# TECHNICAL REPORT

# DNV RESEARCH

## FORMAL SAFETY ASSESSMENT OF ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEM (ECDIS)

REPORT NO. 2005-1565

REVISION NO. 01

DET NORSKE VERITAS

DET NORSKE VERITAS

# TECHNICAL REPORT

DET NORSKE VERITAS AS

*Maritime Solutions*

Veritasveien 1,
1322 HØVIK, Norway
Tel: +47 67 57 99 00
Fax: +47 67 57 99 11
http://www.dnv.com
Org. No: NO 945 748 931 MVA

| | |
|---|---|
| Date of first issue: 08.12.2005 | Project No.: 31100230 |
| Approved by: Sverre Alvik, Principal Consultant | Organisational unit: Maritime Solutions (MONNO 311) |
| Client: DNV Research | Client ref.: Rolf Skjong |

Summary:

A joint project was established involving the Norwegian Maritime Directorate (NMD), Norwegian Hydrographic Service (NHS), Swedish Maritime Administration (SMA), Danish Maritime Authority (DMA) and UK's Maritime and Coastguard Agency (MCA) to carry out a study on cost effectiveness of ECDIS. The background is the FSA study for Large Passenger Ships Navigation, NAV 51/10, that proved that ECDIS is a cost effective risk control options for large passenger vessels.

In the present study, a cost benefit assessment has been undertaken to evaluate the cost effectiveness of this measure for other vessel types as well. The focus has been kept on ECDIS as a risk control option to reduce the grounding risk.

| | |
|---|---|
| Report No.: 2005-1565 | Subject Group: |
| Report title: Formal Safety Assessment of Electronic Chart Display and Information System (ECDIS) | |
| Work carried out by: Linn Kathrin Fjæreide (PM), Anders Mikkelsen, Magnus S. Eide, Sverre Alvik | |
| Work verified by: Peter Hoffmann | |

| Date of this revision: | Rev. No.: | Number of pages: |
|---|---|---|
| 10.01.2006 | 01 | 11 |

**Indexing terms**

| Key words | Service Area |
|---|---|
| FSA<br>ECDIS<br>Cost effectiveness | |
| | Market Sector |

- [x] No distribution without permission from the client or responsible organisational unit (however, free distribution for internal use within DNV after 3 years)
- [ ] No distribution without permission from the client or responsible organisational unit.
- [ ] Strictly confidential
- [ ] Unrestricted distribution

© 2005 Det Norske Veritas AS
All rights reserved. This publication or parts thereof may not be reproduced or transmitted in any form or by any means, including photocopying or recording, without the prior written consent of Det Norske Veritas AS.

## *Table of Content* *Page*





Reference to part of this report which may lead to misinterpretation is not permissible.

# 1 CONCLUSIVE SUMMARY

A joint project was established involving the Norwegian Maritime Directorate (NMD), Norwegian Hydrographic Service (NHS), Swedish Maritime Administration (SMA), Danish Maritime Authority (DMA) and UK's Maritime and Coastguard Agency (MCA) to carry out a study on cost effectiveness of Electronic Chart Display and Information System (ECDIS). The 4 countries participating each paid one quarter of the total cost. The background is the FSA study for Large Passenger Ships Navigation, ref. NAV 51/10, that proved that ECDIS is a cost effective risk control options for large passenger vessels.

In the present study, a cost benefit assessment has been undertaken to evaluate the cost effectiveness of this measure for other vessel types as well. The focus has been kept on ECDIS as a risk control option to reduce the grounding risk.

To evaluate the cost effectiveness of ECDIS for the world fleet, limited time and resources makes it impossible to study the whole fleet with all vessel types and sizes. The present study has therefore selected three cases that are expected to have different cost effectiveness due to the differences in the nature of the trade, cargo, etc. The intention has been to use these cases to generalise for other segments of the fleet. After detailed consideration, the following cases were chosen:

- Tanker for Oil, 80,000 DWT (approx. 40,000 GT) trading between the Middle East (Kuwait) and the Mediterranean (Marseille, France)
- Product Tanker, 4,000 DWT (approx. 2,000 GT), trading between Mongstad (Norway) and Stockholm (Sweden)
- Bulk Carrier, 75,000 DWT (approx. 38,000GT), carrying Coal between Newcastle (Australia) and Tokyo (Japan).

These choices are based on world fleet statistics, world main trade routes, and vessel size distribution on these routes.

Based on a cost-effectiveness assessment of ECDIS for these cases, the following has been concluded:

- ECDIS, as defined in IMO's performance standard, is cost effective for the three selected cases
- The proven cost effectiveness of ECDIS for these cases can also be considered valid for all other vessel types in international trade. It is valid for all vessel sizes, with exception of the smaller vessels.
- Due to a very small reduction in number of saved lives, the GrossCAF values are high, which indicates that as a measure to save lives, ECDIS is not a cost effective measure. However, the NetCAF value is negative, which indicates that the RCO is beneficial in itself, i.e. the net economic benefit exceeds the cost of implementation.

The ratio between costs and benefits is in the range of 2-5 for the three selected cases. With the high GrossCAF, the ratio between costs and benefits is almost equivalent to the robustness of the



Reference to part of this report which may lead to misinterpretation is not permissible.

conclusion result (i.e. the results are robust with a factor of 2 to 5). The robustness of the generalisation to all vessel types is considered equal.

If the suggested “willingness-to-pay” to avoid a ton of oil spilt of $60,000 developed in ref. /2/ had been used instead of only direct cost of an oil spill, the environmental cost would have increased significantly, especially for large tankers. For the largest tanker case (80,000dwt), the total economical benefits would have increased by a factor of 3.5. For smaller tankers the effect is less, in the order of 20% for the smallest tanker case (4,000dwt). The robustness of the Cost Benefit Assessment will increase accordingly. However, the present cost-benefit assessment is based on direct costs of an oil spill only, and not the “willingness-to-pay” value.

An important condition for this robustness is the assumption of 100% Electronic Navigational Charts (ENCs) coverage for the evaluated cases. For routes where only parts of the track are actually covered, the effect is less. It is assumed that if ECDIS is installed, it is also in use and operated by qualified and trained personnel.

The presented results are thus considered robust for the two large vessel cases, but less robust for the smaller tanker case. There could also be other potential economic benefits, e.g. fewer business interruptions and long term effects like improved company reputation, which are not considered. Neither is the additional risk reducing effect that ECDIS may have on the collision risk analysed. Taking this into consideration would make ECDIS even more cost-effective.



Reference to part of this report which may lead to misinterpretation is not permissible.

# 2 INTRODUCTION

According to FSA Large Passenger Ships Navigation, ref. NAV 51/10, ECDIS is one of the risk control options that proved to be cost effective for large passenger vessels. The Gross Cost of Averting a Fatality (GrossCAF) was just $2,000 for ECDIS. The Net Cost of Averting a Fatality (NetCAF), which takes into account potential economic benefits, was negative, indicating that the net economic benefits exceeded the costs. ECDIS could therefore be introduced both for economic reasons as well as a cost effective measure to save lives.

In the present study, a cost benefit assessment has been done to evaluate the cost effectiveness of this measure for other vessel types as well. The FSA study reference above have been used, updated and extended to be useful as a basis for decision-making at IMO relating to ECDIS in general, for all vessel types.

## 2.1 Objective and Scope of Work

The objective is to carry out a Formal Safety Assessment, including cost benefit assessment of Electronic Chart Display and Information System (ECDIS) for relevant vessel types (excl. High Speed Crafts). The cost effectiveness will be measured as Gross/Net CAF values, i.e. the cost invested of averting a fatality.

The following tasks have been carried out:

- Define a set of representative vessel types and trades
- General study on ECDIS and the effect of ECDIS
- Update and extend the risk model for grounding to become valid for an extended set of vessel types. The detailed modelling has been carried out for two vessel types, and extended to other vessel types by more general considerations
- Quantify risk reducing effect of ECDIS, costs of implementation and potential economic benefits to calculate GrossCAF and NetCAF values for the selected cases
- General considerations of other vessel types and sizes
- Reporting

## 2.2 Limitations

The FSA focuses on risk for personnel, risk of environmental damage and risk for property damage.

Limited time and resources makes it impossible to study the whole fleet with all vessel types and sizes. The present study has therefore selected three cases that are expected to have different cost effectiveness due to the differences in the nature of the trade, cargo, etc. The intention is to use these cases to generalise for other segments of the fleet.

The choice of routes used for the estimation of number of dangerous courses is supposed to represent a typical trade for the vessel type and size in question. Routes are assessed to be either neutral or conservative for the cost effectiveness calculations.

The study has assumed 100% Electronic Navigational Charts (ENCs) coverage for the evaluated cases. For routes where only parts of the track are actually covered, the effect is less, and considered low (down to 0) for areas with no coverage. However, availability of an ECDIS



Reference to part of this report which may lead to misinterpretation is not permissible.

system onboard enables use of Raster Navigational Charts (RNCs) when ENCs are not available. This could have a certain positive effect on the navigators understanding of the fairway, in addition to use of paper charts. However, this effect has not been quantified.

For areas with full coverage, it is assumed that paper charts for these areas are not required to be carried onboard.

Statistics have been used to coarsely calibrate the results from the modelling, however, statistics are not considered to be the correct answer. Fatalities as a result of groundings are very rare, and fatality rates based on the available statistics are highly sensitive to single events. The result from the modelling is therefore considered a better estimate on what is the actual risk level for grounding relevant vessel types.

## 2.3 Abbreviations

| | |
|---|---|
| DMA | Danish Maritime Authority |
| DNV | Det Norske Veritas |
| ECDIS | Electronic Chart Display and Information System |
| ENC | Electronic Navigational Chart |
| FSA | Formal Safety Assessment |
| GrossCAF | Gross Cost of Averting a Fatality |
| HSC | High Speed Crafts |
| IMO | International Maritime Organisation |
| MCA | Maritime and Coastguard Agency |
| NetCAF | Net Cost of Averting a Fatality |
| NHS | Norwegian Hydrographic Service |
| NMD | Norwegian Maritime Directorate |
| RCO | Risk Control Option |
| SMA | Swedish Maritime Administration |



Reference to part of this report which may lead to misinterpretation is not permissible.

# 3 METHOD OF WORK

The FSA methodology used in the study is described in Figure 3-1.

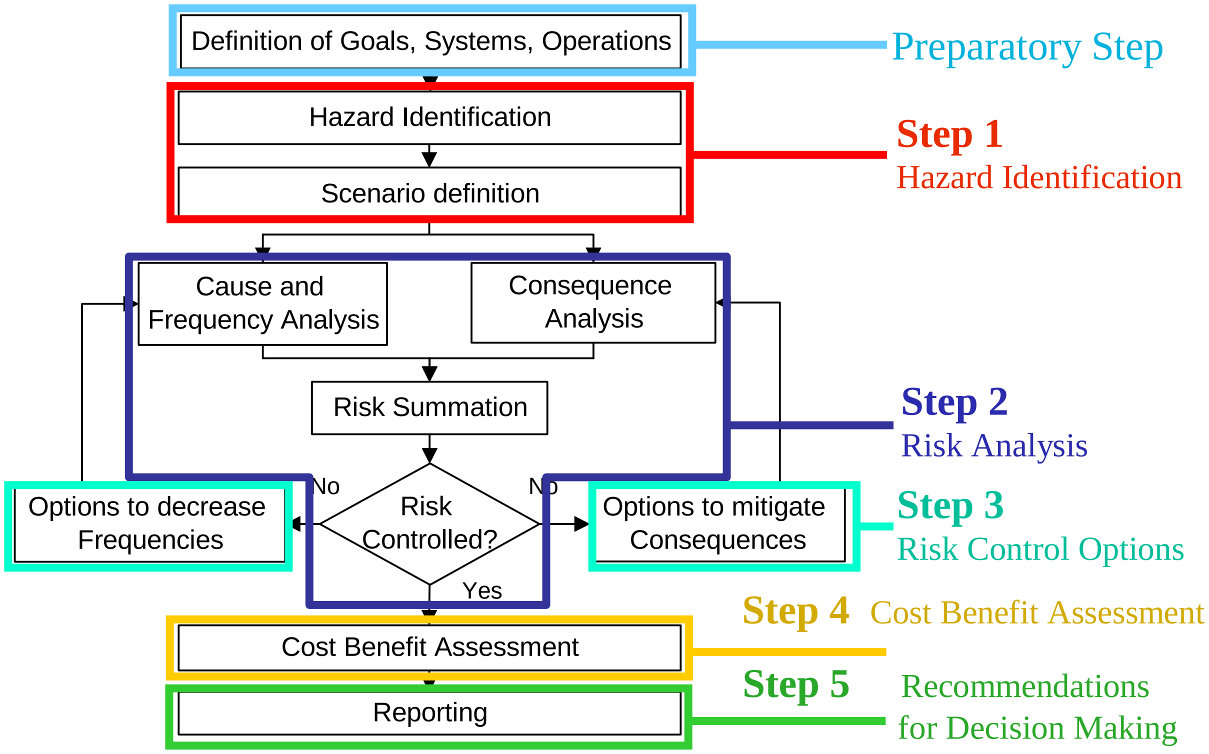



**Figure 3-1 The five steps of Formal Safety Assessment**

The work has been based on the previous study for Large Passenger Ships, ref./1/, however adjusted to evaluate other vessel types.

The main work in the project has been carried out by risk analysts, listed in ANNEX I – Appendix D. 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.

The risk model is based on Bayesian theory and network models were made for a grounding accident scenario. The models are based on ref. /1/, developed further to be valid for new vessel types by a team of risk analysts, and the process was supported and reviewed by navigational experts.

The costs and economic benefits combined with risk reducing effect from the model for selected cases has been used to evaluate the cost effectiveness of ECDIS for all vessel types.

The study was initiated in September, and most of the work was carried out in November/ December 2005.



Reference to part of this report which may lead to misinterpretation is not permissible.

# 4 DESCRIPTION OF THE RESULTS ACHIEVED

## 4.1 Step 1: Hazard Identification

There has not been a need for a separate Hazard Identification for this project. The study has been carried out based on ref. /1/, with additional input from navigators on specific issues related to the new vessel types.

## 4.2 Step 2: Risk Assessment

The objective of FSA Step 2 is to establish a risk model of all important influencing factors involved in avoiding grounding, and to quantify the risk level. The model is based on the need to analyse and evaluate the risk reducing effect of the ECDIS system.

The goal is to evaluate ECDIS as a risk control option for all vessel types, except high speed crafts. As stated earlier, the whole world fleet with all vessel types and sizes has not been studied in detail due to the complexity and size of such a task. The present study has therefore selected three cases that are expected to have different cost effectiveness due to the differences in value of vessel, cargo, nature of the trade, etc. The intention is to use these cases to generalise for other segments of the fleet.

Based on detailed considerations, the following vessels, sizes and trades were chosen:

- Tanker for Oil, 80,000 DWT (approx. 40,000 GT) trading between the Middle East (Kuwait) and the Mediterranean (Marseille, France)
- Product Tanker, 4,000 DWT (approx. 2,000 GT), trading between Mongstad (Norway) and Stockholm (Sweden)
- Bulk Carrier, 75,000 DWT (approx. 38,000GT), carrying Coal between Newcastle (Australia) and Tokyo (Japan).

These choices are based on world fleet statistics, world main trade routes, and vessel size distribution on these routes. Tankers and bulk carriers represent about 65% of the world fleet measured in gross tonnage, thus this is a natural choice. In addition, in order to establish a basis for drawing general conclusions on cargo ships, it was decided to include a ship type providing the combination of relatively low value of the ship itself; low value of its cargo as well as low pollution potential. The bulk carrier carrying coal was chosen for this purpose.

The modelled results as well as statistical risk levels are presented in Table 4-1.



Reference to part of this report which may lead to misinterpretation is not permissible.

**Table 4-1 Comparison of risk level, modelled and statistical**

| | Modelled Grounding Frequency [groundings pr ship year] | Modelled Fatality Frequency [fatalities pr ship year] | Statistical Grounding Frequency [1] [groundings pr ship year] | Statistical Fatality Frequency [fatalities pr ship year] |
|---|---|---|---|---|
| Tank 80' DWT (Kuwait-Marseille) | $7.0 \times 10^{-2}$ | $3.4 \times 10^{-4}$ | $6.4 \times 10^{-3}$ | $4.5 \times 10^{-5}$ |
| Tank 4' DWT (Mongstad-Stockholm) | $1.2 \times 10^{-1}$ | $3.2 \times 10^{-4}$ | $6.4 \times 10^{-3}$ | $4.5 \times 10^{-5}$ |
| Bulk 75' DWT (Newcastle-Tokyo) | $3.2 \times 10^{-2}$ | $5.0 \times 10^{-4}$ | $1.6 \times 10^{-2}$ | $7.6 \times 10^{-5}$ |

1) The statistics are based on the Lloyd's Fairplay casualty database

It needs to be emphasized that the modelled frequencies are route specific, and can not be directly compared to the statistical frequencies.

The figures in the table above shows that a tanker of size 80,000dwt trading between Kuwait and Marseille is expected to experience a grounding every 14 ship year, while the smaller tanker trading between Mongstad and Stockholm has a grounding return period of 8 year. The differences in these two return periods are mainly due to the nature of the trade (waters, geography, etc.), not the internal factors onboard the vessels.

For the bulk carrier case, sailing from Newcastle to Tokyo, the return period is 31 years. This does not mean that the bulk carrier in general is a safer vessel, but the choice of trade means that this ship is less exposed than, for example, the product tanker navigating along the challenging Norwegian coast and into the Baltic Sea.

Compared to statistics, the modelled frequency results are higher. For the tanker cases, the frequency for the selected trades is 10-20 times higher than world wide average statistics. For bulk carriers, the accident frequency is two times higher. There are mainly two reasons for this discrepancy. One reason is that the statistics do not include all grounding incidents. Numerous minor incidents are not reported, and this is accounted for in the modelled frequency. The other reason is that the model evaluates the risk of a specific route, whereas the statistics are generic data for the world fleet. This is more detailed explained in detail in Annex I.

In general, the accident statistics show that grounding scenarios give a very low contribution to the overall risk of fatalities compared to accident scenarios like foundering (especially for bulk carriers) and collisions (for both vessel types).

## 4.3 Step 3: Risk Control Option (RCO)

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. Its purpose is to continuously determining a vessel's position in relation to land, charted objects, navigational aids and possible unseen hazards. 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



Reference to part of this report which may lead to misinterpretation is not permissible.

a more convenient and continuously real time way, enabling the navigator to have a continuous overview of the situation.

It is possible to integrate ECDIS with both the radar system and Automatic Identification System (AIS). However, this study considers a basic ECDIS system as described in the Performance Standard for ECDIS of IMO.

The main benefits of using ECDIS considered in this study include:

- Liberate time for the navigators to focus on navigational tasks
- Improved visual representation of fairway
- More efficient updating of charts

The effect of the RCO has been tested by comparing with a vessel with ECDIS installed and in use, with a vessel without ECDIS.

## 4.4 Step 4: Cost Benefit Assessment

The objective of the cost benefit assessment is to evaluate the cost effectiveness of introducing ECDIS as a mandatory requirement for all vessel types.

The Cost Benefit Assessment has consisted of studying the risk reducing effect expected from using ECDIS as a risk control option for selected segments of the fleet, i.e. for a 4,000dwt product tanker, for an 80,000dwt tanker for oil and for a 75,000dwt bulk carrier, and the costs related to implementing the RCO.

The risk model described in Annex I shows that ECDIS has a risk reducing effect on grounding risk of around 36% for all three cases, which is also in line with previous research in the industry. This is a reduction in grounding frequency when the vessel is already on a dangerous course. The reason for the reduction is complex and is linked to elements (or nodes in the model) like: more available time on the bridge, better overview, updating routines etc. It is assumed that ECDIS is installed and used by qualified and trained personnel.

The costs and economic benefits of implementing the RCO are given in Table 4-2.

**Table 4-2 Costs and benefits of implementing ECDIS**

| **Vessel Type/Size** | **Cost of implementation** (NPV in $)* | **Benefit of implementation** (NPV in $)* |
|---|---|---|
| Tank 80' DWT (Kuwait-Marseille) | 75,000 | 396,000 |
| Tank 4' DWT (Mongstad-Stockholm) | 75,000 | 175,000 |
| Bulk 75' DWT (Newcastle-Tokyo) | 75,000 | 295,000 |

* Figures are given in Net Present Value

The costs of implementation are assumed equal for all vessel types. This is due to the fact that the number of people that needs training is assumed the same for all vessel types and sizes analysed and that the type of equipment is the same. The benefits are in this study considered as reduced accident costs due to fewer accidents, using values for spill cost and property cost and subsequently finding the reduction in accident cost due to use of ECDIS.

Based on the costs, benefits and risk reducing effect, the GrossCAF and NetCAF values are presented in Table 4-3.



Reference to part of this report which may lead to misinterpretation is not permissible.

Main Report_01-02-2006.doc

**Table 4-3 GrossCAF and NetCAF for all RCOs**

| Vessel Type/Size | Gross CAF [$] | NetCAF [$] |
|---|---|---|
| Tank 80' DWT (Kuwait-Marseille) | 23,900,000 | < 0 |
| Tank 4' DWT (Mongstad-Stockholm) | 14,600,000 | < 0 |
| Bulk 75' DWT (Newcastle-Tokyo) | 16,000,000 | < 0 |

Due to a very small reduction in number of saved lives, the GrossCAF values are high, which indicates that as a measure for averting fatalities only, ECDIS is not a cost effective measure. However, the NetCAF value is negative, which indicates that the RCO is beneficial in itself, i.e. the net economic benefit exceeds the cost of implementation. 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. Neither is the effect ECDIS may have on the collision risk. Taking this into consideration might make the RCOs even more cost-effective.

The ratio between costs and benefits is in the range of 2-5 for the three selected cases. With the high GrossCAF, the ratio between costs and benefits is almost equivalent to the robustness of the conclusion result (i.e. the results are robust with a factor of 2 to 5).

The presented results are thus considered robust for the two large vessel cases, but less robust for the smaller tanker case. There could also be other potential economic benefits, e.g. fewer business interruptions and long term effects like improved company reputation, which are not considered. Neither is the additional risk reducing effect that ECDIS may have on the collision risk analysed. Taking this into consideration would make ECDIS even more cost-effective.

There are three factors that influence the cost effectiveness of a measure:

- Cost of implementation
- Economic benefits, in this case: reduced number of accidents and accident costs
- Number of saved lives

It has been concluded that the chosen cases can represent the world fleet, ref Annex I, and that a proven cost effectiveness of ECDIS for tankers and bulk carriers of the selected sizes also is valid for all other ship types in international trade.

It is valid for all vessel sizes, with exception of the smaller vessels. The results are valid for tankers down to 4,000 dwt, which corresponds to around 2,000GT. The limit can be drawn further down, but the uncertainty is significant. Considering that the results for the 4,000 dwt tanker is not very robust, this report does not give a clear lower gross tonnage limit for which the analysis is valid.

The effect of ECDIS is based on 100% Electronic Navigational Charts (ENCs) coverage. For routes where only parts of the track are covered, the effect is less, and down to 0 for areas without coverage of neither ENCs nor Raster Navigational Charts (RNCs). The effect of using RNCs in areas with no ENC coverage has not been assessed.

## 4.5 Step 5: Recommendations

Based on the FSA of ECDIS the following is observed:



Reference to part of this report which may lead to misinterpretation is not permissible.

- ECDIS as defined in IMO’s performance standard is cost-effective for the three selected cases (4,000dwt product tanker, 80,000dwt tanker for oil and 75,000dwt bulk carrier)
- The proven cost-effectiveness of ECDIS for these cases can also be considered valid for all other vessel types in international trade. It is valid for all vessel sizes, with exception of the smaller vessels. The lower limit has not been determined.
- Due to a very small reduction in number of saved lives, the GrossCAF values are high, which indicates that as a measure for averting fatalities only, ECDIS is not a cost effective measure. However, the NetCAF value is negative, which indicates that the RCO is beneficial in itself, i.e. the net economic benefit exceeds the cost of implementation.



Reference to part of this report which may lead to misinterpretation is not permissible.

# 5 REFERENCES

/1/ NAV 51/10 - Full report can be found at: http://research.dnv.com/skj/FSALPS/FSA-LPS-NAV.htm

/2/ Skjong, R, E Vanem and Ø Endresen *Risk Evaluation Criteria* SAFEDOR-D-4.5.2-2005-10-21-DNV

- o0o -



Reference to part of this report which may lead to misinterpretation is not permissible.

# ANNEX I

# RISK ASSESSMENT

REPORT NO. 2005-1565

REVISION NO. 01

DET NORSKE VERITAS

## *Table of Content* *Page*



**APPENDICES**

# 1 INTRODUCTION

To have a risk based approach to the evaluation of cost effectiveness of ECDIS, it is beneficial to first establish a tool to evaluate the risk reducing effect. A risk model will create a good understanding of the failure mechanisms behind the risk, and enables to quantify the effect of risk control options. A model was developed in ref. /1/ and, with some changes, ref. section 2.3, the model has been used in this study.

ECDIS is a measure to improve navigational safety. In particular, grounding is considered to be by far the most important scenario. The focus in the analysis is therefore on this scenario. It is expected, also based on other studies, that ECDIS may have a risk reducing effect on the collision scenario as well. However, as this has proved to be minor for large passenger ships, ref. /1/, this has not been evaluated in the present study.

## 1.1 Objective and Scope of Work

The objective of FSA Step 2 is to establish a risk model of all important influencing factors involved in avoiding grounding, and to quantify the risk level. The model is based on the need to analyse and evaluate the effect of risk control options (RCOs), specifically the ECDIS system.

The risk model for grounding is described in this report. In addition, the report presents quantitative results for accident frequencies and fatality frequencies for this accident scenario which relates to failure in navigation for selected ship types.

This project phase consisted of the following activities:

- Selection of three ship types to be modelled in detail
- Design models that quantify failure probabilities and consequence of grounding for relevant ship types. 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.
- Quantify each influence factor of the model (this includes both expert judgements and use of statistical data)
- Calculation and documentation of results

## 1.2 Limitations

The risk assessment presented in this document concentrates on risk to people onboard, i.e. fatality risk. Reduction of environmental and property risk is considered in monetary terms as benefits in the Cost Benefit Assessment of ECDIS, ref. Annex II.

Statistics have been used to coarsely calibrate the results from the modelling, however, statistics are not considered to be the correct answer. Fatalities as a result of groundings are very rare, and fatality rates based on the available statistics are highly sensitive to single events. The result from the modelling is therefore the best estimate on what is the actual risk level for grounding of relevant ship types.



Reference to part of this report which may lead to misinterpretation is not permissible.

## 1.3 Abbreviations

| | |
|---|---|
| CPT | Conditional Probability Table |
| DNV | Det Norske Veritas |
| DWT | Dead Weight Ton |
| ECDIS | Electronic Chart Display and Information System |
| FSA | Formal Safety Assessment |
| GT | Gross Ton |
| OOW | Officer On Watch |
| RCO | Risk Control Option |
| VTS | Vessel Traffic Service |

# 2 METHODOLOGY

## 2.1 Introduction

The models for grounding are based on previous work carried out by DNV. DNV has extensive experience with risk modelling, e.g. ref. /1/ and /2/, and the models presented in this study are based on a model designed for large passenger ships, ref. /1/. A considerable amount of work has been put into altering the model tailored for cruise operations to other ship types.

A Bayesian Network methodology is used to model the risk for grounding. This method is considered as the best method to reveal dependencies between the contributing factors and the importance of the individual contributors. The model is thus excellent to evaluate the effect of risk reducing measures, including evaluating the effect of possible new regulations, ref. /4/.

As a Bayesian network only calculates the *probability* of "failure" given a critical situation, this is combined with an Excel model that estimates the *frequency* or exposure. The failure frequencies for grounding are estimated by combining the *frequencies* of critical situations with the *probability* of failure from the Bayesian network.

## 2.2 Bayesian Network method for modelling

### 2.2.1 General

A *Bayesian network* is a causal network that enables a graphical representation of causal relations between different parameters. The network consists of a set of nodes representing random variables and a set of links connecting these nodes, illustrated by arrows.

The model reveals explicitly the probabilistic dependence between the set of variables. Each variable could have a number of states, and has assigned a function that describes how the states of the node depend on the parents of the node, i.e. a conditional probability table (abbreviated CPT). This is illustrated in Figure 3.1, together with the network. A CPT quantifies the effects



Reference to part of this report which may lead to misinterpretation is not permissible.

that the parent nodes have on the child node. Each numeric value in the CPT is the probability of being in the state found in the left-most column in the actual row - when the parents (if any) are in the states found in the top of the actual column. Thus, the number of cells in a CPT for a discrete node equals the product of the number of possible states for the node and the number of possible states for the parent nodes. The values in this table are set manually.

The basis for the conditional probabilities in a Bayesian network has background from well-founding theory and statistics as well as subjective estimates and expert judgements.

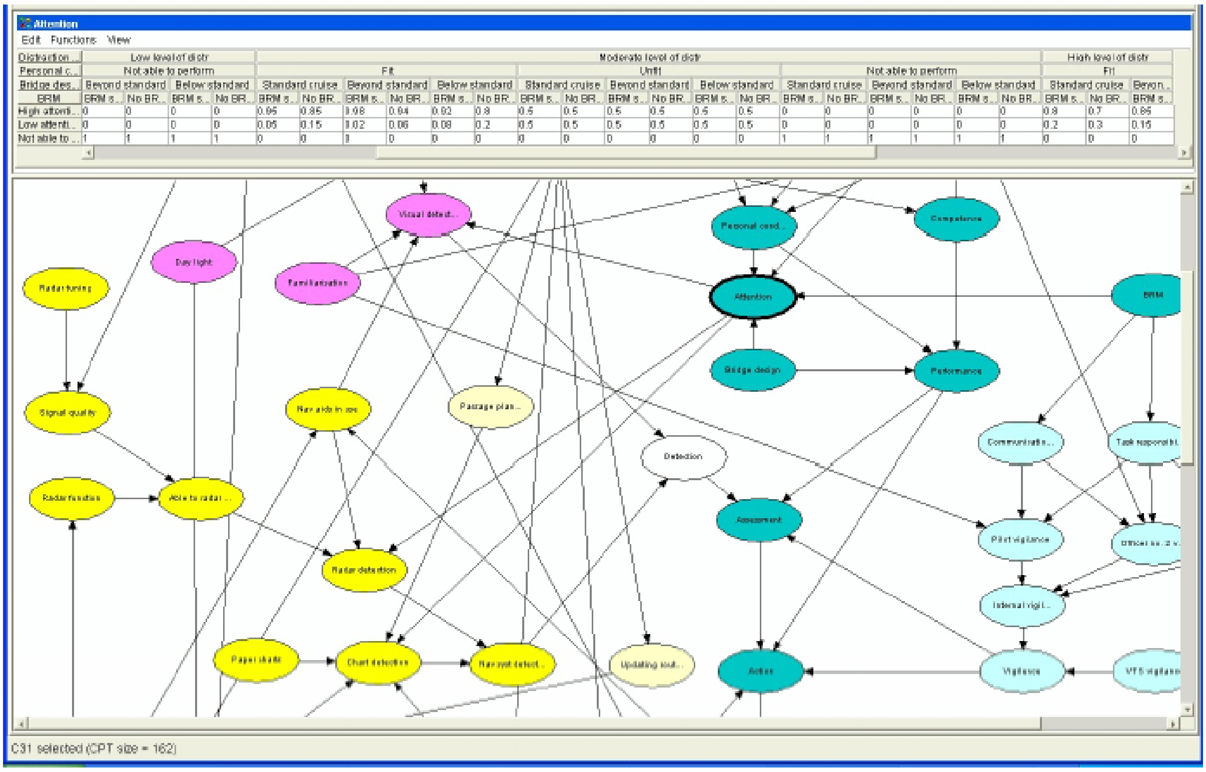



**Figure 3-1 Example of Bayesian network and conditional probability table (CPT)**

### 2.2.2 Bayesian theory

The Bayesian calculus, which is part of classical probability calculus, is based upon the theorem of Thomas Bayes, which states that:

$$P(H|e) = \frac{P(e|H)P(H)}{P(e)}$$

| | | | |
|---|---|---|---|
| where | e | : | Event/Observation |
| | H | : | Hypothesis |
| | P(H\|e) | : | Posterior probability |
| | P(e\|H) | : | Likelihood function |
| | P(H) | : | Prior probability |

A conditional probability statement is of the following kind:

*Given the event e, the probability of the event H is x.*

The notation for this statement is P(H | e) = x. It should be noted that P(H | e) = x does not mean that whenever *e* is true, then the probability for *H* is *x*. It means that if *e* is true, and everything else known is irrelevant for H, then P(H) = x. This is the basic method for establishing the conditional probability tables and calculation of the network as mentioned earlier.

### 2.2.3 HUGIN

HUGIN is the project's Bayesian network tool. The user interface contains a graphical editor, a compiler and a runtime system for construction, maintenance and usage of knowledge bases based on Bayesian network technology.

## 2.3 Data sources

In the work process to establish the failure models for grounding, various experts and data sources were used to ensure a solid foundation for the dependencies and figures entered into the model. The probability input to the grounding model is based on the study for large passenger vessels, ref. /1/, however, tailored to the selected ship types.

The structure of the Bayesian network was examined by navigators to ensure a logical model that included the important factors relevant for navigational performance.

When tailoring the model, statistical data were used where available. This is typically the case for nodes concerning reliability of technical equipment/systems and some input on human factors. The sources used are presented in the node description in Appendix B of ANNEX I. In some cases, statistical data from other ship types was considered where applicable.

For nodes where no statistical information was available, expert interviews have been conducted or experts have been directly involved in the modelling process. Important probabilities of each node related to causes of grounding were discussed and verified.

As stated above, the Bayesian network has been based on the study for large passenger vessels. The above mentioned work has been carried out to adjust the cruise model to a model describing bulk carriers and tankers for oil. The main differences include:

- **Safety culture** is an important aspect of the safety level onboard a vessel. It has been assessed that safety culture onboard cruise vessels are generally more developed than other vessel types.
- **Bridge Design and Level of Manning** is often better on a cruise vessel. A cruise vessel bridge has normally two navigating officers at all times, while this is not the case for cargo carrying vessels. Also the user interface of equipment, the design of the work stations (ergonomic conditions) and bridge arrangements are considered more advanced.
- **Evacuation** is more complex and difficult on a cruise vessel than other vessel types due to the high number of people onboard, not trained to handle an emergency situation.
- **Damage stability** is considered different for a cruise vessel than for a tanker or a bulk carrier due to the tank structure. In case of collision or grounding, the cruise vessel will have a considerably shorter survivability than the bulk carrier and the tanker.



Reference to part of this report which may lead to misinterpretation is not permissible.

- **Escort tug** is an important risk reducing measure used some places when a large oil tanker is entering a port or terminal. This has not been found relevant neither for the cruise vessels nor for the bulk carrier and the smaller tanker.

In addition to the main differences listed above, a number of minor changes have been done to tailor the model to the new selected ship types. E.g. the network structure where the ECDIS system is modelled has been modified. This has been done to get an even better understanding of the effect of ECDIS. Another reason for doing this was to accommodate a clearer separation between the use of paper charts and ENCs. Also technical aspects like probabilities for machinery breakdown have been considered differently.

More on the process and the people involved in this process is presented in Appendix D.



Reference to part of this report which may lead to misinterpretation is not permissible.

# 3 THE RISK MODELLING

## 3.1 Introduction

The accident scenario for grounding has been modelled to be able to evaluate the effect of ECDIS, as relying on accident statistics only is not sufficient. Statistics present 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 include only a few cases representing an accident scenario, one additional serious accident can dramatically change the results. Finally, statistics will always describe the past, which is not necessarily representative for today and the future. When modelling a scenario, all important parameters that influence the frequency and the consequence of the event are included, in a format representative for today and the future.

This cause analysis enables an effective evaluation of introducing ECDIS as an RCO.

## 3.2 Selected Cases

As previously mentioned, the objective of this project is to evaluate ECDIS as a RCO for all ship types, excluding high speed crafts. However, only two ship types have been modelled in detail, and inferences to all other relevant ship types are to be made on the basis of this modelling. For this to be justified, the two ship types being modelled should be as representative as possible for the world fleet. This requires a careful selection of the ships to be modelled, as it is neither desirable to over- or underestimate the cost-effectiveness of ECDIS.

The philosophy behind the selection is to choose a ship type typical to the world fleet, i.e. a large portion of the world fleet should be of this ship type. The next step is to choose a size and trade typical to this type of ship. A specific route is to be chosen, and the grounding risk for the selected ship on this selected route is to be assessed. The resulting risk level may then be considered typical to this ship type. In addition, in order to establish a basis for drawing general conclusions on cargo ships, it was decided to include a ship type providing the combination of relatively low value of the ship itself; low value of its cargo as well as low pollution potential.

As a next step, the cost effectiveness of ECDIS is studied for the selected cases, the results are generalised and used as a basis for discussion on whether ECDIS is recommended for more or all other ship types.

After detailed consideration, ref. the following sections, the decision to model the following ships were made:

- Tanker for Oil, 80,000 DWT (approx. 40,000 GT) trading between the Middle East (Kuwait) and the Mediterranean (Marseille, France)
- Product Tanker, 4,000 DWT (approx. 2,000 GT), trading between Mongstad (Norway) and Stockholm (Sweden)
- Bulk Carrier, 75,000 DWT (approx. 38,000GT) , carrying Coal between Newcastle (Australia) and Tokyo (Japan).

The rationale behind the decision is elaborated on in the following.



Reference to part of this report which may lead to misinterpretation is not permissible.

### 3.2.1 Ship Types and Sizes

Tanker for Oil (incl. product) and Bulk Carrier have been selected as the two ship types to be modelled. According to ref. /3/, tankers represent about 36 % of the world fleet measured in gross tonnage and about 24% measured in number of vessels. Bulk Carriers represent about 29 % of the fleet in terms of gross tonnage (~14% in terms of number of vessels). Tankers are a natural choice as they represent a large portion of the fleet, and as they are different from other vessels considering the potential threat to the environment in terms of oil spill.

Container vessels were considered as an alternative to Bulk Carriers as this vessel type represents about 11% of the fleet, and this number is increasing. However, container vessels generally carry high value cargo, and move at high speeds (20-25 knots). Due to this fact, it is therefore reasonable to expect that the cost effectiveness of ECDIS on Container vessels will be higher than for Bulk Carriers. It was important to include a vessel type providing a combination of relatively low value of the vessel itself; low value of its cargo as well as low pollution potential. By selecting bulk carriers to be modelled, the cost benefit assessment is expected to be more on the conservative side, i.e. if ECDIS is cost effective for bulk carriers, it is reason to believe that the measure is also effective on container vessels.

The choice of Tanker for Oil and Bulk Carriers have been more elaborated in the following.

### 3.2.2 Tanker for oil

For oil tankers, two vessel sizes have been modelled:

- 4,000 dwt, double hull
- 80,000 dwt, double hull

The main reason for this is to account for the great variety in trade patterns for ships of different sizes, as well as the amount of cargo carried onboard. Whereas a large tanker typically have a large proportion of navigation in open waters, a small tanker navigates more in coastal and narrow waters with more frequent port calls. This would make a significant impact on the risk exposure for grounding accidents.

Figure 3-1 illustrates the vast majority of small vessels in the oil tanker fleet. The first column represents vessels below 5,000 dwt. When separating between crude oil tankers and oil product tankers the picture is different. Crude oil tankers are in general large vessels, as Figure 3-2 illustrates. Vessels below 5000 DWT are mainly product tankers.



Reference to part of this report which may lead to misinterpretation is not permissible.

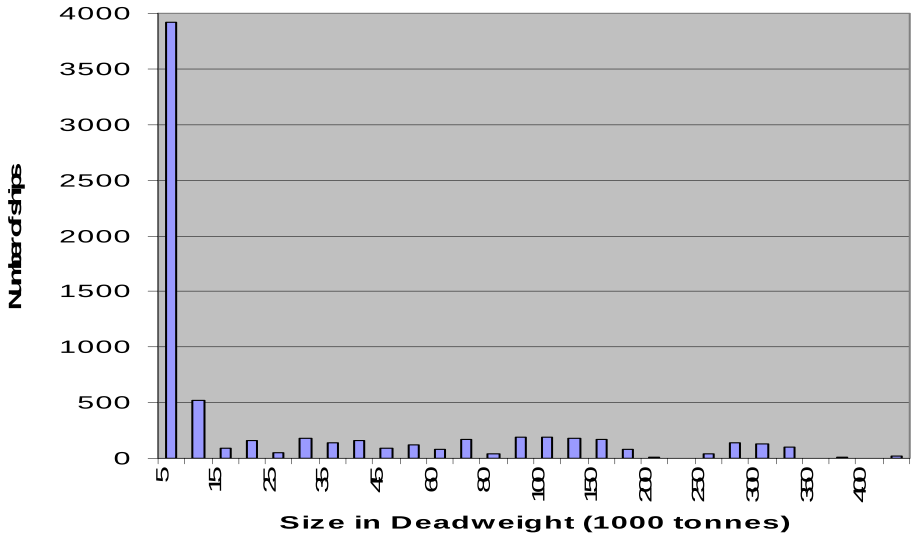



**Figure 3-1 Size Distribution of Oil Tankers (all types)**

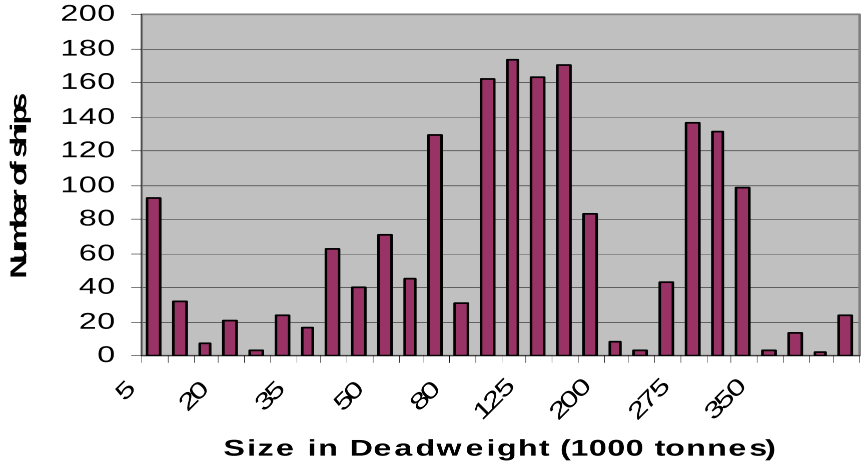



**Figure 3-2 Size distribution of Crude Oil Tankers**

Figure 3-3 is a very coarse presentation of the main oil trade routes in the world. A vessel trading between the Middle East (Kuwait) and the Mediterranean (Marseille, France), through the Suez Canal, has been analysed. Statistics, ref. /7, show that 43 % of total shipment volume into the Mediterranean (ships over 50,000dwt) is transported on vessels between 80,000dwt and 120,000dwt. The chosen tanker is in this range. Worldwide figures show that 30 % of all oil shipments were done on vessels 80-120,000dwt. 43 % of the volumes were on ships above 200,000dwt.



Reference to part of this report which may lead to misinterpretation is not permissible.

ANNEX I Risk Assessment_01-02-2006.doc

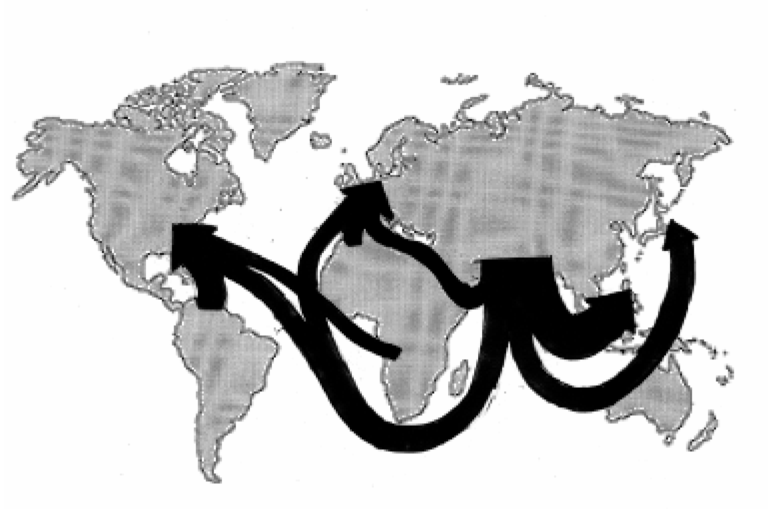


**Figure 3-3 Main Oil Trades (ref. /7)**

For smaller tankers, such as 4,000 DWT, trade patterns are quite different. Smaller ships trade more regionally, e.g. within Northern Europe. A route between Mongstad (Norway) and Stockholm (Sweden) has been chosen, this is one of the typical trades with this vessel types and size.

### 3.2.3 Bulk Carriers

Figure 3-4 illustrates the size distribution of bulk carriers. It has been chosen to study a vessel of 75,000dwt, as this size is fairly representative of the world fleet.

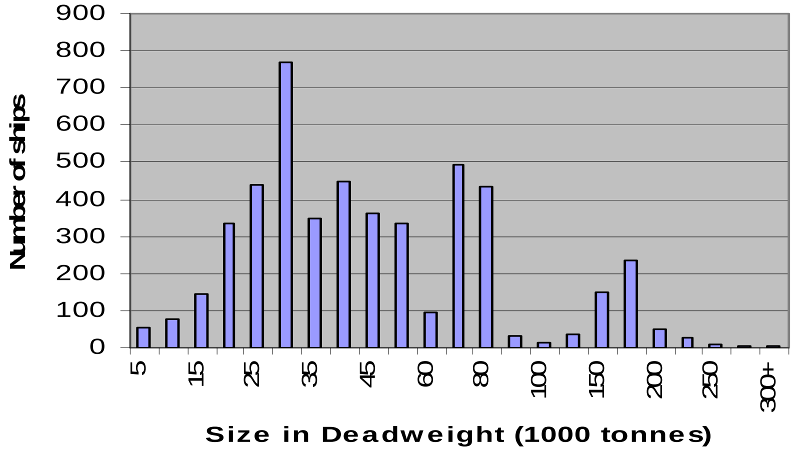



**Figure 3-4 Size Distribution of Bulk Carriers**

The dominant commodities transported by bulk carriers are ore, coal and grain. Of these three commodities, coal is of highest volume transported, with more than two times the volume of grain transported. Ore is number two, but is predominantly transported on very large vessels, typically in the upper tail end of the size distribution. Coal is also transported on big vessels, but to a lesser extent. Globally 30 % of coal shipments were by ships between 60,000dwt and 80,000dwt.

Figure 3-5 shows the main trade routes for coal. Australia dominates the trade patterns as the worlds leading exporter, while Japan is one of the bigger importers. A route between Newcastle (Australia) and Tokyo (Japan) has therefore been chosen.

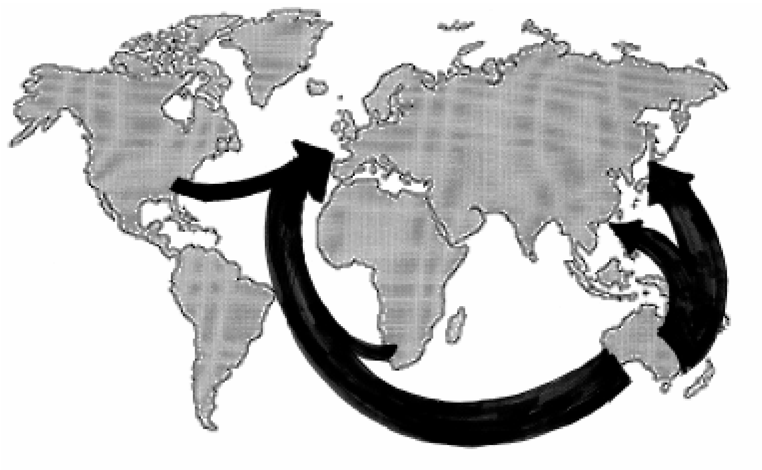


**Figure 3-5 Main Coal Trades (ref. /8/)**

### 3.2.4 Type of Waters

Each of the selected routes was divided into three types of waters: Open waters, Coastal waters and Narrow waters. The types of waters are defined as:

- Open waters: No obstacles within typically 5 nautical miles in all directions
- Coastal waters: No obstacles within typically 2 nautical miles in all directions
- Narrow waters: Obstacles within typically 0.5 nautical miles in all directions

The division into types of waters enables a calculation of the number of critical courses towards shore a vessel is likely to encounter, e.g. a vessel will have more critical courses in narrow waters than coastal waters. In open waters, it is assessed that the vessel has no critical courses towards shore.

The chosen vessel types, vessel sizes, routes and division into types of waters are summarised in Table 3-1. The chosen routes are shown in figure Figure 3-6, Figure 3-7 and Figure 3-8.

**Table 3-1 Vessel type, route and type of waters**

| Vessel Type/Size | Route | Open Waters | Coastal Waters | Narrow Waters |
|---|---|---|---|---|
| Tanker, Oil 80' dwt | Kuwait-Marseilles | 79% | 19% | 2% |
| Tanker, Product 4' dwt | Mongstad-Stockholm | 47% | 51% | 2% |
| Bulk 75' dwt | Newcastle-Tokyo | 84 % | 16 % | 0,1 % |



Reference to part of this report which may lead to misinterpretation is not permissible.

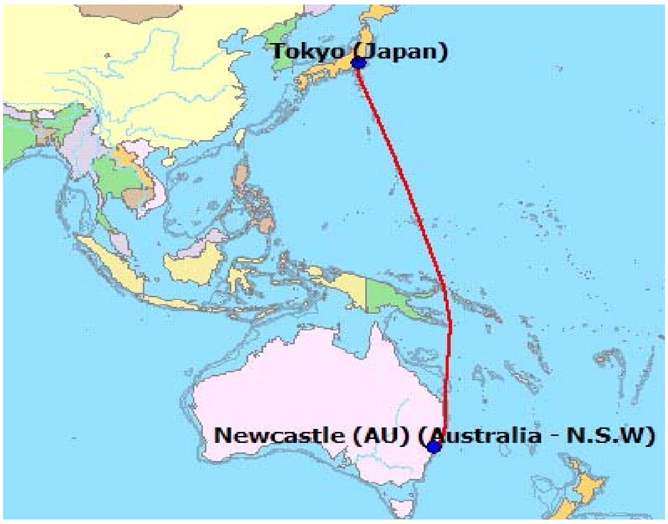



**Figure 3-6 Chosen Bulk Carrier route, Newcastle-Tokyo (ref. /7/)**

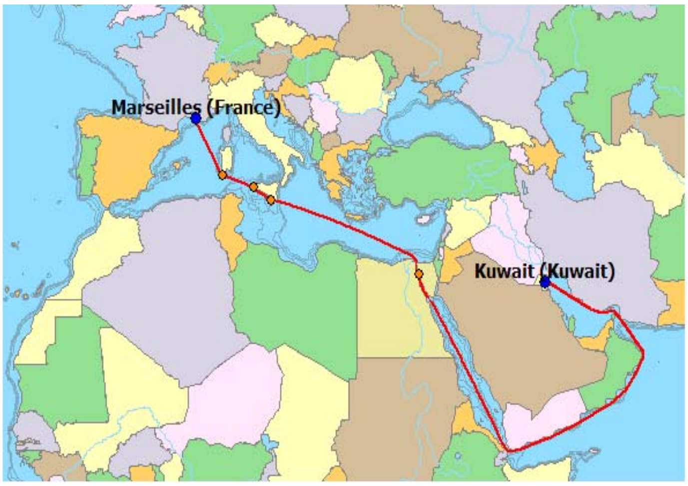



**Figure 3-7 Oil Tanker route (80,000dwt), Kuwait-Marseille (ref. /7/)**

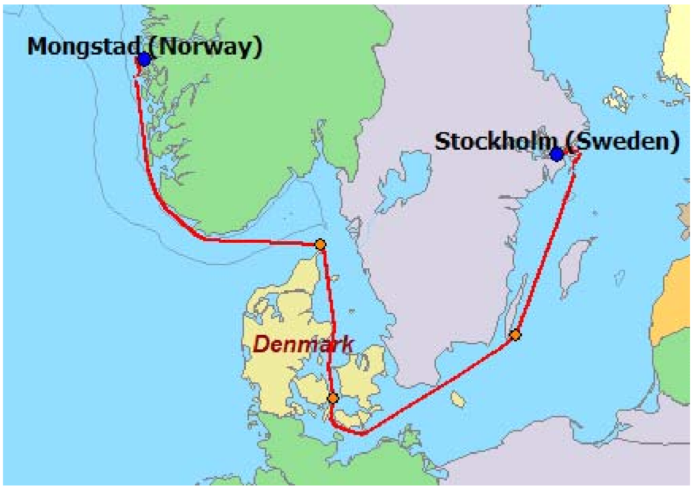



**Figure 3-8 Product Tanker route (4,000dwt), Mongstad-Stockholm (ref. /7/)**

## 3.3 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 report is thus equivalent with 'Powered grounding'.

Figure 3-9 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 and is enclosed in Appendix A.

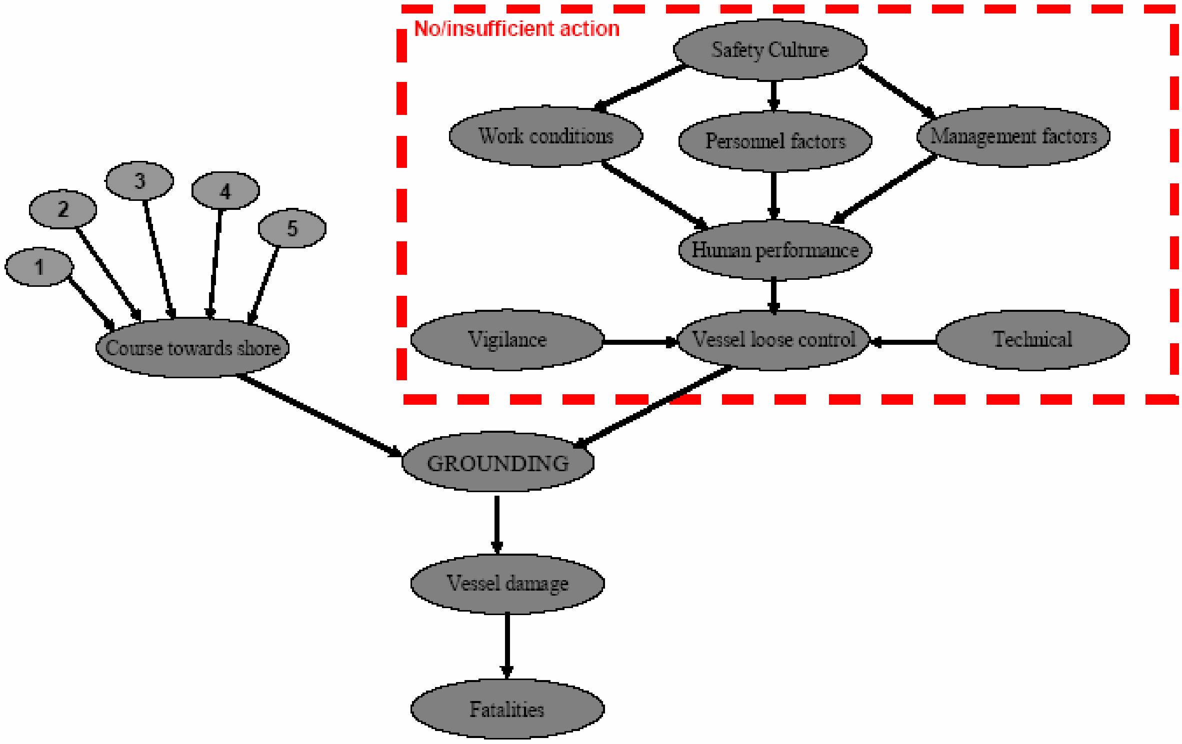



**Figure 3-9 Overview of Bayesian Network Grounding Model**

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 vessel 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.



Reference to part of this report which may lead to misinterpretation is not permissible.

ANNEX I Risk Assessment_01-02-2006.doc

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 3-10.

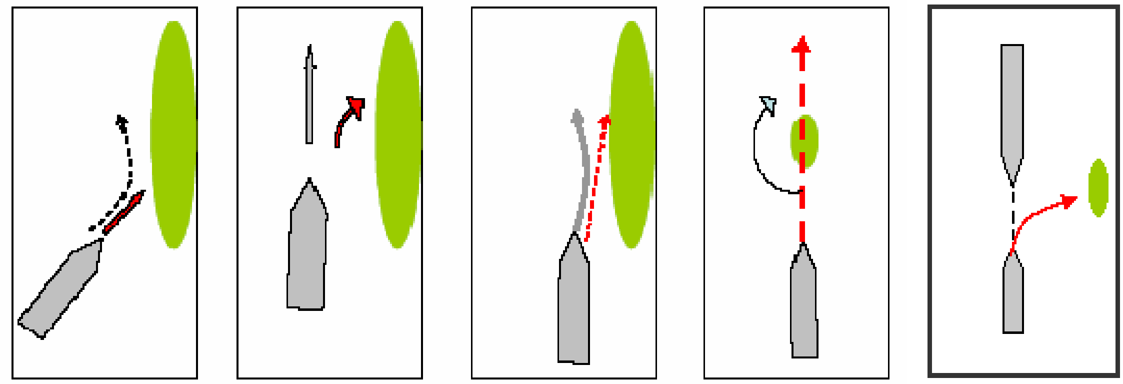


**Figure 3-10 The five grounding scenarios**

The frequencies for "course towards shore" for each of the five scenarios were estimated based on expert judgement, ref. Appendix D. The number of dangerous courses was then calculated for the three selected cases based on the trades.

The right side of the network in Figure 3-9 illustrates that there are many factors influencing that the vessel looses 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



Reference to part of this report which may lead to misinterpretation is not permissible.

- The physical and mental state of the officer on watch (tired, stress level, intoxicated, etc.)

If the Officer On Watch (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. pilot) or externally (e.g. VTS). Also the technical performance of the vessel is important 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 change course 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. The complete models may be found in Appendix A. Included in this appendix is also the probability input to the grounding network. The nodes from the grounding network are described in Appendix B.

The Excel model describing the exposure is included in Appendix C.

# 4 RESULTS

This section presents the results from the grounding model as described in section 3. Absolute levels for grounding frequencies as well as frequencies for grounding related fatalities are given, and compared to generic, statistical figures. However, the objective of this FSA is to evaluate the effect of ECDIS as an RCO, therefore the modelled absolute risk levels are not the main focus, as it is the relative change in risk level associated with the introduction of ECDIS that is of main interest.

## 4.1 Risk results for selected cases

In the calculations of fatality rates pr ship year we have assumed a crew of 24 on the large tanker (80' DWT) and on the Bulk Carrier. The small tanker (4' DWT) has an assumed crew of 14. The modelled results as well as statistical risk levels are presented in Table 4-1.

**Table 4-1 Comparison of risk level, modelled and statistical**

| | **Modelled Grounding Frequency [groundings pr ship year]** | **Modelled Fatality Frequency [Fatalities pr ship year]** | **Statistical Grounding Frequency [groundings pr ship year]** | **Statistical Fatality Frequency [Fatalities pr ship year]** |
|---|---|---|---|---|
| Tank 80' DWT (Kuwait-Marseille) | $7.0 \times 10^{-2}$ | $3.4 \times 10^{-4}$ | $6.4 \times 10^{-3}$ | $4.5 \times 10^{-5}$ |
| Tank 4' DWT (Mongstad-Stockholm) | $1.2 \times 10^{-1}$ | $3.2 \times 10^{-4}$ | $6.4 \times 10^{-3}$ | $4.5 \times 10^{-5}$ |
| Bulk 75' DWT (Newcastle-Tokyo) | $3.2 \times 10^{-2}$ | $5.0 \times 10^{-4}$ | $1.6 \times 10^{-2}$ | $7.6 \times 10^{-5}$ |



Reference to part of this report which may lead to misinterpretation is not permissible.

The figures in the table above shows that a tanker of size 80,000dwt trading between Kuwait and Marseille is expected to experience a grounding every 14 ship year, while the smaller tanker trading between Mongstad and Stockholm have a grounding return period of 8 year. The differences in these two return periods are mainly due to the nature of the trade (waters, geography, etc.), not the internal factors onboard the vessels.

For the bulk carrier case, sailing from Newcastle to Tokyo, the return period is 31 years. This does not mean that the bulk carrier in general is a safer vessel, but the choice of trade means that this ship is less exposed than, for example, the product tanker navigating along the challenging Norwegian coast and into the Baltic Sea.

Based on ref. /5/ and /6/, the modelled frequency results are higher than the statistics. For the tanker cases, the frequency for the selected trades is 10-20 times higher than world wide average statistics. For bulk, the accident frequency is two times higher. There are mainly two reasons for the discrepancy, explained in the following.

Firstly, the statistics does not include all grounding incidents, in contrast to the model where all types of grounding from the least severe cases to the total losses. The statistics are based on the Lloyd’s Register Fairplay casualty database, regarded as the most comprehensive marine accident database in the world. However comprehensive, the database only contains incidents of a certain degree of severity to be reported, and it can be assumed that a great number of non-serious groundings (e.g. touching or stranding on sandbanks) with no/minor consequences are not included in the database. In addition, only serious accidents and total losses are reported reliably to the database. As the modelled groundings are intended to cover all types of groundings, it is expected that the numbers are not directly comparable.

Secondly, the model evaluates the risk on a specific route, whereas the statistics are generic data for the world fleet. For each of the three vessels considered, the modelled frequencies are the results of an analysis of a specific route, while the statistics cover the world and is considered generic. Although the specific route analysed is typical for the relevant vessel type, it is not a generic route.

Regarding the fatality frequencies, the 80,000dwt oil tanker has a return period of about 2,400 years, and for the small tanker  the figure is every 3,100 years. According to the model, fatalities will occur more often on the bulk carrier even though the chosen trade is less exposed to grounding, with a return period of 1,600 year. This could be read as given a grounding accident, it is more dangerous to be onboard the bulk carrier than the tanker.

Compared to the accident statistics, these results are significantly higher, with a factor in the order of 6-8. As opposed to accident frequencies, the fatality frequencies are not expected to be underreported. However, fatalities at sea, especially grounding related fatalities, are very rare. The fatality statistics presented in Table 4-1, are based on 1 accident with one fatality for tankers and two accidents with 10 fatalities in total for the bulk carrier. This means that the statistical fatality rate is very sensitive to single incidents, as one single accident with a few fatalities alone will multiple the statistical fatality frequency. For example, if the bulk carrier that grounded and capsized outside Bergen, Norway, in 2004 with 18 fatalities had been included in the figures, the fatality rate for bulk carriers would almost triple. This sensitivity to single accidents in the statistics holds for both vessel types.

In general, grounding scenario gives a very low contribution to the overall fatality risk compared to accident scenarios like foundering (especially for bulk carriers) and collisions (for both vessel types).

## 4.2 Expected results for other trades, sizes and ship types

Grounding risk has only been modelled for oil tankers and bulk carriers of specific sizes and in specific trades. Expected results for other ship types, other trades and ship sizes have been discussed in Annex II.

# 5 REFERENCES

/1/ NAV 51/10 - Full report can be found at: http://research.dnv.com/skj/FSALPS/FSA-LPS-NAV.htm

/2/ SPIN WP 3.3 Risk modelling report, November 2002

/3/ Lloyd’s World Fleet Statistics, 2000

/4/ R. Skjong and Erik Vanem, DNV Research, ‘Experience with use of Bayesian Networks’ (SAFER EURORO II project)

/5/ FSA Generic Vessel Risk, Tanker for Oil, DNV Report no. 2003-1148

/6/ FSA Generic Vessel Risk, Bulk Carriers, DNV Report no. 2003-1073

/7/ Netpas Distance, port distance calculador: http://netpas.net/product/p2.php

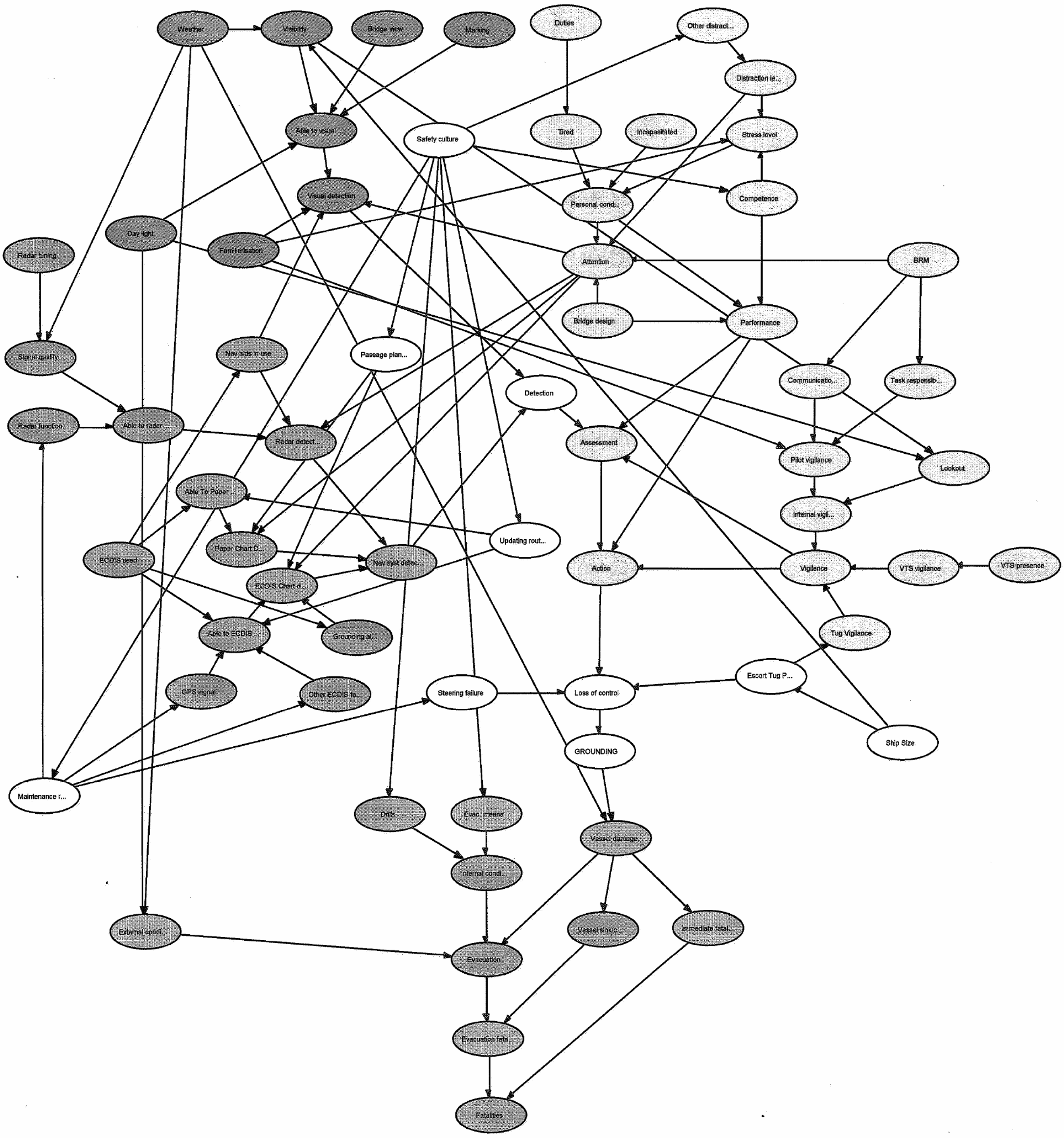
/8/ Fearnleys AS, ‘World Bulk Trades 2001’, Fearnresearch December 2001.

- o0o -



Reference to part of this report which may lead to misinterpretation is not permissible.

# ANNEX I – Appendix A Tank Model



Grounding_model_ECDIS_TANK_Final_Version

## Paper Chart Detection

| C31 | High attention | | | | Low attention | | | | Not able to pay attention | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C5 | Yes | | No | | Yes | | No | | Yes | | No |
| C47 | Standard | Poor | Standard | Poor | Standard | Poor | Standard | Poor | Standard | Poor | Standard |
| Yes | 0.9975 | 0.996 | 0 | 0 | 0.94 | 0.89 | 0 | 0 | 0 | 0 | 0 |
| No | 0.0025 | 0.004 | 1 | 1 | 0.06 | 0.11 | 1 | 1 | 1 | 1 | 1 |

| C31 | Not able |
|---|---|
| C5 | No |
| C47 | Poor |
| Yes | 0 |
| No | 1 |

## Able To Paper Chart Detect

| C25 | Yes | | No | |
|---|---|---|---|---|
| C41_1 | Good | Poor | Good | Poor |
| Yes | 0 | 0 | 0.999 | 0.95 |
| No | 1 | 1 | 0.001 | 0.05 |

## Lookout

| C15 | Day | | Night | |
|---|---|---|---|---|
| C14 | Adequate | Reduced | Adequate | Reduced |
| Yes | 0.05 | 0.5 | 0.8 | 1 |
| No | 0.95 | 0.5 | 0.2 | 0 |

## Ship Size

| | |
|---|---|
| Small | 1.0E−5 |
| Large | 0.99999 |

## Tug Vigilance

| Tug | Present | Not Prese |
|---|---|---|
| Yes | 0.5 | 0 |
| No | 0.5 | 1 |

## Escort Tug Presence

| C1 | Small | Large |
|---|---|---|
| Present | 0 | 0.02 |
| Not Present | 1 | 0.98 |

## Detection

| C4_1 | Yes | | No | |
|---|---|---|---|---|
| C19 | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 1 |

## Bridge view

| | |
|---|---|
| Good | 0.3 |
| Standard | 0.7 |

# Grounding_model_ECDIS_TANK_Final_Version

## Grounding alarm

| C25 | Yes | No |
|---|---|---|
| Yes | 0.8999 | 0 |
| No | 0.0001 | 1 |
| No, not used/i | 0.1 | 0 |

## ECDIS used

| | |
|---|---|
| Yes | 1 |
| No | 1.0E−10 |

## Nav aids in use

| C25 | Yes | No |
|---|---|---|
| More time to c | 1 | 0 |
| No more time | 0 | 1 |

## Distraction level

| C35 | Few | Many |
|---|---|---|
| Low level of d | 1 | 0.7 |
| Moderate leve | 0 | 0.3 |
| High level of c | 0 | 0 |

## Duties

| | |
|---|---|
| Normal (watch | 0.6 |
| High (watch + | 0.4 |

## Internal vigilance

| C43 | Yes | | | No | | |
|---|---|---|---|---|---|---|
| C7 | Able to c | Not able | No pilot | Able to c | Not able | No pilot |
| Yes | 1 | 1 | 1 | 1 | 0 | 0 |
| No | 0 | 0 | 0 | 0 | 1 | 1 |

## Fatalities

| C63 | Yes | | No | |
|---|---|---|---|---|
| C60 | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 1 |

## Evacuation fatalities

| C59 | Yes, within 30 min | | | | Yes, after 30 min | | | | No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C58 | Not initia | Successf | Not succ | Not appli | Not initia | Successf | Not succ | Not appli | Not initia | Successf | Not succ |
| Yes | 0.9 | 0 | 0.02 | 0 | 0.8 | 0 | 0.015 | 0 | 0 | 0 | 0.01 |
| No | 0.1 | 1 | 0.98 | 1 | 0.2 | 1 | 0.985 | 1 | 1 | 1 | 0.99 |

| C59 | No | NA | | | |
|---|---|---|---|---|---|
| C58 | Not appli | Not initia | Successf | Not succ | Not appli |
| Yes | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 |

Grounding_model_ECDIS_TANK_Final_Version

## Immediate fatalities

| C49 | No/mino | Major | Catastro | Not appli |
|---|---|---|---|---|
| Yes | 5.0E-6 | 0.0001 | 0.0005 | 0 |
| No | 0.999995 | 0.9999 | 0.9995 | 1 |

## Vessel sink/capsize

| C49 | No/mino | Major | Catastro | Not appli |
|---|---|---|---|---|
| Yes, within 30 | 0 | 0 | 0 | 0 |
| Yes, after 30 r | 0 | 0 | 0.25 | 0 |
| No | 1 | 1 | 0.75 | 0 |
| NA | 0 | 0 | 0 | 1 |

## Evacuation

| C49 | No/minor | | | | | | | | | Major | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C51 | Good | | | Moderate | | | Difficult | | | Good | |
| C52 | Good | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor | Good | Standard |
| Not initiated | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.2 | 0.2 |
| Successfully | 0.009 | 0.009 | 0.009 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.75 | 0.7 |
| Not successfu | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.05 | 0.1 |
| Not applicable | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C49 | Major | | | | | | | Catastrophic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C51 | Good | Moderate | | | Difficult | | | Good | | | Moderate |
| C52 | Poor | Good | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor | Good |
| Not initiated | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.01 | 0.01 | 0.01 | 0.01 |
| Successfully | 0.65 | 0.73 | 0.68 | 0.63 | 0.7 | 0.65 | 0.6 | 0.89 | 0.84 | 0.79 | 0.85 |
| Not successfu | 0.15 | 0.07 | 0.12 | 0.17 | 0.1 | 0.15 | 0.2 | 0.1 | 0.15 | 0.2 | 0.14 |
| Not applicable | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C49 | Catastrophic | | | | | Not applicable | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C51 | Moderate | | Difficult | | | Good | | | Moderate | | |
| C52 | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor |
| Not initiated | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| Successfully | 0.8 | 0.75 | 0.8 | 0.75 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not successfu | 0.19 | 0.24 | 0.19 | 0.24 | 0.29 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not applicable | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

| C49 | Not applicable | | |
|---|---|---|---|
| C51 | Difficult | | |
| C52 | Good | Standard | Poor |
| Not initiated | 0 | 0 | 0 |
| Successfully | 0 | 0 | 0 |
| Not successfu | 0 | 0 | 0 |
| Not applicable | 1 | 1 | 1 |

## Evac. means

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Above require | 0.5 | 0.1 | 0 |
| Fulfil requiren | 0.5 | 0.89 | 0.95 |
| Below requirel | 0 | 0.01 | 0.05 |

## Drills

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Above require | 0.2 | 0.05 | 0 |
| Fulfil requiren | 0.8 | 0.9 | 0.85 |
| Below requirel | 0 | 0.05 | 0.15 |

## Internal conditions

| C56 | Above requirements | | | Fulfil requirements | | | Below requirements | | |
|---|---|---|---|---|---|---|---|---|---|
| C57 | Above re | Fulfil req | Below re | Above re | Fulfil req | Below re | Above re | Fulfil req | Below re |
| Good | 1 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| Standard | 0 | 0.5 | 0 | 0.5 | 1 | 0 | 0 | 0 | 0 |
| Poor | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |

## External condition

| C15 | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| C13 | Good | Storm/ra | Windy | Fog | Good | Storm/ra | Windy | Fog |
| Good | 1 | 0 | 0 | 0.5 | 0.2 | 0 | 0 | 0.2 |
| Moderate | 0 | 0.1 | 0.8 | 0.5 | 0.8 | 0.05 | 0.6 | 0.8 |
| Difficult | 0 | 0.9 | 0.2 | 0 | 0 | 0.95 | 0.4 | 0 |

## Vessel damage

| C48 | Yes | | | | No | | | |
|---|---|---|---|---|---|---|---|---|
| C13 | Good | Storm/ra | Windy | Fog | Good | Storm/ra | Windy | Fog |
| No/minor | 0.92 | 0.84 | 0.9 | 0.87 | 0 | 0 | 0 | 0 |
| Major | 0.07 | 0.12 | 0.09 | 0.11 | 0 | 0 | 0 | 0 |
| Catastrophic | 0.01 | 0.04 | 0.01 | 0.02 | 0 | 0 | 0 | 0 |
| Not applicable | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

## GROUNDING

| C42 | Loss of d | No loss d |
|---|---|---|
| Yes | 1 | 0 |
| No | 0 | 1 |

## Passage planning

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Standard | 0.99 | 0.85 | 0.75 |
| Poor | 0.01 | 0.15 | 0.25 |

## Maintenance routines

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Followed | 0.95 | 0.8 | 0.4 |
| Not followed | 0.05 | 0.2 | 0.6 |

## Updating routines

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Good | 0.99 | 0.85 | 0.75 |
| Poor | 0.01 | 0.15 | 0.25 |

# Grounding_model_ECDIS_TANK_Final_Version

## Steering failure

| C41_2 | Followed | Not follov |
|---|---|---|
| Function | 0.999999 | 0.999998 |
| Not function | 9.0E−7 | 1.5E−6 |

## Loss of control

| Tug | Present | | | | Not Present | | | |
|---|---|---|---|---|---|---|---|---|
| C6_1 | Correct action | | Wrong action | | Correct action | | Wrong action | |
| C45 | Function | Not funct | Function | Not funct | Function | Not funct | Function | Not funct |
| Loss of contro | 0 | 0.2 | 0.15 | 0.15 | 0 | 1 | 1 | 1 |
| No loss of cor | 1 | 0.8 | 0.85 | 0.85 | 1 | 0 | 0 | 0 |

## Safety culture

| | |
|---|---|
| Excellent | 0.25 |
| Standard | 0.5 |
| Poor | 0.25 |

## Other ECDIS failure

| C41_2 | Followed | Not follov |
|---|---|---|
| No failure | 0.9974 | 0.99 |
| Failure | 0.0026 | 0.01 |

## GPS signal

| C41_2 | Followed | Not follov |
|---|---|---|
| Yes | 0.99938 | 0.9975 |
| No | 0.00062 | 0.0025 |

## Able to ECDIS detect

| C25 | Yes | | | | | | | | No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C30 | Yes | | | | No | | | | Yes | | |
| C39 | No failure | | Failure | | No failure | | Failure | | No failure | | Failure |
| C41_1 | Good | Poor | Good | Poor | Good | Poor | Good | Poor | Good | Poor | Good |
| Yes | 1 | 0.999 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 0 | 0.001 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C25 | No | | | | |
|---|---|---|---|---|---|
| C30 | Yes | No | | | |
| C39 | Failure | No failure | | Failure | |
| C41_1 | Poor | Good | Poor | Good | Poor |
| Yes | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 |

## ECDIS Chart detection

| C31 | High attention | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C29 | Yes | | | | | | No | | | | |
| C47 | Standard | | | Poor | | | Standard | | | Poor | |
| C44 | Yes | No | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes | No |
| Yes | 0.997 | 0.995 | 0.995 | 0.994 | 0.99 | 0.99 | 0 | 0 | 0 | 0 | 0 |
| No | 0.003 | 0.005 | 0.005 | 0.006 | 0.01 | 0.01 | 1 | 1 | 1 | 1 | 1 |

## ECDIS Chart detection

| C31 | High atte | Low attention | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C29 | No | Yes | | | | | | No | | | |
| C47 | Poor | Standard | | | Poor | | | Standard | | | Poor |
| C44 | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes |
| Yes | 0 | 0.97 | 0.95 | 0.95 | 0.94 | 0.9 | 0.9 | 0 | 0 | 0 | 0 |
| No | 1 | 0.03 | 0.05 | 0.05 | 0.06 | 0.1 | 0.1 | 1 | 1 | 1 | 1 |

| C31 | Low attention | | Not able to pay attention | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C29 | No | | Yes | | | | | | No | | |
| C47 | Poor | | Standard | | | Poor | | | Standard | | |
| C44 | No | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes | No | No, not u |
| Yes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C31 | Not able to pay attention | | |
|---|---|---|---|
| C29 | No | | |
| C47 | Poor | | |
| C44 | Yes | No | No, not u |
| Yes | 0 | 0 | 0 |
| No | 1 | 1 | 1 |

## Radar detection

| C22_1 | Yes | | | | | | No | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | High attention | | Low attention | | Not able to pay atte | | High attention | | Low attention | | Not able |
| C23 | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim |
| Yes | 0.997 | 0.995 | 0.97 | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 0.003 | 0.005 | 0.03 | 0.05 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C22_1 | No |
|---|---|
| C31 | Not able |
| C23 | No more |
| Yes | 0 |
| No | 1 |

## Able to radar detect

| C22 | Yes | | No | |
|---|---|---|---|---|
| C21 | Good | Poor | Good | Poor |
| Yes | 1 | 0.5 | 0 | 0 |
| No | 0 | 0.5 | 1 | 1 |

## Radar function

| C41_2 | Followed | Not follov |
|---|---|---|
| Yes | 0.999923 | 0.99969 |
| No | 7.7E−5 | 0.00031 |

## Signal quality

| C13 | Good | | Storm/rain | | Windy | | Fog | |
|---|---|---|---|---|---|---|---|---|
| C4 | Adjusted | Not adjus | Adjusted | Not adjus | Adjusted | Not adjus | Adjusted | Not adjus |
| Good | 0.999 | 0.99 | 0.8 | 0.5 | 1 | 0.9 | 1 | 1 |
| Poor | 0.001 | 0.01 | 0.2 | 0.5 | 0 | 0.1 | 0 | 0 |

Grounding_model_ECDIS_TANK_Final_Version

## Radar tuning

| | |
|---|---|
| Adjusted to co | 0.99 |
| Not adjusted | 0.01 |

## Familiarisation

| | |
|---|---|
| Familiar | 0.45 |
| Quite familiar | 0.45 |
| Not familiar | 0.1 |

## Visual detection

| C17 | Yes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | High attention | | | | | | Low attention | | | | |
| C20 | Familiar | | Quite familiar | | Not familiar | | Familiar | | Quite familiar | | Not fami |
| C23 | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim |
| Yes | 1 | 1 | 0.995 | 0.99 | 0.992 | 0.984 | 0.95 | 0.9 | 0.92 | 0.84 | 0.9 |
| No | 0 | 0 | 0.005 | 0.01 | 0.008 | 0.016 | 0.05 | 0.1 | 0.08 | 0.16 | 0.1 |

| C17 | Yes | | | | | | | No | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | Low atter | Not able to pay attention | | | | | | High attention | | | |
| C20 | Not fami | Familiar | | Quite familiar | | Not familiar | | Familiar | | Quite familiar | |
| C23 | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more |
| Yes | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 0.2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C17 | No | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | High attention | | Low attention | | | | | | Not able to pay attention | | |
| C20 | Not familiar | | Familiar | | Quite familiar | | Not familiar | | Familiar | | Quite far |
| C23 | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim |
| Yes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C17 | No | | |
|---|---|---|---|
| C31 | Not able to pay attention | | |
| C20 | Quite far | Not familiar | |
| C23 | No more | More tim | No more |
| Yes | 0 | 0 | 0 |
| No | 1 | 1 | 1 |

## Able to visual detect

| C14 | Adequate | | | | | | | | Reduced | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C15 | Day | | | | Night | | | | Day | | |
| C16 | Standard | | Poor | | Standard | | Poor | | Standard | | Poor |
| C40 | Good | Standard | Good | Standard | Good | Standard | Good | Standard | Good | Standard | Good |
| Yes | 1 | 0.9995 | 0.999 | 0.9985 | 0.999 | 0.9985 | 0.95 | 0.94 | 0.9 | 0.88 | 0.9 |
| No | 0 | 0.0005 | 0.001 | 0.0015 | 0.001 | 0.0015 | 0.05 | 0.06 | 0.1 | 0.12 | 0.1 |

| C14 | Reduced | | | | |
|---|---|---|---|---|---|
| C15 | Day | Night | | | |
| C16 | Poor | Standard | | Poor | |
| C40 | Standard | Good | Standard | Good | Standard |
| Yes | 0.88 | 0.8 | 0.75 | 0.8 | 0.75 |
| No | 0.12 | 0.2 | 0.25 | 0.2 | 0.25 |

Grounding_model_ECDIS_TANK_Final_Version

## Marking

| | |
|---|---|
| Standard | 0.9 |
| Poor | 0.1 |

## Day light

| | |
|---|---|
| Day | 0.5 |
| Night | 0.5 |

## Visibility

| C1 | Small | | | | Large | | | |
|---|---|---|---|---|---|---|---|---|
| C13 | Good | Storm/ra | Windy | Fog | Good | Storm/ra | Windy | Fog |
| Adequate | 1 | 0.75 | 1 | 0 | 1 | 0.65 | 1 | 0 |
| Reduced | 0 | 0.25 | 0 | 1 | 0 | 0.35 | 0 | 1 |

## Weather

| | |
|---|---|
| Good | 0.6 |
| Storm/rain | 0.15 |
| Windy | 0.2 |
| Fog | 0.05 |

## VTS presence

| | |
|---|---|
| Yes | 0.1 |
| No | 0.9 |

## VTS vigilance

| C12 | Yes | No |
|---|---|---|
| Yes | 0.2 | 0 |
| No | 0.8 | 1 |

## Vigilence

| Tug_Vigilance | Yes | | | | No | | | |
|---|---|---|---|---|---|---|---|---|
| C12_1 | Yes | | No | | Yes | | No | |
| C11 | Yes | No | Yes | No | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

## Task responsibilities

| C3 | BRM sys | No BRM s |
|---|---|---|
| Clear respons | 0.99 | 0.97 |
| Unclear respo | 0.01 | 0.03 |

## Communication level

| C3 | BRM sys | No BRM s |
|---|---|---|
| Beyond standa | 0.45 | 0.2 |
| Standard | 0.5 | 0.6 |
| Substandard | 0.05 | 0.2 |

Grounding_model_ECDIS_TANK_Final_Version

## Pilot vigilance

| C20 | Familiar | | | | | | Quite familiar | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C8 | Beyond standard | | Standard | | Substandard | | Beyond standard | | Standard | | Substand |
| C9 | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res |
| Able to correc | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not able to co | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No pilot | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C20 | Quite far | Not familiar | | | | | |
|---|---|---|---|---|---|---|---|
| C8 | Substand | Beyond standard | | Standard | | Substandard | |
| C9 | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r |
| Able to correc | 0 | 0.9 | 0.85 | 0.85 | 0.8 | 0.7 | 0.65 |
| Not able to co | 0 | 0.1 | 0.15 | 0.15 | 0.2 | 0.3 | 0.35 |
| No pilot | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

## Action

| C10 | Yes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C6 | Correct | | | | Wrong | | | | No assessment | | |
| C27 | Excellent | Standard | Poor | Not able | Excellent | Standard | Poor | Not able | Excellent | Standard | Poor |
| Correct action | 0.999996 | 0.999992 | 0.99998 | 0.999983 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| Wrong action | 4.0E−6 | 8.0E−6 | 2.0E−5 | 1.7E−5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 |

| C10 | Yes | No | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C6 | No asses | Correct | | | | Wrong | | | | No assessment | |
| C27 | Not able | Excellent | Standard | Poor | Not able | Excellent | Standard | Poor | Not able | Excellent | Standard |
| Correct action | 0 | 0.999992 | 0.999984 | 0.99992 | 0 | 0 | 0 | 0 | 0 | 0 | 0.499957 |
| Wrong action | 1 | 8.0E−6 | 1.6E−5 | 8.0E−5 | 1 | 1 | 1 | 1 | 1 | 1 | 0.500043 |

| C10 | No | |
|---|---|---|
| C6 | No assessment | |
| C27 | Poor | Not able |
| Correct action | 0 | 0 |
| Wrong action | 1 | 1 |

## Assessment

| C46 | Yes | | | | | | | | No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C27 | Excellent | | Standard | | Poor | | Not able to perform | | Excellent | | Standard |
| C10 | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Correct | 0.999988 | 0.999985 | 0.999984 | 0.99998 | 0.999968 | 0.99996 | 0.95 | 0 | 0.98 | 0 | 0.97 |
| Wrong | 1.2E−5 | 1.5E−5 | 1.6E−5 | 2.0E−5 | 3.2E−5 | 4.0E−5 | 0.05 | 0 | 0.02 | 0 | 0.03 |
| No assessme | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

| C46 | No | | | | |
|---|---|---|---|---|---|
| C27 | Standard | Poor | | Not able to perform | |
| C10 | No | Yes | No | Yes | No |
| Correct | 0 | 0.95 | 0 | 0.95 | 0 |
| Wrong | 0 | 0.05 | 0 | 0.05 | 0 |
| No assessme | 1 | 0 | 1 | 0 | 1 |

# Grounding_model_ECDIS_TANK_Final_Version

## Nav syst detection (1)

| C28 | Yes | | | | No | | | |
|---|---|---|---|---|---|---|---|---|
| C24 | Yes | | No | | Yes | | No | |
| C26 | Yes | No | Yes | No | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

## BRM

| | |
|---|---|
| BRM system e | 0.2 |
| No BRM syste | 0.8 |

## Attention

| C2 | Low level of distr | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Fit | | | | | | Unfit | | | | |
| C32 | Standard | | Beyond standard | | Below standard | | Standard | | Beyond standard | | Below sta |
| C3 | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys |
| High attention | 0.95 | 0.85 | 0.98 | 0.94 | 0.92 | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Low attention | 0.05 | 0.15 | 0.02 | 0.06 | 0.08 | 0.2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Not able to pa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C2 | Low level of distr | | | | | | | Moderate level of distr | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Unfit | Not able to perform | | | | | | Fit | | | |
| C32 | Below sta | Standard | | Beyond standard | | Below standard | | Standard | | Beyond standard | |
| C3 | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s |
| High attention | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.95 | 0.85 | 0.98 | 0.94 |
| Low attention | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.05 | 0.15 | 0.02 | 0.06 |
| Not able to pa | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

| C2 | Moderate level of distr | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Fit | | Unfit | | | | | | Not able to perform | | |
| C32 | Below standard | | Standard | | Beyond standard | | Below standard | | Standard | | Beyond s |
| C3 | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys |
| High attention | 0.92 | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| Low attention | 0.08 | 0.2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| Not able to pa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

| C2 | Moderate level of distr | | | High level of distr | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Not able to perform | | | Fit | | | | | | Unfit | |
| C32 | Beyond s | Below standard | | Standard | | Beyond standard | | Below standard | | Standard | |
| C3 | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s |
| High attention | 0 | 0 | 0 | 0.8 | 0.6 | 0.92 | 0.8 | 0.4 | 0.4 | 0.4 | 0.4 |
| Low attention | 0 | 0 | 0 | 0.2 | 0.4 | 0.08 | 0.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| Not able to pa | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C2 | High level of distr | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Unfit | | | | Not able to perform | | | | | |
| C32 | Beyond standard | | Below standard | | Standard | | Beyond standard | | Below standard | |
| C3 | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s |
| High attention | 0.4 | 0.4 | 0.4 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Low attention | 0.6 | 0.6 | 0.6 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not able to pa | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

# Grounding_model_ECDIS_TANK_Final_Version

## Bridge design

| | |
|---|---|
| Standard | 0.470588 |
| Beyond standa | 0.058824 |
| Below standar | 0.470588 |

## Performance

| C36 | Fit | | | | | | | | | Unfit | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | | | Standard | | | Low | | | Excellent | |
| C32 | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s |
| Excellent | 0.93 | 0.95 | 0.9 | 0.7 | 0.75 | 0.65 | 0.3 | 0.35 | 0.25 | 0 | 0 |
| Standard | 0.07 | 0.05 | 0.1 | 0.3 | 0.25 | 0.35 | 0.6 | 0.55 | 0.65 | 0.5 | 0.5 |
| Poor | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.5 | 0.5 |
| Not able to pe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C36 | Unfit | | | | | | | Not able to perform | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | Standard | | | Low | | | Excellent | | | Standard |
| C32 | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard |
| Excellent | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Standard | 0.5 | 0.4 | 0.4 | 0.4 | 0.2 | 0.2 | 0.2 | 0 | 0 | 0 | 0 |
| Poor | 0.5 | 0.6 | 0.6 | 0.6 | 0.8 | 0.8 | 0.8 | 0 | 0 | 0 | 0 |
| Not able to pe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

| C36 | Not able to perform | | | | |
|---|---|---|---|---|---|
| C34 | Standard | | Low | | |
| C32 | Beyond s | Below sta | Standard | Beyond s | Below sta |
| Excellent | 0 | 0 | 0 | 0 | 0 |
| Standard | 0 | 0 | 0 | 0 | 0 |
| Poor | 0 | 0 | 0 | 0 | 0 |
| Not able to pe | 1 | 1 | 1 | 1 | 1 |

## Personal condition

| C18 | Capable | | | | Reduced capability | | | | Incapable | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C33 | High | | Standard | | High | | Standard | | High | | Standard |
| C37 | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Fit | 0.7 | 0.9 | 0.9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unfit | 0.3 | 0.1 | 0.1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Not able to pe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

| C18 | Incapable |
|---|---|
| C33 | Standard |
| C37 | No |
| Fit | 0 |
| Unfit | 0 |
| Not able to pe | 1 |

## Tired

| C38 | Normal (\ | High (wa |
|---|---|---|
| Yes | 0.05 | 0.1 |
| No | 0.95 | 0.9 |

# Grounding_model_ECDIS_TANK_Final_Version

## Stress level

| C2 | Low level of distr | | | | | | | | | Moderate level of d | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | | | Standard | | | Low | | | Excellent | |
| C20 | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far |
| High | 0.02 | 0.03 | 0.1 | 0.03 | 0.05 | 0.15 | 0.1 | 0.2 | 0.3 | 0.05 | 0.07 |
| Standard | 0.98 | 0.97 | 0.9 | 0.97 | 0.95 | 0.85 | 0.9 | 0.8 | 0.7 | 0.95 | 0.93 |

| C2 | Moderate level of distr | | | | | | | High level of distr | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | Standard | | | Low | | | Excellent | | | Standard |
| C20 | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar |
| High | 0.15 | 0.08 | 0.1 | 0.15 | 0.2 | 0.3 | 0.5 | 0.5 | 0.6 | 0.7 | 0.6 |
| Standard | 0.85 | 0.92 | 0.9 | 0.85 | 0.8 | 0.7 | 0.5 | 0.5 | 0.4 | 0.3 | 0.4 |

| C2 | High level of distr | | | | |
|---|---|---|---|---|---|
| C34 | Standard | | Low | | |
| C20 | Quite far | Not fami | Familiar | Quite far | Not fami |
| High | 0.7 | 0.9 | 0.7 | 0.9 | 1 |
| Standard | 0.3 | 0.1 | 0.3 | 0.1 | 0 |

## Competence

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Excellent | 0.6 | 0.3 | 0.05 |
| Standard | 0.4 | 0.65 | 0.5 |
| Low | 0 | 0.05 | 0.45 |

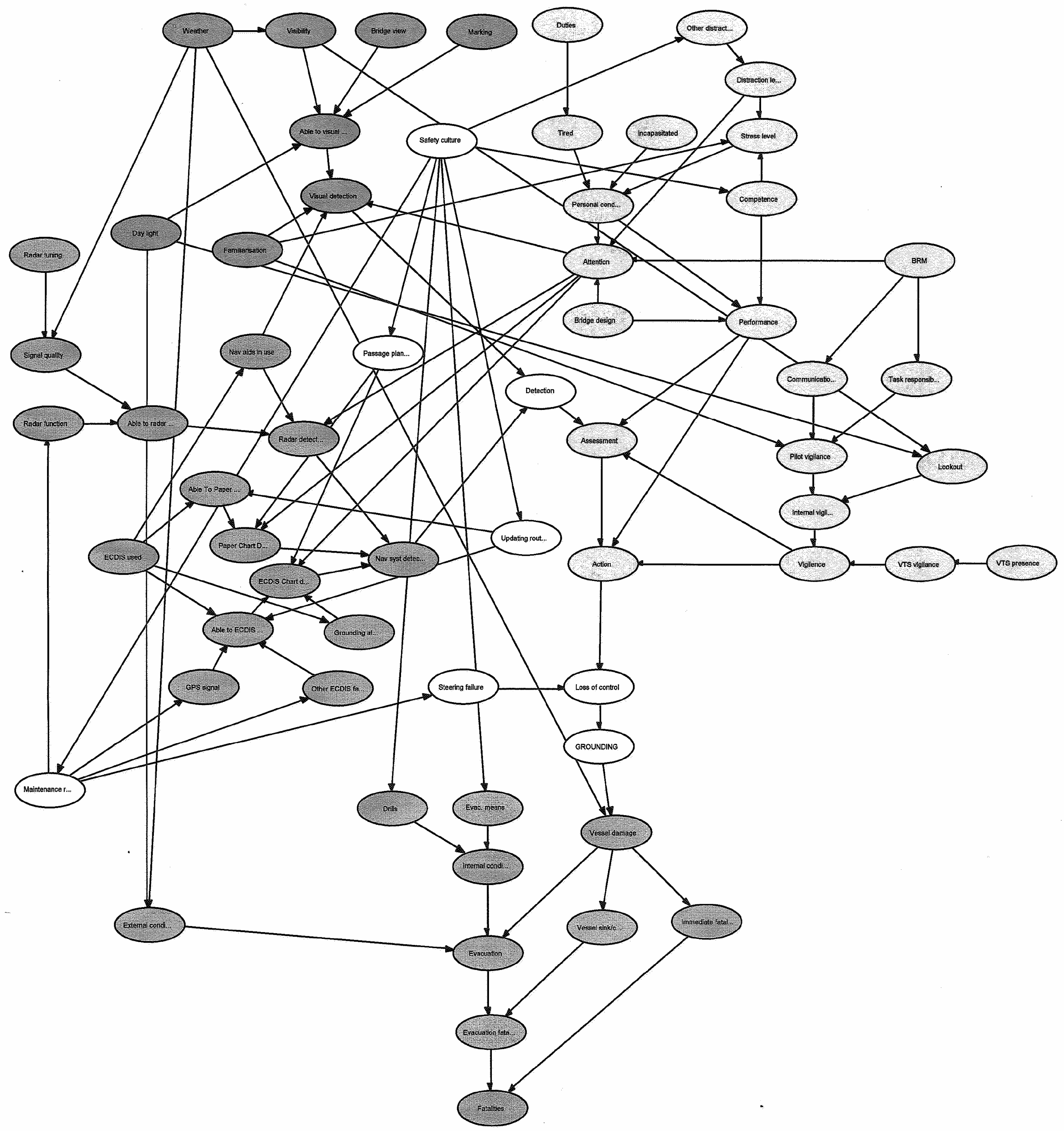
## Other distractions

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Few | 0.99 | 0.85 | 0.75 |
| Many | 0.01 | 0.15 | 0.25 |

## Incapasitated

| | |
|---|---|
| Capable | 0.99992 |
| Reduced capa | 2.99991E |
| Incapable | 4.99985E |

# ANNEX I – Appendix A Bulk Model



Grounding_model_ECDIS_BULK_Final_Version

## Paper Chart Detection

| C31 | High attention | | | | Low attention | | | | Not able to pay attention | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C5 | Yes | | No | | Yes | | No | | Yes | | No |
| C47 | Standard | Poor | Standard | Poor | Standard | Poor | Standard | Poor | Standard | Poor | Standard |
| Yes | 0.9975 | 0.996 | 0 | 0 | 0.94 | 0.89 | 0 | 0 | 0 | 0 | 0 |
| No | 0.0025 | 0.004 | 1 | 1 | 0.06 | 0.11 | 1 | 1 | 1 | 1 | 1 |

| C31 | Not able |
|---|---|
| C5 | No |
| C47 | Poor |
| Yes | 0 |
| No | 1 |

## Able To Paper Chart Detect

| C25 | Yes | | No | |
|---|---|---|---|---|
| C41_1 | Good | Poor | Good | Poor |
| Yes | 0 | 0 | 0.999 | 0.95 |
| No | 1 | 1 | 0.001 | 0.05 |

## Lookout

| C15 | Day | | Night | |
|---|---|---|---|---|
| C14 | Adequate | Reduced | Adequate | Reduced |
| Yes | 0.05 | 0.5 | 0.8 | 1 |
| No | 0.95 | 0.5 | 0.2 | 0 |

## Detection

| C4_1 | Yes | | No | |
|---|---|---|---|---|
| C19 | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 1 |

## Bridge view

| | |
|---|---|
| Good | 0.3 |
| Standard | 0.7 |

## Grounding alarm

| C25 | Yes | No |
|---|---|---|
| Yes | 0.8999 | 0 |
| No | 0.0001 | 1 |
| No, not used/i | 0.1 | 0 |

## ECDIS used

| | |
|---|---|
| Yes | 1 |
| No | 1.0E−10 |

## Nav aids in use

| C25 | Yes | No |
|---|---|---|
| More time to c | 1 | 0 |
| No more time | 0 | 1 |

## Distraction level

| C35 | Few | Many |
|---|---|---|
| Low level of d | 1 | 0.7 |
| Moderate leve | 0 | 0.3 |
| High level of c | 0 | 0 |

## Duties

| | |
|---|---|
| Normal (watch | 0.6 |
| High (watch + | 0.4 |

## Internal vigilance

| C43 | Yes | | | No | | |
|---|---|---|---|---|---|---|
| C7 | Able to c | Not able | No pilot | Able to c | Not able | No pilot |
| Yes | 1 | 1 | 1 | 1 | 0 | 0 |
| No | 0 | 0 | 0 | 0 | 1 | 1 |

## Fatalities

| C63 | Yes | | No | |
|---|---|---|---|---|
| C60 | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 1 |

## Evacuation fatalities

| C59 | Yes, within 30 min | | | | Yes, after 30 min | | | | No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C58 | Not initia | Successf | Not succ | Not appli | Not initia | Successf | Not succ | Not appli | Not initia | Successf | Not succ |
| Yes | 0.9 | 0 | 0.02 | 0 | 0.8 | 0 | 0.015 | 0 | 0 | 0 | 0.01 |
| No | 0.1 | 1 | 0.98 | 1 | 0.2 | 1 | 0.985 | 1 | 1 | 1 | 0.99 |

| C59 | No | NA | | | |
|---|---|---|---|---|---|
| C58 | Not appli | Not initia | Successf | Not succ | Not appli |
| Yes | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 |

## Immediate fatalities

| C49 | No/mino | Major | Catastro | Not appli |
|---|---|---|---|---|
| Yes | 5.0E-6 | 0.0001 | 0.0005 | 0 |
| No | 0.999995 | 0.9999 | 0.9995 | 1 |

## Vessel sink/capsize

| C49 | No/mino | Major | Catastro | Not appli |
|---|---|---|---|---|
| Yes, within 30 | 0 | 0 | 0.1 | 0 |
| Yes, after 30 r | 0 | 0 | 0.15 | 0 |
| No | 1 | 1 | 0.75 | 0 |
| NA | 0 | 0 | 0 | 1 |

## Evacuation

| C49 | No/minor | | | | | | | | | Major | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C51 | Good | | | Moderate | | | Difficult | | | Good | |
| C52 | Good | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor | Good | Standard |
| Not initiated | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.2 | 0.2 |
| Successfully | 0.009 | 0.009 | 0.009 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.75 | 0.7 |
| Not successfu | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.05 | 0.1 |
| Not applicable | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C49 | Major | | | | | | | Catastrophic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C51 | Good | Moderate | | | Difficult | | | Good | | | Moderate |
| C52 | Poor | Good | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor | Good |
| Not initiated | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.01 | 0.01 | 0.01 | 0.01 |
| Successfully | 0.65 | 0.73 | 0.68 | 0.63 | 0.7 | 0.65 | 0.6 | 0.89 | 0.84 | 0.79 | 0.85 |
| Not successfu | 0.15 | 0.07 | 0.12 | 0.17 | 0.1 | 0.15 | 0.2 | 0.1 | 0.15 | 0.2 | 0.14 |
| Not applicable | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C49 | Catastrophic | | | | | Not applicable | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C51 | Moderate | | Difficult | | | Good | | | Moderate | | |
| C52 | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor | Good | Standard | Poor |
| Not initiated | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| Successfully | 0.8 | 0.75 | 0.8 | 0.75 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not successfu | 0.19 | 0.24 | 0.19 | 0.24 | 0.29 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not applicable | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

| C49 | Not applicable | | |
|---|---|---|---|
| C51 | Difficult | | |
| C52 | Good | Standard | Poor |
| Not initiated | 0 | 0 | 0 |
| Successfully | 0 | 0 | 0 |
| Not successfu | 0 | 0 | 0 |
| Not applicable | 1 | 1 | 1 |

## Evac. means

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Above require | 0.5 | 0.1 | 0 |
| Fulfil requiren | 0.5 | 0.89 | 0.95 |
| Below requirei | 0 | 0.01 | 0.05 |

## Drills

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Above require | 0.2 | 0.05 | 0 |
| Fulfil requiren | 0.8 | 0.9 | 0.85 |
| Below requirei | 0 | 0.05 | 0.15 |

## Internal conditions

| C56 | Above requirements | | | Fulfil requirements | | | Below requirements | | |
|---|---|---|---|---|---|---|---|---|---|
| C57 | Above re | Fulfil req | Below re | Above re | Fulfil req | Below re | Above re | Fulfil req | Below re |
| Good | 1 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| Standard | 0 | 0.5 | 0 | 0.5 | 1 | 0 | 0 | 0 | 0 |
| Poor | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |

Grounding_model_ECDIS_BULK_Final_Version

## External condition

| C15 | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| C13 | Good | Storm/ra | Windy | Fog | Good | Storm/ra | Windy | Fog |
| Good | 1 | 0 | 0 | 0.5 | 0.2 | 0 | 0 | 0.2 |
| Moderate | 0 | 0.1 | 0.8 | 0.5 | 0.8 | 0.05 | 0.6 | 0.8 |
| Difficult | 0 | 0.9 | 0.2 | 0 | 0 | 0.95 | 0.4 | 0 |

## Vessel damage

| C48 | Yes | | | | No | | | |
|---|---|---|---|---|---|---|---|---|
| C13 | Good | Storm/ra | Windy | Fog | Good | Storm/ra | Windy | Fog |
| No/minor | 0.76 | 0.56 | 0.7 | 0.61 | 0 | 0 | 0 | 0 |
| Major | 0.21 | 0.36 | 0.27 | 0.33 | 0 | 0 | 0 | 0 |
| Catastrophic | 0.03 | 0.08 | 0.03 | 0.06 | 0 | 0 | 0 | 0 |
| Not applicable | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

## GROUNDING

| C42 | Loss of c | No loss c |
|---|---|---|
| Yes | 1 | 0 |
| No | 0 | 1 |

## Passage planning

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Standard | 0.99 | 0.85 | 0.75 |
| Poor | 0.01 | 0.15 | 0.25 |

## Maintenance routines

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Followed | 0.9 | 0.8 | 0.6 |
| Not followed | 0.1 | 0.2 | 0.4 |

## Updating routines

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Good | 0.99 | 0.85 | 0.75 |
| Poor | 0.01 | 0.15 | 0.25 |

## Steering failure

| C41_2 | Followed | Not follov |
|---|---|---|
| Function | 0.999999 | 0.999998 |
| Not function | 9.0E−7 | 1.5E−6 |

## Loss of control

| C6_1 | Correct action | | Wrong action | |
|---|---|---|---|---|
| C45 | Function | Not funct | Function | Not funct |
| Loss of contrc | 0 | 1 | 1 | 1 |
| No loss of cor | 1 | 0 | 0 | 0 |

# Grounding_model_ECDIS_BULK_Final_Version

## Safety culture

| | |
|---|---|
| Excellent | 0.1 |
| Standard | 0.5 |
| Poor | 0.4 |

## Other ECDIS failure

| C41_2 | Followed | Not follow |
|---|---|---|
| No failure | 0.9974 | 0.99 |
| Failure | 0.0026 | 0.01 |

## GPS signal

| C41_2 | Followed | Not follow |
|---|---|---|
| Yes | 0.99938 | 0.9975 |
| No | 0.00062 | 0.0025 |

## Able to ECDIS detect

| C25 | Yes | | | | | | | | No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C30 | Yes | | | | No | | | | Yes | | |
| C39 | No failure | | Failure | | No failure | | Failure | | No failure | | Failure |
| C41_1 | Good | Poor | Good | Poor | Good | Poor | Good | Poor | Good | Poor | Good |
| Yes | 1 | 0.999 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 0 | 0.001 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C25 | No | | | | |
|---|---|---|---|---|---|
| C30 | Yes | No | | | |
| C39 | Failure | No failure | | Failure | |
| C41_1 | Poor | Good | Poor | Good | Poor |
| Yes | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 |

## ECDIS Chart detection

| C31 | High attention | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C29 | Yes | | | | | | No | | | | |
| C47 | Standard | | | Poor | | | Standard | | | Poor | |
| C44 | Yes | No | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes | No |
| Yes | 0.997 | 0.995 | 0.995 | 0.994 | 0.99 | 0.99 | 0 | 0 | 0 | 0 | 0 |
| No | 0.003 | 0.005 | 0.005 | 0.006 | 0.01 | 0.01 | 1 | 1 | 1 | 1 | 1 |

| C31 | High atte | Low attention | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C29 | No | Yes | | | | | | No | | | |
| C47 | Poor | Standard | | | Poor | | | Standard | | | Poor |
| C44 | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes |
| Yes | 0 | 0.97 | 0.95 | 0.95 | 0.94 | 0.9 | 0.9 | 0 | 0 | 0 | 0 |
| No | 1 | 0.03 | 0.05 | 0.05 | 0.06 | 0.1 | 0.1 | 1 | 1 | 1 | 1 |

| C31 | Low attention | | Not able to pay attention | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C29 | No | | Yes | | | | | | No | | |
| C47 | Poor | | Standard | | | Poor | | | Standard | | |
| C44 | No | No, not u | Yes | No | No, not u | Yes | No | No, not u | Yes | No | No, not u |
| Yes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Grounding_model_ECDIS_BULK_Final_Version

## ECDIS Chart detection

| C31 | Not able to pay attention | | |
|---|---|---|---|
| C29 | No | | |
| C47 | Poor | | |
| C44 | Yes | No | No, not u |
| Yes | 0 | 0 | 0 |
| No | 1 | 1 | 1 |

## Radar detection

| C22_1 | Yes | | | | | | No | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | High attention | | Low attention | | Not able to pay atte | | High attention | | Low attention | | Not able |
| C23 | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim |
| Yes | 0.997 | 0.995 | 0.97 | 0.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 0.003 | 0.005 | 0.03 | 0.05 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C22_1 | No |
|---|---|
| C31 | Not able |
| C23 | No more |
| Yes | 0 |
| No | 1 |

## Able to radar detect

| C22 | Yes | | No | |
|---|---|---|---|---|
| C21 | Good | Poor | Good | Poor |
| Yes | 1 | 0.5 | 0 | 0 |
| No | 0 | 0.5 | 1 | 1 |

## Radar function

| C41_2 | Followed | Not follov |
|---|---|---|
| Yes | 0.999923 | 0.99969 |
| No | 7.7E−5 | 0.00031 |

## Signal quality

| C13 | Good | | Storm/rain | | Windy | | Fog | |
|---|---|---|---|---|---|---|---|---|
| C4 | Adjusted | Not adjus | Adjusted | Not adjus | Adjusted | Not adjus | Adjusted | Not adjus |
| Good | 0.999 | 0.99 | 0.8 | 0.5 | 1 | 0.9 | 1 | 1 |
| Poor | 0.001 | 0.01 | 0.2 | 0.5 | 0 | 0.1 | 0 | 0 |

## Radar tuning

| | |
|---|---|
| Adjusted to co | 0.99 |
| Not adjusted | 0.01 |

## Familiarisation

| | |
|---|---|
| Familiar | 0.45 |
| Quite familiar | 0.45 |
| Not familiar | 0.1 |

Grounding_model_ECDIS_BULK_Final_Version

## Visual detection

| C17 | Yes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | High attention | | | | | | Low attention | | | | |
| C20 | Familiar | | Quite familiar | | Not familiar | | Familiar | | Quite familiar | | Not fami |
| C23 | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim |
| Yes | 1 | 1 | 0.995 | 0.99 | 0.992 | 0.984 | 0.95 | 0.9 | 0.92 | 0.84 | 0.9 |
| No | 0 | 0 | 0.005 | 0.01 | 0.008 | 0.016 | 0.05 | 0.1 | 0.08 | 0.16 | 0.1 |

| C17 | Yes | | | | | | | No | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | Low atter | Not able to pay attention | | | | | | High attention | | | |
| C20 | Not fami | Familiar | | Quite familiar | | Not familiar | | Familiar | | Quite familiar | |
| C23 | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more |
| Yes | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 0.2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C17 | No | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C31 | High attention | | Low attention | | | | | | Not able to pay attention | | |
| C20 | Not familiar | | Familiar | | Quite familiar | | Not familiar | | Familiar | | Quite far |
| C23 | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim | No more | More tim |
| Yes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| C17 | No | | |
|---|---|---|---|
| C31 | Not able to pay attention | | |
| C20 | Quite far | Not familiar | |
| C23 | No more | More tim | No more |
| Yes | 0 | 0 | 0 |
| No | 1 | 1 | 1 |

## Able to visual detect

| C14 | Adequate | | | | | | | | Reduced | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C15 | Day | | | | Night | | | | Day | | |
| C16 | Standard | | Poor | | Standard | | Poor | | Standard | | Poor |
| C40 | Good | Standard | Good | Standard | Good | Standard | Good | Standard | Good | Standard | Good |
| Yes | 1 | 0.9995 | 0.999 | 0.9985 | 0.999 | 0.9985 | 0.95 | 0.94 | 0.9 | 0.88 | 0.9 |
| No | 0 | 0.0005 | 0.001 | 0.0015 | 0.001 | 0.0015 | 0.05 | 0.06 | 0.1 | 0.12 | 0.1 |

| C14 | Reduced | | | | |
|---|---|---|---|---|---|
| C15 | Day | Night | | | |
| C16 | Poor | Standard | | Poor | |
| C40 | Standard | Good | Standard | Good | Standard |
| Yes | 0.88 | 0.8 | 0.75 | 0.8 | 0.75 |
| No | 0.12 | 0.2 | 0.25 | 0.2 | 0.25 |

## Marking

| | |
|---|---|
| Standard | 0.9 |
| Poor | 0.1 |

## Day light

| | |
|---|---|
| Day | 0.5 |
| Night | 0.5 |

# Grounding_model_ECDIS_BULK_Final_Version

## Visibility

| C13 | Good | Storm/ra | Windy | Fog |
|---|---|---|---|---|
| Adequate | 1 | 0.75 | 1 | 0 |
| Reduced | 0 | 0.25 | 0 | 1 |

## Weather

| | |
|---|---|
| Good | 0.6 |
| Storm/rain | 0.15 |
| Windy | 0.2 |
| Fog | 0.05 |

## VTS presence

| | |
|---|---|
| Yes | 0.1 |
| No | 0.9 |

## VTS vigilance

| C12 | Yes | No |
|---|---|---|
| Yes | 0.2 | 0 |
| No | 0.8 | 1 |

## Vigilence

| C12_1 | Yes | | No | |
|---|---|---|---|---|
| C11 | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 1 |

## Task responsibilities

| C3 | BRM sys | No BRM s |
|---|---|---|
| Clear respons | 0.99 | 0.97 |
| Unclear respo | 0.01 | 0.03 |

## Communication level

| C3 | BRM sys | No BRM s |
|---|---|---|
| Beyond standa | 0.45 | 0.2 |
| Standard | 0.5 | 0.6 |
| Substandard | 0.05 | 0.2 |

## Pilot vigilance

| C20 | Familiar | | | | | | Quite familiar | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C8 | Beyond standard | | Standard | | Substandard | | Beyond standard | | Standard | | Substand |
| C9 | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res |
| Able to correc | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not able to co | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No pilot | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Grounding_model_ECDIS_BULK_Final_Version

## Pilot vigilance

| C20 | Quite far | Not familiar | | | | | |
|---|---|---|---|---|---|---|---|
| C8 | Substand | Beyond standard | | Standard | | Substandard | |
| C9 | Unclear r | Clear res | Unclear r | Clear res | Unclear r | Clear res | Unclear r |
| Able to correc | 0 | 0.9 | 0.85 | 0.85 | 0.8 | 0.7 | 0.65 |
| Not able to co | 0 | 0.1 | 0.15 | 0.15 | 0.2 | 0.3 | 0.35 |
| No pilot | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

## Action

| C10 | Yes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C6 | Correct | | | | Wrong | | | | No assessment | | |
| C27 | Excellent | Standard | Poor | Not able | Excellent | Standard | Poor | Not able | Excellent | Standard | Poor |
| Correct action | 0.999996 | 0.999992 | 0.99998 | 0.999983 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| Wrong action | 4.0E−6 | 8.0E−6 | 2.0E−5 | 1.7E−5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 |

| C10 | Yes | No | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C6 | No asses | Correct | | | | Wrong | | | | No assessment | |
| C27 | Not able | Excellent | Standard | Poor | Not able | Excellent | Standard | Poor | Not able | Excellent | Standard |
| Correct action | 0 | 0.999992 | 0.999984 | 0.99992 | 0 | 0 | 0 | 0 | 0 | 0 | 0.499957 |
| Wrong action | 1 | 8.0E−6 | 1.6E−5 | 8.0E−5 | 1 | 1 | 1 | 1 | 1 | 1 | 0.500043 |

| C10 | No | |
|---|---|---|
| C6 | No assessment | |
| C27 | Poor | Not able |
| Correct action | 0 | 0 |
| Wrong action | 1 | 1 |

## Assessment

| C46 | Yes | | | | | | | | No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C27 | Excellent | | Standard | | Poor | | Not able to perform | | Excellent | | Standard |
| C10 | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Correct | 0.999988 | 0.999985 | 0.999984 | 0.99998 | 0.999968 | 0.99996 | 0.95 | 0 | 0.98 | 0 | 0.97 |
| Wrong | 1.2E−5 | 1.5E−5 | 1.6E−5 | 2.0E−5 | 3.2E−5 | 4.0E−5 | 0.05 | 0 | 0.02 | 0 | 0.03 |
| No assessme | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

| C46 | No | | | | |
|---|---|---|---|---|---|
| C27 | Standard | Poor | | Not able to perform | |
| C10 | No | Yes | No | Yes | No |
| Correct | 0 | 0.95 | 0 | 0.95 | 0 |
| Wrong | 0 | 0.05 | 0 | 0.05 | 0 |
| No assessme | 1 | 0 | 1 | 0 | 1 |

## Nav syst detection (1)

| C28 | Yes | | | | No | | | |
|---|---|---|---|---|---|---|---|---|
| C24 | Yes | | No | | Yes | | No | |
| C26 | Yes | No | Yes | No | Yes | No | Yes | No |
| Yes | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| No | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

## BRM

| | |
|---|---|
| BRM system e | 0.2 |
| No BRM syste | 0.8 |

# Grounding_model_ECDIS_BULK_Final_Version

## Attention

| C2 | Low level of distr | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Fit | | | | | | Unfit | | | | |
| C32 | Standard | | Beyond standard | | Below standard | | Standard | | Beyond standard | | Below sta |
| C3 | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys |
| High attention | 0.95 | 0.85 | 0.98 | 0.94 | 0.92 | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Low attention | 0.05 | 0.15 | 0.02 | 0.06 | 0.08 | 0.2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Not able to pa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C2 | Low level of distr | | | | | | | Moderate level of distr | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Unfit | Not able to perform | | | | | | Fit | | | |
| C32 | Below sta | Standard | | Beyond standard | | Below standard | | Standard | | Beyond standard | |
| C3 | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s |
| High attention | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.95 | 0.85 | 0.98 | 0.94 |
| Low attention | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.05 | 0.15 | 0.02 | 0.06 |
| Not able to pa | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

| C2 | Moderate level of distr | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Fit | | Unfit | | | | | | Not able to perform | | |
| C32 | Below standard | | Standard | | Beyond standard | | Below standard | | Standard | | Beyond s |
| C3 | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys |
| High attention | 0.92 | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| Low attention | 0.08 | 0.2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| Not able to pa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

| C2 | Moderate level of distr | | | High level of distr | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Not able to perform | | | Fit | | | | | | Unfit | |
| C32 | Beyond s | Below standard | | Standard | | Beyond standard | | Below standard | | Standard | |
| C3 | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s |
| High attention | 0 | 0 | 0 | 0.8 | 0.6 | 0.92 | 0.8 | 0.4 | 0.4 | 0.4 | 0.4 |
| Low attention | 0 | 0 | 0 | 0.2 | 0.4 | 0.08 | 0.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| Not able to pa | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C2 | High level of distr | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C36 | Unfit | | | | Not able to perform | | | | | |
| C32 | Beyond standard | | Below standard | | Standard | | Beyond standard | | Below standard | |
| C3 | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s | BRM sys | No BRM s |
| High attention | 0.4 | 0.4 | 0.4 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Low attention | 0.6 | 0.6 | 0.6 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Not able to pa | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

## Bridge design

| | |
|---|---|
| Standard | 0.470588 |
| Beyond standa | 0.058824 |
| Below standar | 0.470588 |

Fri Jan 06 13:01:51 CET 2006

# Grounding_model_ECDIS_BULK_Final_Version

## Performance

| C36 | Fit | | | | | | | | | Unfit | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | | | Standard | | | Low | | | Excellent | |
| C32 | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s |
| Excellent | 0.93 | 0.95 | 0.9 | 0.7 | 0.75 | 0.65 | 0.3 | 0.35 | 0.25 | 0 | 0 |
| Standard | 0.07 | 0.05 | 0.1 | 0.3 | 0.25 | 0.35 | 0.6 | 0.55 | 0.65 | 0.5 | 0.5 |
| Poor | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.5 | 0.5 |
| Not able to pe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| C36 | Unfit | | | | | | | Not able to perform | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | Standard | | | Low | | | Excellent | | | Standard |
| C32 | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard | Beyond s | Below sta | Standard |
| Excellent | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Standard | 0.5 | 0.4 | 0.4 | 0.4 | 0.2 | 0.2 | 0.2 | 0 | 0 | 0 | 0 |
| Poor | 0.5 | 0.6 | 0.6 | 0.6 | 0.8 | 0.8 | 0.8 | 0 | 0 | 0 | 0 |
| Not able to pe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

| C36 | Not able to perform | | | | |
|---|---|---|---|---|---|
| C34 | Standard | | Low | | |
| C32 | Beyond s | Below sta | Standard | Beyond s | Below sta |
| Excellent | 0 | 0 | 0 | 0 | 0 |
| Standard | 0 | 0 | 0 | 0 | 0 |
| Poor | 0 | 0 | 0 | 0 | 0 |
| Not able to pe | 1 | 1 | 1 | 1 | 1 |

## Personal condition

| C18 | Capable | | | | Reduced capability | | | | Incapable | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C33 | High | | Standard | | High | | Standard | | High | | Standard |
| C37 | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Fit | 0.7 | 0.9 | 0.9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unfit | 0.3 | 0.1 | 0.1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Not able to pe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

| C18 | Incapable |
|---|---|
| C33 | Standard |
| C37 | No |
| Fit | 0 |
| Unfit | 0 |
| Not able to pe | 1 |

## Tired

| C38 | Normal (v | High (wat |
|---|---|---|
| Yes | 0.05 | 0.1 |
| No | 0.95 | 0.9 |

## Stress level

| C2 | Low level of distr | | | | | | | | | Moderate level of d | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | | | Standard | | | Low | | | Excellent | |
| C20 | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far |
| High | 0.02 | 0.03 | 0.1 | 0.03 | 0.05 | 0.15 | 0.1 | 0.2 | 0.3 | 0.05 | 0.07 |
| Standard | 0.98 | 0.97 | 0.9 | 0.97 | 0.95 | 0.85 | 0.9 | 0.8 | 0.7 | 0.95 | 0.93 |

# Grounding_model_ECDIS_BULK_Final_Version

## Stress level

| C2 | Moderate level of distr | | | | | | | High level of distr | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C34 | Excellent | Standard | | | Low | | | Excellent | | | Standard |
| C20 | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar | Quite far | Not fami | Familiar |
| High | 0.15 | 0.08 | 0.1 | 0.15 | 0.2 | 0.3 | 0.5 | 0.5 | 0.6 | 0.7 | 0.6 |
| Standard | 0.85 | 0.92 | 0.9 | 0.85 | 0.8 | 0.7 | 0.5 | 0.5 | 0.4 | 0.3 | 0.4 |

| C2 | High level of distr | | | | |
|---|---|---|---|---|---|
| C34 | Standard | | Low | | |
| C20 | Quite far | Not fami | Familiar | Quite far | Not fami |
| High | 0.7 | 0.9 | 0.7 | 0.9 | 1 |
| Standard | 0.3 | 0.1 | 0.3 | 0.1 | 0 |

## Competence

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Excellent | 0.6 | 0.3 | 0.05 |
| Standard | 0.4 | 0.65 | 0.5 |
| Low | 0 | 0.05 | 0.45 |

## Other distractions

| C41 | Excellent | Standard | Poor |
|---|---|---|---|
| Few | 0.99 | 0.85 | 0.75 |
| Many | 0.01 | 0.15 | 0.25 |

## Incapasitated

| | |
|---|---|
| Capable | 0.99992 |
| Reduced capa | 2.99991E |
| Incapable | 4.99985E |

# ANNEX I – APPENDIX B

## NODE DESCRIPTION

DET NORSKE VERITAS

## *Table of Contents* *Page*





Reference to part of this report which may lead to misinterpretation is not permissible.

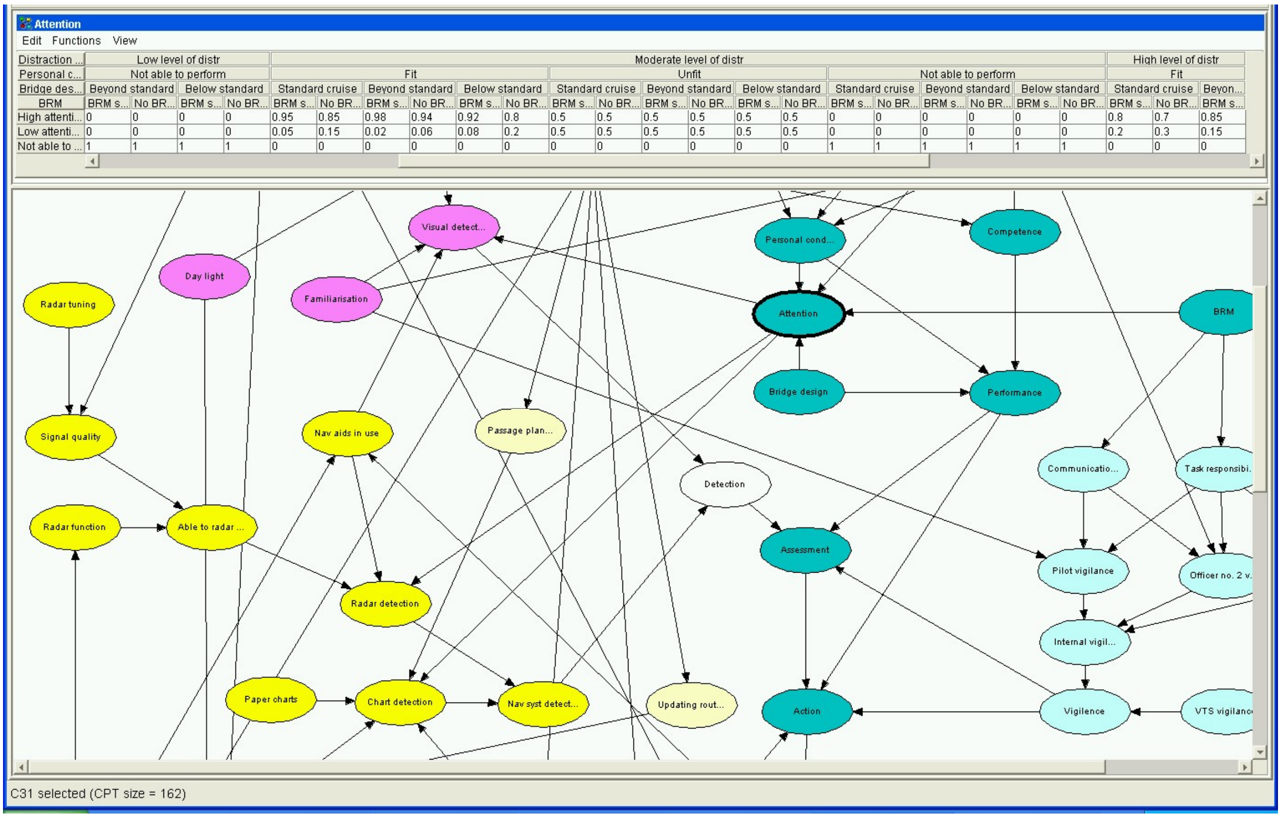
# B1 INTRODUCTION

A node represents a discrete random variable with a number of states. Each node in the Bayesian network is assigned a conditional probability table (abbreviated CPT). The values in this table are set manually, see figure below.

Each numerical value in the CPT is the probability being in the state found in the left most columns in the actual row - when the parents (if any) are in the states found in the top of the actual column.

All nodes, states and probability values are defined by the project. In the following, a short description of each node is given, together with a list of states. The CPTs are included in Appendix A. It is recommended to have the printout of the model structure in Appendix A available when reading the node description.

**Figure B-1 Example of Bayesian network and conditional probability table (CPT)**




# B2 ABBREVIATIONS

| | |
|---|---|
| AIS | Automatic Identification System |
| BRM | Bridge Resource Management |
| CPT | Conditional Probability Table |
| ECDIS | Electronic Chart Display and Information System |
| GPS | Global Positioning System |



Reference to part of this report which may lead to misinterpretation is not permissible.

| | |
|---|---|
| OOW | Officer On Watch |
| VTS | Vessel Traffic Service |

# B3 BULK CARRIER GROUNDING MODEL

In the following, nodes used in the grounding model for the bulk carrier of 75,000 dwt are briefly described.

## B3.1 Visual detection

### Weather

The node describes the most important weather conditions relevant for the operation. The states defined for this node are the following:

States:
- Good (typically good visibility and no critical wind speeds)
- Storm/rain (strong winds including good to significantly reduced visibility)
- Windy (strong winds, no reduced visibility)
- Fog (significantly reduced visibility)

The sum of the probabilities for all states is 1.

### Visibility

The node defines the probability distribution for the visibility, conditional on the weather. The states defined for this node are the following:

States:
- Adequate
- Reduced

The conditional probabilities in this node are based on ref. /1/. Good weather equivalents adequate visibility, while fog is defined as reduced visibility. Storm/rain reduces the visibility by 25%.

### Daylight

The node shows the probability distribution for day/night when the vessel is in operation Ships are assumed equally likely to sail day and night. The states defined for this node are the following:

States:
- Day
- Night

### Bridge view

The node describes the view from the bridge. The view is influenced by the window design, window dividers, windscreen wiper, salt on window, etc. The states defined for this node are the following:

States:
- Good
- Standard



Reference to part of this report which may lead to misinterpretation is not permissible.

The conditional probabilities in this node are based on ref. /1/.

### Marking

This node describes the status of the aids to navigation as a weighted average world wide:

States:
- Standard (i.e. sufficient marking)
- Poor (i.e. not sufficient marking)

The conditional probabilities in this node are based on ref. /1/.

### Able to visual detect

This node describes whether the external environment and conditions makes it possible to visually detect an approaching object in time.

States:
- Yes
- No

The conditional probabilities in this node are based on ref. /1/. The figures are based on a probability of 0.0005 (1 out of 2,000 times) that the officer on watch (OOW) is not able to visually detect the danger in good visibility with standard marking and bridge view in day light. The other probabilities in the node's CPT are an adjustment of this figure, performed by the project team.

### Familiarisation

The node describes whether the OOW has experience in sailing in the area.

States:
- Familiar, i.e. sails in regular trade/route in the area
- Quite familiar, i.e. sails enough to get a pilotage exemption certificate
- Not familiar (i.e. needs pilot onboard)

The conditional probabilities in this node are based on ref. /1/.

### Visual detection

Visual detection indicates whether the OOW visually detects the danger. For the grounding scenario, the danger to detect is the fact that the vessel is heading towards shore, rocks, etc.

His ability depends of course on whether it is physically possible to see the danger. However, also his attention, how familiar the area is and whether navigational aids are used, will influence this node. One navigational aid is ECDIS, as such an instrument will liberate time to danger detection.

States:
- Yes
- No

The conditional probabilities in this node are based on ref. /1/. The figures are based on a probability of 1 that the danger is detected with an OOW with high attention who is familiar in the area. If the OOW is only quite familiar in the area, the probability for visually detection is reduced by 0.5% to 0.995.



Reference to part of this report which may lead to misinterpretation is not permissible.

The other probabilities in the node's CPT are an adjustment of this figure, performed by the project team.

## B3.2 Navigational aid detection

### Radar function

The node describes if the radar system is functioning. This is influenced by the maintenance routines.

States: - Yes
- No

The failure probabilities for the radar are based on ref. /3/. The adjustment for influence from maintenance routines is based on ref. /1/.

### Radar tuning

This node states whether the radar is tuned correctly according to the external conditions (weather, wave conditions, etc.). It also describes whether the radar is adjusted to the optimum range.

States: - Adjusted to conditions
- Not adjusted

The conditional probabilities in this node are based on ref. /1/.

### Signal quality

The signal quality on the radar display is influenced by the weather conditions and the tuning of the radar system.

States: - Good
- Poor

The conditional probabilities in this node are based on ref. /1/. It is assessed that 1 of 1,000 times the radar is displaying poor signal quality in good weather and with the radar tuned to the conditions. Poor signal quality means that it may not be possible to detect the danger on the radar.

The other probabilities in the node's CPT are an adjustment of this figure, performed by the project team.

### Able to radar detection

Depending on the radar reliability and signal quality, this node defines the possibility to detect dangers on the radar in time.

States: - Yes
- No

The conditional probabilities in this node are based on ref. /1/. If the radar is functioning and the signal quality is poor, there is a probability of 0.5 that the danger will not be detected on the radar screen.

### Navigational aids in use

The node describes that use of ECDIS will liberate more time to visual and radar detection.

States: - More time to detection

- No more time to detection

This node is made in order to clarify this aspect of the ECDIS effect. The node has only logical probability input, i.e. probabilities are 1 or 0.

**Radar detection**

Radar detection defines whether the OOW is able to detect the danger on the radar. His ability is of course depending on whether it is physically possible to see the danger on the radar. However, also his attention and whether navigational aids are used, will influence this node. Navigational aids are here meant as ECDIS, as such instruments will liberate time to danger detection.

States: - Yes

- No

The conditional probabilities in this node are based on ref. /1/. The figures are based on a probability of 0.005 (1 out of 200 times) that the danger is not detected by means of radar for an OOW with high attention. The other probabilities in the node's CPT are an adjustment of this figure, performed by the project team. For example, if navigational aids (ECDIS and track control) are not in use/not installed, the failure probability is reduced by 40% to 0.003.

**ECDIS used**

The node describes whether the ECDIS is in use or not.

States: - Yes
- No

This is in effect the "ON/OFF-button" used in the evaluation of the effect of ECDIS.

**Able to paper chart detect**

The node describes the ability to detect a dangerous course on a paper charts if ECDIS is not installed. It is also dependent on the updating routines. If ECDIS is used, this node disables the paper chart function in the model. If ECDIS is not used and the updating routines are Good; there is a 99.9% chance of being able to detect a dangerous course on the paper chart.

States: - Yes

- No

**Paper Chart detection**

The node describes the ability to detect the dangerous course on the paper chart given that the paper chart is updated with the information of the shallows or rocks causing a danger. The node is dependent on the nodes, Attention, Able to Paper Chart Detect and Passage Planning. The attention level of the navigator has the biggest impact on the states.

States: - Yes

- No

**ECDIS chart detection**

The node describes the ability to detect the dangerous course on the ECDIS display. Depending on the Attention of the navigator, if the grounding alarm is on or off and the passage planning, the node tell us whether the dangerous course is detected on the ECDIS or not.



Reference to part of this report which may lead to misinterpretation is not permissible.

States: - Yes

- No

### GPS signal

The node describes the functionality of the GPS signal. This is influenced by the maintenance routines.

States: - Yes

- No

The failure probabilities for the GPS are based on ref. /3/. The adjustment for influence from maintenance routines is based on ref. /1/.

### Other ECDIS failure

The node describes the reliability of the ECDIS system (software, etc.), excluding GPS failures. This is influenced by the maintenance routines.

States: - No failure

- Failure

The failure probabilities for the ECDIS failures are based on ref. /3/. The adjustment for influence from maintenance routines is based on ref. /1/.

### Able to ECDIS detect

Depending on electronic chart updating routines and the ECDIS use and reliability, this node describes whether it is technically possible to detect dangers on the ECDIS in time.

States: - Yes

- No

The conditional probabilities in this node are based on ref. /1/. If the ECDIS is functioning, but the chart updating routines are poor, there is a probability that the danger will not be detected on the electronic chart.

### Grounding alarm

The node describes whether a grounding alarm helps the OOW to navigational system detection, conditioned on the use of ECDIS

States: - Yes

- No

The conditional probabilities in this node are based on ref. /1/. Failure on demand probability for the grounding alarm is set to 1E-05.

### Navigation system detection

The node describes whether the OOW has detected the danger on either the charts, the radar or because of a grounding alarm.

States: - Yes



Reference to part of this report which may lead to misinterpretation is not permissible.

- No

This node is made in order to gather the nodes for detection of the danger on the radar, ECDIS and grounding alarm (radar, AIS and collision avoidance alarm for the collision model). This approach is a software trick to reduce the amount of probability input. If the number of arrows onto the subsequent node is reduced, the size and the complexity of the CPTs also reduced. The node has only logical probability input, i.e. probabilities are 1 or 0.

### Detection

The node joins the nodes 'Visual detection' and 'Navigation system detection', and describes whether the OOW has detected the danger, either with visual means or navigational equipment.

States: - Yes

- No

This node is made in order to gather the nodes 'Visual detection' and 'Navigation system detection' in one node. This approach is a software trick to reduce the amount of probability input. If the number of arrows onto the subsequent node is reduced, the size and the complexity of the CPTs also reduced. The node has only logical probability input, i.e. probabilities are 1 or 0.

## B3.3 Management factors

### Safety culture

The node describes how well the vessel operator deals with safety issues and how well the operator promotes a good safety mindset among its employees. By safety issues it is meant both technical safety onboard the vessel (e.g. standard of life saving equipment) and vessel design, in addition to work procedures/instructions, working conditions, training, drills, attitude, etc.

States: - Excellent

- Standard
- Poor

### Maintenance routines

This node describes whether the maintenance routines of technical systems onboard the vessel are followed.

States: - Followed

- Not followed

The conditional probabilities in this node are based on ref. /1/.

### Update routines

Influenced by the company's safety culture, this node is mainly aimed at updating routines for charts (updating frequency, quality, etc.).

States: - Good

- Poor

The conditional probabilities in this node are based on ref. /1/.



Reference to part of this report which may lead to misinterpretation is not permissible.

**Passage planning**

This node describes the quality of the passage planning. “Poor” means that the trade is not sufficiently planned or that the planned route exposes the vessel to a higher risk than necessary. The node also reflects the ability to detect unknown hazards in the route.

States:
- Standard
- Poor

The conditional probabilities in this node are based on ref. /1/.

## B3.4 Human factors

**Duties**

The node indicates the duties for which the OOW is responsible.

States:
- Normal (watch)
- High (watch + administration)

The conditional probabilities in this node are based on ref. /1/.

**Tired**

Depending on the number of duties, this node describes whether the OOW is tired.

States:
- Yes
- No

The conditional probabilities in this node are based on ref. /1/.

**Other distractions**

The node describes whether the OOW is exposed to many or few distractions, e.g. mobile phones, troublesome situations on board and persons on bridge that will take his attention away from his dedicated tasks as a navigator.

States:
- Few
- Many

The conditional probabilities in this node are based on ref. /1/.

**Distraction level**

The node describes the total level of distractions.

States:
- Low level of distractions
- Moderate level of distractions
- High level of distraction

**Stress level**

The node indicates the stress level of the OOW, mainly influenced by the familiarization in the water, his competence and the number of distractions that take his attention away from the tasks he is set to perform.

States:
- High
- Standard

The conditional probabilities in this node are based on ref. /1/. With moderate level of distractions and sailing in a quite familiar area, it is assumed in ref. /1/ that the probability for high stress level is 10%.



Reference to part of this report which may lead to misinterpretation is not permissible.

**Incapacitated**

The node describes the OOW's physical capability. The capability is assessed to be *reduced* if the OOW is e.g. intoxicated or affected by an illness, and *incapable* if the OOW is asleep, not present, dead, etc.

States:
- Capable
- Reduced capability
- Incapable

The probabilities in this node are based on ref. /2/.

**Personal condition**

The node describes the OOW's physical and mental condition, and indicates whether he is fit to perform his tasks as navigator of the vessel. The node is dependent on the nodes 'Stress level', 'Tired' and 'Incapacitated'.

States:
- Fit
- Unfit
- Not able to perform

The conditional probabilities in this node are based on ref. /1/. It is stated that the OOW is 100% fit if he is capable (i.e. not incapacitated), has standard stress level and is not tired. If he is tired or has high stress level, the fitness is reduced by 10%.

**Competence**

Competence is a combination of knowledge, skills and attitude. The node reflects the OOW's knowledge, the level of training, the way he uses his knowledge and the attitude he has towards the tasks he is set to perform, e.g. to follow procedures and work instructions. This also reflects the technical competence on use of equipment.

States:
- Excellent
- Standard
- Low

The conditional probabilities in this node are based on ref. /1/.

**Bridge design**

This node describes whether the bridge is designed to enable the OOW to perform his tasks properly. The node reflects user interface, the design of the work station (ergonomic conditions) and bridge arrangement.

States:
- Standard
- Beyond standard
- Below standard

The probabilities in this node are based on ref. /1/.

**BRM**



Reference to part of this report which may lead to misinterpretation is not permissible.

/annex i - appendix b node description rev01.doc

The node describes the existence of a Bridge Resource Management (BRM) system. The BRM node covers optimisation of human resources on the bridge given the technical system and bridge design. An optimisation of the human resources is strongly related to communication and task responsibilities. The existence of a BRM system means that the system is developed and implemented, as well as maintained according to the intensions.

States:
- BRM system exists
- No BRM system

The conditional probabilities in this node are based on ref. /1/.

**Attention**

This node describes the OOW's level of attention when performing his tasks. The attention is affected by his physical working place (i.e. bridge design), organisation of work (BRM system) and his personal condition.

States:
- High attention
- Low attention
- Not able to pay attention

The conditional probabilities in this node are based on ref. /1/. With moderate level of distractions, standard bridge design and implemented BRM system, the probability for low attention is set to 0.05. With no BRM system, the probability for low attention is assumed to be increased by a factor of 3.

**Performance**

The node describes how well the OOW performs his tasks. It includes personal condition, bridge design and competence.

States:
- Excellent
- Standard
- Poor

The conditional probabilities in this node are based on ref. /1/.

**Assessment**

This node describes whether the OOW is making the correct assessment of the situation based on his observations.

States:
- Correct
- Wrong
- No assessment

The conditional probabilities in this node are based on ref. /4/. If the danger is detected there is a probability of 2E-05 that the situation will not be assessed correctly given no vigilance.

**Action**

The node defines whether the OOW, given he or someone else has discovered the danger, acts correct or not to avoid an accident.

States:
- Correct action
- Wrong action



Reference to part of this report which may lead to misinterpretation is not permissible.

The conditional probabilities in this node are based on ref. /4/.

## B3.5 Technical reliability

### Steering failure

The node indicates the reliability of the steering system (based on statistics/generic data).

States:
- Function
- Not function

The probabilities in this node are based on ref. /2/.

## B3.6 Support

### Communication level

Depending on the existence of a Bridge Resource Management system, the node describes the level and the quality of the communication between the bridge personnel.

States:
- Beyond standard
- Standard
- Substandard

The conditional probabilities in this node are based on ref. /1/.

### Task responsibilities

Depending on the existence of a Bridge Resource Management system, the node describes whether there exist clear task responsibilities between the bridge personnel.

States:
- Clear responsibility
- Unclear responsibility

The conditional probabilities in this node are based on ref. /1/.

### Pilot vigilance

Influenced by the task responsibilities and the communication level between the bridge personnel and the pilot, this node shows the effect of having a pilot present to correct a critical course.

States:
- Able to correct
- Not able to correct
- No pilot

The conditional probabilities in this node are based on ref. /1/.

### Internal vigilance

The node describes if there is any internal vigilance that can help to warn the OOW of possible danger.

States:
- Yes
- No

This node has only logical probability input, i.e. probabilities are 1 or 0.



Reference to part of this report which may lead to misinterpretation is not permissible.

**VTS presence**

The node shows the probability of that a Vessel Traffic Service (VTS) is monitoring the ship traffic in the area.

States: - Yes

- No

The probabilities in this node are based on ref. /1/.

**VTS vigilance**

This node describes whether the VTS observes the danger and advices the OOW so that he can act in time.

States: - Yes

- No

The conditional probabilities in this node are based on ref. /1/.

**Lookout**

The node describes whether there is a lookout on the bridge or not. This is depending on the weather conditions and time of day. At night, as with reduced visibility, there is always a lookout present. During the day, a lookout may not be present depending upon circumstances.

States: - Yes

- No

**Vigilance**

This is the overall node showing if there is any internal or external vigilance that can help to warn the OOW of dangers.

States: - Yes

- No

This node has only logical probability input, i.e. probabilities are 1 or 0.

## B3.7 Overall

**Loss of control**

The node describes the probability for loss of control of the ship, either due to technical failures or to human errors. If the control is lost, nothing can prevent it from continuing towards the danger, i.e. towards shore.

States: - Loss of control

- No loss of control

This node has only logical probability input, i.e. probabilities are 1 or 0. If correct action is carried out and the steering system is functioning, the probability for loss of control is 0.

**Grounding**

The node states the probability for grounding.

States: - Yes



Reference to part of this report which may lead to misinterpretation is not permissible.

- No

This node has only logical probability input, i.e. probabilities are 1 or 0.

## B3.8 Consequences

### Vessel damage

This node describes what effect the grounding had on the vessel.

States:
- No/minor (i.e. all events that is collision or grounding, however not being categorised as 'Major' or 'Catastrophic')
- Major (i.e. event resulting in the ship being towed or requiring assistance from ashore; flooding of any compartment; or structural of mechanical damage requiring repairs before the ship can continue trading. Not including 'Catastrophic'.)
- Catastrophic (i.e. events where ship ceases to exist after a casualty, either due to it being irrecoverable or due to is subsequently being scrapped)
- No grounding

### Vessel sink

Given the type of vessel damage, this node shows whether the vessel sinks immediately, after some time or not at all.

States:
- Yes, within 30 min
- Yes, after 30 min
- No
- N/A (i.e. not relevant if no accident)

### External conditions

The node describes the external conditions given an accident, in terms of level of difficulty to evacuate. The node is dependent on the weather conditions and whether it is day or night.

States:
- Good
- Moderate
- Difficult

### Evacuation means

The node describes the standard and location of the life saving equipment.

States:
- Above requirements
- Fulfil requirements
- Below requirements

### Drills

The node describes evacuation drills and how they are carried out.

States:
- Above requirements
- Fulfil requirements
- Below requirements



Reference to part of this report which may lead to misinterpretation is not permissible.

## Internal conditions

This node describes the frame conditions for how well the vessel and its crew are prepared for an evacuation.

States:
- Good
- Average
- Poor

## Evacuation

This node shows how successfully the evacuation is carried out, if evacuation is initiated.

States:
- Not Initiated (No order given to evacuate ship. No attempt made to launch LSA)
- Successful (Order to evacuate given and all persons are loaded onto LSA)
- Not Successful (Order to evacuate given, but not all persons are loaded onto LSA. Either someone falls overboard, is accidentally killed during evacuation (e.g. caught between lifeboat and shipside) or is left behind on the ship. )
- Not Applicable (No grounding occurs)

## Evacuation fatalities

The node indicates whether a person is killed during evacuation following the accident.

States:
- Yes
- No

## Immediate fatalities

The node indicates whether a person is killed immediately, given the type of damage on the vessel.

States:
- Yes
- No

## Fatalities

Summing up both the immediate fatalities and the evacuation fatalities, this node indicates whether a person is killed onboard the ship due to the accident scenario, i.e. the total individual risk per person.

States:
- Yes
- No



Reference to part of this report which may lead to misinterpretation is not permissible.

# B4 TANKER GROUNDING MODEL

The grounding models for bulk and tank are very similar. All the nodes described in the previous chapter are also included in the tank grounding model. Three additional nodes are included in the tank model, and described below. Also, one node (Visibility) has been changed to accommodate the two different sizes of tankers being modelled.

It is important to emphasize that although the definition of the nodes and the states are the same for tank and bulk, the probability distribution on the different states, i.e. the values in the conditional probability tables, might be different in the two models. For more detail on these differences, see Appendix A.

## B4.1 Tanker specific nodes

The following nodes are not included in the grounding model used for bulk carriers, or they are fundamentally changed to fit tankers.

**Ship Size**

The node is used as a switch to control the size of vessel being analysed. The state ”Small” is used to analyse the 4 000 dwt tanker, the state “Large” is used to analyse the 80 000 dwt tanker.

States:
- Small
- Large

**Escort Tug Presence**

Large tankers are assumed to have assistance by tugs in narrow waters when loaded. Small tankers are assumed not to have tug assistance. This node is only dependant on the ship size.

States:
- Present
- Not Present

**Tug Vigilance**

This node describes whether the Tug observes the danger and warns the OOW so that he can act in time.

States:
- Yes
- No

**Visibility**

The node is now dependant on ship size. The assumption is that smaller ships may characterize the visibility as adequate under the same conditions that a larger tanker would characterize the visibility as reduced. This is due to the fact that larger ships are harder to manoeuvre, and would thus need a longer line of sight and more time to avoid an obstacle.

States:
- Adequate
- Reduced



Reference to part of this report which may lead to misinterpretation is not permissible.

# B5 REFERENCES

/1/ NAV 51/10 - Full report can be found at: http://research.dnv.com/skj/FSALPS/FSA-LPS-NAV.htm

/2/ DNV, Safety Analysis Handbook, December 2001

/3/ Technical memo on failure probabilities of navigation equipment, DNV's department for Nautical Safety and Communication Systems, March 2003

/4/ Managing the risks of organizational accidents, James Reason, 1997

/5/ *The formal safety assessment methodology applied to the survival capability of passenger ships*, paper to be published by Odd Olufsen (DNV Norway), John Spouge (DNV UK), Liv Hovem (DNV Norway)

- o0o -



Reference to part of this report which may lead to misinterpretation is not permissible.

# ANNEX I - APPENDIX C

## RISK EXPOSURE – ESTIMATION OF NUMBER OF CRITICAL SITUATIONS

DET NORSKE VERITAS

## *Table of Contents* *Page*





Reference to part of this report which may lead to misinterpretation is not permissible.

# C1 INTRODUCTION

This document describes the modelling of risk exposure, i.e. the number of critical situations a vessel is subjected to in a year. The risk exposure has been modelled for:

- Tanker for Oil, 80 000 DWT, trading between the Middle East (Kuwait) and the Mediterranean (Marseille, France)
- Product Tanker, 4000 DWT, trading between Mongstad (Norway) and Stockholm (Sweden)
- Bulk Carrier, 75 000 DWT, carrying Coal between Newcastle (Australia) and Tokyo (Japan).

These choices are based on world fleet statistics, world main trade routes, and ship size distribution on these routes, as described in Annex I.

Each of the routes modelled has been divided into three types of waters: 'Open waters', 'Coastal waters' and 'Narrow waters'. The types of waters are defined as:

- Open waters: No obstacles within 30 minutes in all directions
- Coastal waters: No obstacles within 30-10 min in all directions
- Narrow waters: Obstacles within less than 10 min in any direction

The results are used further in the Excel model to estimate the exposure for dangerous situations for grounding and collision.

# C2 CALCULATION OF DANGEROUS COURSES

## C2.1 Grounding model

Ref. section 3.3 in Annex I, there are defined five scenarios which lead to dangerous course towards shore:

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

An Excel spreadsheet was applied to calculate the total number of critical courses towards shore from the grounding scenarios. Figure C-2 to C-4 show printouts of the spreadsheets.

## C2.2 Description of spreadsheets

The description below refers to the printout of the spreadsheets included in Figure C-2 to C-4.



Reference to part of this report which may lead to misinterpretation is not permissible.

### C2.2.1 Results

On top, the grounding frequency per trade is presented. The result is the product of the number of critical courses towards shore (N) and the probability of loss of control (P) from the Bayesian network.

### C2.2.2 Input data

As earlier mentioned, the sailed route is divided into three types of waters: ‘Open waters’, ‘Coastal waters’ and ‘Narrow waters’. The distance sailed in each category is input and the sum is the length of the whole sailed route.

The traffic intensity is divided in three groups: ‘High’, ‘Medium’ and ‘Low’. The probability for high, medium and low traffic intensity is input for each type of waters. Further, the environmental forces (wind, current), are divided in three groups, ‘Strong’, ‘Moderate’ and ‘Benign’. The probability for strong, moderate or benign environmental forces is input for each type of waters.

The spreadsheet has included the possibility to adjust for speed reduction and safety culture level in company, but this has not been done in this study.

### C2.2.3 Scenarios

From Scenario 1 to Scenario 5 the number of events for each scenario is estimated per nautical mile in each type of waters. Then the probability or ratio of this event being critical is estimated. The sum of the two figures gives the number of critical courses towards shore for each scenario. The results are summarized in the bottom of the spreadsheet.

### C2.2.4 Differences between ship types

The model for calculation of number of dangerous courses is similar for all three ships and routes. However, the length of the route is different, and so is the division into types of waters. There is also one difference related to Scenario 5, Meeting traffic. For this scenario the number of turns is lower for the large tanker and large bulk carrier, than for the small tanker. This is due to the fact that small ships have a tendency to give way more often than larger ships.



Reference to part of this report which may lead to misinterpretation is not permissible.

| | | | |
|---|---|---|---|
| **FREQUENCY OF GROUNDING:** | **F (Grounding) =** | 3,2E-03 | per trade |
| | | **7,04E-02** | **per yr** |
| **Probability of loss of control from bayesian network:** | P (grounding) = | 8,83E-05 | per course |
| **Number of critical courses towards shore:** | N (Courses towards shore) = | 36,2 | per trade |

Middle East (Kuwait) - Mediterranian (Marseilles)
Tanker for Oil 80 000 DWT
CALCULATION of number of critical courses:

| **INPUT** | **States** | **Open sea** | **Coastal** | **Narrow** | | |
|---|---|---|---|---|---|---|
| **Waters, distribution in %** | | **79,1 %** | **19,0 %** | **1,9 %** | **4863** | |
| **Waters** | | **3846,6** | **924,0** | **92,4** | | [nm] |
| Traffic intensity (Probability) | High | 0,1 | 0,2 | 0,3 | | |
| | Medium | 0,2 | 0,5 | 0,5 | | |
| | Low | 0,7 | 0,3 | 0,2 | | |
| Environmental forces (Probability) | Strong | 0,1 | 0,1 | 0,1 | | |
| | Moderate | 0,4 | 0,4 | 0,4 | | |
| | Benign | 0,5 | 0,5 | 0,5 | | |
| Speed (Probability) | Full | 1 | 1 | 1 | | |
| | Reduced | 0 | 0 | 0 | | |
| Safety culture | Excellent | - | - | - | 0 | |
| (Choose one, 'Standard' is default) | Standard | - | - | - | 1 | |
| | Poor | - | - | - | 0 | |
| Water adjustment factor (criticality) | | 0 | 1 | 1 | | |
| **CRITICAL COURSES TWDS SHORE PER NM** | | | | | | |
| **Scenario 1** | | | | | | |
| Number of course changes per nm | | 0,025 | 0,04 | 0,2 | | |
| Ratio of dangerous course changes | | 0 | 0,4 | 0,8 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 0,8 | |
| N (critical course changes) | | 0E+00 | 2E-02 | 2E-01 | | |
| **Scenario 2** | | | | | | |
| N (turns per nm) (when not supposed to turn) | | 1E-03 | 1E-03 | 1E-03 | | |
| P (danagerous to turn) | | 0 | 0,4 | 0,8 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 0,7 | |
| Adjustment for safety culture | Excellent | | | | 0,5 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (critical turns per nm) | | 0E+00 | 4E-04 | 8E-04 | | |
| **Scenario 3** | | | | | | |
| N (drift-offs per nm given env.cond) | Strong | 0,008 | 0,008 | 0,008 | | |
| | Moderate | 0,0008 | 0,0008 | 0,0008 | | |
| | Benign | 0 | 0 | 0 | | |
| P (dangerous location to drift off) | | 0 | 0,2 | 0,4 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 1,5 | |
| Adjustment for safety culture | Excellent | | | | 0,75 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (critical drift-offs per nm) | Strong | 0E+00 | 2E-04 | 3E-04 | | |
| | Moderate | 0E+00 | 6E-05 | 1E-04 | | |
| | Benign | 0E+00 | 0E+00 | 0E+00 | | |
| | Total sc. 3 | 0E+00 | 2E-04 | 4E-04 | | |
| **Scenario 4** | | | | | | |
| N (Wrong position per nm) | | 0,001 | 0,001 | 0,001 | | |
| P (Wrong position leads to dangerous course) | | 0 | 0,2 | 0,4 | | |
| Adjustment for safety culture | Excellent | | | | 0,8 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (Critical wrong position per nm) | | 0E+00 | 2E-04 | 4E-04 | | |
| **Scenario 5** | | | | | | |
| N (Turns because of traffic per nm) | High TI | 0,1 | 0,1 | 0,1 | | |
| | Medium TI | 0,05 | 0,05 | 0,05 | | |
| | Low TI | 0,01 | 0,01 | 0,01 | | |
| P (Turn is critical) | | 0 | 0,1 | 0,25 | | |
| N (Critical turns because of traffic per nm) | High TI | 0E+00 | 2E-03 | 8E-03 | | |
| | Medium TI | 0E+00 | 3E-03 | 6E-03 | | |
| | Low TI | 0E+00 | 3E-04 | 5E-04 | | |
| | Total sc. 5 | 0E+00 | 5E-03 | 1E-02 | | |
| **OUTPUT** | | | | | | |
| Scenario 1 | # | 0,0 | 14,8 | 14,8 | 29,6 | 81,6% |
| Scenario 2 | # | 0,0 | 0,4 | 0,1 | 0,4 | 1,2% |
| Scenario 3 | # | 0,0 | 0,2 | 0,0 | 0,2 | 0,7% |
| Scenario 4 | # | 0,0 | 0,2 | 0,0 | 0,2 | 0,6% |
| Scenario 5 | # | 0,0 | 4,4 | 1,3 | 5,8 | 15,9% |
| **Number of critical courses towards shore:** | | | | | **36,2** | |
| **Number of critical courses towards shore / nm:** | | | | | **0,007** | |

Trade length for one trip distributed in three water categories

Speed adjustment not included

Safety culture set to standard for all vessels

In open sea no course change is critical for grounding

Each scenario contributes to the total frequency of critical courses towards shore

Relative importance for each scenario

**Figure C-1 Printout of Excel spreadsheet of grounding exposure model, TANK 80,000dwt**

| | | | |
|---|---|---|---|
| **FREQUENCY OF GROUNDING:** | F (Grounding) = | 1,4370E-03 | per trade |
| | | **1,1496E-01** | **per yr** |
| **Probability of loss of control from bayesian network:** | P (loss of control) = | 9,0200E-05 | per course |
| **Number of critical courses towards shore:** | N (Courses towards shore) = | 1,5932E+01 | per trade |

Mongstad - Stockholm

| CALCULATION of number of critical courses: | | | | | | |
|---|---|---|---|---|---|---|
| **INPUT** | States | Open sea | Coastal | Narrow | | |
| **Waters, distribution in %** | | **47,4 %** | **51,0 %** | **1,6 %** | 979 | |
| **Waters** | | **464,046** | **499,29** | **15,664** | | [nm] |
| Traffic intensity (Probability) | High | 0,1 | 0,2 | 0,3 | | |
| | Medium | 0,2 | 0,5 | 0,5 | | |
| | Low | 0,7 | 0,3 | 0,2 | | |
| Environmental forces (Probability) | Strong | 0,1 | 0,1 | 0,1 | | |
| | Moderate | 0,4 | 0,4 | 0,4 | | |
| | Benign | 0,5 | 0,5 | 0,5 | | |
| Speed (Probability) | Full | 1 | 1 | 1 | | |
| | Reduced | 0 | 0 | 0 | | |
| Safety culture | Excellent | - | - | - | 0 | |
| (Choose one, 'Standard' is default) | Standard | - | - | - | 1 | |
| | Poor | - | - | - | 0 | |
| Water adjustment factor (criticality) | | 0 | 1 | 1 | | |
| **CRITICAL COURSES TWDS SHORE PER NM** | | | | | | |
| **Scenario 1** | | | | | | |
| Number of course changes per nm | | 0,025 | 0,04 | 0,2 | | |
| Ratio of dangerous course changes | | 0 | 0,4 | 0,8 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 0,8 | |
| N (critical course changes) | | 0E+00 | 2E-02 | 2E-01 | | |
| **Scenario 2** | | | | | | |
| N (turns per nm) (when not supposed to turn) | | 1E-03 | 1E-03 | 1E-03 | | |
| P (danagerous to turn) | | 0 | 0,4 | 0,8 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 0,7 | |
| Adjustment for safety culture | Excellent | | | | 0,5 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (critical turns per nm) | | 0E+00 | 4E-04 | 8E-04 | | |
| **Scenario 3** | | | | | | |
| N (drift-offs per nm given env.cond) | Strong | 0,08 | 0,08 | 0,08 | | |
| | Moderate | 0,008 | 0,008 | 0,008 | | |
| | Benign | 0 | 0 | 0 | | |
| P (dangerous location to drift off) | | 0 | 0,2 | 0,4 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 1,5 | |
| Adjustment for safety culture | Excellent | | | | 0,75 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (critical drift-offs per nm) | Strong | 0E+00 | 2E-03 | 3E-03 | | |
| | Moderate | 0E+00 | 6E-04 | 1E-03 | | |
| | Benign | 0E+00 | 0E+00 | 0E+00 | | |
| | Total sc. 3 | 0E+00 | 2E-03 | 4E-03 | | |
| **Scenario 4** | | | | | | |
| N (Wrong position per nm) | | 0,001 | 0,001 | 0,001 | | |
| P (Wrong position leads to dangerous course) | | 0 | 0,2 | 0,4 | | |
| Adjustment for safety culture | Excellent | | | | 0,8 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (Critical wrong position per nm) | | 0E+00 | 2E-04 | 4E-04 | | |
| **Scenario 5** | | | | | | |
| N (Turns because of traffic per nm) | High TI | 0,15 | 0,15 | 0,15 | | |
| | Medium TI | 0,075 | 0,075 | 0,075 | | |
| | Low TI | 0,015 | 0,015 | 0,015 | | |
| P (Turn is critical) | | 0 | 0,1 | 0,25 | | |
| N (Critical turns because of traffic per nm) | High TI | 0E+00 | 3E-03 | 1E-02 | | |
| | Medium TI | 0E+00 | 4E-03 | 9E-03 | | |
| | Low TI | 0E+00 | 5E-04 | 8E-04 | | |
| | Total sc. 5 | 0E+00 | 7E-03 | 2E-02 | | |
| **OUTPUT** | | | | | | |
| Scenario 1 | # | 0,0 | 8,0 | 2,5 | 10,5 | 65,9% |
| Scenario 2 | # | 0,0 | 0,2 | 0,0 | 0,2 | 1,3% |
| Scenario 3 | # | 0,0 | 1,1 | 0,1 | 1,2 | 7,5% |
| Scenario 4 | # | 0,0 | 0,1 | 0,0 | 0,1 | 0,7% |
| Scenario 5 | # | 0,0 | 3,6 | 0,3 | 3,9 | 24,7% |
| **Number of critical courses towards shore:** | | | | | 15,9 | |
| **Number of critical courses towards shore / nm:** | | | | | 0,016 | |

Trade length for one round trip distributed in three water categories

Speed adjustment not included

Safety culture set to standard for all vessels

In open sea no course change is critical for grounding

Each scenario contributes to the total frequency of critical courses towards shore

Relative importance for each scenario

**Figure C-2 Printout of Excel spreadsheet of grounding exposure model, TANK 4,000dwt**

| | | | | | | |
|---|---|---|---|---|---|---|
| **FREQUENCY OF GROUNDING:** | | **F (Grounding) =** | | | 1,5E-03 per trade<br>**3,5E-02 per yr** | |
| **Probability of loss of control from bayesian network:** | | P (loss of control) = | | | 9,24E-05 per course | |
| **Number of critical courses towards shore:** | | N (Courses towards shore) = | | | 15,9 per trade | |
| Australia (Newcastle) - Japan (Tokyo) Bulk Carrier, Coal 75000DWT | 4272 nm, 12 days | | | | | |
| CALCULATION of number of critical courses: | | | | | | |
| **INPUT** | States | Open sea | Coastal | Narrow | | |
| **Waters, distribution in %** | | 83,50 % | 16,40 % | 0,10 % | 4 272 | |
| **Waters** | | **3567** | **701** | **4** | | [nm] |
| Traffic intensity (Probability) | High | 0,1 | 0,2 | 0,3 | | |
| | Medium | 0,2 | 0,5 | 0,5 | | |
| | Low | 0,7 | 0,3 | 0,2 | | |
| Environmental forces (Probability) | Strong | 0,1 | 0,1 | 0,1 | | |
| | Moderate | 0,4 | 0,4 | 0,4 | | |
| | Benign | 0,5 | 0,5 | 0,5 | | |
| Speed (Probability) | Full | 1 | 1 | 1 | | |
| | Reduced | 0 | 0 | 0 | | |
| Safety culture | Excellent | - | - | - | 0 | |
| (Choose one, 'Standard' is default) | Standard | - | - | - | 1 | |
| | Poor | - | - | - | 0 | |
| Water adjustment factor (criticality) | | 0 | 1 | 1 | | |
| **CRITICAL COURSES TWDS SHORE PER NM** | | | | | | |
| **Scenario 1** | | | | | | |
| Number of course changes per nm | | 0,025 | 0,04 | 0,2 | | |
| Ratio of dangerous course changes | | 0 | 0,4 | 0,8 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 0,8 | |
| N (critical course changes) | | 0E+00 | 2E-02 | 2E-01 | | |
| **Scenario 2** | | | | | | |
| N (turns per nm) (when not supposed to turn) | | 1E-03 | 1E-03 | 1E-03 | | |
| P (danagerous to turn) | | 0 | 0,4 | 0,8 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 0,7 | |
| Adjustment for safety culture | Excellent | | | | 0,5 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (critical turns per nm) | | 0E+00 | 4E-04 | 8E-04 | | |
| **Scenario 3** | | | | | | |
| N (drift-offs per nm given env.cond) | Strong | 0,008 | 0,008 | 0,008 | | |
| | Moderate | 0,0008 | 0,0008 | 0,0008 | | |
| | Benign | 0 | 0 | 0 | | |
| P (dangerous location to drift off) | | 0 | 0,2 | 0,4 | | |
| Speed adjustment | Full | | | | 1 | |
| | Reduced | | | | 1,5 | |
| Adjustment for safety culture | Excellent | | | | 0,75 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (critical drift-offs per nm) | Strong | 0E+00 | 2E-04 | 3E-04 | | |
| | Moderate | 0E+00 | 6E-05 | 1E-04 | | |
| | Benign | 0E+00 | 0E+00 | 0E+00 | | |
| | Total sc. 3 | 0E+00 | 2E-04 | 4E-04 | | |
| **Scenario 4** | | | | | | |
| N (Wrong position per nm) | | 0,001 | 0,001 | 0,001 | | |
| P (Wrong position leads to dangerous course) | | 0 | 0,2 | 0,4 | | |
| Adjustment for safety culture | Excellent | | | | 0,8 | |
| | Standard | | | | 1 | |
| | Poor | | | | 2 | |
| N (Critical wrong position per nm) | | 0E+00 | 2E-04 | 4E-04 | | |
| **Scenario 5** | | | | | | |
| N (Turns because of traffic per nm) | High TI | 0,1 | 0,1 | 0,1 | | |
| | Medium TI | 0,05 | 0,05 | 0,05 | | |
| | Low TI | 0,01 | 0,01 | 0,01 | | |
| P (Turn is critical) | | 0 | 0,1 | 0,25 | | |
| N (Critical turns because of traffic per nm) | High TI | 0E+00 | 2E-03 | 8E-03 | | |
| | Medium TI | 0E+00 | 3E-03 | 6E-03 | | |
| | Low TI | 0E+00 | 3E-04 | 5E-04 | | |
| | Total sc. 5 | 0E+00 | 5E-03 | 1E-02 | | |
| **OUTPUT** | | | | | | |
| Scenario 1 | # | 0,0 | 11,2 | 0,7 | 11,9 | 74,8% |
| Scenario 2 | # | 0,0 | 0,3 | 0,0 | 0,3 | 1,8% |
| Scenario 3 | # | 0,0 | 0,2 | 0,0 | 0,2 | 1,0% |
| Scenario 4 | # | 0,0 | 0,1 | 0,0 | 0,1 | 0,9% |
| Scenario 5 | # | 0,0 | 3,4 | 0,1 | 3,4 | 21,5% |
| **Number of critical courses towards shore:** | | | | | **15,9** | |
| **Number of critical courses towards shore / nm:** | | | | | **0,004** | |

Trade length for one trip distributed in three water categories

Speed adjustment not included

Safety culture set to standard for all vessels

In open sea no course change is critical for grounding

Each scenario contributes to the total frequency of critical courses towards shore

Relative importance for each scenario

**Figure C-3 Printout of Excel spreadsheet of grounding exposure model, BULK 75,000dwt**



Reference to part of this report which may lead to misinterpretation is not permissible.

# ANNEX I - APPENDIX D

## EXPERT JUDGEMENTS

DET NORSKE VERITAS

## *Table of Contents* *Page*





Reference to part of this report which may lead to misinterpretation is not permissible.

# APPENDIX

## D

## EXPERT JUDGEMENTS



Reference to part of this report which may lead to misinterpretation is not permissible.

# D1 THE EXPERT JUDGEMENT PROCESS AND PEOPLE INVOLVED

## D1.1 Project team

The project team consisted of the following persons:

**Table D-1 Project team**

| Project team | Experience |
|---|---|
| Linn Kathrin Fjæreide | Senior Consultant, DNV Maritime Solutions<br>Educated Master of Science in naval architecture. Has 5 years experience with risk management and technical risk assessments within the maritime and offshore industry. Experience from several FSA projects, e.g. the FSA Navigation of Large Passenger Ships. Currently working in DNV Maritime Solutions. |
| Sverre Alvik | Principal consultant, DNV Maritime Solutions<br>Educated Master of Science in naval architecture. Has 8 years experience with management and risk consultancy, technical risk assessment and navigational assessments within maritime and offshore industry. Also involved in the FSA Navigation of Large Passenger Ships. Is currently working in DNV Maritime Solutions. |
| Anders Mikkelsen | Consultant, DNV Maritime Solutions<br>Educated Master of Science in naval architecture. Two years experience with risk analysis and risk assessments for yards, ship owners and maritime authorities, as well as experience with surveying and stability documentation approval. |
| Magnus S. Eide | Research Engineer, DNV Research<br>Educated Master of Science in Industrial Mathematics and Statistics. Has experience with ECDIS and navigation from field studies onboard one chemical tanker, and two passenger ships in the fall of 2005. Attended IACS FSA Training Course, “Train the Trainer”, fall 2005. |
| Rolf Skjong | Dr, Chief Scientist, DNV Research<br>FSA and Structural Reliability specialist with more than 20 years experience within risk and reliability analysis. Project manager and project responsible in a number of international Joint Industry Projects for the maritime, offshore and process industry. Chairman IACS EG/FSA |

## D1.2 Expert judgements

The risk modelling in this project is largely based on the FSA Navigation Large Passenger Ships. Much of the expert judgements documented though workshops and interviews in that project has thus been utilised in the current project.



Reference to part of this report which may lead to misinterpretation is not permissible.

However, important alterations have been made to the model constructed for passenger ships, and in this process several experts has been involved in addition to the team members.

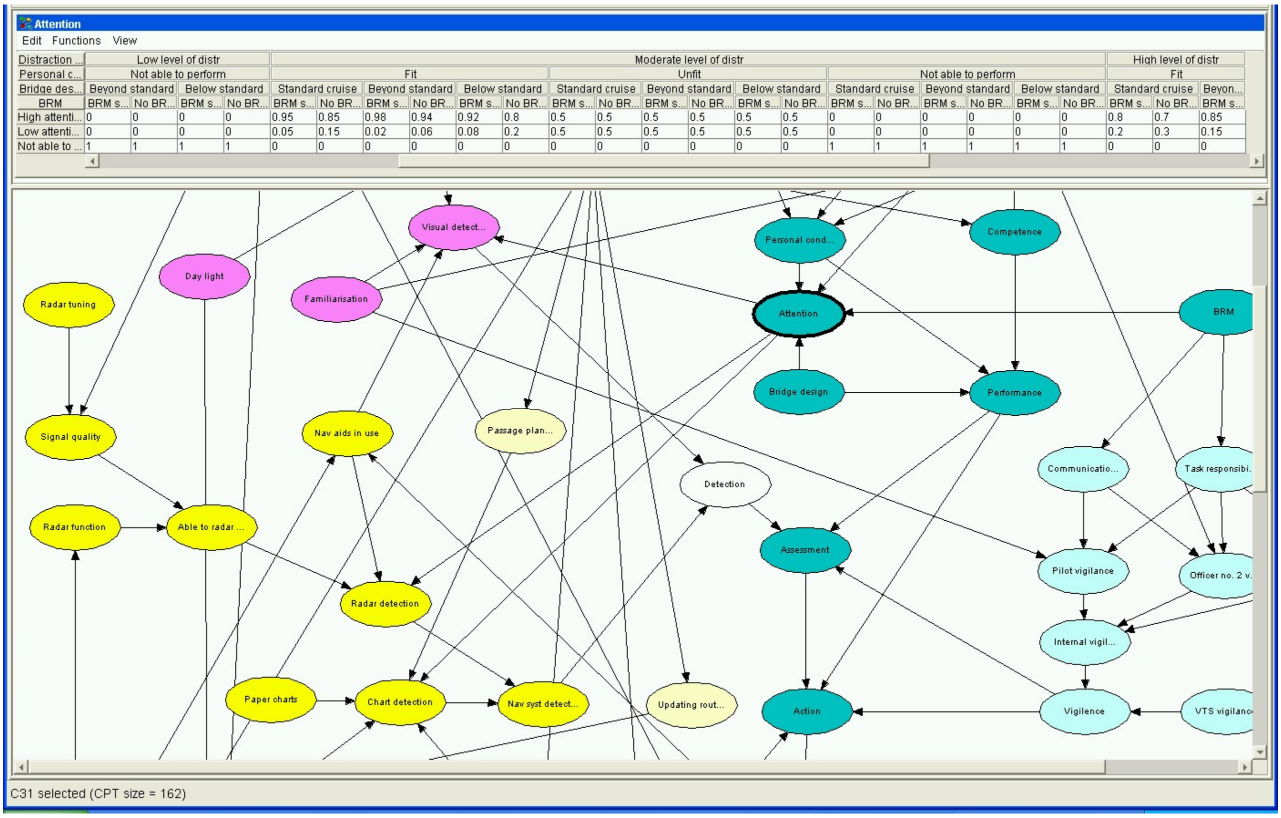
In the work process to establish the failure models for grounding, both in the FSA Navigation Large Passenger Ships project and the current project, various experts and data sources were used to ensure a solid foundation for the dependencies and figures entered into the model. Statistical data were used where available. If statistical data was not available, experts were interviewed or directly involved in the modelling process.

The persons involved during the project process in addition to the project team, are presented in Table D-2, in addition to a description of their contribution..

The structure of the Bayesian network was examined by navigators to ensure a logical model that included the important factors relevant for navigational performance, ref. Table D-2.

For nodes where no statistical information was available, expert interviews have provided input. Important probabilities in each node related to causes of grounding were discussed and verified. Figure D-1 shows an example of a conditional probability table behind each node. Bayesian networks are more thoroughly described in Annex I.

**Figure D-1 Example of Bayesian network and conditional probability table (CPT)**






Reference to part of this report which may lead to misinterpretation is not permissible.

**Table D-2 Experts involved in the process**

| Name | Expertise | What? |
|---|---|---|
| Arve Lepsøe | Nautical Surveyor, DNV dept for Nautical Safety<br>Working with tasks within plan approval, testing, certification, type approval and advisory services within the fields of bridge design and navigation systems.<br>Previous work experience as Navigator on Norwegian Navy Vessels and as deck officer on several chemical tankers in international trade.<br>Appointed as Norwegian member of two IEC standardisation working groups since April 1999. Appointed as advisor to the Norwegian delegation in IMO (NAV 46) meeting July 2000. | * Discussions on and verification of the structure of the network models.<br>* Quantification of probability input |
| Torkel Soma | Senior consultant, DNV Maritime Solutions<br>Ph.D. in Maritime Operations and Tech. Currently working within three areas of expertise: risk modelling, training and measurement of crew safety attitudes. | * Input on safety culture |
| Egil Dragsund | Chief Specialist, DNV Maritime Solutions<br>Experience with environmental monitoring, environmental impact and risk assessments and environmental research since 1980. | * Input on oil spill consequences |
| Inge Seglem | Approval Engineer, DNV dept for Stability, Loadline and Tonnage<br>Educated Master of Science in naval architecture. Several years experience with approval work on stability. | * Input on damage stability and probabilities of ship sinking |



Reference to part of this report which may lead to misinterpretation is not permissible.

# ANNEX II

## COST BENEFIT ASSESSMENT OF ECDIS

REPORT NO. 2005-1565

REVISION NO. 01

DET NORSKE VERITAS

***Table of Content*** ***Page***





Reference to part of this report which may lead to misinterpretation is not permissible.

# 1 INTRODUCTION

## 1.1 Objective and scope of work

The objective of the cost benefit assessment is to evaluate the cost effectiveness of introducing ECDIS as a mandatory requirement for the world fleet.

As discussed in Annex I, the task consists of studying the risk reduction expected by using ECDIS as a risk control option (RCO) for selected segments of the fleet, i.e. for a 4,000dwt product tanker, for an 80,000dwt tanker for oil and for a 75,000dwt bulk carrier, and the costs related to implementing the RCO. The task is divided into two main activities:

**Risk reduction:**

- Retrieving risk reduction in terms of loss of lives from the risk model presented in Annex I
- Retrieving risk reduction in terms of reduced accident frequency for the benefit of implementing the measures, i.e. reduced accident costs

**Costs:**

- Deriving a cost model
- Retrieving relevant cost data from the industry
- Carry out cost calculations

The cost effectiveness of the RCO is expressed as GrossCAF and NetCAF, see section 3.1.

## 1.2 Limitations

When evaluating the cost effectiveness of ECDIS for the world fleet, limited time and resources makes it impossible to study the whole fleet with all ship types and sizes. The present study has therefore selected three cases that are expected to have different cost effectiveness due to the differences in the nature of the trade, cargo, etc. The intention is to use these cases to generalise for other segments of the fleet.

The choice of routes used for the estimation of number of dangerous courses is supposed to represent a typical trade for the vessel type and size in question. Routes are assessed to be either neutral or conservative for the cost effectiveness calculations.

The study has assumed 100% Electronic Navigational Charts (ENCs) coverage for the evaluated cases. For routes where only parts of the track are actually covered, the effect is less, and very low (down to 0) for areas with no coverage. However, availability of an ECDIS system onboard enables use of Raster Navigational Charts (RNCs) when ENCs are not available. This could have a positive effect on the navigators understanding and overview of the fairway, in addition to use of paper charts. This effect has not been quantified.

For areas with full coverage, it is assumed that paper charts for these areas are not available onboard.



Reference to part of this report which may lead to misinterpretation is not permissible.

## 1.3 Abbreviations

| | |
|---|---|
| AIS | Automatic Identification System |
| ECDIS | Electronic Chart Display and Information System |
| ENC | Electronic Navigational Chart |
| Gross CAF | Gross Cost of Averting a Fatality |
| IMO | International Maritime Organization |
| Net CAF | Net Cost of Averting a Fatality |
| NPV | Net Present Value |
| RCO | Risk Control Option |
| RNC | Raster Navigational Charts |



Reference to part of this report which may lead to misinterpretation is not permissible.

# 2 ECDIS AS A RISK CONTROL OPTION (RCO)

## 2.1 Electronic Chart Display and Information System (ECDIS)

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. Its purpose is to continuously determining a vessel's position in relation to land, charted objects, navigational aids and possible unseen hazards. 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.

It is possible to integrate ECDIS with both the radar system and Automatic Identification System (AIS). However, this study considers a basic ECDIS system as described in the Performance Standard for ECDIS of IMO, ref. /5/.

The main benefits of using ECDIS considered in this study include:

- Liberate time for the navigators to focus on navigational tasks
- Improved visual representation of fairway
- More efficient updating of charts

The effect of the RCO has been tested by comparing with a vessel with ECDIS installed and in use, with a vessel without ECDIS.

## 2.2 Electronic Navigational Charts (ENC) coverage

This study assumes that the routes chosen for the vessel types in question have coverage of ENC. There is not 100% ENC coverage in the world today. However, if and when IMO makes the decision to amend the SOLAS convention to introduce mandatory carriage requirements for ECDIS, this could become a strong incentive for States to increase ENC coverage in their coastal areas.

In Figure 2-1 is a map showing the current coverage in the world today. The main shipping routes are already covered by ENCs, and the coverage is constantly improving. Figure 2-2 shows the areas for which ENCs are currently in production. Generally, it can be seen that areas with low water complexity and/or low traffic volumes are also areas with the no/limited coverage. Africa, South-America and Australia are the continents with the poorest coverage today, but the coverage is improving, especially for South America and southern parts of Africa. It is reasonable to believe that if ECDIS becomes mandatory in a few years from now, the process of achieving chart coverage will speed up.



Reference to part of this report which may lead to misinterpretation is not permissible.

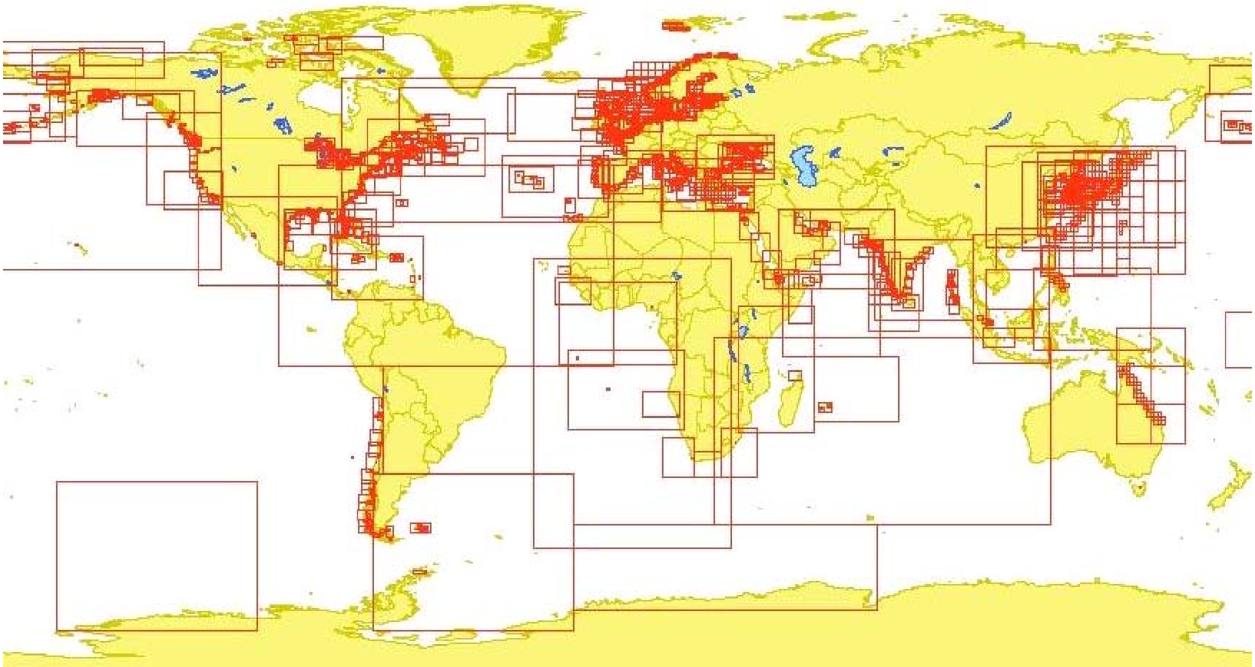


**Figure 2-1 World coverage of Electronic Navigational Charts, ref. /3/**

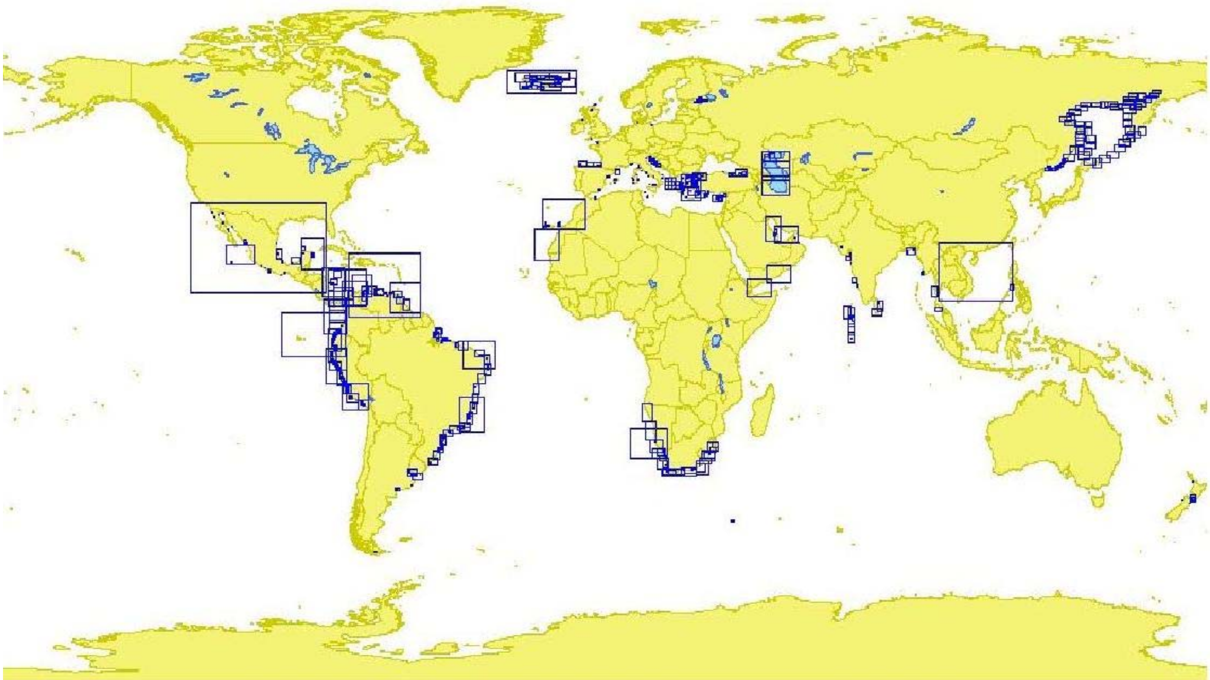


**Figure 2-2 Electronic Navigational Charts currently in production, ref. /3/**

Figure 2-3 is an example of the present coverage for one of the routes evaluated in this study, Kuwait–Marseille. The coverage on this route is very good, with ENCs available on the necessary scale on the whole route. The coverage is also 100% on for the smaller tanker route Mongstad-Stockholm.



Reference to part of this report which may lead to misinterpretation is not permissible.

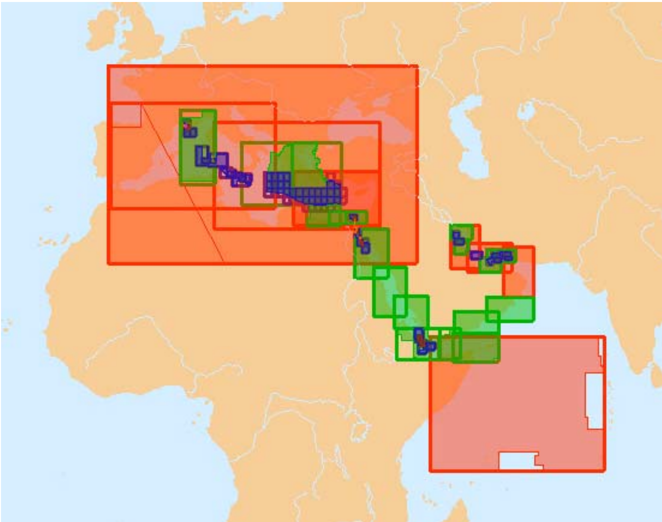


**Figure 2-3 Coverage of Electronic Navigational Charts, Kuwait – Marseille, ref. /4/**

For the bulk carrier route, Newcastle–Tokyo, the coverage is far less extensive. Figure 2-4 shows the available ENCs as red squares. The route in question is marked by a blue line, and areas with insufficient coverage along the route are indicated by green circles. The areas indicated as having insufficient ENC coverage have been selected as the ENCs available there are restricted to large scale overview charts, not suited for navigating in coastal waters. There are additional areas with overview charts only, but these areas are regarded as open sea. Table 2-1 gives a rough overview of the coverage on the route, corresponding to the circles on Figure 2-4.

**Table 2-1 Poor Chart Quality in Coastal Waters, Newcastle – Tokyo route**

| Area | Chart Quality | Chart Size [nm x nm] | Areas with poor coverage in coastal waters [nm] | Percentage of total route |
|---|---|---|---|---|
| Newcastle – Brisbane | Overview | 1000x1000 | 470 | 11% |
| Papa New Guinea South – Papa New Guinea North | Overview | 1000x1000 | 90 | 2% |
| Micronesia – Guam | Overview | 1000x1000 | 20 | 0.5% |
| North. Mariana Islands – Volcano/ Bonin Islands | Overview | 1000x1000 | 20 | 0.5% |
| **TOTAL, areas with poor coverage in coastal waters** | **-** | **-** | **600** | **15%** |

Beginning in the south, the first indicated area is between Newcastle and Brisbane on the Australian east coast. The second area indicated is the coastal areas of Papua New Guinea and nearby islands. Further north the coverage is insufficient around the Micronesian archipelago and the fourth are indicated is the area of Guam and the Northern Mariana Islands. When approaching the area of the Volcano Islands and Bonin Islands the coverage is deemed sufficient (a small cluster of red squares), and close to the Japanese coast the coverage is good.

Comparing the above with the distribution of type of waters in Annex I, section 3, more or less all navigation in coastal waters on this route has poor ENC coverage. Only navigation into



Reference to part of this report which may lead to misinterpretation is not permissible.

Tokyo and the areas around the Volcano Islands and Bonin Islands is considered to have good coverage in coastal navigation. This means that the cost-effectiveness of ECDIS will be significantly reduced if the actual ENC coverage is taken into account. However, availability of an ECDIS system onboard enables use of Raster Navigational Charts (RNCs) when ENCs are not available. This could have a positive effect on the cost effectiveness; however, this effect has not been quantified.

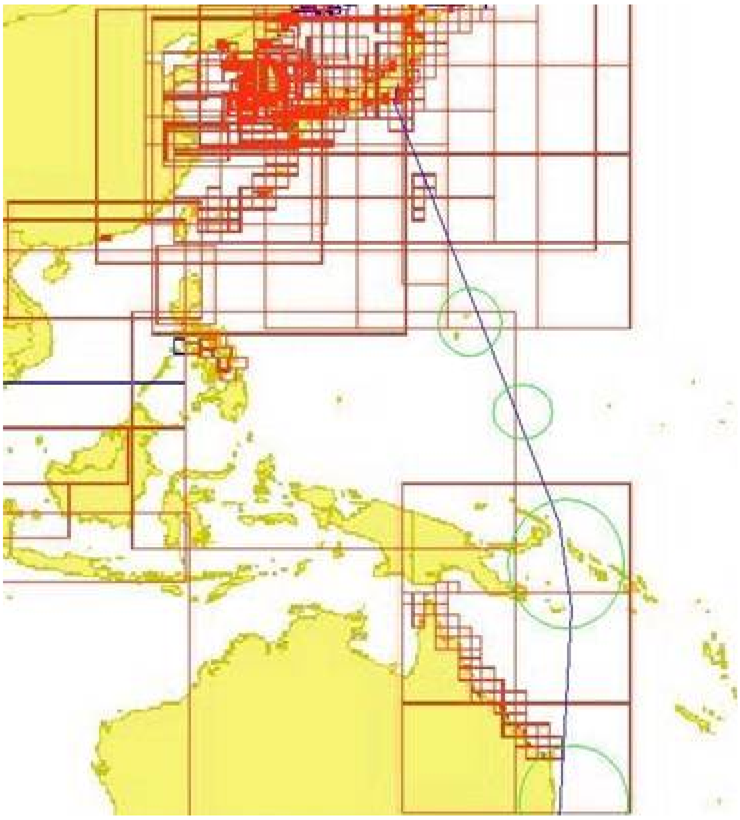


**Figure 2-4 Coverage of Electronic Navigational Charts, Newcastle – Tokyo, ref. /3/, circles indicate coastal areas with insufficient ENC coverage**



Reference to part of this report which may lead to misinterpretation is not permissible.

# 3 METHODOLOGY FOR COST BENEFIT ASSESSMENT

## 3.1 Assessment criteria

The cost-effectiveness of ECDIS is expressed in terms of Gross Cost of Averting a Fatality (GrossCAF) and Net Cost of Averting a Fatality (NetCAF). Their definitions are:

$$GrossCAF = \frac{\Delta C}{\Delta R}$$

and

$$NetCAF = \frac{\Delta C - \Delta B}{\Delta R}$$

where:

ΔC is the cost per ship of the risk control option during the lifetime of the vessel

ΔB is the economic benefit per ship resulting from the implementation of the risk control option

ΔR is the risk reduction per ship, in terms of the number of fatalities averted, as a result of the risk control option.

## 3.2 Work processes and data sources

The work with the cost benefit assessment consisted of estimating the three parameters *cost*, *benefit* and *risk reduction* for each of the vessel types and to calculate GrossCAF and NetCAF values.

The costs of implementing ECDIS have been based on discussions with DNV experts, information from suppliers of ENCs and ECDIS equipment and previous DNV reports. This has resulted in a highest and lowest cost estimate.

For the economical benefit of introducing a measure, this is only accounted for in terms of reduced accident costs.

A risk model was made in Annex I, which was established to have a tool to estimate the risk reduction of implementing the RCOs.

## 3.3 Risk calculations

For estimating the risk reduction of implementing ECDIS, the risk model is used. The model was made by using Bayesian theory. More information on the model can be found in ANNEX I.

Figure 3-1 gives a brief overview of the risk model. The nodes are only illustrative and are not the nodes used in the actual model, which are of a far higher level of detail.

By changing the properties in the ECDIS node in the network it is possible to simulate the vessel with or without ECDIS on the bridge. In this way the risk reducing effect of ECDIS can be studied by looking at the reduced likelihood of grounding and reduced number of fatalities. This has served as input for the GrossCAF and NetCAF calculations.



Reference to part of this report which may lead to misinterpretation is not permissible.

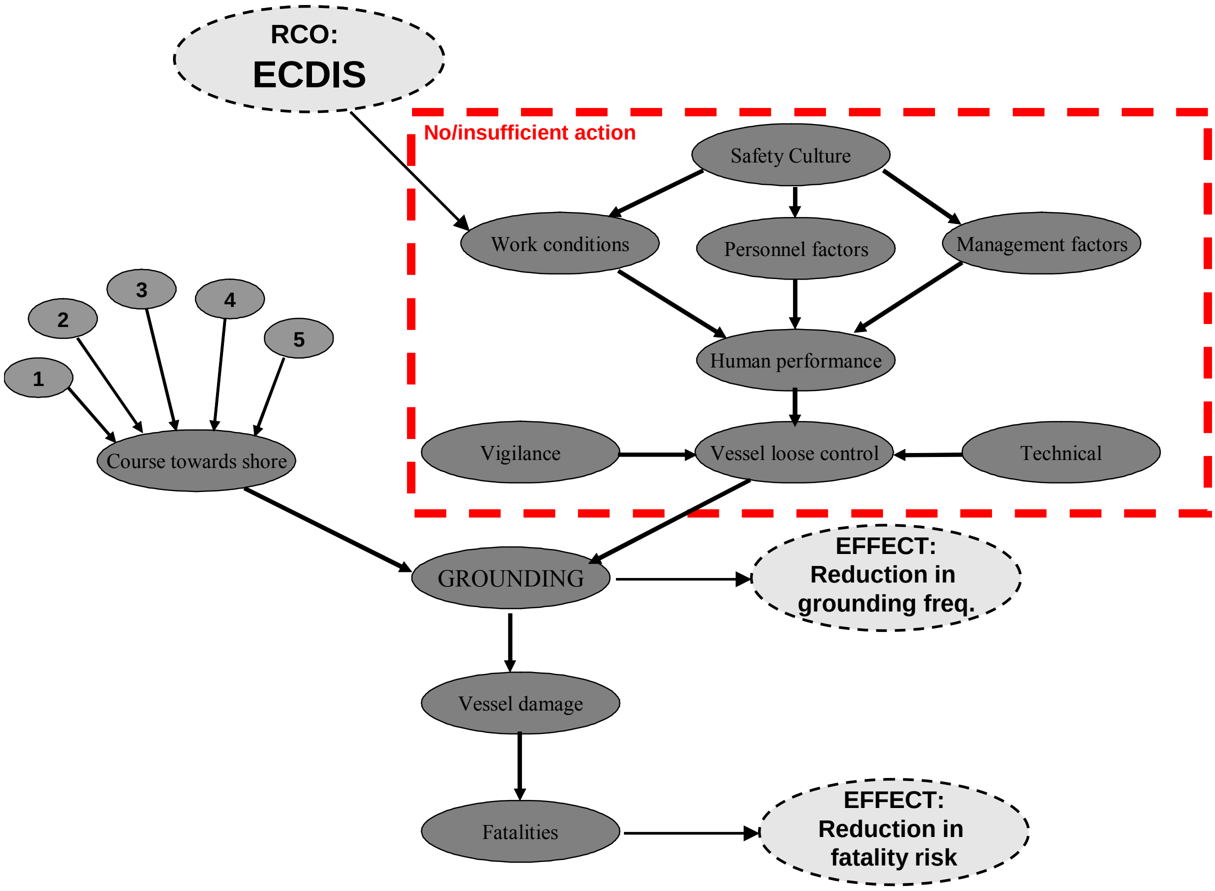



**Figure 3-1 Use of the Bayesian grounding model to estimate the effect of ECDIS**

## 3.4 Cost and benefit calculations

The cost and benefit of ECDIS will be spread over the lifetime of the vessel. Some of the costs recur every year while others only involve an initial investment cost. 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 formula 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 = interest rate

### 3.4.1 Direct cost of ECDIS

The direct costs of ECDIS 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. In addition costs at regular intervals is assumed in order to maintain the effect of the measure, e.g. equipment service and refreshment courses. The additional costs are assumed to be annual.

A vessel lifetime of 25 years has been assumed.

### 3.4.2 Benefits

The implementation of ECDIS as a mandatory requirement for the world fleet has other benefits than reducing number of fatalities. Other benefits are reduced expected annual damage to property cost and reduced annual environmental damage cost.

The reduced expected accident cost for ECDIS has been found by accessing the potential risk reduction for each vessel type, using the risk model for Tanker 80,000dwt, Tanker 4,000dwt and Bulk Carrier 75,000dwt as shown in chapter 3.3. Using the potential risk reduction, the annual costs for environmental damage and property damage, based on ref. /2/, has been reduced accordingly. It is assumed that only the damage categories Total loss and Serious Casualties can result in oil spills, while the property damage costs include all property damages from Non-serious incidents to Total Losses.



Reference to part of this report which may lead to misinterpretation is not permissible.

# 4 RESULTS

## 4.1 Risk reducing effect

The table below describes the expected risk reduction due to implementation of ECDIS. The vessels are assumed to have a life time of 25 years which is the basis for the number of lives saved. The results are given in number of lives saved during a vessel's life time and as a percentage of reduction in fatalities.

**Table 4-1 Risk reduction of implementing ECDIS**

| Vessel Type/Size | Average lifetime [years] | No. of crew members | No. of lives saved [per lifetime] | % reduction in number of fatalities* |
|---|---|---|---|---|
| Tank 80' DWT | 25 | 24 | 3.1E-03 | 36% |
| Tank 4' DWT | 25 | 14 | 5.2E-03 | 36% |
| Bulk 75' DWT | 25 | 24 | 4.7E-03 | 36% |

The effect of ECDIS is compared to the use of paper charts. In other words, the vessels are assumed to have either ECDIS or paper charts. This differs from the situation onboard some vessels today, where there are both ECDIS and paper charts available. The intention of introducing ECDIS as a mandatory requirement is to remove the need for paper charts to liberate more time for the bridge personnel to focus on other tasks.

The reduction in number of groundings and fatalities is calculated to be about 36%. This is in accordance with previous research carried out in the industry, e.g. ref. /6/.

Use of ECDIS is expected to also have a risk reducing effect on the collision scenario. For large passenger vessels, ref. /1/, this effect was estimated to 3%, mainly due to liberation of time to focus on monitoring of the traffic picture. However, this effect is not quantified for other ship types in the present study.

## 4.2 Cost and benefit estimates

The following section describes the cost and benefits of implementing ECDIS on the chosen vessel types. The explanation of the costs included is given in Appendix 1. Thus, this section does not describe further explanation of what costs are included and which are not.

The costs and benefits of implementing the RCOs are given in Table 4-2.

**Table 4-2 Costs and benefits of implementing ECDIS**

| Vessel Type/Size | **Cost of implementation** (NPV in $)* | **Benefit of implementation** (NPV in $)* |
|---|---|---|
| Tank 80' DWT (Kuwait-Marseille) | 75,000 | 396,000 |
| Tank 4' DWT (Mongstad-Stockholm) | 75,000 | 175,000 |
| Bulk 75' DWT (Newcastle-Tokyo) | 75,000 | 295,000 |

* Figures are given in Net Present Value

The costs of implementation are assumed the same for all vessel types. This is due to the fact that the number of people that needs training is assumed the same for all the vessel types and sizes



Reference to part of this report which may lead to misinterpretation is not permissible.

analysed and that the type of equipment is the same. The benefits are calculated using values for spill cost and property cost and subsequently finding the reduction in cost due to use of ECDIS.

Further details regarding the average cost of oil spills and the cost of different sized vessels damages can be found in appendix A.

## 4.3 GrossCAF and NetCAF values

The GrossCAF and NetCAF values are presented in Table 4-3.

**Table 4-3 GrossCAF and NetCAF for all RCOs**

| Vessel Type/Size | Gross CAF [$] | NetCAF [$] |
|---|---|---|
| Tank 80' DWT (Kuwait-Marseille) | 23,900,000 | < 0 |
| Tank 4' DWT (Mongstad-Stockholm) | 14,600,000 | < 0 |
| Bulk 75' DWT (Newcastle-Tokyo) | 16,000,000 | < 0 |

Due to a very small reduction in number of saved lives, the GrossCAF values are high, which indicates that as a measure for averting fatalities only, ECDIS is not a cost effective measure.

However, the NetCAF value is negative, which indicates that the RCO is beneficial in itself, i.e. the net economic benefits exceed the cost of implementation. The economical benefit is in this assessment only measured in terms of reduced accident costs. Other economical benefits, e.g. fewer business interruptions and long term effects like improved company reputation, are not considered. Neither is the effect ECDIS may have on the collision risk taken into account. Taking this into consideration would make the RCOs even more cost-effective.

The ratio between costs and benefits is in the range of 2-5 for the three selected cases. With the high GrossCAF, the ratio between costs and benefits is almost equivalent to the robustness of the conclusion result (i.e. the results are robust with a factor of 2 to 5). The presented results are thus considered robust the two large vessel cases, but less robust for the smaller tanker case.

If the suggested "willingness-to-pay" to avoid a ton of oil spilt of $60,000 developed in ref. /8/ had been used instead of only direct cost of an oil spill, the environmental cost would have increased significantly, especially for large tankers. For the largest tanker case (80,000dwt), the total economical benefits of ECDIS would have increased by a factor of 3.5. For smaller tankers the effect is less, in the order of 20% for the smallest tanker case (4,000dwt). The robustness of the cost-benefit assessment would have increased accordingly. However, the present cost-benefit assessment is based on direct costs of an oil spill only, and not the "willingness-to-pay" value.

## 4.4 Discussion of results

There are three factors that influence the cost effectiveness of a measure:

- Cost of implementation
- Economic benefits, in this case: reduced number of accidents and accident costs
- Number of saved lives



Reference to part of this report which may lead to misinterpretation is not permissible.

We make the following assumptions:

- Cost of implementation will be more or less constant for different vessel types
- Number of saved lives is relatively low for all vessel types

These two assumptions are robust, implying that the GrossCAF for ECDIS as RCO will be high for all vessel types. The interesting parameter is then to conclude on the robustness of the benefits exceeding the costs.

Based on this, the reduction in accident costs is the most important factor when assessing the cost effectiveness. This item is again influenced mainly by the following factors:

- Effect of ECDIS
- Grounding probability
- Trade and exposure
- Value of ship
- Value of cargo
- Type of cargo (ref. environmental impact)
- Size of ship

The chosen routes are considered to be representative. It is obvious that a vessel sailing from e.g. one easy port in Europe directly into another easy port in North or South America will be less exposed than the vessels chosen in this study. Such assessments are not considered relevant, as no vessels are only trading on easy routes. Further, there are of course a lot of routes which are significantly more difficult and exposed than the routes chosen. The results are thus considered robust and representative for the vessel types chosen, when sailing in world-wide trade. The condition is of course there is ENC coverage where the vessel sails; without this, ECDIS has no effect.

Considering the accident reduction by introducing ECDIS, there is little reason to believe that the risk reducing effect would be significantly less for other ship types. The ECDIS is part of the bridge equipment and bridge design and operation are fairly similar among the ship types most common in the world fleet. Based on this, it is expected that ECDIS' risk reducing effect on groundings is similar for all vessel types.

Grounding has different importance and costs for different ship types and sizes. When discussing exposure to grounding risk it is assumed that the ship types not analysed in this study have a similar trade to the ones included in the study. It is not likely that any ship type has a route less exposed to coastal waters (and thus to grounding) than the large tanker and bulk carrier chosen in this study. This holds also for the third major ship type for international trade, container vessels.

Studying other ship types, it could be argued that these ship types generally have more expensive cargo than the bulk carrier modelled in this study. The same argument can be used when considering the cost of repairing a vessel. Tankers and bulk carriers are considered the cheapest ship types per tonnage delivered from the newbuilding yards. Based on this, the cost given grounding will be equivalent or higher to the one modelled for all other relevant ship types.

It could be possible that some vessel types were less exposed to grounding due to their excellent manning or other similar characteristics. The manning onboard the different vessel types in the world trade are however not considered to be very different, and statistics from the generic FSA



Reference to part of this report which may lead to misinterpretation is not permissible.

studies previously carried out by DNV shows that the annual cost of groundings are higher for the other large ship types in the world fleet, ref. /7/.

The last discussion should be around vessel sizes. The cost of installing and training for ECDIS is more or less the same for all vessel types. The benefit will in general increase with the vessel size and value/cargo value. Smaller vessels are, however, often exposed to more coastal waters than the larger vessels, and as such more exposed to grounding risk. The actual exposure per sailed nautical mile in coastal waters is based on relevant DNV statistics not considered to be very different. Thus, the increased exposure will to some extent make up for the reduced benefit per grounding. It is however obvious, that for very small vessels, the expense of installing and training for an ECDIS could exceed the benefit. Where this limit is, is difficult to tell exactly. This study demonstrated that for a 4,000 dwt oil tanker sailing in relatively coastal water (regional trade), ECDIS is cost-effective. Based on the argumentation above, this would be the same also for other vessel types of similar size. However, no specific lower limit has been determined.

These arguments all support that the chosen vessel types can represent the world fleet and that a proven cost effectiveness of ECDIS for tankers and bulk carriers also is valid for all other ship types in international trade. It is valid for all ship sizes, with exception of the very small vessel. The condition to this is that ENC coverage exists in the area.



Reference to part of this report which may lead to misinterpretation is not permissible.

# 5 REFERENCES

/1/ NAV 51/10 - Full report can be found at: http://research.dnv.com/skj/FSALPS/FSA-LPS-NAV.htm

/2/ DNV Report *A Simple Model of The Costs of Ship Accidents for DNV FSA Based Ship Rules Project*, Rev. 1 (2001)

/3/ Hydrographical office of Portugal web site: http://ih-net-www.hidrografico.pt/website/icenc

/4/ Primar Stavanger, Eva Hegland

/5/ The IMO "Performance Standards for Electronic Chart Display and Information Systems" IMO Res. A.817(19)

/6/ Article on electronic charts – Frode Klepsvik, Haugesundkonferansen 14-16 Feb 2000

/7/ FSA generic vessel risk assessments for various ship types, DNV reports

/8/ Skjong, R, E Vanem and Ø Endresen *Risk Evaluation Criteria* SAFEDOR-D-4.5.2-2005-10-21-DNV

– o0o –

# ANNEX II – APPENDIX A

## COST ESTIMATES

REPORT NO. 2005-1565

REVISION NO.01

DET NORSKE VERITAS

## *Table of Contents* *Page*





Reference to part of this report which may lead to misinterpretation is not permissible.

# A1 INTRODUCTION

This appendix includes the calculation of the cost and benefit estimates. The estimates are based on the methodology given in Annex II.

The interest rate is set to 5 % for all the Net Present Value (NPV) calculations. This value is commonly used and represents a believed return on an investment in todays market.

# A2 COST ESTIMATES

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

**Table A-1 Input to the cost estimate for RCO 4**

| Required Input | Low Value | High Value | Input Value | References |
|---|---|---|---|---|
| ECDIS | $29,000 | $41,000 | $32,000 | /1/ |
| Back Up arrangements | $16,000 | $26,000 | $20,000 | /1/ |
| Annual Cost (maintenance) | | $500 | $500 | /1/ |
| Initial Training | $6,000 | | $6,000 | /3/, /4/ |
| Annual Training | $750 | | $750 | /3/, /4/ |
| Net Annual Chart updates* | $0* | | $0 | /2/ |

*Net difference between cost of ENCs and cost of paper charts. It is assumed that the annual cost of paper charts is larger or equal to the annual cost of ENCs (paper chart equivalent), ref. /2/ and ref. /6/.

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, ref. /1/.

Annual expenses for regular service and maintenance purposes are represented as a possible future system failure and the need for replacing parts and software. This assumption is the same as was done in the FSA study for cruise vessels, ref. /1/.

It is assumed that 6 officers pr vessel need training in ECDIS use. This means that 6 initial courses are needed in addition to the annual training for new officers joining the vessel during its lifetime. During the lifetime of the vessel this study assumes a turnover over of in total 8x6 navigational officers in need of training when joining the vessel. This means that in average every 3.1 years the 6 persons in need of training are replaced. The course prices are based on ref. /3/ and /4/.

Please note that the net annual chart update cost is the cost difference between ENCs and paper charts. Thus a positive value would indicate that the annual costs of updating ENCs are more expensive than for paper charts, ref. /2/. The input value is set to $0 meaning that the annual cost of paper charts is assumed equal to the annual cost of ENCs. This is a conservative assumption based on input from ref. /2/ and ref /6/.

Using the above assumptions and values the net present value for the implementation of the RCO is calculated to be $75,000.



Reference to part of this report which may lead to misinterpretation is not permissible.

# A3 BENEFIT ESTIMATES

The benefit estimates are developed combining the costs related to repairs to the ship, loss of cargo, delays, off-hire, etc. and costs related to environmental clean up costs. Only short term losses are included. Long term business impacts, such as loss of reputation and client contracts, are not taken into account. Neither is long term environmental impact such as impact on sensitive areas, tourism, etc. If such reduction of long term effects had been quantified, the benefits are expected to increase significantly.

In addition to the benefits mentioned above there are several benefits related to the shorter time it takes for the weekly updating of charts. With less time spent on updating of charts the personnel can spend more time on other tasks. In addition, there will in general be less overtime for the officers resulting in less fatigue and more rest and spare time. This is important in itself, and will in addition reduce overtime pay if this is applicable and increase the satisfaction of the crew on the bridge. This benefit is not quantified.

The annual savings are summarised and the net present value is calculated for the lifetime of the ship. The benefits are compared to the net present value of the implementations costs.

## A3.1 Property Costs

The property damage costs are based on the distribution of damage levels for each of the vessel types and the costs related to the different levels, ref. /5/. The reduction in grounding frequency of about 36% is then used to calculate the benefits.

**Oil Tanker 80,000 dwt**

| Damage level | % | Cost pr incident [$] | Average Annual Costs [$] |
|---|---|---|---|
| Non serious | 89.6 | 179,000 | 8,000 |
| Serious | 8.7 | 4,300,000 | 15,000 |
| Catastrophic | 1.7 | 12,000,000 | 11,000 |

**Bulk Carrier 75,000 dwt**

| Damage level | % | Cost pr incident [$] | Average Annual Costs [$] |
|---|---|---|---|
| Non serious | 70.4 | 150,000 | 3,700 |
| Serious | 25.5 | 3 600,000 | 32,000 |
| Catastrophic | 4.1 | 7,700,000 | 11,000 |

**Product Tanker 4,000 dwt**

| Damage level | % | Cost pr incident [$] | Average Annual Costs [$] |
|---|---|---|---|
| Non serious | 89.6 | 79,000 | 11,000 |
| Serious | 8.7 | 1,500,000 | 26,000 |
| Catastrophic | 1.7 | 5,500,000 | 14,000 |



Reference to part of this report which may lead to misinterpretation is not permissible.

## A3.2 Environmental Costs

### A3.2.1 Direct costs

The environmental costs are based on Serious and Catastrophic accidents only. The grounding frequency of the serious accidents is combined with the frequency of oil spill given that grounding has occurred resulting in a frequency of oil spill pr. year. Using the average spill cost for the vessel types in question, an estimate of annual environmental damage costs can be calculated, ref. /5/.

**Table A-1**

| Vessel Type/Size | Average Annual Costs [$] |
|---|---|
| Tank 80' DWT | 26,000 |
| Tank 4' DWT | 4,000 |
| Bulk 75' DWT | 11,000 |

The actual spill cost, e.g. clean up cost, will vary in different parts of the world. However, these figures are average figures, and not adjusted with regional factors.

In the distribution of accident severity, this study has assumed a certain amount of incidents occurring without being reported. These are assumed to be of a non-serious character, thus only contributing to the annual property costs.

### A3.2.2 Willingness to Pay

It could be discussed whether the value used in the estimates for environmental costs are far too low since it only includes clean-up costs and short term business losses. If long term costs are included, the average annual costs are expected to be significantly higher. In addition, the willingness to pay to *avoid* an oil spill will make the cost effectiveness even more robust.

Some work has been undertaken to develop a CATS (Cost of Averting a Ton Spilt) value, similar to the CAF (Cost of Averting a Fatality) value for human losses. This is an expression for the willingness to pay for avoiding a ton of oil spilt, which is obviously higher from society's point of view than costs of cleaning up only. In ref. /7/, a CATS value has been developed and suggested to $60,000, which is far higher than the cost per ton used in the estimates in Table A-1.

If a cost per ton spilt of $60,000 had been applied in this cost-benefit assessment, the cost of environmental spills would have increased the potential benefits significantly, especially for larger tankers. For the largest tanker case (80,000dwt) the benefits in terms of environmental savings would have increased by a factor of 8, and the total economical benefits (also including property damage costs) by a factor of 3.5. For smaller tankers the effect is less, in the order of 2.5 on the environmental savings and 20% on the total economical benefits for the smallest tanker case (4,000dwt).



Reference to part of this report which may lead to misinterpretation is not permissible.

## A4 REFERENCES

/1/ NAV 51/10 – Full report can be found at: http://research.dnv.com/skj/FSALPS/FSA-LPS-NAV.htm

/2/ Primar Stavanger, Eva Hegland

/3/ www.Warashcentre.co.uk

/4/ www.Lairdside-Maritime.com

/5/ DNV Report "A Simple model of The Cost of Ship Accidents", rev.01, 2001

/6/ Phone conversation Frode Klepsvik – Norwegian Hydrographic Service, 2006-01-09

/7/ Skjong, R, E Vanem and Ø Endresen *Risk Evaluation Criteria* SAFEDOR-D-4.5.2-2005-10-21-DNV

- o0o -



Reference to part of this report which may lead to misinterpretation is not permissible.