EMSA/OP/01/2016

Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE)

Appendix: Sensitivity and Uncertainty Analyses

European Maritime Safety Agency
SP Technical Research Institute of Sweden AB
Bureau Veritas
Stena Rederi AB

Project name:	EMSA/OP/01/2016 SP BV STENA
Report title:	Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE) Appendix: Sensitivity and Uncertainty Analyses
Customer:	European Maritime Safety Agency,
Contact person:	Mr. Sifis Papageorgiou
Date of issue:	2017-01-13
Project No.:	6P05070
Report No.:	6P05070-2

Authors

SP Technical Research Institute of Sweden AB:

Johan Wikman,
Naval Architect, (ship fire safety, regulations, RCOs, risk models, fire safety)

Franz Evegren,
Risk Management, (FSA, risk models, statistics, RCOs, fire safety)

Michael Rahm,
Fire Safety Engineer, (FSA, fire modelling, risk models, RCOs, fire safety)

Bureau Veritas:

Jérome Leroux,
Risk Engineer (FSA, CBA, risk models, statistics)

Antoine Breuillard,
Risk Engineer (FSA, CBA, risk models, statistics)

Stena Rederi AB:

Mattias Kjellberg,
Captain, (ship operational questions, ship fire safety, RCOs, costs estimates)

Lisa Gustin,
Naval Architect, (ship fire safety, RCOs)

Fredrik Efraimsson,
Naval Architect (ship related questions, ship fire safety, RCOs, costs estimates)

Disclaimer

"*The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of EMSA. EMSA does not guarantee the accuracy of the data included in this study. Neither EMSA nor any person acting on EMSA's behalf may be held responsible for the use which may be made of the information contained therein.*"

Scope

This appendix is attached to the main report FIRESAFE EMSA contract EMSA/OP/01/2016, FIRESAFE report 6P05070-1 "Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE)" published 22/12/2017, referenced as "FIRESAFE report" in this appendix

Contents

List of figures

List of tables

Acronyms

CBA: Cost-Benefit Analysis
EMSA: European Safety Maritime Agency
FSA: Formal Safety Assessment
GCAF: Gross Cost of Averting a Fatality
NPV: Net Present Value
PLL: Potential Loss of Life
POB: Persons On Board
RCM: Risk Control Measure
RCO: Risk Control Option

Definitions & FSA Guidelines quotes

Definitions

SENSITIVITY ANALYSIS AND UNCERTAINTY ANALYSIS (adapted from the FSA Guidelines)

Sensitivity analysis is the study of how uncertainty in output of a model (numerical or otherwise) can be apportioned to different specific sources of uncertainty in the model input. A related practice is uncertainty analysis which focuses rather on quantifying uncertainty in model output. Ideally, uncertainty and sensitivity analysis should be run in parallel.

Uncertainty analysis investigates the uncertainty of the variables that are used in decision-making problems with observations and models as knowledge base. The uncertainty of each variable is estimated and used to quantify the uncertainty of the model output. In other words, uncertainty analysis aims to make a technical contribution to decision-making through the quantification of uncertainties in the relevant variables. Uncertainty and sensitivity analysis investigate the robustness of a study when the study includes some form of statistical modelling.

In conclusion, an uncertainty analysis estimates the uncertainty of the output from estimated uncertainty in input variables, whilst a sensitivity analysis studies how sensitive the output is to variations in each input variable.

FSA guidelines quotes

Part of Step 2 – Risk Analysis

6.2.3 Sensitivity analysis and uncertainty analysis should be considered in the quantified and/or qualified risk and risk models and the results should be reported together with the quantitative data and explanation of models used. Methodologies of sensitivity analysis and uncertainty analysis would depend on the method of risk analysis and/or risk models used.

Part of Step 3 – Risk Control Options

7.2.3.6 Sensitivity analysis and uncertainty analysis should be considered in the analysis of effectiveness of RCMs and RCOs, and the results of sensitivity analysis and uncertainty analysis should be reported.

Part of Step 4 – Cost Benefit Assessment

8.2.4 Sensitivity analysis and uncertainty analysis should be considered in the cost-benefit analysis and cost-effectiveness, and the results should be reported.

1. Introduction / Executive Summary

According to the FSA guidelines, sensitivity and uncertainty analyses should be performed and documented in the FSA report. These should apply to the risk quantification (STEP 2), the risk reduction quantification (STEP 3) and to costs (STEP 4), as noted above in the FSA guidelines quotes.

The present document provides the sensitivity analysis in the first part and the uncertainty analysis in the second part. The combination of both sensitivity analysis and uncertainty analysis enlightens the reader to assess the robustness of the conclusion provided in the FIRESAFE report and further expanded here.

The sensitivity analysis investigated variation of several parameters and dependent probabilities of the main risk model. The main outcome of the sensitivity analysis was that most of the conclusions are relatively robust against the selected parameter variations (*i.e.* the conclusions do not change with variations of the different parameters, or for most of the RCOs the risk assessment was not sensitive to variations in input parameters). This is a strength of the FSA guidelines, that they require a comparative approach (delta PLLs, delta Costs) and not absolute evaluation.

For a few RCOs, the conclusions changed with regard to cost-effectiveness, namely for the RCOs called "only ship cables" (El 2), dedicated CCTV (Su 6), and dedicated CCTV and drencher remote control (Su 7). For existing ships, the conclusion regarding dedicated CCTV for garage fire safety was found sensitive to every parameter evaluated, except containment. However, the same system combined with remote drencher control is always better in terms of efficiency, irrespective of the newbuilding/existing ship status, and it is less sensitive. The most sensitive input parameters were the initial accident frequency as well as the probability of unsuccessful evacuation.

The uncertainty analysis determined that even though the uncertainty of the GCAF Factors in many cases was large, the conclusions on the cost-effectiveness of most RCOs did not change. Most of the static GCAF Factors were well above or well below 1 and thus had a high level of confidence. For the RCOs with static GCAF Factors close to 1, uncertainty analysis resulted in confidence levels for the RCOs to be cost-effective. No threshold was set for the confidence levels, i.e. to evaluate whether the conclusions on cost-effectiveness of the RCOs are certain enough to be recommended.

2. Sensitivity analysis

2.1. Method

The method used for the sensitivity analysis followed the subsequent procedure:

- Selected parameters and probabilities of the model were increased and decreased by a certain percentage or by adding fictitious occurrences of an event or by changing the rules used for the model when data was missing (see FIRESAFE report section 2.8.5)
- Each parameter was as a rule changed individually. However, considering the large number of parameters and RCOs in the model, the probabilities under each TIER of the main model were increased and decreased together. This is to some extent justified by that those probabilities are correlated and dependent (see FIRESAFE report section 2.8.5). Each parameter was increased and decreased, providing an upper and a lower bound for the GCAF factor, one for each TIER.
- No combination was made of the sensitivity of parameters and dependent probabilities under the different TIERs. Complex combinations of parameters was rather performed in the uncertainty analysis (*e.g.* Tier 3 with RCO contributions), as described below.
- The increases and decreases were evaluated depending on the dataset content and the presumed uncertainty of the parameters.
- Since it was not possible to assess the uncertainty of the bottom nodes of the sub risk models (*i.e. electrical sub-model* and *suppression failure* sub-model), variations were only made of the top nodes of each model (*i.e. initial accident frequency* and *Extinguishment/suppression failure*).
- The effects on each RCO GCAF Factor were recorded and plotted in graphs around the static values of the FIRESAFE report sections 3.5.3 and 4.5.3.
- The results are presented for each parameter variation, and
    - The corresponding PLL is given
    - Three types of effects are scrutinized:
        - GCAF Factors insensitive: remaining far above 1 or far below 1
        - GCAF Factors sensitive, type 1: upper value passing above 1
        - GCAF Factors sensitive, type 2: lower value passing below 1
    - For each RCO the upper values of GCAF Factors and lower values of GCAF Factors are given by the black segments, depending on the existing/newbuilding status of the ship (see figures in *Annex 1: Sensitivity Analysis detailed results*).

2.1.1. Range of parameter variations

Table A 1 presents the different parameters selected for the sensitivity analysis and the range of variations considered.

Table A 1: Ranges of variations for the parameters considered.

Where in the model	Parameters	Descriptions of range of variations
Ini. freq. Tier 0	Initial frequency	Assumes +/- 10 fire events[1] in the fleet at risk, vs. 32 originally
Origin. per deck type Tier 1	Fire origin per deck type	Assumes variations around the average value defined for the reference ship model: proportion of fire occurring on Closed-Open-Weather (45-50-5 or 75-20-5, vs. 60-35-5 in the static model)[2]
Early/Late Tier 2	Early/late decision	Among the 32 events, 4 were unknown. It is assumed that these unknowns are either all early decisions, either all late decisions.
Extinc. Suppress. Tier 3	Extinction or Suppression	This is only performed to analyse the sensitivity on the PLL. For early/extinction, 2 events were unknowns. They are added and assumed as either extinction successes or as extinction failures. Regarding late decision/suppress., there was no unknown. 1 additional accident is assumed either as a suppression success or as a suppression failure. For the sensitivity on RCO the combination of effects are too complex and are rather taken into account in the uncertainty analysis
Contain. Tier 4	Containment	Where applicable, additionally to the recorded events, assumes + 1 event contained, and alternatively + 1 event uncontained. Else, for those nodes where the 90-10 assumption[3] was taken, it is changed to 80-20 and alternatively 99-1 as well as for the 95-5 assumption which is changed to 90-10 and alternatively 99.5-0.5.
Evac. Tier 5	Evacuation	Where applicable, additionally to the recorded events, assumes + 1 accident with unsuccessful evacuation, and alternatively - 1 accident with unsuccessful evacuation. Else, expert judgement 75-25 is altered to 65-35, and alternatively, 85-15, as well as the 90-10 assumption is altered to 80-20, and alternatively 99-1.
Fatality Model	Number of fatality given a event tree branch	Assumes + 1 fatality where 1 was assumed or -0.5, and 11% or 5% for the fatality rate, vs. 8% in static model
Costs NPV	Net Present Values	Assumes plus or minus 20% to NPV

1- "+/- 10" means "plus or minus ten"

2- "45-50-5" means 45% of fires occuring on closed deck, 50% on open decks and 5% on weather deck see FIRESAFE 2.8.5

3- "90-10" means 90% and 10%, see FIRESAFE 2.8.5

2.2. Results

2.2.1. Results on PLL

Table A 2 presents the effects of the parameters' variations on the reference PLL of the model.

Table A 2: Results of the parameters variations on the reference PLL.

Where in the model	Parameters	Lower PLL (fat/s.y)	Static PLL (original model)	Upper PLL (fat/s.y)
Ini. freq. Tier 0	Initial frequency	1.45E-02	2.10E-02	2.76E-02
Origin. per deck type Tier 1	Fire origin per deck type	1.91E-02	2.10E-02	2.30E-02
Early/Late Tier 2	Early/late decision	1.88E-02	2.10E-02	2.58E-02
Extinc. Suppress. Tier 3	Extinction or Suppression	1.94E-02	2.10E-02	2.27E-02
Contain. Tier 4	Containment	1.83E-02	2.10E-02	2.38E-02
Evac. Tier 5	Evacuation	1.37E-02	2.10E-02	2.65E-02
Fatality Model	Number of fatality given a event tree branch	1.60E-02	2.10E-02	3.62E-02
Costs NPV	Net Present Values	2.10E-02	2.10E-02	2.10E-02

Except for the Fatality model parameters, the event tree model Tier 0 to Tier 5 provide variations of PLL which are in similar ranges, and not exceptionally far from original static values. It can be noted that the modelled PLL is quite sensitive to the Fatality model.

2.2.2. Results on RCOs

Table A 3 summaries the sensitivity of the conclusion of the FIRESAFE report. The detailed graphical results are found in *Annex 1: Sensitivity Analysis detailed results*.

Table A 3: Change on the conclusion about the RCOs.

		GCAF Factors (Static)		Sensitivity: change on the conclusion about the RCO ?													
				Ini. freq. Tier 0		Origin. per deck type Tier 1		Early/Late Tier 2		Contain. Tier 4		Evac. Tier 5		Fatality Model		Costs NPV	
RCO #	Description	New	Exist.	New	Exist.	New	Exist.	New	Exist.	New	Exist.	New	Exist.	New	Exist.	New	Exist.
El 1	Robust connection boxes	0.05	0.11	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El 2	Only ship cables	0.52	0.81	No	T1	No	≈T1	No	≈T1	No	≈T1	No	T1	No	T1	No	≈T1
El 3	IR camera	0.06	0.09	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El 4	Training for awareness	0.01	0.02	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El 5	Only crew connections	0.01	0.01	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El 6	Cable reeling drums	4.47	7.68	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Su 1	Remote control	0.24	0.56	No	No	No	No	No	No	No	No	No	≈T1	No	No	No	No
Su 3	Rolling shutters	3.83	10.47	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Su 4	Efficient activation routines	0.00	0.00	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Su 5	Fresh water activation/flushing	0.02	0.09	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Su 6	CCTV	0.51	1.14	No	T2	No	≈T2	No	≈T2	No	No	No	≈T2	No	T2	No	≈T2
Su 7	CCTV + Remote control	0.27	0.63	No	≈T1	No	No	No	No	No	No	No	≈T1	No	No	No	No

On the left side, Table A 3 presents the original GCAF Factors for the various RCOs for newbuildings and existing ships. On the right side, the sensitivity of the model is checked by "No" when the conclusions are unchanged by the variation of parameters, "T1" when the calculated upper GCAF Factor exceeds 1 while the original GCAF Factor did not, and finally "T2" when the calculated lower GCAF factor is below 1 while the original GCAF factor was not. Green cells represent cost-effective RCOs and red cells represent non cost-effective RCOs. The sign "≈" means that the value is in the vicinity of 1.

2.3. Conclusion of the sensitivity analysis

The main outcome of the sensitivity analysis was that most of the conclusions are relatively robust against the selected parameter variations (*i.e.* the conclusions do not change with variations of the different parameters, or for most of the RCOs the risk assessment was not sensitive to variations in input parameters). This is a strength of the FSA guidelines, that they require a comparative approach (deltaPLLs, delta Costs) and not absolute evaluation.

For a few RCOs, the conclusions changed with regard to cost-effectiveness, namely for the RCOs called "only ship cables" (El 2), dedicated CCTV (Su 6), and dedicated CCTV and drencher remote control (Su 7). For existing ships, the conclusion regarding dedicated CCTV for roro-space fire safety was found sensitive to every parameter evaluated, except containment. However, the same system combined with remote drencher control is always better in terms of efficiency, irrespective of the newbuilding/existing ship status, and it is less sensitive. The most sensitive input parameters were in many cases the initial accident frequency as well as the probability of unsuccessful evacuation.

3. Uncertainty analysis

The quantification of the frequency of fires on ro-ro decks and dependent probabilities of the main risk model mainly originated from casualty data, reliability data and statistics from previous projects as well as from expert judgement. This results in a degree of uncertainty in the output of the model.

As required in the FSA Guidelines, uncertainty analyses were considered in the quantification of the risk model and in the effectiveness quantifications of RCOs. No uncertainty was considered for the cost estimations.

As for the sensitivity analysis, no uncertainty was explicitly considered for the bottom nodes of the sub risk models. Uncertainty was instead estimated for the top events of each sub-model, *i.e.* for the initial accident frequency and for extinguishment/suppression failure.

Uncertainty of the estimated parameters was explicitly modelled with probability distributions for each uncertain parameter. The risk assessment software @Risk (Palisade Decision Tool ©), an add-in to Microsoft Excel, was then used to perform Monte Carlo simulations (sampling of the parameters from their probability distribution) to estimate confidence intervals for the PLL and GCAF Factors.

3.1. Method

Two methodologies were applied to quantify the uncertainty of the parameters, depending on the ways static values were estimated in the main FIRESAFE report.

3.1.1. Methodology A

For the event tree probabilities, estimated based on casualty data, the same methodology as in the EMSA III study was applied to determine the parameter distributions. This is referred to as "Methodology A" in *Annex 2.1: Inputs: Frequency and dependent probabilities* and it is based on the assumption that accidents are Poisson distributed. This allows the calculation of the standard deviation from "the limits for the confidence interval and the mean value". A lognormal distribution was selected for the initial accident frequency (since the bounds of the confidence interval were not symmetric to the mean) and uncertainties of the dependent probabilities were modelled with normal distributions. Normal distributions were truncated between 0 and 1 and the standard deviation was as a general rule set to 20% of the average value if no better statistical information was available.

3.1.2. Methodology B

For the nodes following the 90-10 assumption (assumption made in the quantification process in the main FIRESAFE report), it was assumed that the uncertainty was large and could be represented by a triangular distribution. This is referred to "Methodology B" in *Annex 2.1: Inputs: Frequency and dependent probabilities*. Where the static value was 0.9, the most likely value of the triangular distribution was set to 0.9, the minimum to 0.5 and the maximum to 1. Where the static value was 0.1, the most likely value of the triangular distribution was set to 0.1, the minimum to 0 and the maximum to 0.5.

> Example: For the dependant probability 'Open Deck / Early Decision / Unsuccessful suppression / Not Contained' the uncertainty has been modelled with a triangular distribution with its maximum at 1, most likely value at 0.9 and minimum at 0.5 to reflect the fact that it is assumed that it is most likely for the fire to be uncontained in case of unsuccessful suppression.

3.1.3. Correlations

Selected important correlations between input parameters were provided to maintain consistency in the model. These were specified by cross correlations in @Risk. The correlation matrices are provided in *Annex 2.2: Correlations*.

3.1.4. Effectiveness of RCOs

The uncertainty of the effects of each RCO was quantified following the same methodology (presented below) for each RCO. The effects of each RCO had previously been estimated by three partners. A triangular distribution was therefore selected to represent the uncertainty of this estimation, where the average of the estimations was calculated (which is the static value that has been used in the main FIRESAFE report) and used as the most likely value (mode) of the triangular distribution. The lowest estimation was used to calculate the minimum of the triangular distribution (estimation minus 20% of the average of the estimations). Similarly, the highest estimation was used to calculate the maximum of the triangular distribution (estimations plus 20% of the average of the estimations).

> Example: From the following estimated values [30%; 50%; 60%], the parameters of the triangular distribution would be [20%; 50%; 70%].

The above assumptions were made to reflect the fact that the "true" value of the effectiveness of the RCO is somewhere between the maximum and minimum of the estimations, and most likely close to the average, but accounting for that it could also be slightly below or above the minimum or maximum of the estimations.
When the lower bound was below 0 (in particular when one of the estimations was 0), the triangular distribution was truncated to 0. This implies that the RCO has no effect but it does not add additional risk.
The distributions for the 'Electrical fire as ignition source' part and 'Fire suppression failure' (for Open Deck / Early Decision fault tree) are provided in *Annex 2.3: Inputs: Risk reduction efficiency estimation* as examples.

3.2. Results

3.2.1. Potential Loss of Life

Based on the risk model, quantified with the above described distributions as inputs, it is possible to present a probability distribution of the estimated Potential Loss of Life, shown in Figure A 1. The mean value of the PLL is 2.22E-2 (equivalent) fatalities per shipyear (higher than the calculated value using the static values, namely 2.10E-2 equivalent fatalities per shipyear), the 5^{th} percentile is 6.9E-3 and the 95^{th} percentile 4.63E-2 equivalent fatalities per shipyear.

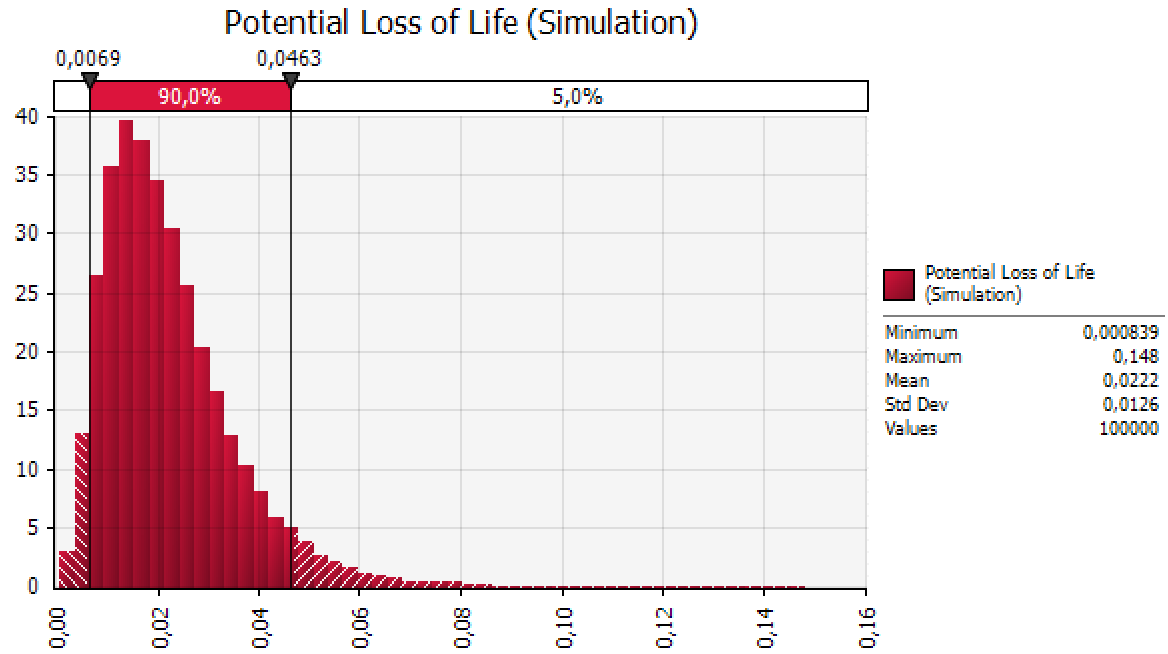


Figure A 1: Potential Loss of Life distribution.

3.2.2. CBA tables

The above modelling allowed calculating the distribution of the GCAF Factor and elaborate the confidence for it to be below 1 (i.e. "the probability for the GCAF Factor to be below 1" based on the output distribution from the uncertainty analysis). This information provides valuable information on the soundness of the CBA result.

Table A 4: GCAF factors (static and mean) for the various *Electrical fire* RCOs for newbuildings and existing ships and the confidence for the GCAF Factor to be below 1.

		GCAF Factors (static)		GCAF Factors (mean)		Confidence GCAF Factor < 1	
RCO #	Description	Newbuilding	Existing ship	Newbuilding	Existing ship	Newbuilding	Existing ship
El 1	Robust connection boxes	0.05	0.11	0.07	0.15	100.0%	99.8%
El 2	Only ship cables	0.52	0.81	0.77	1.20	78.4%	55.3%
El 3	IR camera	0.06	0.09	0.08	0.11	100.0%	99.9%
El 4	Training for awareness	0.01	0.02	0.01	0.02	100.0%	100.0%
El 5	Only crew connections	0.01	0.01	0.01	0.02	100.0%	100.0%
El 6	Cable reeling drums	4.47	7.68	6.85	11.78	0.5%	0.0%

Table A 5: GCAF factors (static and mean) for the various *Suppression failure* RCOs for newbuildings and existing ships and the confidence for the GCAF Factor to be below 1.

		GCAF Factors (static)		GCAF Factors (mean)		Confidence GCAF Factor < 1	
RCO #	Description	Newbuilding	Existing ship	Newbuilding	Existing ship	Newbuilding	Existing ship
Su 1	Remote control	0.24	0.56	0.36	0.85	97.1%	74.9%
Su 3	Rolling shutters	3.83	10.47	7.96	21.79	0.0%	0.0%
Su 4	Efficient activation routines	0.00	0.00	0.00	0.00	100.0%	100.0%
Su 5	Fresh water activation/flushing	0.02	0.09	0.03	0.12	100.0%	99.9%
Su 6	CCTV	0.51	1.14	0.80	1.79	78.0%	26.2%
Su 7	CCTV + Remote control	0.27	0.63	0.42	0.98	95.0%	67.1%

3.3. Conclusion on the uncertainty analysis

Three particular situations were observed with regards to conclusions on the cost effectiveness of the RCOs after the uncertainty analysis:

- For RCOs having static GCAF Factors well below one, the uncertainty analysis informed that the GCAF Factor is below 1 with high confidence. This is the case for El 1, El 3, El 4, El 5 and Su 1 (for newbuildings), Su 4, Su 5 and Su 7 (for newbuildings). An illustration of the GCAF Factor distribution for RCO El 3 for Newbuildings is shown as example in Figure A 2.

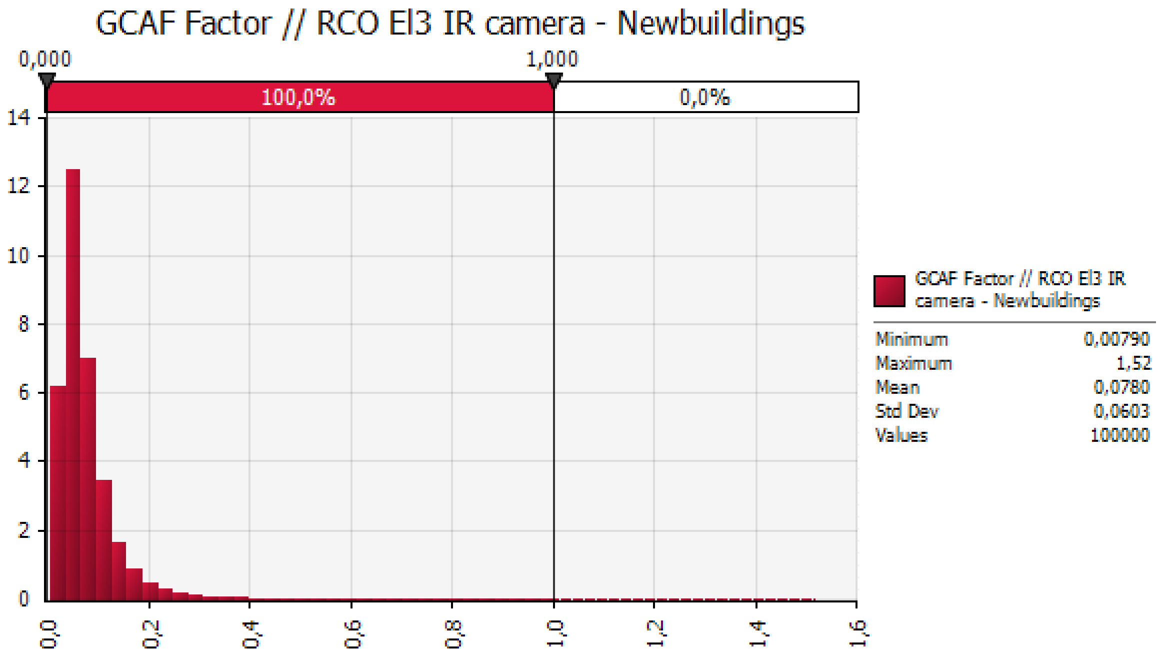


Figure A 2: GCAF Factor distribution for RCO El 3 for Newbuildings.

- For RCOs having GCAF factors well above one, the uncertainty analysis informed that the GCAF Factor is above 1 with high confidence. This is the case for El 6, Su 3, and Su 6 (for existing ships). An illustration of the GCAF Factor distribution for RCO El 6 for newbuildings is shown as example in Figure A 3.

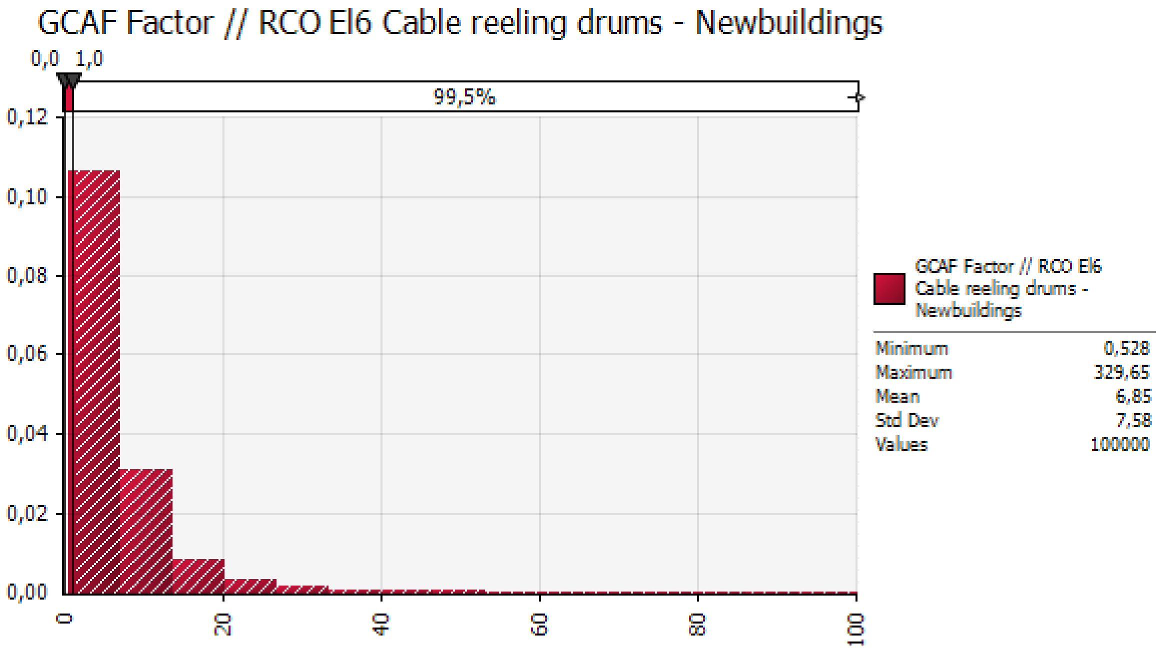


Figure A 3: GCAF Factor distribution for RCO El 6 for Newbuildings.

- For RCOs having GCAF Factor in the vicinity of 1, the uncertainty analysis informed that the GCAF Factor is below 1 with a specific confidence. This is the case for El 2, Su 1 (for existing ships), Su 6 (for newbuildings) and Su 7 (for Existing ships). An illustration of the GCAF Factor distribution for RCO El 2 for newbuildings is shown as example in Figure A 4. The distributions of the GCAF Factor for the other RCOs are presented in Annex 2.4: GCAF Factor (simulated) distributions for RCOs having a static GCAF Factor in the vicinity of 1. No threshold was set for the confidence levels, i.e. to evaluate whether the conclusions on cost-effectiveness of the RCOs are certain enough to be recommended.

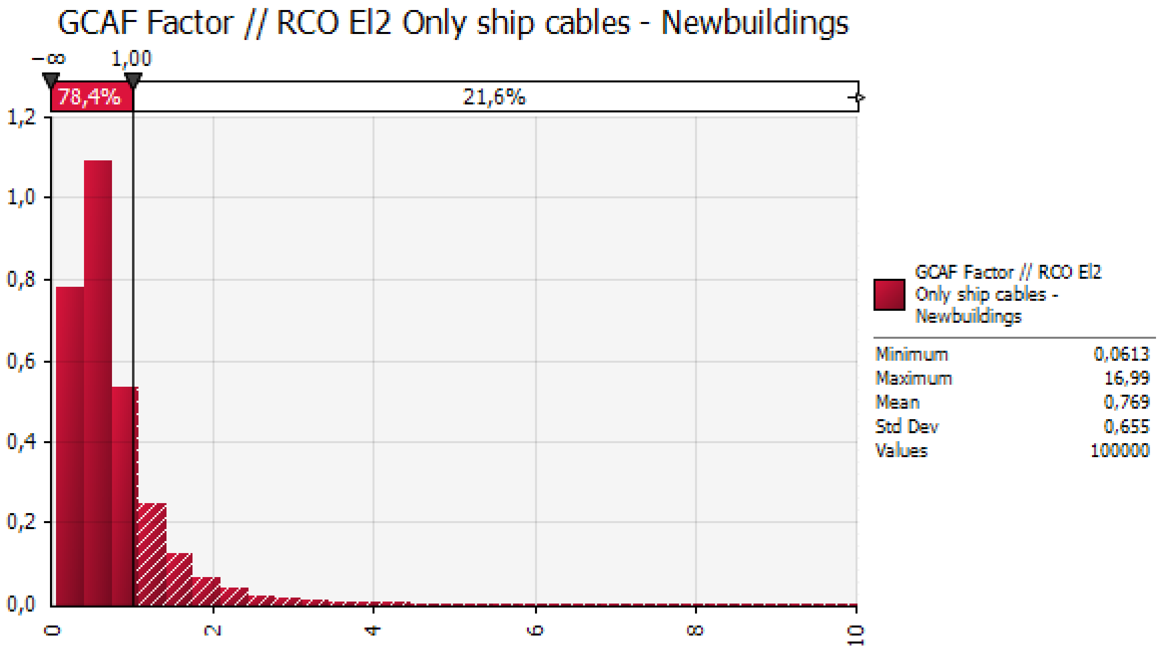
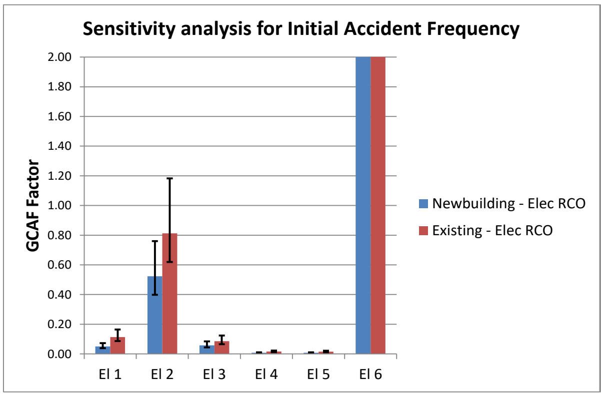
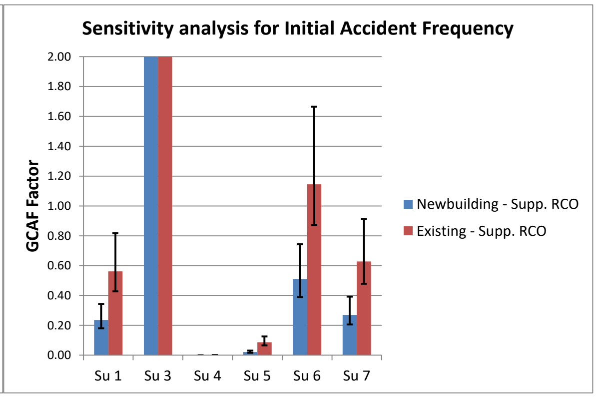


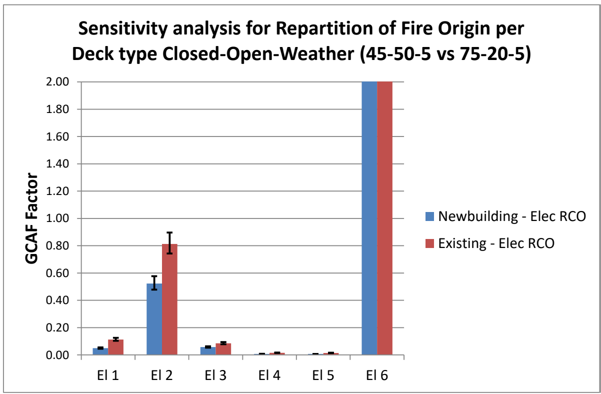
Figure A 4: GCAF Factor distribution for RCO El 2 for Newbuildings.

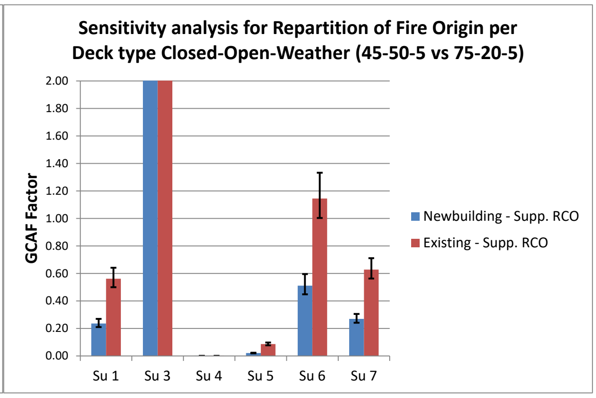
Annexes

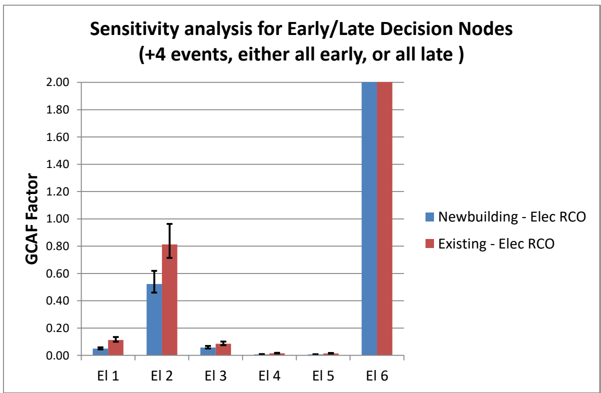
Annex 1: Sensitivity Analysis detailed results

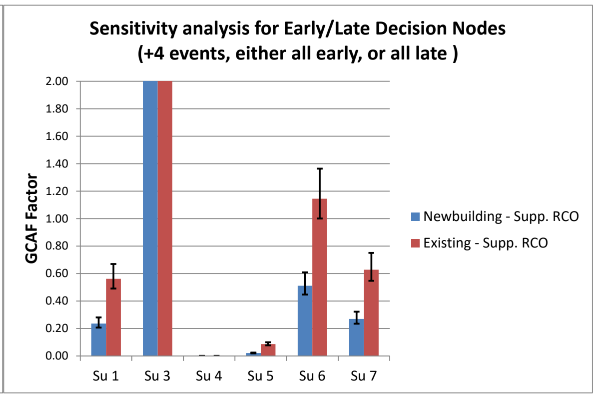


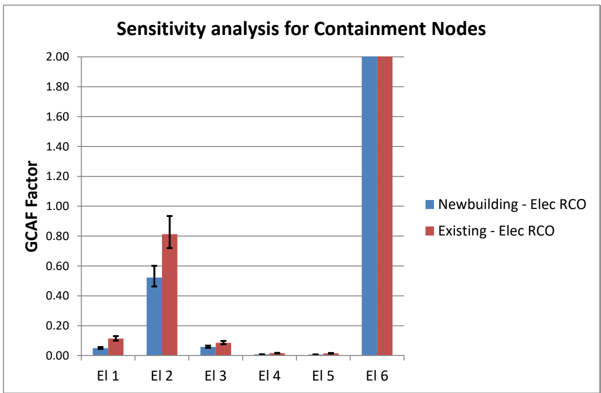


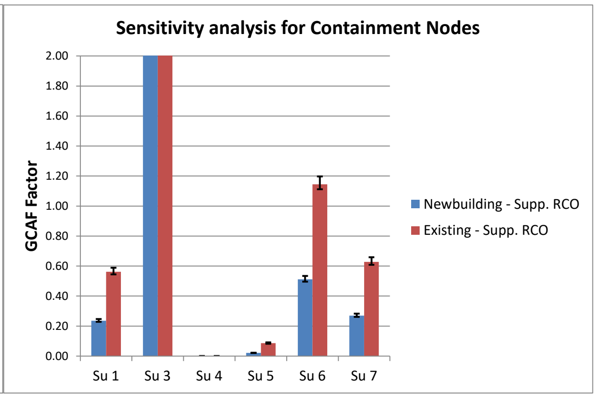


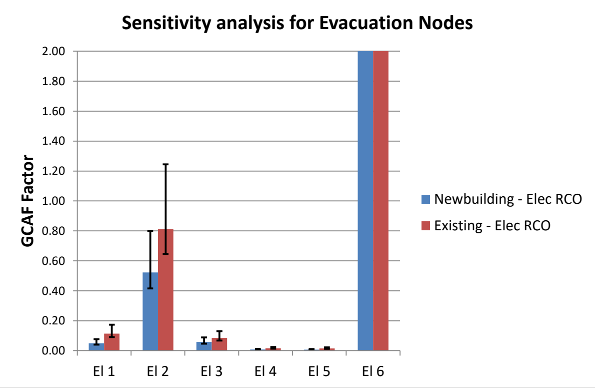


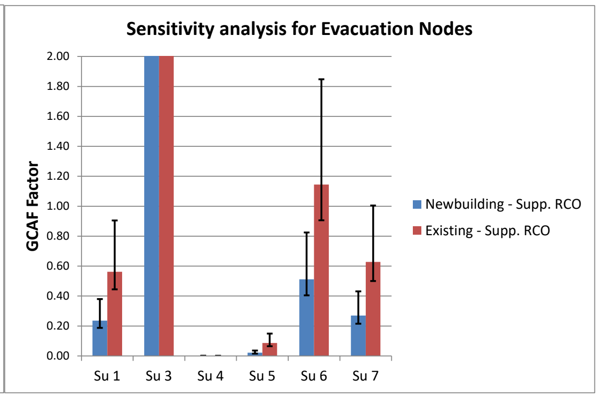


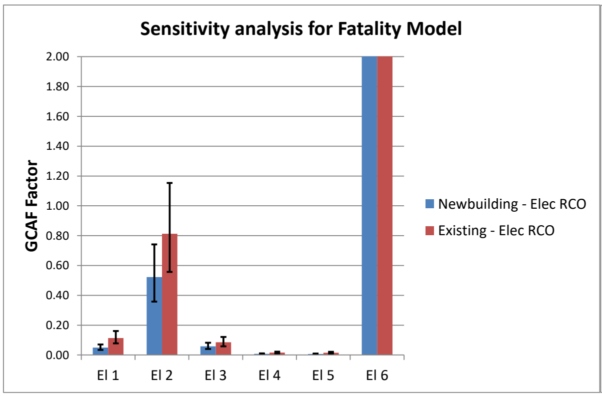


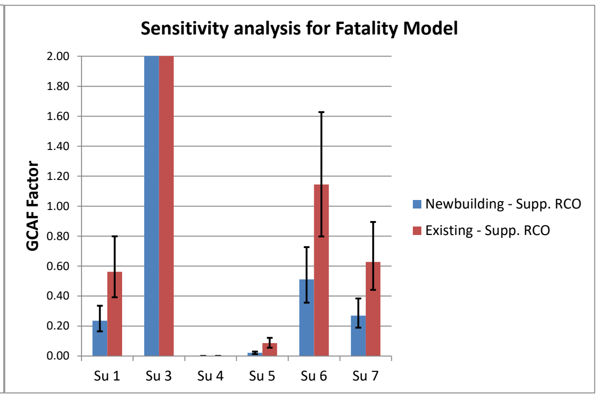


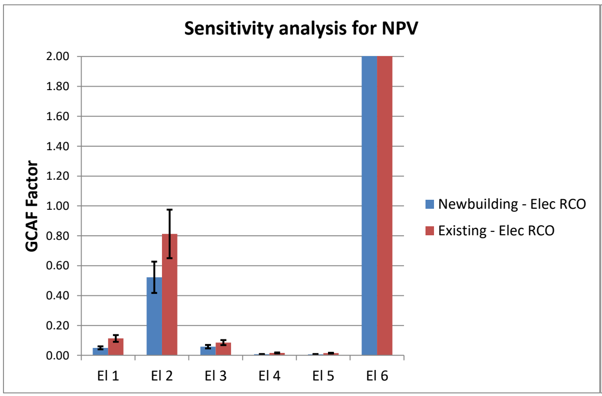


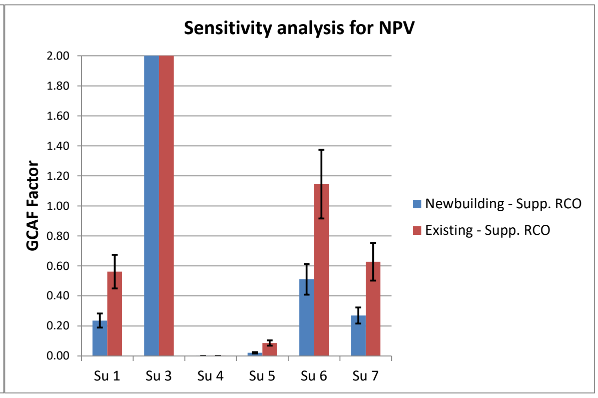

Sensitivity analysis for Evacuation Nodes
GCAF Factor
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
El 1
El 2
El 3
El 4
El 5
El 6
Newbuilding - Elec RCO
Existing - Elec RCO


Sensitivity analysis for Evacuation Nodes
GCAF Factor
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Su 1
Su 3
Su 4
Su 5
Su 6
Su 7
Newbuilding - Supp. RCO
Existing - Supp. RCO


Sensitivity analysis for Fatality Model
GCAF Factor
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
El 1
El 2
El 3
El 4
El 5
El 6
Newbuilding - Elec RCO
Existing - Elec RCO

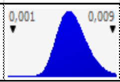
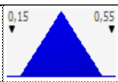
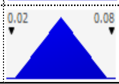
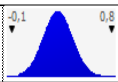
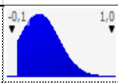
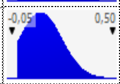
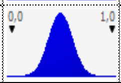
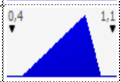
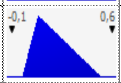
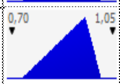
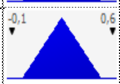
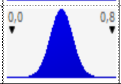
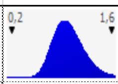
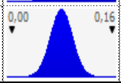

Sensitivity analysis for Fatality Model
GCAF Factor
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Su 1
Su 3
Su 4
Su 5
Su 6
Su 7
Newbuilding - Supp. RCO
Existing - Supp. RCO


Sensitivity analysis for NPV
GCAF Factor
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
El 1
El 2
El 3
El 4
El 5
El 6
Newbuilding - Elec RCO
Existing - Elec RCO


Sensitivity analysis for NPV
GCAF Factor
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Su 1
Su 3
Su 4
Su 5
Su 6
Su 7
Newbuilding - Supp. RCO
Existing - Supp. RCO

Annex 2: Uncertainty analysis

Annex 2.1: Inputs: Frequency and dependent probabilities

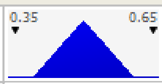
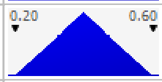
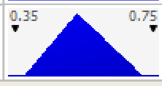
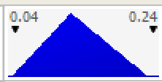
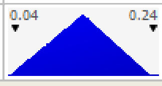
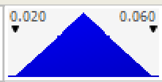
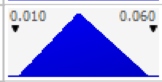
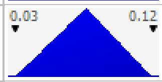
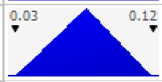
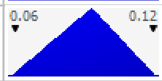
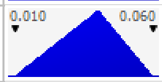
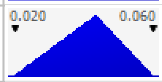
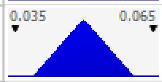
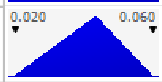
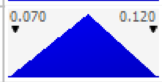
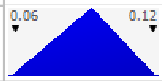
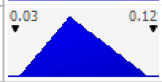
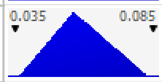
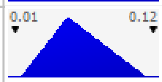
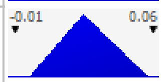
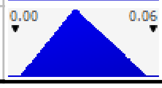
Name	Graph	Function	Note
Tier 0: Fire ignition			
Initital Accident Frequency		RiskLognorm((32/5530,5);0,00108)	Parameters calculated with metholodogy A.
Tier 1: Closed, Open, and Weather deck			
Open Deck		RiskTriang(0.175;0.35;0.525)	Uncertainty of -/+ 50% on the static value
Weather Deck		RiskTriang(0.025;0.05;0.075)	Uncertainty of -/+ 50% on the static value
Tier 2: Early / Late Decision			
Late Decision		RiskNormal((9/28);0,11953;RiskTruncate(0;1))	Parameters calculated with methodology A Applies to all deck type
Tier 3: Extinguishment			
Closed / Late / Suppression		RiskNormal((2/9);0,20064;RiskTruncate(0;1))	Parameters calculated with methodology A
Open / Early / Unsuccess (no Ext., no Suppr.)		RiskNormal((2/17);0,10622;RiskTruncate(0;1))	Parameters calculated with methodology A
Weather / Early / Unsuccess (no Ext., no Suppr.)		RiskNormal((25/51);0,10729;RiskTruncate(0;1))	Parameters calculated with methodology A
Tier 4: Containment			
Closed / Late / Suppression / Not Contained		RiskTriang(0;0,1;0,5;RiskCorrmat(Containment;5))	Methodology B
Closed / Late / Unsuccess (no suppr.) / Not Contained		RiskTriang(0;0,5;1);RiskCorrmat(Containment;4))	Methodology B
Open / Early / Unsuccess (no Ext., no suppr.) / Not Contained		RiskTriang(0,5;0,9;1;RiskCorrmat(Containment;3))	Methodology B
Open / Late / Suppression / Not Contained		RiskTriang(0;0,1;0,5;RiskCorrmat(Containment;1))	Methodology B
Open / Late / Unsuccess (no Ext., no Suppr.) / Not Contained		RiskTriang(0,75;0,95;1;RiskCorrmat(Containment;2))	Methodology similar to Methodology B (adapted)
Tier 5: Evacuation			
Closed / Early / Unsuccess (no Ext., no Suppr.) / Not Contained / Success. Evac.		RiskTriang(0,5;0,9;1;RiskCorrmat(Evacuation;3))	Methodology B
Closed / Late / Suppression / Not Contained / Unsuccess. Evac.		RiskTriang(0;0,25;0,5;RiskCorrmat(Evacuation;2))	Methodology similar to 'Methodology B' (adapted)
Closed / Late / Unsuccess (no Suppr.) / Not Contained / Unsuccess. Evac.		RiskNormal((2/5);(2/25);RiskTruncate(0;1);RiskCorrmat(Evacuation;1))	Mean = static value (taken from previous report) Standard deviation assumed to be 1/5 of the mean
Consequences			
Number of fatalities in case of successful abandonment or disemb.		RiskLognorm(1;1/5)	Mean = static value (assumed) Standard deviation assumed to be 1/5 of the mean
Fatality rate in case of Unsuccessful Evac.		RiskNormal(0,08;(0,08/5);RiskTruncate(0;1))	Mean = static value (taken from previous report) Standard deviation assumed to be 1/5 of the mean

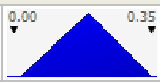
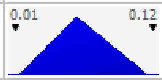
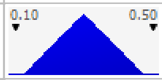
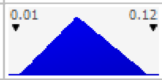
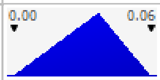
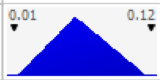
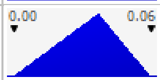
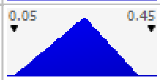
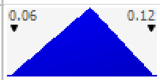
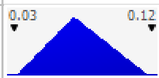
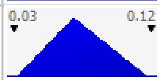
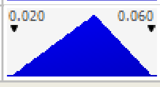
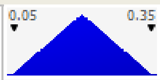
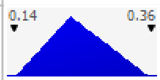
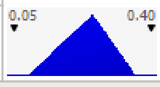
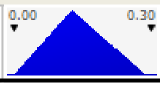
Annex 2.2: Correlations

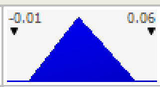
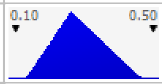
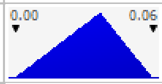
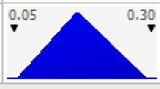
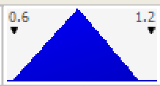
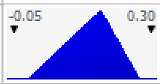
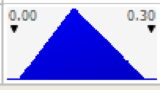
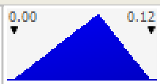
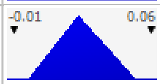
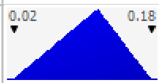
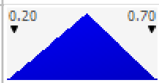
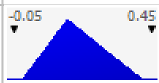
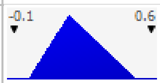
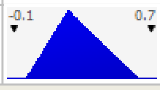
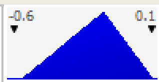
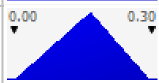
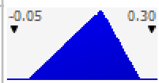
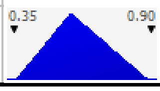
@RISK Correlations	Late Decision / Unsuccess (no suppr.) / Not Contained / Unsuccessful Evac	Late Decision / Suppression / Not Contained / Unsuccessful evac	Early Decision / Unsuccessful (no Ext., no suppr.) / Not Contained / Success abandonment or disemb.
Late Decision / Unsuccess (no suppr.) / Not Contained / Unsuccessful Evac	1		
Late Decision / Suppression / Not Contained / Unsuccessful evac	1	1	
Early Decision / Unsuccessful (no Ext., no suppr.) / Not Contained / Success abandonment or disemb.	-1	-1	1

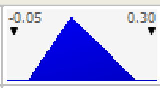
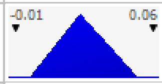
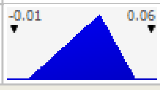
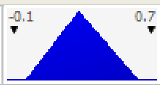
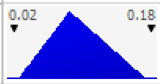
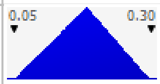
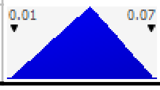
@RISK Correlations	Open Deck / Late Decision / Suppression / Not Contained	Open Deck / Late Decision / Unsuccess (no suppr.) / Not Contained	Open Deck / Early Decision / Unsuccessful (no Ext., no suppr.) / Not Contained	Closed Deck / Late Decision / Unsuccess (no suppr.) / Not Contained	Closed Deck / Late Decision / Suppression / Not Contained
Open Deck / Late Decision / Suppression / Not Contained	1				
Open Deck / Late Decision / Unsuccess (no suppr.) / Not Contained	1	1			
Open Deck / Early Decision / Unsuccessful (no Ext., no suppr.) / Not Contained	1	1	1		
Closed Deck / Late Decision / Unsuccess (no suppr.) / Not Contained	1	1	1	1	
Closed Deck / Late Decision / Suppression / Not Contained	1	1	1	1	1

Annex 2.3: Inputs: Risk reduction efficiency estimation

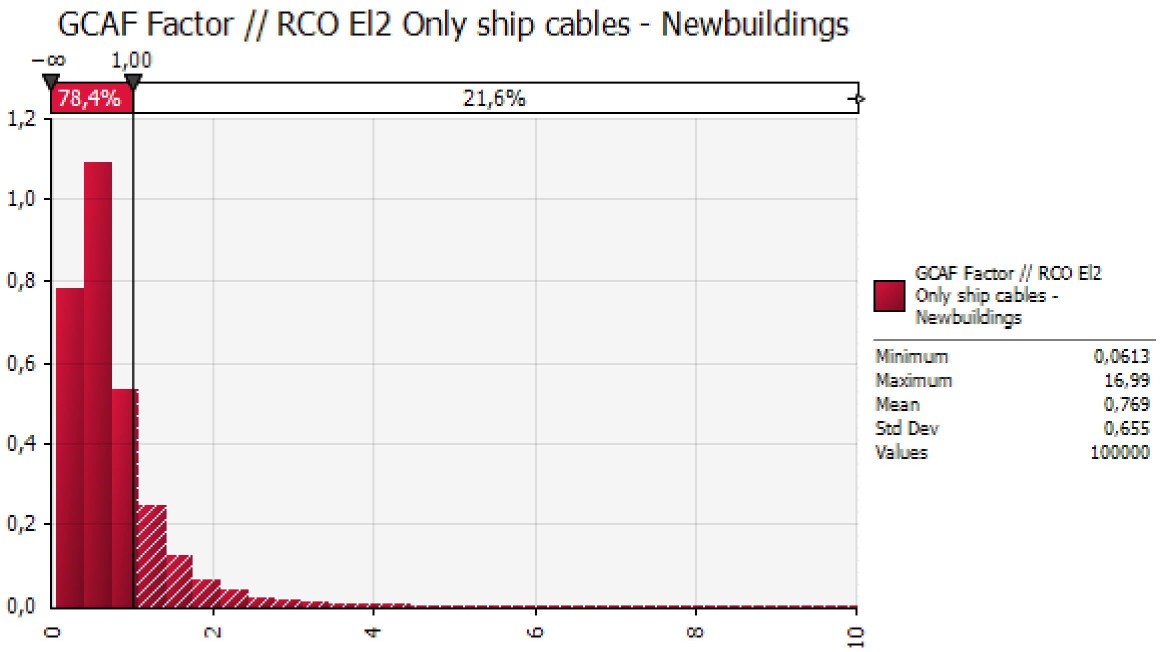
Affected Nodes	Graph	Function
RCO: El1 Robust connection boxes		
Electrical-Ship equipment		RiskTriang(0.4;0.5;0.6)
Connected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.22;0.4;0.58)
Connected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.393;0.544;0.707)
RCO: El2 Only ship cables		
Connected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.045;0.131;0.225)
Connected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.042;0.137;0.228)
RCO: El3 IR camera		
Electrical-Ship equipment		RiskTriang(0.022;0.04;0.058)
Other-Ship equipment		RiskTriang(0.013;0.034;0.057)
Electrical-Cab-Vehicle-Ship cargo		RiskTriang(0.035;0.076;0.115)
Other-Cab-Vehicle-Ship cargo		RiskTriang(0.035;0.076;0.115)
Connected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.061;0.091;0.119)
Unonnected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.012;0.037;0.058)
Other-Powertrain-Vehicle-Ship cargo		RiskTriang(0.021;0.041;0.059)
Electrical-Other-Vehicle-Ship cargo		RiskTriang(0.04;0.05;0.06)
Other-Other-Vehicle-Ship cargo		RiskTriang(0.021;0.041;0.059)
Connected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.071;0.096;0.119)
Unconnected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.061;0.091;0.119)
Other-Reefer-Cargo unit-Ship cargo		RiskTriang(0.037;0.072;0.113)
Electrical-Not reefer-Cargo unit-Ship cargo		RiskTriang(0.039;0.059;0.081)
Other-Not reefer-Cargo unit-Ship cargo		RiskTriang(0.019;0.061;0.111)
Electrical-Other cause		RiskTriang(0;0.027;0.055)
Other-Other cause		RiskTriang(0.005;0.029;0.055)

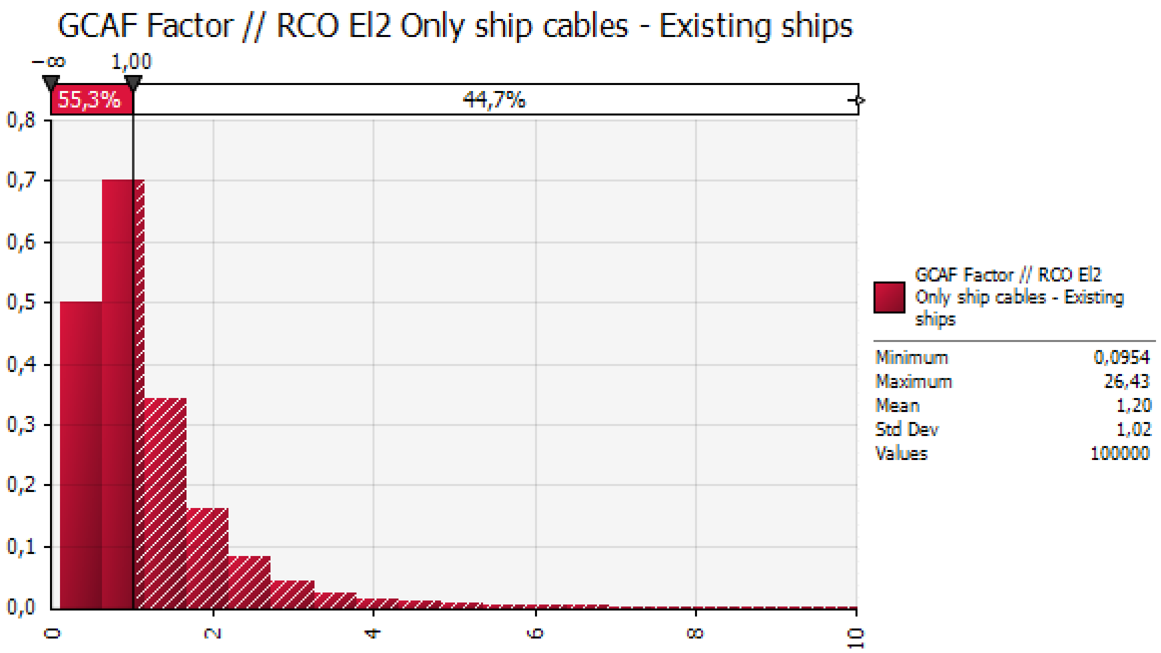
Affected Nodes	Graph	Function
RCO: EI4 Training for awareness		
Electrical-Cab-Vehicle-Ship cargo		RiskTriang(0.032;0.187;0.338)
Other-Cab-Vehicle-Ship cargo		RiskTriang(0.018;0.063;0.112)
Connected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.14;0.3;0.46)
Unonnected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.018;0.063;0.112)
Other-Powertrain-Vehicle-Ship cargo		RiskTriang(0.003;0.032;0.057)
Electrical-Other-Vehicle-Ship cargo		RiskTriang(0.018;0.063;0.112)
Other-Other-Vehicle-Ship cargo		RiskTriang(0.003;0.032;0.057)
Connected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.069;0.242;0.401)
Unconnected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.061;0.091;0.119)
Other-Reefer-Cargo unit-Ship cargo		RiskTriang(0.036;0.073;0.114)
Electrical-Not reefer-Cargo unit-Ship cargo		RiskTriang(0.036;0.073;0.114)
Other-Not reefer-Cargo unit-Ship cargo		RiskTriang(0.021;0.041;0.059)
RCO: EI5 Only crew connections		
Electrical-Ship equipment		RiskTriang(0.06;0.2;0.34)
Connected-Electrical-Powertrain-Vehicle-Ship cargo		RiskTriang(0.153;0.244;0.347)
Connected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.1;0.233;0.35)
RCO: EI6 Cable reeling drums		
Connected-Electrical-Reefer-Cargo unit-Ship cargo		RiskTriang(0.014;0.14;0.276)

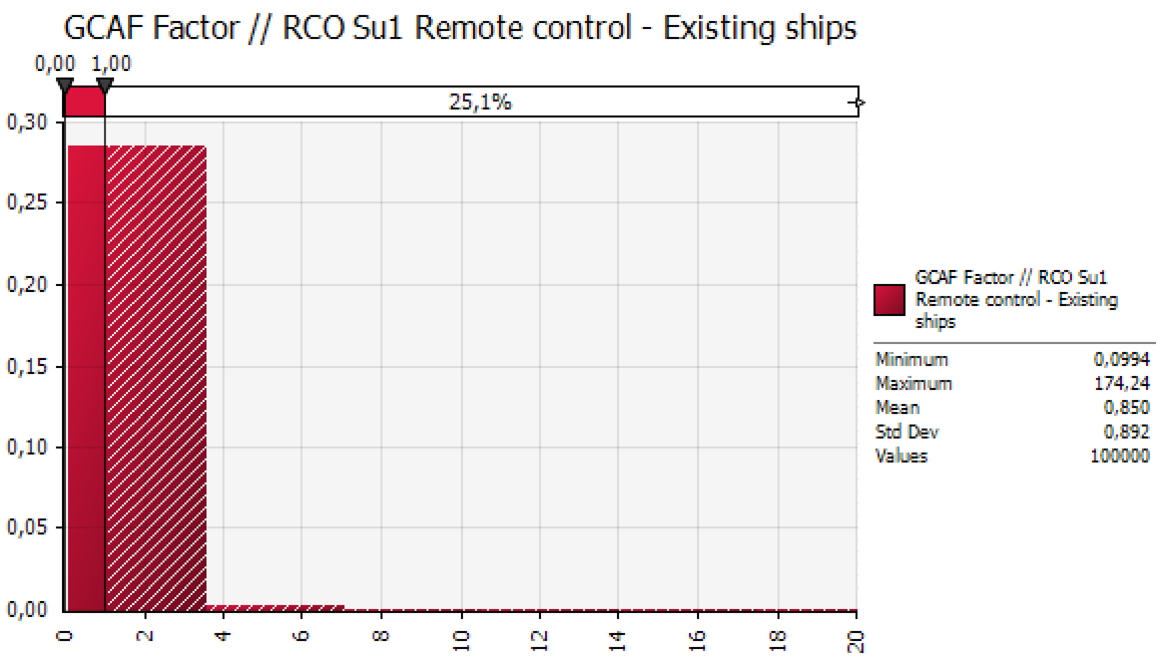
Affected Nodes	Graph	Function
RCO: Su1Remote control		
Pumps-Supply-Technical-Fixed system		RiskTriang(0;0.024;0.05)
Sectioning valves-Distribution-Technical-Fixed system		RiskTriang(0.147;0.289;0.453)
Scuppers-Removal-Technical-Fixed system		RiskTriang(0.003;0.032;0.057)
Design incapacity-Fixed system		RiskTriang(0.067;0.172;0.283)
RCO: Su3 Rolling shutters		
Wind-Distribution-Technical-Fixed system		RiskTriang(0.623;0.878;1.127)
Scuppers-Removal-Technical-Fixed system		RiskTriang(0;0.143;0.26)
Design incapacity-Fixed system		RiskTriang(0.023;0.144;0.277)
RCO: Su4 Efficient activation routines		
Valves-Supply-Technical-Fixed system		RiskTriang(0.005;0.064;0.115)
Pipes-Supply-Technical-Fixed system		RiskTriang(0;0.024;0.05)
Pumps-Supply-Technical-Fixed system		RiskTriang(0.027;0.106;0.173)
Sectioning valves-Distribution-Technical-Fixed system		RiskTriang(0.207;0.456;0.693)
Scuppers-Removal-Technical-Fixed system		RiskTriang(0;0.183;0.4)
Valves-Removal of water-Technical-Fixed system		RiskTriang(0;0.23;0.5)
Design incapacity-Fixed system		RiskTriang(0;0.276;0.6)
RCO: Su5 Fresh water activation/flushing		
Valves-Supply-Technical-Fixed system		RiskTriang(-0.53;-0.2;0.08)
Pumps-Supply-Technical-Fixed system		RiskTriang(0.017;0.156;0.283)
Sectioning valves-Distribution-Technical-Fixed system		RiskTriang(0;0.143;0.26)
Pipes&Nozzles-Distribution-Technical-Fixed system		RiskTriang(0.383;0.611;0.867)

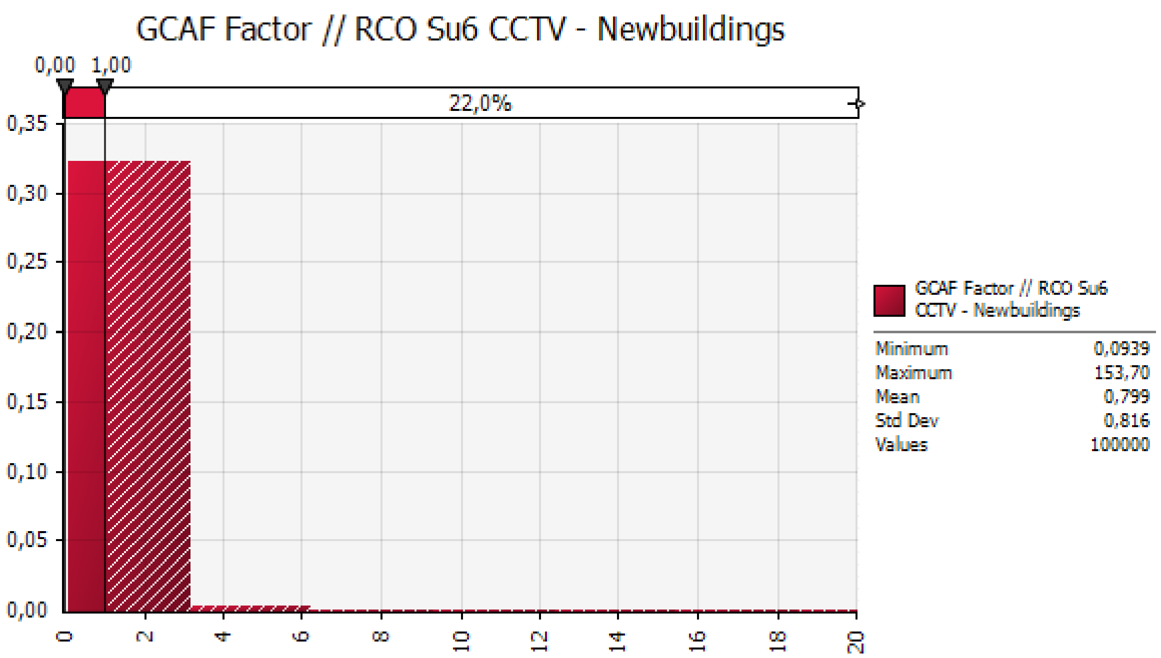
Affected Nodes	Graph	Function
RCO: Su6 CCTV		
Sectioning valves-Distribution-Technical-Fixed system		RiskTriang(0;0.117;0.25)
Scuppers-Removal-Technical-Fixed system		RiskTriang(0;0.024;0.05)
Design incapacity-Fixed system		RiskTriang(0;0.028;0.05)
RCO: Su7 CCTV + Remote control		
Sectioning valves-Distribution-Technical-Fixed system		RiskTriang(0;0.294;0.6)
Scuppers-Removal-Technical-Fixed system		RiskTriang(0.033;0.096;0.167)
Design incapacity-Fixed system		RiskTriang(0.063;0.178;0.287)
Pumps-Supply-Technical-Fixed system		RiskTriang(0.011;0.041;0.069)

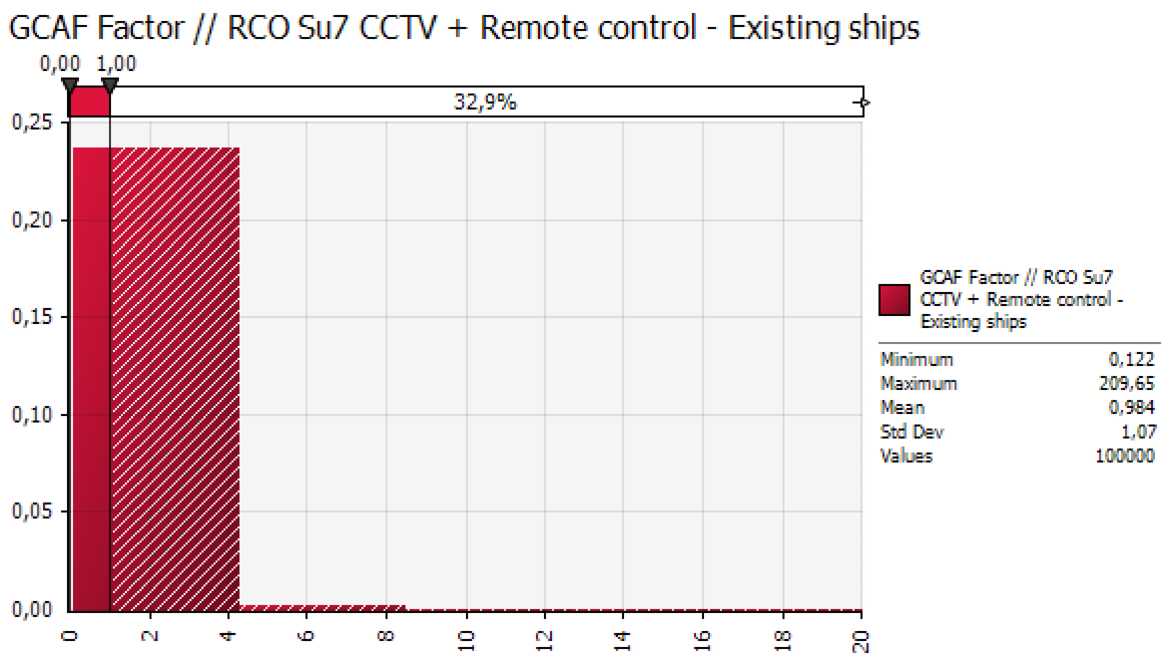
Annex 2.4: GCAF Factor (simulated) distributions for RCOs having a static GCAF Factor in the vicinity of 1.






GCAF Factor // RCO Su1 Remote control - Existing ships
0,00
1,00
25,1%
0,30
0,25
0,20
0,15
0,10
0,05
0,00
0
2
4
6
8
10
12
14
16
18
20
GCAF Factor // RCO Su1 Remote control - Existing ships
Minimum 0,0994
Maximum 174,24
Mean 0,850
Std Dev 0,892
Values 100000


GCAF Factor // RCO Su6 CCTV - Newbuildings
0,00
1,00
22,0%
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
0
2
4
6
8
10
12
14
16
18
20
GCAF Factor // RCO Su6 CCTV - Newbuildings
Minimum 0,0939
Maximum 153,70
Mean 0,799
Std Dev 0,816
Values 100000


GCAF Factor // RCO Su7 CCTV + Remote control - Existing ships
0,00
1,00
32,9%
0,25
0,20
0,15
0,10
0,05
0,00
0
2
4
6
8
10
12
14
16
18
20
GCAF Factor // RCO Su7 CCTV + Remote control - Existing ships
Minimum 0,122
Maximum 209,65
Mean 0,984
Std Dev 1,07
Values 100000