios were estimated based on expert judgement. The trades described in section I.2 of this appendix were used as basis to estimate an overall frequency for a generic trade.

The right side of the network in Figure 2 illustrates that there are many factors influencing that the vessel loses control. Experience and statistics show that human failures are more important to powered grounding than technical performance; a typically ratio between human and technical failures resulting in accidents is 80%-20%. The navigators’ main tasks are to:

- **Perceive** the situation correctly and collect all necessary information;
- **Assess** of the perceived information, *make decisions* and give orders;
- **Act** in the form of navigational courses or changes in speed;
- **Quality assure** to ensure correct decision and/or executed action.

The ability to perform the tasks with high attention and under an acceptable stress level is influenced by several factors:

- Management factors – training of personnel, planning routines, checklists before start-up, evacuation drills, etc.
- Working conditions:
  - Internal: hours on watch, responsibilities, bridge design, distraction level, etc.
  - External: weather, visibility, marking of lane, day/night, etc.
Personal factors - the physical and mental state of the officer on watch (tired, stress level, intoxicated, etc.)

If the OOW is not able to react or has not discovered the dangerous course, it is taken into account in the model that there may be some sort of vigilance onboard the vessel (e.g. OOW No.2 or pilot) or externally (VTS). Also the technical performance of the ship is important in order to avoid grounding. However, loss of propulsion resulting in drift grounding is not considered in this project. Failure of steering is, however, modelled as this is necessary to avoid the danger. Both human and technical performance is influenced by the company’s safety culture, i.e. how well the vessel operating company deals with safety issues and how well the company promotes a good safety mindset among its employees.

The combination of a critical course and no avoiding action (human or technical) is represented as the vessel has lost control. Grounding is then the result. The degree of severity in vessel damage and internal and external circumstances will influence the probability of fatality per person on board, i.e. individual risk.

Due to the complexity and the extent of the model, the model is not included in full. The complete model may be found in Appendix A to Annex II of the full FSA report where also the probability input to the grounding network is included. The nodes from the grounding network are described in Appendix C and the Excel model describing the exposure is included in Appendix D of Annex II of the full FSA report.

I.4 The collision scenario

Collision is in this study defined as one vessel hitting another vessel. Navigational or technical failures, which cause loss of control on one of the vessels, will cause collision if the other vessel is not able to prevent the collision. The two vessels are addressed as own vessel and other vessel. Figure 4 gives an overview of the risk model developed in the Bayesian network for collision.

Collision is based on the same model as grounding, taking into account the following differences:

- collision with an object that moves
- the object’s exact position can not be planned on beforehand
- collision is with an object that can react to the situation
- unpredictable reactions from other object are possible.
The modelling of loss of control of the vessel is more or less the same as for grounding, except that interaction with the other vessel (give-way rules and practices, communication, etc.) is included.

The number of collision courses is modelled in Excel. As for the grounding scenario, the five cruise trades were used as basis with a generic route. For each trade, the traffic intensity was estimated based on data from the AMVER database. The types of waters were divided in three categories; open waters, coastal waters or narrow waters as explained in section I.2. The geometric frequency of collision courses is calculated by taking into account the type of waters, the traffic intensity and the vessel dimensions and speeds. Three collision scenarios were included in the model:

- Collision with meeting vessels
- Collision with crossing vessels
- Collision with overtaking vessels.

The cruise vessel is “our” vessel and the “other” vessel is modelled as any other merchant vessel, including passenger and fishing vessels. Leisure crafts are not included. It is assumed that damage to hull structure or injuries to crew or passengers for cruise ships colliding with recreations crafts are negligible.
Due to the complexity and the extent of the model, the model is not included in full. The complete model may be found in Appendix B of Annex II of the full FSA report where also the probability input to the grounding network is included. The nodes from the collision network are described in Appendix C and the Excel model describing the exposure is included in Appendix D of Annex II of the full FSA report.

### I.5 Results – Grounding

The results from the grounding model when using input that are representative for large cruise vessels world wide are presented in Table 6 below.

<table>
<thead>
<tr>
<th>Risk results</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability for powered grounding given course towards shore</td>
<td>1.3E-05</td>
</tr>
<tr>
<td>Fatality rate per person given course towards shore</td>
<td>7.9E-09</td>
</tr>
<tr>
<td>Fatality rate per person given grounding</td>
<td>6.1E-04</td>
</tr>
<tr>
<td>Number of courses towards shore per nautical mile</td>
<td>3.6E-02</td>
</tr>
<tr>
<td>Frequency for grounding per nautical mile</td>
<td>4.7E-07</td>
</tr>
<tr>
<td>Frequency for fatalities per nautical mile</td>
<td>2.8E-10</td>
</tr>
</tbody>
</table>

Directly compared with accident statistics the modelling results for accident frequencies are a factor of 3.5 higher. This is due to the fact that only serious accidents are reported to Lloyd’s/Fairplay’s accident database, while the risk model includes all grounding events. The risk model shows that 89% of the events have consequences ‘No/minor’, 10% is ‘Major’ and 1% is ‘Catastrophic’. Many of the ‘No/minor’ accidents are not severe enough to be reported to the database. Hitting sand banks is a common problem, e.g. in Caribbean, but rarely causing damage to the vessel.

Due to the high proportion of minor accidents, which would not be included in the accident statistics, the total accident frequencies estimated from the model are believed to be lower than the statistics. This is reasonable due to the fact that the statistics are based on history, which demonstrates a declining accident trend the last years. Taking into account the increasing standard of navigational equipment and new grounding avoidance systems entering the industry, it is expected that the grounding frequencies are in fact well below the accident statistics.

However, the poor damage stability makes the cruise vessel vulnerable to hull damage, and therefore the consequences of both grounding and collision are considered to be severe. This is taken into account in the risk model, mainly based on data from SLF 46/INF.5 and other reports. The individual risk in this model shows a frequency of 2.8E-10 per nm, i.e. 2.2E-05 per person year with a typical weekly trade of 1500 nm. This means that a cruise vessel trading with 2,000 people on board has a fatality frequency of 4.4E-02 per ship year due to grounding (1 fatality every 23 years).

The model shows that the potential risk for a catastrophic grounding accident with more than 100 people killed is 2.4E-04 per ship year, i.e. every 3,900 years per vessel in the fleet.
I.6 Results – Collision

The results from the collision model when using input that are representative for large cruise vessels world wide are presented in Table 7.

<table>
<thead>
<tr>
<th>Risk results</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability for collision given collision course</td>
<td>8.6E-06 [pr critical course]</td>
</tr>
<tr>
<td>Fatality rate per person given collision course</td>
<td>4.6E-08 [pr critical course]</td>
</tr>
<tr>
<td>Fatality rate per person given collision</td>
<td>5.4E-03 [pr collision event]</td>
</tr>
<tr>
<td>Number of collision courses per nautical mile</td>
<td>4.4E-03 [pr nm]</td>
</tr>
<tr>
<td>Frequency for collision per nautical mile</td>
<td>3.8E-08 [pr nm]</td>
</tr>
<tr>
<td>Frequency for fatalities per nautical mile</td>
<td>2.0E-10 [pr nm]</td>
</tr>
</tbody>
</table>

Compared with accident statistics the collision frequencies are about 30% lower. The risk model shows that 60% of the events have consequences ‘No/minor’, 39% is ‘Major’ and 1% is ‘Catastrophic’. However, only serious accidents are reported to Lloyd’s/Fairplay’s accident database, while the risk model includes all collision events. Many of these accidents are not severe enough to be reported to the database. However as earlier mentioned, the statistics are based on history, which demonstrates a declining accident trend the last years. Taking into account the increasing standard of navigational equipment and new collision avoidance systems entering the industry, it is expected, as for the grounding scenario, that the collision frequencies are well below the accident statistics.

The statistics shows an individual fatality frequency of 1.9E-05 per person year. Assuming a typical weekly trade of 1500 nm, the individual risk in this model shows a frequency of 1.6E-05 per person year. This means that a cruise vessel having a typical trade with 2,000 people on board has a fatality frequency of 3.1E-02 per ship year due to collision (1 fatality every 32 years).

The model shows that the potential risk for a catastrophic collision accident with more than 100 people killed is 3.9E-05 per ship year, i.e. every 25,000 years per vessel in the fleet.

The model results show that powered grounding represents 40% higher risk for loss of lives than collision. This is due to a higher accident frequency for grounding than for collision. Due to the high proportion of non-serious groundings, a collision is nine times as dangerous for people on board than a grounding accident.
APPENDIX II – Risk Control Options

In the following, the prioritized list of risk control options that were established within the project will be described. The risk control options are divided into four categories, i.e. RCOs to reduce the distraction level for the navigators, RCOs to liberate more time to observations, RCOs for improved human performance and RCOs for improved technical performance.

II.1 RCOs to reduce the distraction level for the navigators

The navigator on watch is often exposed to many distractions and has tasks that are not related to navigation. These distractions and tasks take away some of the attention from the navigation and thus increase the risk for the vessel. The following RCOs are proposed to minimize the level of distractions for the navigators.

RCO1: Introduction of Onboard Safety and Security Centre

The bridge is a “continuously manned central control station”, as defined in SOLAS, and the bridge has therefore a number of functions that are not related to navigation. These non-navigational functions might take away the attention towards navigation from the officers on watch. Some of the non-navigational functions are:

- Fire safety system
- Damage Control Equipment
- Decision support system
- Non-navigational external communication.

The non-navigational functions could be reorganized into a continuously manned safety centre, located separately from the bridge. The centre could for example be located close to the hotel reception, which is already continuously manned.

The operation of such a centre would require one additional officer on watch at any given time. A space for repeaters and other equipment would also be needed. The space required for such a centre is assumed to be the same size as one passenger cabin of the smallest size.

RCO2: Automatic logging of information

SOLAS specifies the type and frequency of necessary entries into a vessel’s deck log book. Such entries involve almost all operations taking place onboard the vessel (route details, entering and leaving port, watch information, drills carried out, etc.). The task of manually entering data into the deck log book is somewhat time-consuming, and could result in distractions for the operating officer from his observation duties.

A number of the required entries into the deck log book could be done automatically, without interference of human presence, by adopting an electronic logbook (ELB). Such a system is based on IT technology, and replaces paper versions of logbooks. ELBs will be online with most of the bridge’s navigational equipment and other vital sensors for the vessel’s operation, providing automatic entry of chosen online information, either continuously or on predetermined time intervals. Such information could be:
- Navigation related (Speed, distance, position, heading, etc.)
- Safety related (Alarms and relevant panels)
- Vessel’s operation related (tank status).

Manual entries can be made for everything related to the vessel’s operation, either in text form or filling up of a pre-specified table.

Finally, exchange of data between the vessel and the company will become easier, enabling shore personnel to have a continuous overview of the vessel’s status. Adopting ELBs into the daily operations of a vessel is assessed to make routine work easier, resulting into more dedication to navigational tasks, and thereby somewhat improving safety as a whole.

**RCO3: Two officers on the bridge**

The minimum safe manning of the bridge is regulated by IMO resolution A.890(21). The resolution defines minimum safe manning for navigation as being able to:

1. plan and conduct safe navigation
2. maintain a safe navigational watch
3. manoeuvre and handle the ship under all conditions
4. moor and unmoor the ship safely.

The resolution calls for one navigational officer and one lookout on the bridge. However, the manning in the cruise industry is most commonly to have two navigational officers on watch, and one extra watch in difficult or critical situations, e.g. congested areas. Typically, the tasks and responsibilities are clearly defined by having one officer to focus on navigating the vessel in the waters and one to focus on the traffic situation in the area or other tasks that have to be taken care of. The risk for navigational mistakes is reduced by having two officers compared to one officer on watch.

One additional officer on watch requires 6 extra officers per ship, 3 onboard and 3 onshore at any given time. The officers onboard will require 3 additional officers’ cabins, which would reduce the number of passenger cabins by 3.

**II.2 RCOs to liberate more time to observations**

The bridge watch has to keep track of other vessels in the area to avoid collisions and also to carefully observe the geography, i.e. shore both above and under water, in order to avoid grounding. As the navigators have many time-consuming and distractive tasks, navigational aids can make navigation easier and liberate more time to visual observations. The following RCOs are electronic aids that assist the bridge watch in performing their tasks, and thus are contributing to reduce the risk of the vessel.

**RCO4: Electronic Chart Display and Information System (ECDIS)**

Electronic Chart Display and Information System (ECDIS) is a navigation aid that can be used instead of nautical paper charts and publications to plan and display the ship’s route, plot and monitor positions throughout the intended voyage.
ECDIS is a real-time geographic information system. It is capable of continuously determining a vessel’s position in relation to land, charted objects, navigational aids, possible unseen hazards, and represents a new approach to maritime navigation. In daily navigational operations, it should reduce the workload of the navigating officers compared to using paper charts. Route planning, monitoring and positioning will be performed in a more convenient and continuously real time way, enabling the navigator to have a continuous overview of the situation.

ECDIS is a sophisticated electronic navigation system, which is possible to integrate with both the radar system and Automatic Identification System (AIS). The ECDIS is thus a powerful navigational tool, which has proved to have a high risk reducing effect.

This RCO has been evaluated in two different manners:

1. With ECDIS and track control compared to the risk level without ECDIS and track control
2. Without track control. The RCO has been tested by comparing with ECDIS and without ECDIS.

**RCO5: Integration of AIS with ARPA radar**

An Automatic Identification System (AIS) is designed to send and receive information in relation with a vessel’s identity (e.g. name, call sign, and dimensions), course (e.g. route, speed) and cargo. Current regulations, implemented mainly due to security reasons, require the information to be presented into an AIS display. The most common type of installed display (minimum required) provides three lines of data consisting of basic information of a selected target (name, range and bearing). Additional information regarding the target can be provided by scrolling. A huge amount of information received by the AIS is hidden behind the small display, and it is time consuming and distractive for the navigator to search for the information.

The AIS can be connected to the radar’s ARPA (Automatic Radar Plotting Aid) function, and provide all the additional “hidden” data into the radar display. By selecting an AIS target into the ARPA display, the navigator will be able to see all available information for the particular vessel. Besides the easier access of AIS information through the ARPA, there are five more areas where the AIS integration improves the radar performance:

- Detection of targets which are in radar shadow areas
- Identification of radar targets into ship’s names
- Takes account of the ships rate of turn (ROT), hence, predicting more accurate the target’s path
- In some cases extents radar’s range
- Clarifies the target intentions.

AIS can become a useful source of supplementary information and an important tool in enhancing situation awareness of the traffic conditions. Benefits deriving from the AIS-ARPA interface, will improve the navigator’s ability to make early decisions based on real-time data, and avoid potential collisions.
RCO6: Track control

Track control and track keeping systems were developed on the basis of continuously comparing the vessel’s actual course, with the originally planned one. The route of the vessel is planned before departure and is entered in the track control system. Through real time information from navigational equipment, the system ensures that the planned route is followed. In case a deviation occurs, e.g. due to environmental forces, the vessel is automatically corrected to follow the track.

The basic philosophy for developing track control systems is that a vessel can not run aground if the route is properly planned and the ship follows the route for the entire voyage. Even though this is a powerful tool, the navigator has of course to ensure that the plotted track is actually followed.

Implementation of track control systems will also liberate more time for the operating officer to monitor traffic conditions.

II.3 RCOs for improved human performance

The following RCOs are suggested to improve the performance of the officers on watch. These are related both to improved working environment, competence and optimal use of the human resources on the bridge.

RCO7: Improved bridge design

Improved bridge design was decided to be one of the most important RCOs during the HAZID process with navigation experts (see NAV 49/INF.2). By the term “improved”, it is implied upgrading from a standard/minimum SOLAS bridge, which is equipped with the minimum required equipment and which gives very limited requirements regarding the bridge layout. It is common for cruise vessels to go beyond the minimum required standards in relation to bridge design, and to upgrade to a more sophisticated level. The degree of this upgrading depends on the policy of each cruise vessel operator.

In order to quantify “improved bridge design” and the degree of the upgrading, DNV’s voluntary class notation NAUT-AW is used for description as input to the cost benefit assessment. The aim for developing DNV Rules for nautical safety was to reduce the probability of a failure, caused by any reason, within the bridge team and therefore enhance safety. NAUT-AW or similar, as an addition to the SOLAS requirements, regulates the following sectors:

- Design of the workspace and the bridge layout
- Navigational equipment
- Human-machine interface.

As a result of implementing NAUT-AW or similar, the efficient performance of all navigation related tasks as well as good co-operation within the bridge team is enhanced by improved bridge design to enable efficient management of all operating conditions of the vessel. The following aspects of improved bridge design are included:

- Bridge layout and workstation arrangement
- Task specific workstations
- Design and ergonomics of workstations including location of instruments
- Field of vision from workstations
- Bridge physical working environment.

**RCO8: Improved navigator training**

The basic training requirements for the navigators are defined in the IMO safety convention International Convention on Standards of Training, Certification and Watch-keeping for Seafarers (STCW). STCW defines what kind of training the navigators should have and how often they need to take refreshment training. The requirements cover all basic navigational skills.

The training as required by STCW is a minimum, and it is further assessed that improved navigator training would have positive effect on the safety level of the vessel. An example of improved navigator training is advanced ship manoeuvring, including training of crisis situations which can only be done safely in simulators. The training should be done with simulators to give a real life experience of the given situations and thus preparing the navigators in case they face a similar incident.

Improved navigator training is here defined as sending all crew members forming part of the bridge team on simulator training in topics exceeding STCW requirements every 5 years.

**RCO9: Implementation of guidelines for Bridge Resource Management**

Bridge Resource Management (BRM) is designed to ensure efficient use of personnel and equipment during vessel operations. BRM is designed to reduce errors and omissions in bridge operations through a simple system of checks and delegation of duties. BRM system emphasizes a co-ordinated effort among bridge personnel to ensure smooth, efficient and safe operation of the vessel. The 1995 amendments to the STCW include a requirement for training in bridge team procedures and a recommendation for training in BRM techniques.

The main objectives of BRM are:

- To assist the ship master in managing the vessel’s bridge team for each voyage so that personnel are rested, trained and prepared to handle any situation.
- To help the ship master recognize workload demands and other risk factors that may affect decisions in setting watch conditions.
- To ensure bridge team members are trained and aware of their responsibilities.
- To help bridge team members interact with and support the master and/or the pilot.

The implementation of BRM is assumed to involve some initial preparations of procedures to be followed and definition of relevant responsibilities. In addition, the bridge teams are assumed to go through a BRM course to assist the implementation. For communication and responsibilities that are connected to the onshore personnel, such training should also include key onshore personnel.

**II.4 RCOs for improved technical performance**

One concern that was raised in the HAZID was the technical performance of the integrated bridge systems. Only one risk control option is proposed for this issue, and this is related to improving the availability of the navigational equipment.
RCO10: Improved navigational systems availability

The navigational systems availability is assumed mainly to be influenced by the redundancy of the navigational components. The interface between different systems might also be a problem, especially software interfaces, but this problem has not been included.

The navigational equipment, as required by SOLAS, is mostly redundant on standard bridges today. The important exceptions are the gyroscopic compass and the Global Positioning System (GPS). These items are not required to be duplicated and therefore they are most often not.

Improved navigational systems availability is here defined as installation of one extra gyroscopic compass and one extra GPS.
APPENDIX III – Cost Benefit Assessment

III.1 Methodology for cost benefit assessment

III.1.1 Assessment criteria

The cost-effectiveness of the RCOs is expressed in terms of Gross Cost of Averting a Fatality (GrossCAF) and Net Cost of Averting a Fatality (NetCAF). Their definitions are (in accordance with MSC/Circ.1023-MEPC/Circ.392):

\[ \text{GrossCAF} = \frac{\Delta C}{\Delta R} \]

and

\[ \text{NetCAF} = \frac{\Delta C - \Delta B}{\Delta R} \]

where:

- \( \Delta C \) is the cost per ship of the risk control option during the lifetime of the vessel
- \( \Delta B \) is the economic benefit per ship resulting from the implementation of the risk control option
- \( \Delta R \) is the risk reduction per ship, in terms of the number of fatalities averted, implied by the risk control option.

Comparison of cost effectiveness for RCOs may be made by calculating such indices.

III.1.2 Work processes and data sources

The work with the cost benefit assessment consisted mainly of estimating the three parameters cost, benefit and risk reduction for each proposed RCO in order to calculate GrossCAF and NetCAF values.

Regarding the costs, indications were given from suppliers of navigational equipment, ship owners, yards, training centres, DNV, etc. Where possible and appropriate, several sources of information were used to get a highest and lowest cost estimate.

For the economical benefit of introducing a measure, this is mainly accounted for in terms of reduced accident costs. A risk model was made in Step 3 of the FSA, which has shown to be a powerful tool when estimating the risk reduction of implementing the RCOs.

All RCOs are assessed independently from the others, meaning that all numbers are based on introduction of one RCO at a time only. Introduction of one RCO will lead to higher GrossCAFs for all other RCOs, as the remaining risk is less. The only exception is the “Improved Bridge Design”, which will imply also implementation of ECDIS, AIS integrated with radar and Track Control system.
III.1.3 Risk calculations

For estimating the possible risk reduction of implementing the measures, the risk model from Step 3 of the FSA was used. The model was made by using Bayesian theory and a Bayesian network software package, which gives a useful tool for evaluating effects of risk reducing measures. More information on the model can be found in Annex II of the full FSA report.

Figure 5 gives a brief overview of the risk model for collision. The nodes are only illustrative and are not the nodes used in the actual model, which are of a far higher level of detail. The model has been used by changing the conditions for one node in the network corresponding to what the RCO implies and studied the risk reducing effect this will have.

An example: “Improved bridge design” is taken as upgrading a standard SOLAS bridge to a design corresponding to the DNV’s class notation NAUT-AW. The node “Bridge Design” in the network was then changed from fulfilling the minimum requirements to fulfil the requirements of NAUT-AW. By doing this, the difference in fatality frequency has been reduced. The risk reduction could then be recorded.

The risk reduction has been found in terms of lives saved per vessel lifetime, and served as input to the GrossCAF and NetCAF calculations.

Figure 5: Overview of collision model
III.1.4 Cost and benefit calculations

The cost and benefit of the RCOs will be spread over the lifetime of the vessel. Some RCOs might involve costs every year while others only involve costs at given intervals. In order to be able to compare the costs and benefits and calculate the NetCAF and GrossCAF, Net Present Value (NPV) calculations have been performed using the formulae as given below:

\[
NPV = A + \frac{X}{(1 + r)} + \frac{X}{(1 + r)^2} + \frac{X}{(1 + r)^3} + \ldots + \frac{X}{(1 + r)^t} = A + \sum_{t=1}^{t} \frac{X}{(1 + r)^t}
\]

where:
- \( X \) = cost or benefit of RCO any given year
- \( A \) = amount spent initially for implementation of RCO
- \( r \) = depreciation rate

The direct costs of the measures have been divided into two parts: Initial costs and yearly costs over the lifetime of the vessel. The initial costs include all costs of implementing the measure, e.g. acquiring and installing equipment, writing of procedures and training of crew. Thereafter there might be additional costs at regular intervals in order to maintain the effect of the measure, e.g. equipment service and refreshment courses. The additional cost might be annual, but in some cases it is bi-annual or fifth-annual.

The implementation of a RCO might have other benefits than reducing the number of fatalities. Other benefits might be reduced maintenance cost, reduced expected annual accident cost and less time off-hire. For RCOs connected with cruise navigation only potential reduced accident costs have been included.

The reduced expected accident cost for each RCO has been found by assessing the potential risk reduction for each case, using the risk model for cruise navigation as outlined in III.1.3. The potential risk reduction is then used to find the expected reduction in annual accident cost. The measures will not only reduce the annual expected number of fatalities, but will also decrease the expected annual property damage. The property damage cost includes cost for all from minor incidents to total losses.

III.2 Cost benefit assessment

III.2.1 Risk reduction

The table below describes the expected risk reduction due to implementation of the different RCOs. The numbers are given in percentage and number of lives saved during a cruise vessel’s life time.
### Table 8: Risk reduction of implementing the RCOs

<table>
<thead>
<tr>
<th>No.</th>
<th>Risk Control Option</th>
<th>No. of lives saved [per lifetime]</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Onboard Safety and Security Centre</td>
<td>0.98</td>
<td>17%</td>
</tr>
<tr>
<td>2</td>
<td>Automatic logging of information</td>
<td>0.02</td>
<td>0.3%</td>
</tr>
<tr>
<td>3</td>
<td>Two officers on the bridge</td>
<td>0.83</td>
<td>13%</td>
</tr>
<tr>
<td>4a</td>
<td>ECDIS</td>
<td>25</td>
<td>82%</td>
</tr>
<tr>
<td>4b</td>
<td>ECDIS (No track control)</td>
<td>20</td>
<td>66%</td>
</tr>
<tr>
<td>5</td>
<td>AIS integration with radar</td>
<td>0.72</td>
<td>12%</td>
</tr>
<tr>
<td>6</td>
<td>Track control system</td>
<td>5.7</td>
<td>66%</td>
</tr>
<tr>
<td>7a</td>
<td>Improved bridge design (above SOLAS)</td>
<td>0.67</td>
<td>12%</td>
</tr>
<tr>
<td>7b</td>
<td>Improved bridge design (above average)</td>
<td>0.31</td>
<td>6%</td>
</tr>
<tr>
<td>8</td>
<td>Improved Navigator Training</td>
<td>0.34</td>
<td>6%</td>
</tr>
<tr>
<td>9</td>
<td>Implementation of guidelines for BRM</td>
<td>0.21</td>
<td>5.3%</td>
</tr>
<tr>
<td>10</td>
<td>Navigation system reliability</td>
<td>0.005</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

The effects of the RCOs in Table 8 are dependent on what risk level the implementation is compared to. This varies for the different RCOs. E.g. the evaluation of *RCO1 Onboard Safety and Security Centre* is a comparison between implementing this measure or not, i.e. a comparison between the average risk level in the cruise industry today and the future risk level if it is implemented. This shows that the implementation of this measure is saving 0.98 statistical lives during the vessel lifetime, which means an effect of 17%.

However, e.g. *RCO4 ECDIS* is already implemented on most vessels, but not required by IMO. This RCO is then tested by investigating the effect of ECDIS compared to a risk level where the measure is not implemented, i.e. use of paper charts. Implementation of ECDIS is saving 25 statistical lives, which corresponds to an effect of 82%.

The risk reduction percentages must therefore not be compared directly with each other without knowing the basis for the evaluation. All numbers are based on introduction of one RCO only. Introduction of one RCO will lead to lower risk “budget” for all other RCOs as the risk reduction will be less.

#### III.2.2 Cost estimates

This section includes all the calculation of the cost estimates. The estimates are based on the description as given in appendix II and the methodology as outlined in section III.1. Explanations of the costs included for each RCO were given in appendix II. Thus, this section does not include further explanation of what costs are included and which are not. The depreciation rate is set to 5% for all the Net present Value (NPV) calculations. Relevant references can be found in Appendix A of Annex III of the full FSA report.
RCO1: Onboard Safety and Security Centre

The input to the cost estimates are given in the table below.

<table>
<thead>
<tr>
<th>Required input</th>
<th>Low estimate</th>
<th>High estimate</th>
<th>Input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment</td>
<td></td>
<td></td>
<td>$20,000</td>
</tr>
<tr>
<td>Officers salary</td>
<td>$18,000</td>
<td>$55,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>Passenger cabin, lowest standard</td>
<td>$38,000</td>
<td>$102,000</td>
<td>$70,000*</td>
</tr>
<tr>
<td>Number of officers required</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Number of cabins lost</td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

* Based on 70% utilization

The initial investment is for buying equipment, e.g. repeaters and communication, and installing it in the centre. What specific equipment is needed has not been established, but is based on discussion with personnel with navigational experience.

The number of officers needed is based on the assumption of 3 shifts on the vessel. With 3 shifts 3 officers are required on the vessel and an additional 3 onshore to complete the rotation. It is assumed that each officer will have a separate cabin, thus 3 cabins are needed for the officers and an additional for the centre.

The above assumptions and values give a yearly cost of $580,000 over the lifetime of the vessel. The NPV is calculated to $8,900,000 using the formulae as previously presented.

RCO2: Automatic logging of information

The input to the cost estimates is given in table below.

<table>
<thead>
<tr>
<th>Required input</th>
<th>Low estimate</th>
<th>High estimate</th>
<th>Input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Logging of information-Vessel</td>
<td>$8,500</td>
<td>$14,500</td>
<td>$11,500</td>
</tr>
<tr>
<td>Software for Shore support</td>
<td>$14,500</td>
<td>$14,500</td>
<td>$14,500</td>
</tr>
<tr>
<td>Annual Cost (maintenance)</td>
<td></td>
<td>$500</td>
<td>$500</td>
</tr>
</tbody>
</table>

The cost for implementing this RCO is split down into:

- Necessary equipment and software which has to be installed onboard the vessel.
- Necessary equipment at shore in order to have the ability to process relevant data received from the vessel’s system.

The average value as found from different sources has been chosen, while the annual maintenance cost is kept somehow high in order to represent possible future damages and acquisition cost of relative spare parts. Such assumption was based on discussions we had with manufacturers of such systems.
The NPV for the implementation of RCO2 is calculated to be $34,000.

**RCO3: Two officers on the bridge**

The input to the cost estimates is given in table below.

<table>
<thead>
<tr>
<th>Required input</th>
<th>Low estimate</th>
<th>High estimate</th>
<th>Input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Officers salary</td>
<td>$18,000</td>
<td>$55,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>Passenger cabin, lowest standard</td>
<td>$38,000</td>
<td>$102,000</td>
<td>$70,000*</td>
</tr>
<tr>
<td>Number of officers required</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Number of cabins lost</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>*Based on 70% utilization</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The number of officers needed is based on the assumption of 3 shifts on the vessel. With 3 shifts 3 officers is required on the vessel and an additional 3 onshore to complete the rotation. It is assumed that each officer will have a separate cabin, thus 3 cabins are needed for the officers.

The above assumptions and values give a yearly cost of $510,000 over the lifetime of the vessel. The NPV is calculated to $7,800,000.

**RCO4: ECDIS**

The input to the cost estimates is given in the table below.

<table>
<thead>
<tr>
<th>Required Input</th>
<th>Low Value</th>
<th>High Value</th>
<th>Input Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECDIS</td>
<td>$29,000</td>
<td>$41,000</td>
<td>$32,000</td>
</tr>
<tr>
<td>Back Up arrangements</td>
<td>$16,000</td>
<td>$26,000</td>
<td>$20,000</td>
</tr>
<tr>
<td>Annual Cost (maintenance)</td>
<td>$500</td>
<td>$500</td>
<td></td>
</tr>
</tbody>
</table>

The amount spent initially represents acquisition and installation costs for all necessary equipment. Estimations on initial cost is somehow conservative, but is based on relevant feedback from personnel with navigational experience. On the other hand, annual expenses for regular service and maintenance purposes are high so as to represent a possible future breakdown and the need for replacing some parts of the installation. This assumption was based on discussions with personnel with relevant experience.

Using the above assumptions and values the NPV for the implementation of the RCO is calculated to be $60,000.
RCO5: AIS (Integration with radar)

The input for the cost estimates is given in the table below.

<table>
<thead>
<tr>
<th>Required Input</th>
<th>Low Value</th>
<th>High Value</th>
<th>Input Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration of AIS with ARPA</td>
<td>$0</td>
<td>$2,500</td>
<td>$2,000</td>
</tr>
<tr>
<td>(provided as standard)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Cost (maintenance)</td>
<td></td>
<td>$100</td>
<td></td>
</tr>
</tbody>
</table>

The initial amount represents all necessary equipment and upgrading for the integration of the AIS into the ARPA. Both AIS and ARPA are mandatory on Passenger Vessels, so in most cases the integration will be installation of software on existing production units. The whole process of the integration is simple and fairly easy to accomplish, therefore some manufacturers provide it as a standard feature with currently available units. Based on discussions with experts and as numbers are very small, a high initial estimate has been chosen.

The NPV for the implementation of RCO5 is calculated to be $3,500 and has the lowest implementation cost from all suggested RCOs.

RCO6: Track control system

The input for the cost estimates is given in the table below.

<table>
<thead>
<tr>
<th>Required Input</th>
<th>Input Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Control System</td>
<td>$4,000</td>
</tr>
<tr>
<td>Annual cost (maintenance)</td>
<td>$200</td>
</tr>
</tbody>
</table>

The input value represents acquisition costs for the system. Some manufacturers provide such systems as an extra to the autopilot without giving a separate price. Annual maintenance costs were decided upon discussions with relevant DNV personnel. However, relevant cost is small and represents maintenance work and possible breakdowns during the expected lifetime of the system.

The NPV for implementing RCO6 is calculated to be $7,100.
RCO7a: Improved bridge design (over SOLAS)

The input for the cost estimates is given in the table below.

<table>
<thead>
<tr>
<th>Required Input</th>
<th>Input Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost for the upgrading from a standard SOLAS bridge</td>
<td>$200,000</td>
</tr>
<tr>
<td>Annual cost (maintenance)</td>
<td>$2,000</td>
</tr>
</tbody>
</table>

The input value represents all costs necessary for the additional equipment and all ergonomic modifications that have to be performed over a standard SOLAS (minimum required) bridge in order to meet NAUT AW standards. For a new ship the costs would be lower and the cost effectiveness better. Estimations used derived from calculations from relevant DNV department based on current market prices for necessary equipment and previous experience from implementing the NAUT AW Class Notation.

The NPV for implementing RCO7a is calculated to be $230,000.

RCO7b: Improved bridge design (above Average Cruise vessel Bridge Design)

Based on information received from DNV’s Department for Nautical Safety and Communication Systems, the input for the cost estimates is given in the table below.

<table>
<thead>
<tr>
<th>Required Input</th>
<th>Input Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost for the upgrading from a standard SOLAS bridge</td>
<td>$80,000</td>
</tr>
<tr>
<td>Annual additional expenses for maintenance</td>
<td>$2,000</td>
</tr>
</tbody>
</table>

The input value represents all costs necessary for the additional equipment and all ergonomic modifications that have to be performed over an average cruise ship bridge in order to meet NAUT AW standards. For a new ship the costs would be lower and the cost effectiveness better. Many of the NAUT AW requirements are met by most of the cruise ships built today. Estimations used are derived from relevant DNV department based on previous experience from implementing the NAUT AW Class Notation on cruise vessels.

The NPV for implementing RCO7b is calculated to be $110,000.
RCO8: Improved Navigator Training

The input to the cost estimates are given in the table below.

<table>
<thead>
<tr>
<th>Required input</th>
<th>Input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course fee</td>
<td>$3,000</td>
</tr>
<tr>
<td>Board and lodging</td>
<td>$800</td>
</tr>
<tr>
<td>Travel expenses</td>
<td>$1,500</td>
</tr>
<tr>
<td>Officers to send on course</td>
<td>6</td>
</tr>
<tr>
<td>Frequency of course</td>
<td>5 years</td>
</tr>
</tbody>
</table>

The course fee is based on standard 5 day courses as given by the training centres and thus the boarding and lodging expenses are for 5 days and covers transport to/from the local airport, hotel and food for the period. The travel expenses are an average value and will vary with the distance the participants have to travel in order to get to the training centre. The number of officers needed is based on the assumption of 3 shifts on the vessel. With 3 shifts 3 officers are required on the vessel and an additional 3 onshore to complete the rotation.

The above assumptions and values give a cost of $32,000 every 5th year over the lifetime of the vessel. The NPV is calculated to be $120,000 for this RCO.

RCO9: Implementation of guidelines for BRM

The input to the cost estimates are given in the table below.

<table>
<thead>
<tr>
<th>Required input</th>
<th>Input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course fee</td>
<td>$3,700</td>
</tr>
<tr>
<td>Board and lodging</td>
<td>$800</td>
</tr>
<tr>
<td>Travel expenses</td>
<td>$1,500</td>
</tr>
<tr>
<td>Officers to send on course</td>
<td>6</td>
</tr>
<tr>
<td>Onshore personnel</td>
<td>2</td>
</tr>
<tr>
<td>Frequency of course</td>
<td>5 years</td>
</tr>
</tbody>
</table>

The course fee is based on standard 5-day courses as given by the training centres and thus the boarding and lodging expenses are for 5 days and covers transport to/from the local airport, hotel and food for the period. The travel expenses are an average value and will vary with the distance the participants have to travel in order to get to the training centre. The number of officers needed is based on the assumption of 3 shifts on the vessel.

In order to maintain and update the procedures and ensure clear communication and understanding between the bridge and onshore office in case of an emergency, some of the onshore personnel should also attend the BRM course. It is assumed that 2 employees from the onshore office would be sufficient.
The above assumptions and values give a cost of $48,000 every 5th year over the lifetime of the vessel. The NPV is calculated to be $180,000.

### III.2.3 Costs and benefits of implementing the RCOs

The costs and benefits of implementing the RCOs are summarized in Table 19:

<table>
<thead>
<tr>
<th>No</th>
<th>Risk Control Option</th>
<th>Cost of implementation (NPV in $)</th>
<th>Benefit of implementation (NPV in $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Onboard Safety and Security Centre</td>
<td>8,900,000</td>
<td>1,900,000</td>
</tr>
<tr>
<td>2</td>
<td>Automatic logging of information</td>
<td>34,000</td>
<td>35,000</td>
</tr>
<tr>
<td>3</td>
<td>Two officers on the bridge</td>
<td>7,800,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>4a</td>
<td>ECDIS</td>
<td>60,000</td>
<td>6,700,000</td>
</tr>
<tr>
<td>4b</td>
<td>ECDIS (no track control)</td>
<td>60,000</td>
<td>5,400,000</td>
</tr>
<tr>
<td>5</td>
<td>AIS (Integration with radar)</td>
<td>4,000</td>
<td>950,000</td>
</tr>
<tr>
<td>6</td>
<td>Track control system</td>
<td>7,000</td>
<td>5,700,000</td>
</tr>
<tr>
<td>7a</td>
<td>Improved bridge design (above SOLAS)</td>
<td>230,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td>7b</td>
<td>Improved bridge design (above average)</td>
<td>110,000</td>
<td>620,000</td>
</tr>
<tr>
<td>8</td>
<td>Improved Navigator Training</td>
<td>120,000</td>
<td>720,000</td>
</tr>
<tr>
<td>9</td>
<td>Implementation of guidelines for BRM</td>
<td>180,000</td>
<td>540,000</td>
</tr>
<tr>
<td>10</td>
<td>Navigation system reliability</td>
<td>34,000</td>
<td>11,000</td>
</tr>
</tbody>
</table>

### III.2.4 Results and presentation of GrossCAF and NetCAF values

As a basis for the cost benefit calculations, the following important assumptions are made:

- The total number of persons on board: 5,000
- The average lifetime of the cruise vessel: 30 years

The GrossCAF and NetCAF values are presented in Table 20.
Table 20: GrossCAF and NetCAF for all RCOs

<table>
<thead>
<tr>
<th>No</th>
<th>Risk Control Option</th>
<th>Gross CAF</th>
<th>NetCAF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[$]</td>
<td>[$]</td>
</tr>
<tr>
<td>1</td>
<td>Onboard Safety and Security Centre</td>
<td>$9,200,000</td>
<td>$7,200,000</td>
</tr>
<tr>
<td>2</td>
<td>Automatic logging of information</td>
<td>$2,000,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>3</td>
<td>Two officers on the bridge</td>
<td>$9,400,000</td>
<td>$7,600,000</td>
</tr>
<tr>
<td>4a</td>
<td>ECDIS</td>
<td>$2,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>4b</td>
<td>ECDIS (no track control)</td>
<td>$3,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>5</td>
<td>AIS (Integration with radar)</td>
<td>$5,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>6</td>
<td>Track control system</td>
<td>$1,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>7a</td>
<td>Improved bridge design (above SOLAS)</td>
<td>$340,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>7b</td>
<td>Improved bridge design (above average)</td>
<td>$350,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>8</td>
<td>Improved Navigator Training</td>
<td>$350,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>9</td>
<td>Implementation of guidelines for BRM</td>
<td>$870,000</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>10</td>
<td>Navigation system reliability</td>
<td>$7,100,000</td>
<td>$4,800,000</td>
</tr>
</tbody>
</table>

All numbers are based on introduction of only one RCO at the time. Introduction of one RCO will lead to higher NetCAF/GrossCAFs for all other RCOs as the remaining risk is less.

The results show that RCO1 Onboard Safety and Security Centre, RCO3 Two officers on the bridge and RCO10 Navigation System Reliability have high values for both GrossCAF and NetCAF compared to the other RCOs. The GrossCAFs are above $7M and NetCAFs above $4.8M. All other RCOs have GrossCAF below $3M and negative NetCAFs.

A negative NetCAF indicates that the RCO is beneficial in itself, i.e. the costs of implementing the RCO is less than the economical benefit of implementing it, regardless of how many lives that are saved. It should therefore be implemented. The economical benefit is in this assessment only measured in terms of reduced accident costs. Other economical benefits, e.g. fewer business interruptions, are not considered. Such would make the RCOs more cost-effective. Thus, the presented results are robust.

Some of these RCOs are already implemented on most cruise vessels. For example, RCO4 ECDIS is installed on practically every vessel in the cruise fleet and proves in this assessment to be very cost effective. This measure is not, however, a requirement in SOLAS. In addition, RCO5 AIS integration with radar and RCO6 Track control are among the most cost effective measures in this evaluation. Both the GrossCAF and the NetCAF values are low. RCO7 Improved bridge design and RCO8 Improved navigator training seem also to be areas for improvement, and the assessment indicates high cost-effectiveness.

As a final note, it should be pointed out that in the evaluation of the cost-effectiveness of the different risk control options, a required index of R = 0.9 has been assumed. However, in accordance with current developments within IMO and the draft revised SOLAS regulations in annex 1 of SLF 47/17 it seems most likely that a required index of about 0.8 will be adopted. If a required index of R = 0.8 were used as the basis for the cost-effectiveness assessment of the risk control options considered herein, much lower GrossCAF and NetCAF values would have been found. As a crude estimate, a required index of 0.8 would correspond to twice the risk reduction
potential compared to 0.9\textsuperscript{1}, and the risk control options would be approximately twice as cost-effective (i.e. values for Gross CAF and NetCAF would be diminished). If recommendations were to be based on estimates revised in this way, it can be seen that RCO\textit{10 Navigation System Reliability} would also be cost-effective, although this RCO is associated with limited risk reduction effect (see Table ). The two other RCOs that were previously found to be not cost-effective, RCO\textit{1 Onboard Safety and Security Centre} and RCO\textit{3 Two officers on the bridge} might also prove to be cost-effective if $R = 0.8$ were assumed, and although further scrutiny is needed in order to conclude that they are cost-effective, they should not immediately be regarded as not cost effective.

\textsuperscript{1} Actually, the required index $R$ is related to collision damage stability only, but it can be assumed that a higher required index $R$ would also enhance the survivability in grounding scenarios.