Horizon 2020

Project acronym: **LASH FIRE**

Project full title: **Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**

Grant Agreement No: **814975**

Coordinator: **RISE Research Institutes of Sweden**

Deliverable D04.7

Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report

March 2023

Dissemination level: **Public**

Abstract

The Formal Safety Assessment carried out in LASH FIRE requires the cost-effectiveness assessment of a selection of technical and operational solutions developed by the partners of the project. The objective is to compare the effectiveness to reduce the fire risk of ro-ro spaces and the costs associated with the implementation of selected Risk Control Options (RCOs).

For this purpose, the marginal costs for each Risk Control Option were estimated in terms of life cycle costs at present value. The performances of each Risk Control Option were assessed by the Development & Demonstration Work Packages and then used to feed the risk model in order to estimate the risk reduction in terms of fatalities, cargo losses and ship losses. Finally, the cost-effectiveness indices were computed and analysed. This was presented in deliverable D04.6 “Cost-effectiveness assessment report”.

The present deliverable, D04.7, presents the conducted sensitivity and uncertainty analyses that were performed to conclude on the cost-effectiveness of each Risk Control Option:

1. **Ro-ro passenger ships - Newbuildings:** 13 RCOs were found cost-effective in terms of life safety, saving the cargo and ship;
2. **Ro-ro passenger ships - Existing ships:** 9 RCOs were found cost-effective in terms of life safety, saving the cargo and ship and 2 RCOs in saving the cargo and ship;
3. **Ro-ro cargo ships - Newbuildings:** No RCO was found cost-effective in terms of life safety but 6 RCOs were found cost-effective in saving the cargo and ship;
4. **Ro-ro cargo ships - Existing ships:** No RCO was found cost-effective in terms of life safety but 2 RCOs were found cost-effective in saving the cargo and ship;
5. **Vehicle carriers - Newbuildings:** No RCO was found cost-effective in terms of life safety but 7 RCOs were found cost-effective in saving the cargo and ship; and
6. **Vehicle carriers - Existing ships:** No RCO was found cost-effective in terms of life safety but 2 RCO was found cost-effective in saving the cargo and ship.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 814975

The information contained in this deliverable reflects only the view(s) of the author(s). The Agency (CINEA) is not responsible for any use that may be made of the information it contains.

The information contained in this report is subject to change without notice and should not be construed as a commitment by any members of the LASH FIRE consortium. In the event of any software or algorithms being described in this report, the LASH FIRE consortium assumes no responsibility for the use or inability to use any of its software or algorithms. The information is provided without any warranty of any kind and the LASH FIRE consortium expressly disclaims all implied warranties, including but not limited to the implied warranties of merchantability and fitness for a particular use.

© COPYRIGHT 2019 The LASH FIRE Consortium

This document may not be copied, reproduced, or modified in whole or in part for any purpose without written permission from the LASH FIRE consortium. In addition, to such written permission to copy, acknowledgement of the authors of the document and all applicable portions of the copyright notice must be clearly referenced. All rights reserved.

Document data

Document Title:	D04.7 – Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report
Work Package:	WP04 – Formal safety assessment
Related Task(s):	T04.6, T04.7
Dissemination level:	Public
Deliverable type:	R, Report
Lead beneficiary:	8 – BV
Responsible author:	Eric De Carvalho
Co-authors:	Léon Lewandowski
Date of delivery:	2023-03-31
References:	D04.4, D04.5 D04.6, D05.8
Approved by	Jon Steinlein on 2023-03-27 / Stina Andersson on 2023-03-17 / Maria Hjohlman on 2023-03-27

Involved partners

No.	Short name	Full name of Partner	Name and contact info of persons involved
1	RISE	Research Institutes of Sweden	Stina Andersson – stina.andersson@ri.se Roshni Pramanik – roshni.pramanik@ri.se Sixten Dahlbom – sixten.dahlbom@ri.se
8	BV	Bureau Veritas Marine & Offshore Registre International De Classification De Navires Et De Plateformes Offshore	Eric De Carvalho – eric.de-carvalho@bureauveritas.com Léon Lewandowski – leon.lewandowski@bureauveritas.com

Document history

Version	Date	Prepared by	Description
01	2022-01-04	Léon Lewandowski	Draft of structure
02	2023-03-09	Eric De Carvalho	Draft of final report, circulated to reviewers
03	2023-03-31	Eric De Carvalho	Final report

Content

1 Executive summary

1.1 Problem definition

The LASH FIRE project aims to develop solutions to enhance fire safety in ro-ro spaces by the development of innovative technologies as well as by the modification of operations and applications. An evaluation of each solution developed in the project will be carried out, in line with the IMO Formal Safety Assessment (FSA) procedures [1]. This implies the cost-effectiveness assessment of a selection of solutions.

The cost-effectiveness assessment constitutes the step 4 of an FSA. It compares the effectiveness to reduce the risk and the costs associated with the implementation of selected Risk Control Options. The effectiveness should answer to the question "how much better would it be?" and the cost should answer to the question "how much will it cost?". It is an important step that will drive the development of recommendations for decision-making (step 5 of FSA). Uncertainty and sensitivity analyses should be considered in the analysis of the cost-effectiveness results. It is a mean to investigate the robustness of a study and conclude.

1.2 Method

Several sensitivity and uncertainty analyses were performed in accordance with the IMO FSA guidelines [1].

1.3 Results and achievements

Table 37 and Table 38 summarize the final cost-effectiveness results for all RCOs. The uncertainty and sensitivity analyses finalize the cost-effectiveness assessment.

1.4 Contribution to LASH FIRE objectives

The IMO strategic plan for 2018-2023 highlights the importance of integrating new and advancing technologies in the regulatory framework. One of the objectives of LASH FIRE is to support the aforementioned strategic plan regarding marine accident response, in part through this deliverable. This deliverable will furthermore lay the groundwork for achieving the LASH FIRE objective 3:

> LASH FIRE will provide a **technical basis** for future revisions of regulations by **assessing risk reduction and economic properties of solutions**.

This is particularly achieved by contributing to the goal of action 4-B:

> **Cost-effectiveness assessment** of at least 15 regulatory proposals, based on developed operational and technical solutions, in line with FSA procedure.

1.5 Exploitation

The results of the cost-effectiveness assessment will be used to identify the best candidates for recommendations for decision-making (action 4-C).

2 List of symbols and abbreviations

APV	Alternatively Powered Vehicle
CRS	Close Ro-ro Space
D&D	Development and Demonstration
CEU	Car Equivalent Unit
CRS	Closed Ro-ro Spaces
ET	Event Tree
EV	Electric Vehicle
FSA	Formal Safety Assessment
FT	Fault Tree
GCAF	Gross Cost of Averting a Fatality
IMO	International Maritime Organization
IR	InfraRed
LCC	Life Cycle Cost
LM	Lane Meter
NCAF	Net Cost of Averting a Fatality
ORS	Open Ro-ro Space
PLC	Potential Loss of Cargo
PLL	Potential Loss of Life
PLS	Potential Loss of Ship
POB	Persons On Board
RCM	Risk Control Measure
RCO	Risk Control Option
Ro-Pax	Ro-ro passenger ships
Ro-Ro Cargo	Ro-ro cargo ships
VC	Vehicle Carriers
WD	Weather Deck
WP	Work Package
WP04	Work package on Formal Safety Assessment
WP05	Work package on ship integration

3 Introduction

Main author of the chapter: Eric De Carvalho, BV

Started in 2019, the LASH FIRE project funded by the European Union's Horizon 2020 research and innovation programme aims at providing a technical basis for future revisions of regulations by assessing risk reduction and economic properties of design and operational solutions for all types of ro-ro ships and all types of ro-ro spaces. This objective is founded on the cost-effectiveness assessment of a selection of solutions developed by the partners of the LASH FIRE project.

The cost-effectiveness assessment constitutes the step 4 of a Formal Safety Assessment (FSA), as described in the IMO FSA guidelines [1]. It compares the effectiveness to reduce the risk and the costs associated with the implementation of selected Risk Control Options (RCOs). The effectiveness should answer to the question "how much better would it be?" and the cost should answer to the question "how much will it cost?". It is an important step that will drive the development of recommendations for decision-making (step 5 of FSA).

According to the IMO FSA guidelines [1], sensitivity and uncertainty analyses should be considered in the cost-effectiveness assessment. This document summarizes the sensitivity and uncertainty analyses of the cost-effectiveness assessment. Chapter 4 recaps the results of the cost-effectiveness assessment for the generic ships (detailed in the deliverable D04.6 "Cost-effectiveness assessment report" [2]). Chapter 5 details the different sensitivity analyses. Chapter 6 describes the uncertainty analysis. The final conclusions of the cost-effectiveness assessment are summarized in the Chapter 7.

4 Results of the cost-effectiveness assessment for the generic ships

Main author of the chapter: Eric De Carvalho, BV

The deliverable D04.6 [2] details the results of the cost-effectiveness assessment for the three generic ships (ro-ro passenger ship, ro-ro cargo ship and vehicle carrier). Table 1 and Table 2 recap the Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF) factors per RCO, calculated for the generic ships. These will be the basis for the sensitivity and uncertainty analyses.

Table 1. GCAF factor calculated for generic ships. NB = newbuildings, Ex = existing ships.

		Ro-pax		Ro-ro cargo		Vehicle carrier	
Ref	Designation	NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	0.05	0.07	6.56	9.49	126.16	172.36
RCO 2	Impr. signage and markings for effective localiz.	0.07	0.25	19.07	63.23	48.88	164.62
RCO 3	Developed efficient first response	0.05	0.07	6.83	9.32	8.31	11.15
RCO 4	Developed manual firefighting for APVs	0.31	0.43	36.91	53.05	141.61	188.19
RCO 5	Alarm system interface prototype	0.07	Not assessed	10.71	Not assessed	32.89	Not assessed
RCO 6	Process [...] for efficient activation of exting.	0.04	0.31	11.08	69.06	27.14	38.49
RCO 7	Training module for efficient activat. of exting.	0.18	0.26	39.59	54.68	156.64	204.29
RCO 8	Safe electrical connection for reefers	0.17	0.35	129.80	244.83	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	0.22	0.44	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	1.70	2.85	39.25	63.63	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	0.41	Not assessed	99.84	Not assessed	245.64	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	0.34	0.84	127.91	204.35	931.82	1605.05
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	634.57	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	0.52	0.91	17.24	28.80	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	0.61	1.08	19.96	33.15	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	3.15	4.34	1687.38	2233.40	Not assessed	Not assessed

Table 2. NCAF factor calculated for generic ships. NB = newbuildings, Ex = existing ships.

		NCAF factor					
		Ro-pax		Ro-ro cargo		Vehicle carrier	
Ref	Designation	NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	-0.84	-0.62	-36.68	-14.23	-178.24	-92.03
RCO 2	Impr. signage and markings for effective localiz.	-0.69	-0.33	-18.42	41.92	-215.46	-75.24
RCO 3	Developed efficient first response	-0.84	-0.62	-39.32	-15.89	-84.96	-69.59
RCO 4	Developed manual firefighting for APVs	-0.57	-0.25	-5.74	30.02	-160.26	-68.98
RCO 5	Alarm system interface prototype	-0.80	Not assessed	-34.21	Not assessed	-257.58	Not assessed
RCO 6	Process [...] for efficient activation of exting.	-0.85	-0.38	-41.67	40.70	-277.26	-225.90
RCO 7	Training module for efficient activat. of exting.	-0.71	-0.43	-13.01	26.40	-147.76	-60.10
RCO 8	Safe electrical connection for reefers	-0.80	-0.40	73.37	214.37	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	-0.75	-0.32	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	1.03	2.34	9.46	46.86	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	-0.36	Not assessed	56.93	Not assessed	75.06	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	-0.54	0.16	80.45	178.74	628.78	1344.53
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	331.03	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	-0.07	0.48	-10.46	13.24	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	0.02	0.64	-8.11	17.36	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	1.88	3.34	1622.11	2198.99	Not assessed	Not assessed

5 Sensitivity analysis

Main author of the chapter: Eric De Carvalho, BV

Several sets of sensitivity analyses were conducted to test the model:

1-

The IMO FSA guidelines [1, p. 39] define sensitivity analysis as "*the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input*". Sensitivity analysis can also be defined as the study of the "*degree to which results of a model or calculation are affected by variations in the inputs*" [3, p. 156].

A sensitivity analysis of the bottom nodes of the risk model was conducted previously and was reported in the deliverable D04.5 "Development of holistic risk model report" [4]. This analysis identified the most sensitive bottom nodes of the risk model. The main sensitive parameters of the risk model were also identified and discussed in the FIRESAFE studies [5] and [6]. In addition to those sensitivity analyses on the risk model, a new sensitivity analysis was conducted to provide information on which of the risk reduction inputs to the different RCOs have the largest impact on the Potential Loss of Life (PLL) (Sensitivity 1).

2-

Another definition of sensitivity analysis was found in [7, pp. 256, 261]: "*Sensitivity analysis procedures explore and quantify the impact of possible errors in input data on predicted model outputs and system performance indices.*" "*A sensitivity analysis attempts to determine the change in model output values that results from modest changes in model input values. A sensitivity analysis thus measures the change in the model output in a localized region of the space of inputs.*"

Indeed, some assumptions made in the risk assessment for the main parameters of the risk model were analysed. The results of those sensitivity analyses are presented below (Sensitivity 2-5).

5.1 Sensitivity 1: Sensitivity of PLL to risk reduction inputs

Main author of the chapter: Sixten Dahlbom, RISE

The sensitivity of PLL to the estimations of the risk reductions for the different RCOs was studied in this subtask. This was made by reducing the risk reduction by 10% (multiplying the risk reduction by 0.9). That means, if the estimated risk reduction for a certain RCO and a certain bottom node was originally estimated to 80%, the risk reduction was changed to 72% and the recalculated PLL was noted. The relative change in PLL was calculated as the difference between the original PLL (at 80% risk reduction in the example) and the PLL with the lower risk reduction (72 % risk reduction in the example), the difference was divided by the original PLL to get the relative change.

$$Relative\ change = \frac{PLL_{original} - PLL_{reduced\ risk\ reduction}}{PLL_{original}}$$

Only risk reduction for one type of bottom node and in one type of fault tree (FT) or event tree (ET) was changed at a time. However, it was changed simultaneously for the different ro-ro space types relevant for that specific bottom node.

The current sensitivity analysis provides information on which of the risk reduction inputs that have the largest impact on the PLL. The result from this analysis could indicate where there is a need to have more accurate risk reduction estimations, in order to have a more reliable result of the FSA study. In the following tables (Table 3 to Table 8), only bottom nodes with a relative change in PLL > 0.5% are reported.

When the result from the current sensitivity analysis is compared to the sensitivity analysis reported in the deliverable D04.5 [4] (*sensitivity analysis of bottom nodes*), many of the bottom nodes are identified in both sensitivity analyses – as could be expected. However, in the current study, some additional nodes were identified. This is mainly due to relatively high risk reductions; when the risk reduction is multiplied by 0.9, it becomes a large number which has a significant impact on PLL. Another difference between this sensitivity analysis and the previous is the cut-off limit with regards to change in PLL; in this analysis it was set to 0.5% while it in the previous analysis was 1.0%.

5.1.1 Ro-ro passenger ships

5.1.1.1 Ro-ro passenger ships - Newbuildings

The result of the sensitivity analysis is presented in Table 3. For RCO8 “Safe electrical connection for reefers” and RCO9 “Safe electrical connection of reefers and electric vehicles (EVs)”, the result is found to be relatively sensitive to the risk reduction input. Both RCOs address the probability of ignition and reduces the probability of the current bottom node by 90%. Reducing the probability of ignition is expected to have a noticeable impact on the PLL (since ignition occurs first in the chain of events).

Table 3. Bottom nodes for which the risk reduction has the largest impact on the result. Ro-ro passenger ships – Newbuildings.

RCO#	ET/FT	Bottom node	Rel. change
9	Ignition	Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection	2.1%
8	Ignition	Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection	2.1%
5	Late decision, Early detection	Late assessment \ Lack of relevant information	1.0%
1	First response failure	Failure by first responder \ Accessibility problems	1.0%
3	First response failure	Failure by first responder \ Accessibility problems	1.0%
5	Late decision, Late detection	Late assessment \ Lack of relevant information	0.7%
1	First response failure	Failure by first responder \ Tactical failure	0.7%
3	First response failure	Failure by first responder \ Tactical failure	0.7%
11	Late detection	System detection failure \ Internal failure \ Manual deactivation for operational purpose \ System	0.6%
5	Late decision, Early detection	Late assessment \ Information is not made readily	0.6%
11	Late decision, Early detection	Late assessment \ Lack of relevant information	0.6%
12	Late decision, Early detection	Late confirmation \ Late technical confirmation	0.6%
12	Late decision, Early detection	Late implementation	0.5%

5.1.1.2 Ro-ro passenger ships – Existing ships

The result of the sensitivity analysis is presented in Table 4. The result is similar to the result for newbuildings (of ro-ro passenger ships). Refer to the previous section for comments.

Table 4. Bottom nodes for which the risk reduction has the largest impact on the result. Ro-ro passenger ships – Existing ships.

RCO#	ET/FT	Bottom node	Rel. change
9	Ignition	Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection	2.1%
8	Ignition	Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection	2.1%
1	First response failure	Failure by first responder \ Accessibility problems	1.0%
3	First response failure	Failure by first responder \ Accessibility problems	1.0%
1	First response failure	Failure by first responder \ Tactical failure	0.7%
3	First response failure	Failure by first responder \ Tactical failure	0.7%

5.1.2 Ro-ro cargo ships

5.1.2.1 Ro-ro cargo ships - Newbuildings

The result of the sensitivity analysis is presented in Table 5. A large relative change in PLL can be observed for several of the bottom nodes affected by RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” and RCO15 “Fixed autonomous fire monitor system using water for weather decks”. This is assumed to be due to the affected FT having only three bottom nodes (not much of a smoothing effect) and to high estimated risk reductions (> 90%).

Table 5. Bottom nodes for which the risk reduction has the largest impact on the result. Ro-ro cargo ships – Newbuildings.

RCO#	ET/FT	Bottom node	Rel. change
14	Failure of containment, Successful suppression	Failure of smoke containment	4.0%
15	Failure of containment, Successful suppression	Failure of smoke containment	3.2%
14	Failure of containment, Successful suppression	Failure of fire containment \ Heat spread	2.3%
15	Failure of containment, Successful suppression	Failure of fire containment \ Heat spread	1.8%
14	Failure of containment, Successful suppression	Failure of fire containment \ Flame spread	0.9%
5	Late decision, Late detection	Late assessment \ Lack of relevant information	0.8%
15	Failure of containment, Successful suppression	Failure of fire containment \ Flame spread	0.8%
5	Late decision, Late detection	Late assessment \ Information is not made readily	0.6%
1	First response failure	Failure by first responder \ Accessibility problems	0.5%
5	Late decision, Early detection	Late assessment \ Lack of relevant information	0.5%
3	First response failure	Failure by first responder \ Accessibility problems	0.5%

5.1.2.2 Ro-ro cargo ships – Existing ships

The result of the sensitivity analysis is presented in Table 6. The result is similar to the result for newbuildings (of ro-ro cargo ships). Refer to the previous section for comments.

Table 6. Bottom nodes for which the risk reduction has the largest impact on the result. Ro-ro cargo ships – Existing ships.

RCO#	ET/FT	Bottom node	Rel. change
14	Failure of containment, Successful suppression	Failure of smoke containment	4.0%
15	Failure of containment, Successful suppression	Failure of smoke containment	3.2%
14	Failure of containment, Successful suppression	Failure of fire containment \ Heat spread	2.3%
15	Failure of containment, Successful suppression	Failure of fire containment \ Heat spread	1.8%
14	Failure of containment, Successful suppression	Failure of fire containment \ Flame spread	0.9%
15	Failure of containment, Successful suppression	Failure of fire containment \ Flame spread	0.8%
1	First response failure	Failure by first responder \ Accessibility problems	0.5%
3	First response failure	Failure by first responder \ Accessibility problems	0.5%

5.1.3 Vehicle carriers

5.1.3.1 Vehicle carriers - Newbuildings

The result of the sensitivity analysis is presented in Table 7. The fact that less RCOs (compared to the other ship types) have an impact on the risk reduction is reflected by the sensitivity analysis.

Table 7. Bottom nodes for which the risk reduction has the largest impact on the result. Vehicle carriers – Newbuildings.

RCO#	ET/FT	Bottom node	Rel. change
13	Extinguishment/suppression failure, Late decision	Extinguishment\Suppression failure	1.3%
3	First response failure	Failure by first responder \ Accessibility problems	0.7%

5.1.3.2 Vehicle carriers – Existing ships

The result of the sensitivity analysis is presented in Table 8. The fact that less RCOs (compared to the other ship types) have an impact on the risk reduction is reflected by the sensitivity analysis.

Table 8. Bottom nodes for which the risk reduction has the largest impact on the result. Vehicle carriers – Existing ships.

RCO#	ET/FT	Bottom node	Rel. change
3	First response failure	Failure by first responder \ Accessibility problems	0.7%

5.2 Sensitivity 2: Variation of ΔCost

Main author of the chapter: Eric De Carvalho, BV

Both GCAF and NCAF indices follow a linear regression with the marginal cost (ΔCost) as parameter [2]. Therefore, any variations of ΔCost have a direct impact on the results of cost-effectiveness. The ΔCost of each RCO were estimated by WP05 for the different generic ships. The methodology and the assumptions used for the life cycle cost (LCC) assessment of the RCOS are reported in the deliverable D05.8 "Ship integration cost and environmental assessment" [8].

This sensitivity aims at verifying the robustness of the cost-effectiveness of each RCO to credible variations of their marginal cost (ΔCost). As variation of ΔCost, +/-15% was taken for "operational" RCOs and +/-30% for "equipment" RCOs. Those values are deemed credible in terms of short-term variation of prices of goods or hourly rates of work.

Table 9 to Table 14 present the GCAF and NCAF factors for the sensitivity 2, compared to the results for the generic ships (base case).

Table 9. Sensitivity 2 - GCAF and NCAF factor values for ro-ro passenger ships, newbuildings.

			GCAF Factor			NCAF Factor		
Ref	Designation	ΔCost +/-XX%	ΔCost-XX%	Base Case	ΔCost+XX%	ΔCost-XX%	Base Case	ΔCost+XX%
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	15%	0.04	0.05	0.06	-0.85	-0.84	-0.83
RCO 2	Impr. signage and markings for effective localiz.	30%	0.05	0.07	0.09	-0.71	-0.69	-0.67
RCO 3	Developed efficient first response	15%	0.05	0.05	0.06	-0.85	-0.84	-0.83
RCO 4	Developed manual firefighting for APVs	15%	0.26	0.31	0.35	-0.62	-0.57	-0.53
RCO 5	Alarm system interface prototype	30%	0.05	0.07	0.09	-0.82	-0.80	-0.78
RCO 6	Process [...] for efficient activation of exting.	15%	0.03	0.04	0.05	-0.86	-0.85	-0.85
RCO 7	Training module for efficient activat. of exting.	15%	0.15	0.18	0.21	-0.74	-0.71	-0.69
RCO 8	Safe electrical connection for reefers	30%	0.12	0.17	0.22	-0.85	-0.80	-0.75
RCO 9	Safe electrical connection of reefers and Evs	30%	0.16	0.22	0.29	-0.81	-0.75	-0.68
RCO 10	Fire detection on weather decks	30%	1.19	1.70	2.21	0.52	1.03	1.54
RCO 11	Alternative fire detection in CRS & ORS	30%	0.28	0.41	0.53	-0.48	-0.36	-0.24
RCO 12	Visual system for fire confirmation and localiz.	30%	0.24	0.34	0.44	-0.64	-0.54	-0.44
RCO 14	Remote.-control. fire monitor using water for WD	30%	0.36	0.52	0.67	-0.22	-0.07	0.09
RCO 15	Autonomous fire monitor using water for WD	30%	0.43	0.61	0.80	-0.16	0.02	0.21
RCO 16	Guideline for fire ventilation in CRS	15%	2.68	3.15	3.62	1.41	1.88	2.35

For new ro-ro passenger ships (Table 9), the variations of ΔCost do not change the results of cost-effectiveness of RCOs, except for RCO10 "Fire detection on weather decks".

Table 10. Sensitivity 2 - GCAF and NCAF factor values for ro-ro passenger ships, existing ships.

			GCAF Factor			NCAF Factor		
Ref	Designation	ΔCost +/-XX%	ΔCost-XX%	Base Case	ΔCost+XX%	ΔCost-XX%	Base Case	ΔCost+XX%
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	15%	0.06	0.07	0.08	-0.63	-0.62	-0.61
RCO 2	Impr. signage and markings for effective localiz.	30%	0.17	0.25	0.32	-0.40	-0.33	-0.26
RCO 3	Developed efficient first response	15%	0.06	0.07	0.09	-0.63	-0.62	-0.61
RCO 4	Developed manual firefighting for APVs	15%	0.37	0.43	0.50	-0.31	-0.25	-0.18
RCO 6	Process [...] for efficient activation of exting.	15%	0.26	0.31	0.36	-0.43	-0.38	-0.34
RCO 7	Training module for efficient activat. of exting.	15%	0.22	0.26	0.30	-0.47	-0.43	-0.39
RCO 8	Safe electrical connection for reefers	30%	0.25	0.35	0.46	-0.51	-0.40	-0.30
RCO 9	Safe electrical connection of reefers and Evs	30%	0.31	0.44	0.57	-0.45	-0.32	-0.18
RCO 10	Fire detection on weather decks	30%	1.99	2.85	3.70	1.49	2.34	3.20
RCO 12	Visual system for fire confirmation and localiz.	30%	0.59	0.84	1.09	-0.10	0.16	0.41
RCO 14	Remote.-control. fire monitor using water for WD	30%	0.63	0.91	1.18	0.21	0.48	0.75
RCO 15	Autonomous fire monitor using water for WD	30%	0.75	1.08	1.40	0.32	0.64	0.97
RCO 16	Guideline for fire ventilation in CRS	15%	3.69	4.34	4.99	2.69	3.34	3.99

For existing ro-ro passenger ships (Table 10), the variations of ΔCost do not change the results of cost-effectiveness of RCOs, except for RCO12 "Visual system for fire confirmation and localization", RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” and RCO15 “Fixed autonomous fire monitor system using water for weather decks”.

Table 11. Sensitivity 2 - GCAF and NCAF factor values for ro-ro cargo ships, newbuildings.

			GCAF Factor			NCAF Factor		
Ref	Designation	ΔCost +/-XX%	ΔCost-XX%	Base Case	ΔCost+XX%	ΔCost-XX%	Base Case	ΔCost+XX%
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	15%	5.57	6.56	7.54	-37.66	-36.68	-35.70
RCO 2	Impr. signage and markings for effective localiz.	30%	13.35	19.07	24.79	-24.14	-18.42	-12.70
RCO 3	Developed efficient first response	15%	5.81	6.83	7.85	-40.34	-39.32	-38.29
RCO 4	Developed manual firefighting for APVs	15%	31.38	36.91	42.45	-11.27	-5.74	-0.20
RCO 5	Alarm system interface prototype	30%	7.50	10.71	13.92	-37.42	-34.21	-31.00
RCO 6	Process [...] for efficient activation of exting.	15%	9.42	11.08	12.75	-43.33	-41.67	-40.01
RCO 7	Training module for efficient activat. of exting.	15%	33.65	39.59	45.53	-18.95	-13.01	-7.08
RCO 8	Safe electrical connection for reefers	30%	90.86	129.80	168.74	34.43	73.37	112.31
RCO 10	Fire detection on weather decks	30%	27.48	39.25	51.03	-2.31	9.46	21.24
RCO 11	Alternative fire detection in CRS & ORS	30%	69.89	99.84	129.80	26.98	56.93	86.89
RCO 12	Visual system for fire confirmation and localiz.	30%	89.53	127.91	166.28	42.07	80.45	118.82
RCO 14	Remote.-control. fire monitor using water for WD	30%	12.07	17.24	22.41	-15.63	-10.46	-5.29
RCO 15	Autonomous fire monitor using water for WD	30%	13.98	19.96	25.95	-14.09	-8.11	-2.12
RCO 16	Guideline for fire ventilation in CRS	15%	1434.27	1687.38	1940.49	1369.01	1622.11	1875.22

For new ro-ro cargo ships (Table 11), the variations of ΔCost do not change the results of cost-effectiveness of RCOs, except for RCO10 “Fire detection on weather decks”.

Table 12. Sensitivity 2 - GCAF and NCAF factor values for ro-ro cargo ships, existing ships.

			GCAF Factor			NCAF Factor		
Ref	Designation	ΔCost +/-XX%	ΔCost-XX%	Base Case	ΔCost+XX%	ΔCost-XX%	Base Case	ΔCost+XX%
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	15%	8.07	9.49	10.92	-15.65	-14.23	-12.80
RCO 2	Impr. signage and markings for effective localiz.	30%	44.26	63.23	82.19	22.95	41.92	60.88
RCO 3	Developed efficient first response	15%	7.92	9.32	10.71	-17.28	-15.89	-14.49
RCO 4	Developed manual firefighting for APVs	15%	45.09	53.05	61.01	22.06	30.02	37.97
RCO 6	Process [...] for efficient activation of exting.	15%	58.70	69.06	79.42	30.34	40.70	51.06
RCO 7	Training module for efficient activat. of exting.	15%	46.48	54.68	62.88	18.20	26.40	34.60
RCO 8	Safe electrical connection for reefers	30%	171.38	244.83	318.28	140.92	214.37	287.81
RCO 10	Fire detection on weather decks	30%	44.54	63.63	82.72	27.77	46.86	65.95
RCO 12	Visual system for fire confirmation and localiz.	30%	143.04	204.35	265.65	117.43	178.74	240.04
RCO 14	Remote.-control. fire monitor using water for WD	30%	20.16	28.80	37.44	4.60	13.24	21.88
RCO 15	Autonomous fire monitor using water for WD	30%	23.20	33.15	43.09	7.42	17.36	27.31
RCO 16	Guideline for fire ventilation in CRS	15%	1898.39	2233.40	2568.41	1863.98	2198.99	2534.00

Table 13. Sensitivity 2 - GCAF and NCAF factor values for vehicle carriers, newbuildings.

			GCAF Factor			NCAF Factor		
Ref	Designation	ΔCost +/-XX%	ΔCost-XX%	Base Case	ΔCost+XX%	ΔCost-XX%	Base Case	ΔCost+XX%
RCO 1	Improved fire confirmation & localization	15%	107.23	126.16	145.08	-197.17	-178.24	-159.32
RCO 2	Impr. signage and markings for effective localiz.	30%	34.22	48.88	63.55	-230.12	-215.46	-200.79
RCO 3	Developed efficient first response	15%	7.07	8.31	9.56	-86.21	-84.96	-83.71
RCO 4	Developed manual firefighting for APVs	15%	120.37	141.61	162.85	-181.50	-160.26	-139.02
RCO 5	Alarm system interface prototype	30%	23.02	32.89	42.76	-267.45	-257.58	-247.72
RCO 6	Process [...] for efficient activation of exting.	15%	23.07	27.14	31.21	-281.33	-277.26	-273.19
RCO 7	Training module for efficient activat. of exting.	15%	133.15	156.64	180.14	-171.25	-147.76	-124.26
RCO 11	Alternative fire detection in CRS & ORS	30%	171.95	245.64	319.34	1.37	75.06	148.75
RCO 12	Visual system for fire confirmation and localiz.	30%	652.28	931.82	1211.37	349.24	628.78	908.33
RCO 13	Dry-pipe sprinkler system for VC	30%	444.20	634.57	824.93	140.66	331.03	521.40

Table 14. Sensitivity 2 - GCAF and NCAF factor values for vehicle carrier, existing ships.

			GCAF Factor			NCAF Factor		
Ref	Designation	ΔCost +/-XX%	ΔCost-XX%	Base Case	ΔCost+XX%	ΔCost-XX%	Base Case	ΔCost+XX%
RCO 1	Improved fire confirmation & localization	15%	146.50	172.36	198.21	-117.89	-92.03	-66.18
RCO 2	Impr. signage and markings for effective localiz.	30%	115.24	164.62	214.01	-124.62	-75.24	-25.85
RCO 3	Developed efficient first response	15%	9.48	11.15	12.83	-71.27	-69.59	-67.92
RCO 4	Developed manual firefighting for APVs	15%	159.96	188.19	216.42	-97.21	-68.98	-40.75
RCO 6	Process [...] for efficient activation of exting.	15%	32.71	38.49	44.26	-231.67	-225.90	-220.13
RCO 7	Training module for efficient activat. of exting.	15%	173.65	204.29	234.93	-90.74	-60.10	-29.45
RCO 12	Visual system for fire confirmation and localiz.	30%	1123.53	1605.05	2086.56	863.02	1344.53	1826.04

For the other types of ro-ro ships (Table 12, Table 13 and Table 14), the variations of ΔCost do not change the results of cost-effectiveness of RCOs.

In conclusion, most of the results of cost-effectiveness are not impacted by credible variations of ΔCost, except for RCOs whose GCAF or NCAF factor are close to 1 (as was expected).

5.3 Sensitivity 3: Variation of the price of a cargo unit

Main author of the chapter: Eric De Carvalho, BV

For ro-ro cargo ships, the price of one cargo unit was considered to be 168 000€ (i.e. price of a truck, trailer and transported goods) [4]. This price has a direct impact on the Potential Loss of Cargo (PLC).

This sensitivity aims at verifying the robustness of the cost-effectiveness for ro-ro cargo ships to a variation of this parameter. As variation, the price of one cargo unit was increased from 168 000€ to 250 000€.

Table 15 and Table 16 present the GCAF and NCAF factors for the sensitivity 3, compared to the results for the generic ships (base case). The variation of the price of a cargo unit does not change the results of cost-effectiveness. In conclusion, the results of cost-effectiveness of ro-ro cargo ships are not impacted by variation of this parameter.

Table 15. Sensitivity 3 - GCAF and NCAF factor values for ro-ro cargo ships, newbuildings.

		GCAF Factor		NCAF Factor	
Ref	Designation	Base Case	Sensitivity	Base Case	Sensitivity
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	6.56	6.56	-36.68	-43.17
RCO 2	Impr. signage and markings for effective localiz.	19.07	19.07	-18.42	-24.67
RCO 3	Developed efficient first response	6.83	6.83	-39.32	-46.17
RCO 4	Developed manual firefighting for APVs	36.91	36.91	-5.74	-12.06
RCO 5	Alarm system interface prototype	10.71	10.71	-34.21	-40.94
RCO 6	Process [...] for efficient activation of exting.	11.08	11.08	-41.67	-49.34
RCO 7	Training module for efficient activat. of exting.	39.59	39.59	-13.01	-20.66
RCO 8	Safe electrical connection for reefers	129.80	129.80	73.37	65.31
RCO 10	Fire detection on weather decks	39.25	39.25	9.46	4.64
RCO 11	Alternative fire detection in CRS & ORS	99.84	99.84	56.93	50.15
RCO 12	Visual system for fire confirmation and localiz.	127.91	127.91	80.45	73.46
RCO 14	Remote.-control. fire monitor using water for WD	17.24	17.24	-10.46	-15.03
RCO 15	Autonomous fire monitor using water for WD	19.96	19.96	-8.11	-12.72
RCO 16	Guideline for fire ventilation in CRS	1687.38	1687.38	1622.11	1613.01

Table 16. Sensitivity 3 - GCAF and NCAF factor values for ro-ro cargo ships, existing ships.

		GCAF Factor		NCAF Factor	
Ref	Designation	Base Case	Sensitivity	Base Case	Sensitivity
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	9.49	9.49	-14.23	-22.27
RCO 2	Impr. signage and markings for effective localiz.	63.23	63.23	41.92	34.16
RCO 3	Developed efficient first response	9.32	9.32	-15.89	-24.38
RCO 4	Developed manual firefighting for APVs	53.05	53.05	30.02	22.18
RCO 6	Process [...] for efficient activation of exting.	69.06	69.06	40.70	31.19
RCO 7	Training module for efficient activat. of exting.	54.68	54.68	26.40	16.92
RCO 8	Safe electrical connection for reefers	244.83	244.83	214.37	204.36
RCO 10	Fire detection on weather decks	63.63	63.63	46.86	40.88
RCO 12	Visual system for fire confirmation and localiz.	204.35	204.35	178.74	170.07
RCO 14	Remote.-control. fire monitor using water for WD	28.80	28.80	13.24	7.58
RCO 15	Autonomous fire monitor using water for WD	33.15	33.15	17.36	11.64
RCO 16	Guideline for fire ventilation in CRS	2233.40	2233.40	2198.99	2187.70

For vehicle carriers, the price of one cargo unit was considered to be 40 000€ (i.e. average price of a new car) [4]. This price has a direct impact on the Potential Loss of Cargo (PLC) and is deeply dependent on what is transported by the vehicle carrier.

This sensitivity aims at verifying the robustness of the cost-effectiveness for vehicle carriers to a variation of this parameter. As variation, the price of one cargo unit was increased from 40 000€ to 60 000€ in order to consider more expensive cars (e.g. luxury cars, electric cars) or more expensive vehicles (e.g. trucks).

Table 17 and Table 18 present the GCAF and NCAF factors for the sensitivity 3, compared to the results for the generic ships (base case). The variation of the price of a cargo unit does not change the results of cost-effectiveness. In conclusion, the results of cost-effectiveness of vehicle carriers are not impacted to this variation of parameter.

Table 17. Sensitivity 3 - GCAF and NCAF factor values for vehicle carriers, newbuildings.

		GCAF Factor		NCAF Factor	
Ref	Designation	Base Case	Sensitivity	Base Case	Sensitivity
RCO 1	Improved fire confirmation & localization	126.16	126.16	-178.24	-275.28
RCO 2	Impr. signage and markings for effective localiz.	48.88	48.88	-215.46	-305.96
RCO 3	Developed efficient first response	8.31	8.31	-84.96	-114.46
RCO 4	Developed manual firefighting for APVs	141.61	141.61	-160.26	-255.21
RCO 5	Alarm system interface prototype	32.89	32.89	-257.58	-352.41
RCO 6	Process […] for efficient activation of exting.	27.14	27.14	-277.26	-374.30
RCO 7	Training module for efficient activat. of exting.	156.64	156.64	-147.76	-244.80
RCO 11	Alternative fire detection in CRS & ORS	245.64	245.64	75.06	16.79
RCO 12	Visual system for fire confirmation and localiz.	931.82	931.82	628.78	532.86
RCO 13	Dry-pipe sprinkler system for VC	634.57	634.57	331.03	234.70

Table 18. Sensitivity 3 - GCAF and NCAF factor values for vehicle carrier, existing ships.

		GCAF Factor		NCAF Factor	
Ref	Designation	Base Case	Sensitivity	Base Case	Sensitivity
RCO 1	Improved fire confirmation & localization	172.36	172.36	-92.03	-208.15
RCO 2	Impr. signage and markings for effective localiz.	164.62	164.62	-75.24	-183.53
RCO 3	Developed efficient first response	11.15	11.15	-69.59	-104.89
RCO 4	Developed manual firefighting for APVs	188.19	188.19	-68.98	-182.60
RCO 6	Process […] for efficient activation of exting.	38.49	38.49	-225.90	-342.02
RCO 7	Training module for efficient activat. of exting.	204.29	204.29	-60.10	-176.22
RCO 12	Visual system for fire confirmation and localiz.	1605.05	1605.05	1344.53	1229.75

5.4 Sensitivity 4: Size of weather decks

Main author of the chapter: Eric De Carvalho, BV

In deliverable D04.6 [2], it was spotted out that the influence of weather decks should be further analysed in a sensitivity analysis. Indeed, the size and arrangement of the weather decks have a high impact on the cost-effectiveness assessment of weather deck-related RCOs. For example, the weather deck on deck 5 of Stena Flavia (Figure 1) and the aft weather deck of Magnolia Seaways have an engine casing located on the centre line, which obstructs the coverage of fire detection or extinguishment devices. As a consequence, the targeted coverage can be reached by adding more devices.

Figure 1. Weather decks of Stena Flavia.

This sensitivity aims at investigating the influence of weather decks for RCO10 “Fire detection on weather decks”, RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” and RCO15 “Fixed autonomous fire monitor system using water for weather decks”. An *optimal case* was defined as the maximal coverage for a minimal number of devices (as assessed in the cost-effectiveness assessment) and a *less favourable case* was defined as half of the maximal coverage for the minimal number of devices.

Optimal case - “500 LM”:

- Weather deck of 500 LM
- RCO10: 1 × IR camera or 2 × flame detector
- RCO14: 2 × fire monitors
- RCO15: 2 × fire monitors + 2 × IR camera or 2 × fire monitors + 4 × flame detector

Less favourable case - “250 LM”:

- Weather deck of 250 LM
- RCO10: 1 × IR camera or 2 × flame detector
- RCO14: 2 × fire monitors
- RCO15: 2 × fire monitors + 2 × IR camera or 2 × fire monitors + 4 × flame detector

The *less favourable case* enables to verify if those RCOs can be cost-effective or not for a smaller weather deck, considering the minimal number of devices.

Table 19 to Table 22 present the GCAF and NCAF factors for the sensitivity 4, compared to the results for the generic ships (base case).

Table 19. Sensitivity 4 - GCAF and NCAF factor values for ro-ro passenger ships, newbuildings.

		GCAF Factor			NCAF factor		
Ref	Designation	Base Case	500 LM	250 LM	Base Case	500 LM	250 LM
RCO 10	Fire detection on weather decks	1.70	0.44	0.89	1.03	-0.23	0.21
RCO 14	Remote.-control. fire monitor using water for WD	0.52	0.16	0.31	-0.07	-0.44	-0.27
RCO 15	Autonomous fire monitor using water for WD	0.61	0.20	0.38	0.02	-0.41	-0.21

For new ro-ro passenger ships (Table 19), RCO10 becomes cost-effective in the *optimal case* and *less favourable case*.

Table 20. Sensitivity 4 - GCAF and NCAF factor values for ro-ro passenger ships, existing ships.

		GCAF Factor			NCAF factor		
Ref	Designation	Base Case	500 LM	250 LM	Base Case	500 LM	250 LM
RCO 10	Fire detection on weather decks	2.85	0.83	1.66	2.34	0.32	1.15
RCO 14	Remote.-control. fire monitor using water for WD	0.91	0.31	0.58	0.48	-0.13	0.16
RCO 15	Autonomous fire monitor using water for WD	1.08	0.38	0.71	0.64	-0.08	0.27

For existing ro-ro passenger ships (Table 20), RCO10 is still not cost-effective in the *less favourable case* but becomes cost-effective in the *optimal case*. RCO15 becomes cost-effective in the *optimal case* and *less favourable case*.

Table 21. Sensitivity 4 - GCAF and NCAF factor values for ro-ro cargo ships, newbuildings.

		GCAF Factor			NCAF factor		
Ref	Designation	Base Case	500 LM	250 LM	Base Case	500 LM	250 LM
RCO 10	Fire detection on weather decks	39.25	35.61	71.21	9.46	5.82	41.43
RCO 14	Remote.-control. fire monitor using water for WD	17.24	16.00	30.56	-10.46	-11.36	3.86
RCO 15	Autonomous fire monitor using water for WD	19.96	18.93	36.17	-8.11	-8.80	9.12

For new ro-ro cargo ships (Table 21), RCO14 and RCO15 becomes not cost-effective in saving cargo and ship in the *less favourable case*.

Table 22. Sensitivity 4 - GCAF and NCAF factor values for ro-ro cargo ships, existing ships.

		GCAF Factor			NCAF factor		
Ref	Designation	Base Case	500 LM	250 LM	Base Case	500 LM	250 LM
RCO 10	Fire detection on weather decks	63.63	63.43	126.87	46.86	46.66	110.09
RCO 14	Remote.-control. fire monitor using water for WD	28.80	26.19	50.01	13.24	10.78	34.90
RCO 15	Autonomous fire monitor using water for WD	33.15	33.44	63.91	17.36	17.81	48.58

For existing ro-ro cargo ships (Table 22), there is no change of the results of cost-effectiveness.

In conclusion, this sensitivity tends to demonstrate that (unlike for the generic ships):

- **RCO10:**
  - Ro-ro passenger ships, newbuildings and existing ships: RCO10 can be found cost-effective for other configurations of weather decks than the generic ship;
- **RCO14 and RCO15:**
  - Ro-ro passenger ships, existing ships: RCO15 can be found cost-effective for other configurations of weather decks than the generic ship; and
  - Ro-ro cargo ships, newbuildings: RCO14 and RCO15 can be found not cost-effective in saving cargo and ship for other configurations of weather decks than the generic ship.

Reducing the number of fire monitors from two to one may be beneficial for small size of weather decks. But this was not analysed because it was not fully assessed in terms of cost-effectiveness. The same remark can be drawn for detection device.

The results do not address the global size of the ship but only the size of the weather decks, independently of the rest. Smaller weather decks than the ones studied for the generic ro-ro passenger ship may be found on large ro-ro ships (same characteristics as the generic ships, excepted weather deck) but also on smaller ro-ro ships (significantly different from the generic ship). The second configuration will result in smaller ΔRisk and therefore higher GCAF and NCAF. The next sensitivity will provide elements to answer to this question.

5.5 Sensitivity 5: Size of ships

Main author of the chapter: Eric De Carvalho, BV

After reviewing the FIRESAFE studies, one of the comments made by the IMO FSA Experts Group was that the “the effectiveness of the RCOs depended on the size and the arrangement of the ships” [9, p. 4]. In deliverable D04.2 “Ro-ro space fire database and statistical analysis report” [10], the ignition frequency was estimated as a function of cargo capacity (lane meter or car equivalent unit) and the number of equivalent fatalities as a function of people on board (POB) (only valid for ro-ro passenger ships). Those two parameters of the risk model were identified among the most sensitive of the risk model [5] and [6].

In order to investigate the impact of the ship size on the result of the cost-effectiveness assessment, the cost-effectiveness of the RCOs for other cargo capacities and for other POB than the generic ships’ were re-calculated. It was decided to calculate the GCAF or NCAF factor for each ro-ro ship in the WP04 Fleet Database [10]. This exercise should not be considered as providing a real picture of the cost-effectiveness for the ro-ro fleet (because only up to four parameters of the model were varying), but rather as a sensitivity varying parameters on a dataset of ships.

For each ship of the dataset, the ignition frequency and the number of equivalent fatalities were calculated as a function of the number of lane meters or car equivalent units in closed, open ro-ro spaces and weather decks and POB. It resulted in a different ΔRisk per RCO for each ship. For some RCOs, the ΔCost was also calculated as a function of lane meters (LM) or car equivalent units (CEU) in order to scale the costs to the ship size. To make it simple, it was considered that ΔCost is linearly dependent on the number of lane meters or car equivalent units, with a lower limit of ΔCost (because there will be minimal costs whatever the size of the ship).

The results of this analysis are provided in terms of how many ships (%) result in GCAF or NCAF factor less than 1, i.e. how many ships of the dataset are cost-effective. For an RCO to be considered cost-effective whatever the ship size, it was deemed that the RCO should be cost-effective for half (50%) of the ships of the dataset.

Table 23 to Table 28 present the overall results of sensitivity 5, i.e. if the RCO was found cost-effective for the generic ship (base case) and for the dataset of ro-ro ships (sensitivity). ANNEX A: Sensitivity 5 – Size of ships provides the different tables with the quantitative results.

Table 23. Sensitivity 5 for ro-ro passenger ships, newbuildings.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes
RCO 3	Developed efficient first response	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	Yes
RCO 5	Alarm system interface prototype	Yes	Yes
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	Yes
RCO 8	Safe electrical connection for reefers	Yes	Yes
RCO 9	Safe electrical connection of reefers and EVs	Yes	Yes
RCO 10	Fire detection on weather decks	No	No
RCO 11	Alternative fire detection in CRS & ORS	Yes	Yes
RCO 12	Visual system for fire confirmation and localiz.	Yes	Yes
RCO 14	Remote.-control. fire monitor using water for WD	Yes	Yes
RCO 15	Autonomous fire monitor using water for WD	Yes	No
RCO 16	Guideline for fire ventilation in CRS	No	No

For new ro-ro passenger ships (Table 23), the same conclusion applies to the generic ship and the ro-ro passenger dataset, except for RCO15 “Fixed autonomous fire monitor system using water for weather decks”. It should be noted that RCO15 (48%) is very close to the criterion for the dataset.

Table 24. Sensitivity 5 for ro-ro passenger ships, existing ships.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes
RCO 3	Developed efficient first response	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	No
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	Yes
RCO 8	Safe electrical connection for reefers	Yes	Yes
RCO 9	Safe electrical connection of reefers and EVs	Yes	No
RCO 10	Fire detection on weather decks	No	No
RCO 12	Visual system for fire confirmation and localiz.	Yes	Yes
RCO 14	Remote.-control. fire monitor using water for WD	Yes	No
RCO 15	Autonomous fire monitor using water for WD	No	No
RCO 16	Guideline for fire ventilation in CRS	No	No

For existing ro-ro passenger ships (Table 24), the same conclusion applies to the generic ship and the ro-ro passenger dataset, except for RCO4 “Developed manual firefighting for Alternatively Powered Vehicles”, RCO9 “Safe electrical connection of reefers and electric vehicles (EVs)” and RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks”. It should be noted that RCO4 (45%) and RCO9 (49%) are very close to the criterion for the dataset.

Table 25. Sensitivity 5 for ro-ro cargo ships, newbuildings.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes
RCO 2	Impr. signage and markings for effective localiz.	Yes	No
RCO 3	Developed efficient first response	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	No
RCO 5	Alarm system interface prototype	Yes	Yes
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	No
RCO 8	Safe electrical connection for reefers	No	No
RCO 10	Fire detection on weather decks	No	No
RCO 11	Alternative fire detection in CRS & ORS	No	No
RCO 12	Visual system for fire confirmation and localiz.	No	No
RCO 14	Remote.-control. fire monitor using water for WD	Yes	Yes
RCO 15	Autonomous fire monitor using water for WD	Yes	Yes
RCO 16	Guideline for fire ventilation in CRS	No	No

For new ro-ro cargo ships (Table 25), the same conclusion applies to the generic ship and the ro-ro cargo dataset, except for RCO2 “Improved signage and markings for effective wayfinding and localization”, RCO4 “Developed manual firefighting for Alternatively Powered Vehicles” and RCO7 “Training module for efficient activation of extinguishing system”. It should be noted that RCO2 (49%) is very close to the criterion for the dataset.

Table 26. Sensitivity 5 for ro-ro cargo ships, existing ships.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes
RCO 2	Impr. signage and markings for effective localiz.	No	No
RCO 3	Developed efficient first response	Yes	Yes
RCO 4	Developed manual firefighting for APVs	No	No
RCO 6	Process [...] for efficient activation of exting.	No	No
RCO 7	Training module for efficient activat. of exting.	No	No
RCO 8	Safe electrical connection for reefers	No	No
RCO 10	Fire detection on weather decks	No	No
RCO 12	Visual system for fire confirmation and localiz.	No	No
RCO 14	Remote.-control. fire monitor using water for WD	No	No
RCO 15	Autonomous fire monitor using water for WD	No	No
RCO 16	Guideline for fire ventilation in CRS	No	No

For existing ro-ro cargo ships (Table 26), the same conclusion applies to the generic ship and the ro-ro cargo dataset.

Table 27. Sensitivity 5 for vehicle carriers, newbuildings.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Improved fire confirmation & localization	Yes	Yes
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes
RCO 3	Developed efficient first response	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	Yes
RCO 5	Alarm system interface prototype	Yes	Yes
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	Yes
RCO 11	Alternative fire detection in CRS & ORS	No	No
RCO 12	Visual system for fire confirmation and localiz.	No	No
RCO 13	Dry-pipe sprinkler system for VC	No	No

Table 28. Sensitivity 5 for vehicle carriers, existing ships.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Improved fire confirmation & localization	Yes	Yes
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes
RCO 3	Developed efficient first response	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	Yes
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	Yes
RCO 12	Visual system for fire confirmation and localiz.	No	No

For new and existing vehicle carriers (respectively, Table 27 and Table 28), the same conclusion applies to the generic ship and the vehicle carrier dataset.

In conclusion, the cost-effectiveness results for most of the RCOs are found not sensitive to the ship size. For the ones which are, the above results will provide additional information for step 5 of FSA.

6 Uncertainty analysis

Main author of the chapter: Stina Andersson, RISE

The IMO FSA guidelines [1, p. 39] define uncertainty analysis as "*uncertainty analysis investigates the uncertainty of variables that are used in decision-making problems in which observations and models represent the knowledge base. In other words, uncertainty analysis aims to make a technical contribution to decision-making through the quantification of uncertainties in the relevant variables.*"

An uncertainty analysis was carried out to verify the results of the cost-effectiveness assessment and to demonstrate the extent of uncertainties in the results. The uncertainty analysis was made to analyse how the uncertainty of the inputs (bottom node probabilities and risk reduction estimations for the RCOs) affects the GCAF and NCAF factors.

6.1 Methodology

The uncertainty analysis was made using Monte Carlo simulations in the Microsoft Excel add-in tool @RISK. @RISK works by substituting the fixed estimates (in this case, bottom nodes and risk reduction probabilities) with probability distributions. In a Monte Carlo simulation, values from the input probability distributions are sampled randomly to calculate the output. By performing several iterations, different possible input values create different possible outputs, creating a distribution of possible outcome values.

In LASH FIRE, data from the FIRESAFE II study [6] have been used during the quantification of the risk model as well as for the risk reduction estimations. In the FIRESAFE II uncertainty analysis, Beta-distribution was used for the bottom node probabilities and risk reduction estimations. Therefore, it was decided to use the same distribution in the LASH FIRE uncertainty analysis, i.e., Beta-distribution:

$$beta_{distribution}(\alpha; \beta; P_{bottom\,node/riskreduction}).$$

This means that all bottom node and risk reduction estimates were converted into Beta-distributions. Beta-distributions are a function of the two parameters alpha (α) and beta (β) which were calculated according to the following equations [6]:

$$\alpha = (N+1) * P_{bottom\,node/risk\,reduction}$$

$$\beta = (N+1) * (1 - P_{bottom\,node/risk\,reduction})$$

To decide the value of N, the three confidence levels presented in FIRESAFE II [6], was used:

a. $N_{LowConfidence} = 10$
b. $N_{MediumConfidence} = 50$
c. $N_{HighConfidence} = 250$

For the bottom nodes of the risk model, the confidence level was decided based on the quantification method for each node. The established confidence level for each quantification method is presented in Table 29.

Table 29. Decided confidence level for each quantification method used in LASH FIRE.

Quantification method for bottom node	Confidence level
Expert judgement	Ro-pax: Medium
	Ro-ro cargo: Medium
	VC: Low
FIRESAFE II	Same as in FIRESAFE II
Calculations	Medium
Statistics (mainly for ignition frequency)	Ro-pax: High
	Ro-ro cargo: Medium
	VC: High

For the risk reduction inputs, the confidence level was decided based on the overall perceived level of confidence for each RCO's risk reduction inputs. The level of confidence is based on the methods of evaluation and performance assessment for each RCO. The established confidence level for each RCO is presented in Table 30.

Table 30. Decided confidence level for each RCO.

Risk Control Option	Confidence level
RCO1	Medium
RCO2	Medium
RCO3	Medium
RCO4	Medium
RCO5	High
RCO6	Low
RCO7	Medium
RCO8	Medium
RCO9	Medium
RCO10	Medium
RCO11	Medium
RCO12	Medium
RCO13	High
RCO14	High
RCO15	High
RCO16	Low

By changing both the reference case and a specific RCOs risk reduction simultaneously, it is possible to obtain the probability of the GCAF and NCAF factor of the RCO being lower than 1 (1 being the cost-effective criterion). This should reflect the confidence in the conclusion of the cost-effectiveness assessment, i.e. for how many iterations the RCO is found cost-effective. A high probability should confirm the cost-effectiveness of the RCO, while a low probability should confirm that the RCO is not cost-effective.

The simulations were run with 5000 iterations in @RISK v8.1. The input was the probability distributions for the bottom nodes and the risk reductions, and the output was the GCAF and NCAF factors.

6.2 Results

Main author of the chapter: Léon Lewandowski, BV

Table 31 to Table 36 show the probability for each RCO of having a GCAF/NCAF factor lower than 1 (i.e. to be cost-effective). ANNEX B: Uncertainty analysis provides the different graph outputs. The results of the uncertainty analysis confirm the results of the cost-effectiveness assessment for the generic ships, i.e. high probability of having GCAF factor or NCAF factor lower to 1 was found when the GCAF factor or NCAF factor was lower than 1 for the generic ships.

Table 31. Uncertainty analysis. Probability of having GCAF/NCAF factor lower than 1. Ro-ro passenger ships, newbuildings.

Ref	Designation	P(GCAF Fact. <1)	P(NCAF Fact. <1)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	> 99%	> 99%
RCO 2	Impr. signage and markings for effective localiz.	> 99%	> 99%
RCO 3	Developed efficient first response	> 99%	> 99%
RCO 4	Developed manual firefighting for APVs	> 99%	> 99%
RCO 5	Alarm system interface prototype	> 99%	> 99%
RCO 6	Process [...] for efficient activation of exting.	> 99%	> 99%
RCO 7	Training module for efficient activat. of exting.	> 99%	> 99%
RCO 8	Safe electrical connection for reefers	> 99%	> 99%
RCO 9	Safe electrical connection of reefers and EVs	> 99%	> 99%
RCO 10	Fire detection on weather decks	< 1%	50%
RCO 11	Alternative fire detection in CRS & ORS	> 99%	> 99%
RCO 12	Visual system for fire confirmation and localiz.	> 99%	> 99%
RCO 14	Remote.-control. fire monitor using water for WD	> 99%	> 99%
RCO 15	Autonomous fire monitor using water for WD	> 99%	> 99%
RCO 16	Guideline for fire ventilation in CRS	< 1%	20%

Table 32. Uncertainty analysis. Probability of having GCAF/NCAF factor lower than 1. Ro-ro passenger ships, existing ships.

Ref	Designation	P(GCAF Fact. <1)	P(NCAF Fact. <1)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	> 99%	> 99%
RCO 2	Impr. signage and markings for effective localiz.	> 99%	> 99%
RCO 3	Developed efficient first response	> 99%	> 99%
RCO 4	Developed manual firefighting for APVs	> 99%	> 99%
RCO 6	Process [...] for efficient activation of exting.	> 99%	> 99%
RCO 7	Training module for efficient activat. of exting.	> 99%	> 99%
RCO 8	Safe electrical connection for reefers	> 99%	> 99%
RCO 9	Safe electrical connection of reefers and EVs	> 99%	> 99%
RCO 10	Fire detection on weather decks	< 1%	< 1%
RCO 12	Visual system for fire confirmation and localiz.	80%	> 99%
RCO 14	Remote.-control. fire monitor using water for WD	75%	> 99%
RCO 15	Autonomous fire monitor using water for WD	25%	98%
RCO 16	Guideline for fire ventilation in CRS	20%	25%

Table 33. Uncertainty analysis. Probability of having GCAF/NCAF factor lower than 1. Ro-ro cargo ships, newbuildings.

Ref	Designation	P(GCAF Fact. <1)	P(NCAF Fact. <1)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	< 1%	> 99%
RCO 2	Impr. signage and markings for effective localiz.	< 1%	> 99%
RCO 3	Developed efficient first response	< 1%	> 99%
RCO 4	Developed manual firefighting for APVs	< 1%	80%
RCO 5	Alarm system interface prototype	< 1%	> 99%
RCO 6	Process [...] for efficient activation of exting.	< 1%	> 99%
RCO 7	Training module for efficient activat. of exting.	< 1%	90%
RCO 8	Safe electrical connection for reefers	< 1%	< 1%
RCO 10	Fire detection on weather decks	< 1%	5%
RCO 11	Alternative fire detection in CRS & ORS	< 1%	< 1%
RCO 12	Visual system for fire confirmation and localiz.	< 1%	< 1%
RCO 14	Remote.-control. fire monitor using water for WD	< 1%	> 99%
RCO 15	Autonomous fire monitor using water for WD	< 1%	98%
RCO 16	Guideline for fire ventilation in CRS	< 1%	< 1%

Table 34. Uncertainty analysis. Probability of having GCAF/NCAF factor lower than 1. Ro-ro cargo ships, existing ships.

Ref	Designation	P(GCAF Fact. <1)	P(NCAF Fact. <1)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	< 1%	> 99%
RCO 2	Impr. signage and markings for effective localiz.	< 1%	< 1%
RCO 3	Developed efficient first response	< 1%	> 99%
RCO 4	Developed manual firefighting for APVs	< 1%	< 1%
RCO 6	Process [...] for efficient activation of exting.	< 1%	< 1%
RCO 7	Training module for efficient activat. of exting.	< 1%	< 1%
RCO 8	Safe electrical connection for reefers	< 1%	< 1%
RCO 10	Fire detection on weather decks	< 1%	< 1%
RCO 12	Visual system for fire confirmation and localiz.	< 1%	< 1%
RCO 14	Remote.-control. fire monitor using water for WD	< 1%	< 1%
RCO 15	Autonomous fire monitor using water for WD	< 1%	< 1%
RCO 16	Guideline for fire ventilation in CRS	< 1%	< 1%

Table 35. Uncertainty analysis. Probability of having GCAF/NCAF factor lower than 1. Vehicle carriers, newbuildings.

Ref	Designation	P(GCAF Fact. <1)	P(NCAF Fact. <1)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	< 1%	90%
RCO 2	Impr. signage and markings for effective localiz.	< 1%	> 99%
RCO 3	Developed efficient first response	< 1%	> 99%
RCO 4	Developed manual firefighting for APVs	< 1%	95%
RCO 5	Alarm system interface prototype	< 1%	> 99%
RCO 6	Process [...] for efficient activation of exting.	< 1%	> 99%
RCO 7	Training module for efficient activat. of exting.	< 1%	80%
RCO 11	Alternative fire detection in CRS & ORS	< 1%	5%
RCO 12	Visual system for fire confirmation and localiz.	< 1%	< 1%
RCO 13	Dry-pipe sprinkler system for VC	< 1%	< 1%

Table 36. Uncertainty analysis. Probability of having GCAF/NCAF factor lower than 1. Vehicle carriers, existing ships.

Ref	Designation	P(GCAF Fact. <1)	P(NCAF Fact. <1)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	< 1%	50%
RCO 2	Impr. signage and markings for effective localiz.	< 1%	50%
RCO 3	Developed efficient first response	< 1%	99%
RCO 4	Developed manual firefighting for APVs	< 1%	50%
RCO 6	Process [...] for efficient activation of exting.	< 1%	99%
RCO 7	Training module for efficient activat. of exting.	< 1%	50%
RCO 12	Visual system for fire confirmation and localiz.	< 1%	< 1%

7 Conclusion

Main author of the chapter: Eric De Carvalho, BV

Sensitivity and uncertainty analyses were conducted on the results of the cost-effectiveness assessment based on the generic ships.

- **Ro-ro passenger ships - Newbuildings:**

The results of the cost-effectiveness assessment for the new ro-ro passenger ship studied as generic ship, presented in D04.6 [2], were confirmed by the sensitivity and uncertainty analyses.

Initially found with a GCAF factor greater than 1 for the generic ship, RCO10 “Fire detection on weather decks” was found with a GCAF factor lower than 1 for an optimal arrangement of weather deck(s). However, for most of the studied ship arrangements in sensitivity 5, it was found with a GCAF factor greater than 1. The uncertainty analysis showed high confidence in the result for the generic ship. As a consequence, RCO10 is considered as not cost-effective in terms of life safety.

Initially found with a NCAF factor greater than 1 for the generic ship, RCO10 was found with a NCAF factor lower than 1 for some arrangements of weather deck(s). The uncertainty analysis showed medium confidence in the result for the generic ship. As a consequence, further evaluation is needed to conclude on the cost-effectiveness of RCO10 in saving cargo and ship.

Initially found with a NCAF factor greater than 1 for the generic ship, the uncertainty analysis showed high confidence in this result for RCO16 “Guideline for fire ventilation in closed ro-ro space”. As a consequence, RCO16 is considered as not cost-effective in saving cargo and life.

- **Ro-ro passenger ships - Existing ships:**

The results of the cost-effectiveness assessment for the existing ro-ro passenger ship studied as generic ship, presented in D04.6 [2], were confirmed by the sensitivity and uncertainty analyses.

Initially found with a GCAF factor lower than 1 for the generic ship, the sensitivity and uncertainty analyses confirmed this result for RCO12 “Visual system for fire confirmation and localization”. As a consequence, RCO12 is considered as cost-effective in terms of life safety.

Initially found with a GCAF factor lower than 1 for the generic ship, RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” was found with a NCAF factor greater than 1 for some arrangements of weather deck(s). The uncertainty analysis showed medium confidence in the result for the generic ship. As a consequence, further evaluation is needed to conclude on the cost-effectiveness of RCO14 in terms of life safety.

Initially found with a GCAF factor greater than 1 for the generic ship, RCO15 “Fixed autonomous fire monitor system using water for weather decks” was found with a NCAF factor lower than 1 for some arrangements of weather deck(s). The uncertainty analysis showed medium confidence in the result for the generic ship. As a consequence, further evaluation is needed to conclude on the cost-effectiveness of RCO15 in terms of life safety.

- **Ro-ro cargo ships - Newbuildings:**

The results of the cost-effectiveness assessment for the new ro-ro cargo ship studied as generic ship, presented in D04.6 [2], were confirmed by the sensitivity and uncertainty analyses.

Initially found with a negative NCAF but low ΔRisk and ΔCost-ΔBenefits for the generic ship, RCO2 “Improved signage and markings for effective wayfinding and localization”, RCO4 “Developed manual firefighting for Alternatively Powered Vehicles” and RCO7 “Training module for efficient activation of extinguishing system” were found with a NCAF factor greater than 1 for several studied ship arrangements in sensitivity 5. The uncertainty analysis showed high confidence in the result for the generic ship. As a consequence, further evaluation is needed to conclude on the cost-effectiveness of RCO2, RCO4 and RCO7 in saving cargo and ship.

Initially with a negative NCAF, high ΔCost-ΔBenefits but low ΔRisk for the generic ship, the sensitivity and uncertainty analyses confirmed this result for RCO3 “Developed efficient first response” and RCO6 “Process for development of procedures and design for efficient activation of extinguishing system”. As a consequence, RCO3 and RCO6 are considered as cost-effective in increasing saving cargo and ship.

- **Ro-ro cargo ships - Existing ships:**

The results of the cost-effectiveness assessment for the existing ro-ro cargo ship studied as generic ship, presented in D04.6 [2], were confirmed by the sensitivity and uncertainty analyses.

- **Vehicle carriers - Newbuildings:**

The results of the cost-effectiveness assessment for the new vehicle carrier studied as generic ship, presented in D04.6 [2], were confirmed by the sensitivity and uncertainty analyses.

Initially with a negative NCAF, high ΔCost-ΔBenefits but low ΔRisk for the generic ship, the sensitivity and uncertainty analyses confirmed this result for RCO1 “Improved fire confirmation & localization”, RCO2 “Improved signage and markings for effective wayfinding and localization” and RCO4 “Developed manual firefighting for Alternatively Powered Vehicles”. As a consequence, RCO1, RCO2 and RCO4 are considered as cost-effective in increasing saving cargo and ship.

- **Vehicle carriers - Existing ships:**

The results of the cost-effectiveness assessment for the existing vehicle carrier studied as generic ship, presented in D04.6 [2], were confirmed by the sensitivity and uncertainty analyses.

Initially found with a negative NCAF but low ΔRisk and ΔCost-ΔBenefits for the generic ship, the uncertainty analyses showed medium confidence in this result for RCO1 “Improved fire confirmation & localization”, RCO2 “Improved signage and markings for effective wayfinding and localization”, RCO4 “Developed manual firefighting for Alternatively Powered Vehicles” and RCO7 “Training module for efficient activation of extinguishing system”. As a consequence, further evaluation is needed to conclude on the cost-effectiveness of RCO1, RCO2, RCO4 and RCO7 in saving cargo and ship.

Initially with a negative NCAF, high ΔCost-ΔBenefits but low ΔRisk for the generic ship, the sensitivity and uncertainty analyses confirmed this result for RCO6 “Process for development of procedures and design for efficient activation of extinguishing system”. As a consequence, RCO6 is considered as cost-effective in increasing saving cargo and ship.

Table 37 and Table 38 summarize the final cost-effectiveness results for all RCOs.

Table 37. Cost-effective RCOs in terms of life safety. CRS = closed ro-ro space, ORS = open ro-ro space, WD = weather deck, NB = newbuildings, Ex = existing ships.

		Cost-effective in terms of life safety?					
		Ro-pax		Ro-ro cargo		Vehicle carrier	
Ref	Designation	NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes	No	No	No	No
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes	No	No	No	No
RCO 3	Developed efficient first response	Yes	Yes	No	No	No	No
RCO 4	Developed manual firefighting for APVs	Yes	Yes	No	No	No	No
RCO 5	Alarm system interface prototype	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes	No	No	No	No
RCO 7	Training module for efficient activat. of exting.	Yes	Yes	No	No	No	No
RCO 8	Safe electrical connection for reefers	Yes	Yes	No	No	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	Yes	Yes	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	No	No	No	No	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	Yes	Yes	No	No	No	No
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	No	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	Yes	Note 1	No	No	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	Yes	Note 2	No	No	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	No	No	No	No	Not assessed	Not assessed
Note 1	Found cost-effective for the generic ship. Medium confidence in this result. Found not cost-effective for some weather deck arrangements. Further evaluation needed to conclude.						
Note 2	Found not cost-effective for the generic ship. Medium confidence in this result. Found cost-effective for some weather deck arrangements. Further evaluation needed to conclude.						

Table 38. Cost-effective RCOs in saving cargo and ship. CRS = closed ro-ro space, ORS = open ro-ro space, WD = weather deck, NB = newbuildings, Ex = existing ships.

		Cost-effective in saving cargo and ship?					
		Ro-pax		Ro-ro cargo		Vehicle carrier	
Ref	Designation	NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes	Yes	Yes	Yes	Note 4
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes	Note 3	No	Yes	Note 4
RCO 3	Developed efficient first response	Yes	Yes	Yes	Yes	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	Yes	Note 3	No	Yes	Note 4
RCO 5	Alarm system interface prototype	Yes	Not assessed	Yes	Not assessed	Yes	Not assessed
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes	Yes	No	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	Yes	Note 3	No	Yes	Note 4
RCO 8	Safe electrical connection for reefers	Yes	Yes	No	No	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	Yes	Yes	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	Note 2	No	No	No	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	Yes	Yes	No	No	No	No
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	No	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	Yes	Yes	Yes	No	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	Yes	Yes	Yes	No	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	No	No	No	No	Not assessed	Not assessed
Note 2	Found not cost-effective for the generic ship. Medium confidence in this result. Found cost-effective for some weather deck arrangements. Further evaluation needed to conclude.						
Note 3	Negative NCAF, low ΔRisk and low ΔCost-ΔBenefits for the generic ship. High confidence in these results. Found not cost-effective in some ship arrangements. Further evaluation needed to conclude.						
Note 4	Negative NCAF, low ΔRisk and low ΔCost-ΔBenefits for the generic ship. Medium confidence in these results. Further evaluation needed to conclude.						

Note 1 and 2 refer to weather deck-related RCOs and the further evaluation needed to conclude will not be conducted in LASH FIRE's WP04. Note 3 and 4: further evaluation related to the compatibility of RCOs with the existing regulations will be conducted in T04.9 in order to conclude.

The work presented in this deliverable finalize the cost-effectiveness assessment. The next step will be to develop recommendations on decision-making (T04.9) based on these conclusions.

This deliverable (with deliverable D04.6 [2]) is the summary of task T04.6 and T04.7, respectively '*Cost and benefit (risk reduction) integration for operational and technical solutions*' and '*Cost-effectiveness assessment*'. It contributes to the strategic objective:

> "To provide a **recognized technical basis** for the revision of international **IMO regulations**, which greatly **enhances fire prevention** and **ensures independent management of fires** on ro-ro ships in current and **future** fire safety challenges";

and to the specific objective 3:

> "LASH FIRE will provide a **technical basis** for future revisions of regulations by **assessing risk reduction and economic properties of solutions**".

8 References

[1] IMO, *Revised Guidelines for Formal Safety Assessment (FSA) for the use in the IMO rule-making process, MSC-MEPC.2/Circ.12/Rev.2,* 2018.

[2] E. De Carvalho and L. Lewandowski, *Cost-effectiveness assessment report (D04.6),* LASH FIRE, 2023.

[3] J. Spouge, *A guide to quantative risk assessment for offshore installations,* CMPT, 1999.

[4] L. Lewandowski, E. De Carvalho and A. Cassez, *Development of holistic risk model report (D04.5),* LASH FIRE, 2022.

[5] J. Wikman et al., *FIRESAFE Appendix: Sensitivity and Uncertainty Analyses, EMSA/OP/01/2016,* EMSA, 2017.

[6] J. Leroux et al., *FIRESAFE II Detection and Decision, Final Report, Version 1.1, 2017/EMSA/OP/17/2017,* EMSA, 2018.

[7] D. P. Loucks and E. van Beek, *Water resources systems planning and management: an introduction to methods, models and applications,* UNESCO, 2005.

[8] V. Radolovic, *Ship integration cost and environmental assessment (D05.8),* LASH FIRE, 2023.

[9] IMO, *Review of SOLAS Chapter II-2 [...] to minimize the incidence and consequences of fires on ro-ro spaces and special category spaces of new and existing ro-ro passenger ships, Report of the intersessional meeting of the Experts Group on FSA, SSE 7/6,* 2019.

[10] M. Gadel, E. De Carvalho and L. Lewandowski, *Ro-ro space fire database and statistical analysis report (D04.2),* 2020.

[11] L. Lewandowski, E. De Carvalho and A. Cassez, *Holistic risk model (D04.4),* LASH FIRE, 2022.

[12] E. De Carvalho and L. Lewandowski, *Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report (D04.7),* LASH FIRE, 2023.

9 Indexes

9.1 Index of tables

9.2 Index of figures

10 ANNEXES

10.1 ANNEX A: Sensitivity 5 – Size of ships

Table 39. Sensitivity 5 for ro-ro passenger ships, newbuildings. Quantitative results.

Ref	Designation	GCAF factor (generic ship)	% of ships with GCAF factor < 1 (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	0.05	95%
RCO 2	Impr. signage and markings for effective localiz.	0.07	93%
RCO 3	Developed efficient first response	0.05	95%
RCO 4	Developed manual firefighting for APVs	0.31	57%
RCO 5	Alarm system interface prototype	0.07	93%
RCO 6	Process [...] for efficient activation of exting.	0.04	97%
RCO 7	Training module for efficient activat. of exting.	0.18	71%
RCO 8	Safe electrical connection for reefers	0.17	75%
RCO 9	Safe electrical connection of reefers and EVs	0.22	69%
RCO 10	Fire detection on weather decks	1.70	11%
RCO 11	Alternative fire detection in CRS & ORS	0.41	80%
RCO 12	Visual system for fire confirmation and localiz.	0.34	80%
RCO 14	Remote.-control. fire monitor using water for WD	0.52	57%
RCO 15	Autonomous fire monitor using water for WD	0.61	48%
RCO 16	Guideline for fire ventilation in CRS	3.15	5%

Table 40. Sensitivity 5 for ro-ro passenger ships, existing ships. Quantitative results.

Ref	Designation	Cost-effective? (generic ship)	Cost-effective? (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	0.07	90%
RCO 2	Impr. signage and markings for effective localiz.	0.25	64%
RCO 3	Developed efficient first response	0.07	90%
RCO 4	Developed manual firefighting for APVs	0.43	45%
RCO 6	Process [...] for efficient activation of exting.	0.31	57%
RCO 7	Training module for efficient activat. of exting.	0.26	62%
RCO 8	Safe electrical connection for reefers	0.35	56%
RCO 9	Safe electrical connection of reefers and EVs	0.44	49%
RCO 10	Fire detection on weather decks	2.85	6%
RCO 12	Visual system for fire confirmation and localiz.	0.84	53%
RCO 14	Remote.-control. fire monitor using water for WD	0.91	36%
RCO 15	Autonomous fire monitor using water for WD	1.08	29%
RCO 16	Guideline for fire ventilation in CRS	4.34	2%

Table 41. Sensitivity 5 for ro-ro cargo ships, newbuildings. Quantitative results.

Ref	Designation	NCAF factor (generic ship)	% of ships with NCAF factor < 1 (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	-36.68	98%
RCO 2	Impr. signage and markings for effective localiz.	-18.42	49%
RCO 3	Developed efficient first response	-39.32	98%
RCO 4	Developed manual firefighting for APVs	-5.74	17%
RCO 5	Alarm system interface prototype	-34.21	87%
RCO 6	Process [...] for efficient activation of exting.	-41.67	91%
RCO 7	Training module for efficient activat. of exting.	-13.01	23%
RCO 8	Safe electrical connection for reefers	73.37	2%
RCO 10	Fire detection on weather decks	9.46	1%
RCO 11	Alternative fire detection in CRS & ORS	56.93	2%
RCO 12	Visual system for fire confirmation and localiz.	80.45	< 1%
RCO 14	Remote.-control. fire monitor using water for WD	-10.46	92%
RCO 15	Autonomous fire monitor using water for WD	-8.11	89%
RCO 16	Guideline for fire ventilation in CRS	1622.11	< 1%

Table 42. Sensitivity 5 for ro-ro cargo ships, existing ships. Quantitative results.

Ref	Designation	NCAF factor (generic ship)	% of ships with NCAF factor < 1 (dataset of ships)
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	-14.23	63%
RCO 2	Impr. signage and markings for effective localiz.	41.92	< 1%
RCO 3	Developed efficient first response	-15.89	66%
RCO 4	Developed manual firefighting for APVs	30.02	< 1%
RCO 6	Process [...] for efficient activation of exting.	40.70	1%
RCO 7	Training module for efficient activat. of exting.	26.40	2%
RCO 8	Safe electrical connection for reefers	214.37	< 1%
RCO 10	Fire detection on weather decks	46.86	< 1%
RCO 12	Visual system for fire confirmation and localiz.	178.74	< 1%
RCO 14	Remote.-control. fire monitor using water for WD	13.24	< 1%
RCO 15	Autonomous fire monitor using water for WD	17.36	< 1%
RCO 16	Guideline for fire ventilation in CRS	2198.99	< 1%

Table 43. Sensitivity 5 for vehicle carriers, newbuildings. Quantitative results.

Ref	Designation	NCAF factor (generic ship)	% of ships with NCAF factor < 1 (dataset of ships)
RCO 1	Improved fire confirmation & localization	-178.24	78%
RCO 2	Impr. signage and markings for effective localiz.	-215.46	92%
RCO 3	Developed efficient first response	-84.96	99%
RCO 4	Developed manual firefighting for APVs	-160.26	84%
RCO 5	Alarm system interface prototype	-257.58	97%
RCO 6	Process [...] for efficient activation of exting.	-277.26	99%
RCO 7	Training module for efficient activat. of exting.	-147.76	82%
RCO 11	Alternative fire detection in CRS & ORS	75.06	< 1%
RCO 12	Visual system for fire confirmation and localiz.	628.78	< 1%
RCO 13	Dry-pipe sprinkler system for VC	331.03	< 1%

Table 44. Sensitivity 5 for ro-ro vehicle carriers, existing ships. Quantitative results.

Ref	Designation	NCAF factor (generic ship)	% of ships with NCAF factor < 1 (dataset of ships)
RCO 1	Improved fire confirmation & localization	-92.03	63%
RCO 2	Impr. signage and markings for effective localiz.	-75.24	71%
RCO 3	Developed efficient first response	-69.59	94%
RCO 4	Developed manual firefighting for APVs	-68.98	69%
RCO 6	Process [...] for efficient activation of exting.	-225.90	94%
RCO 7	Training module for efficient activat. of exting.	-60.10	65%
RCO 12	Visual system for fire confirmation and localiz.	1344.53	< 1%

10.2 ANNEX B: Uncertainty analysis

The following graphs show the simulations results for GCAF factors and NCAF factors for the RCOs.

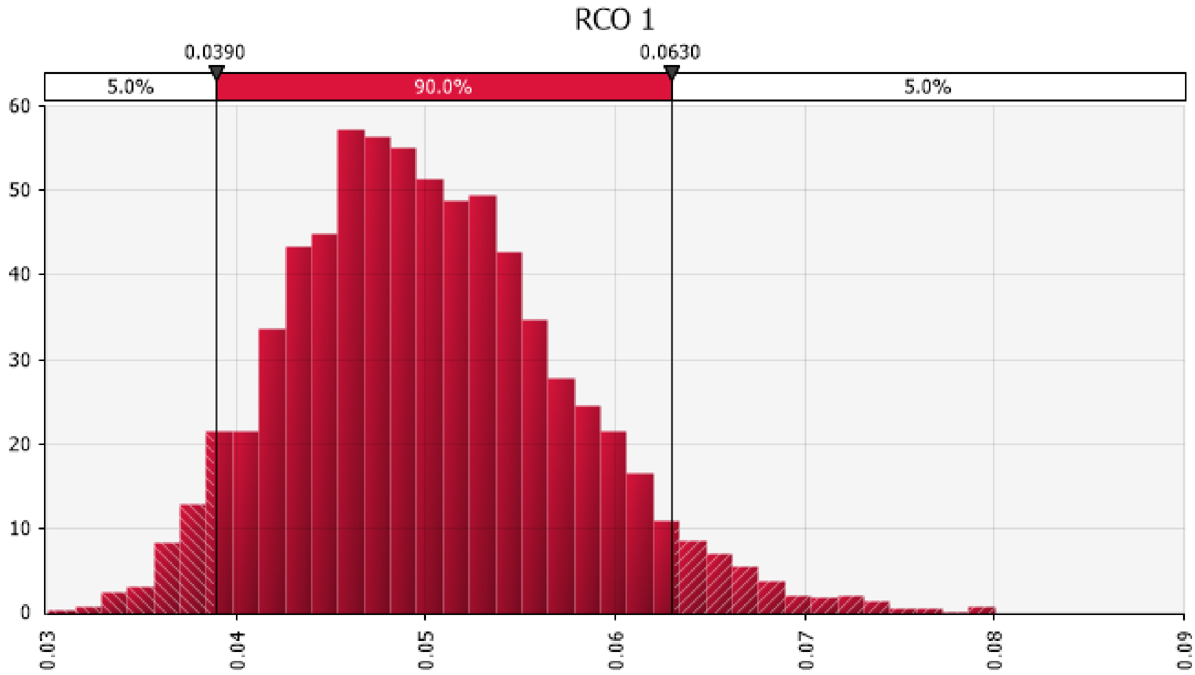

Figure 2. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO1 GCAF factor graph output.

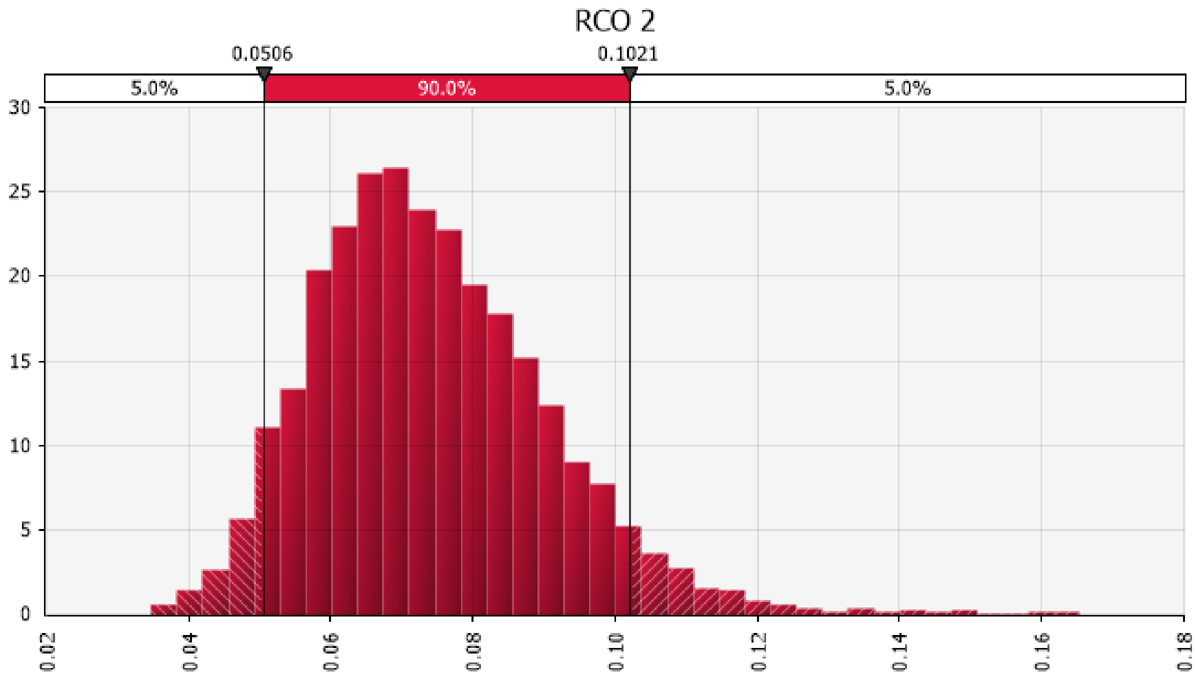

Figure 3. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO2 GCAF factor graph output.

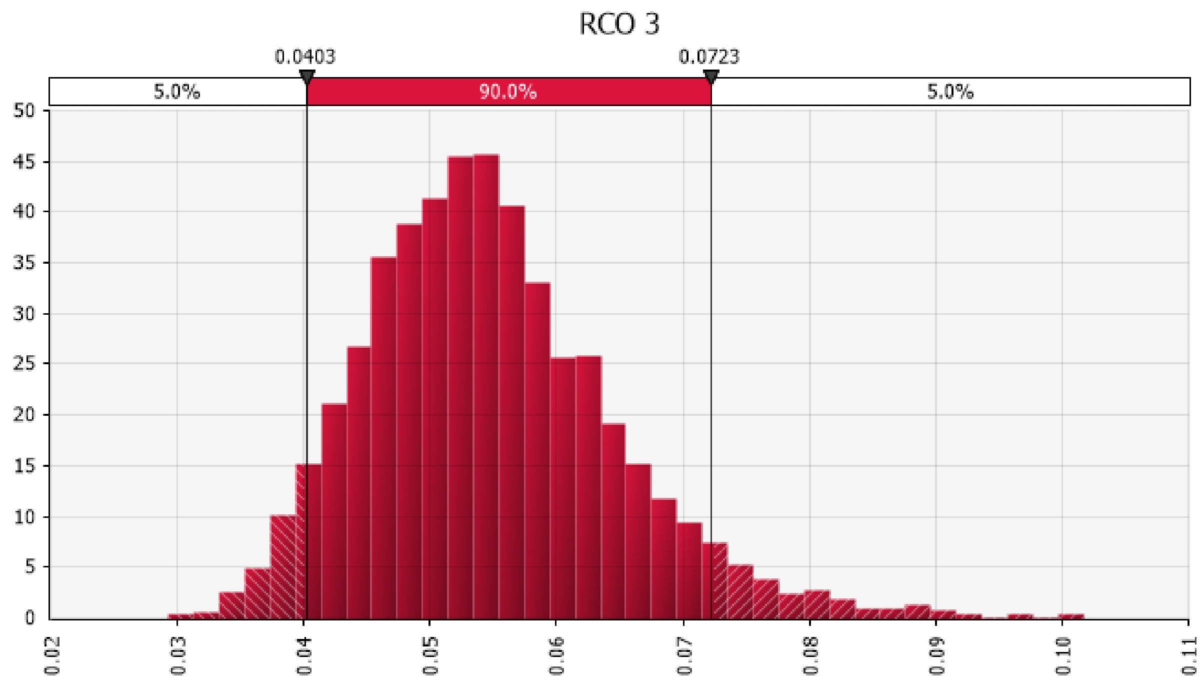

Figure 4. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO3 GCAF factor graph output.

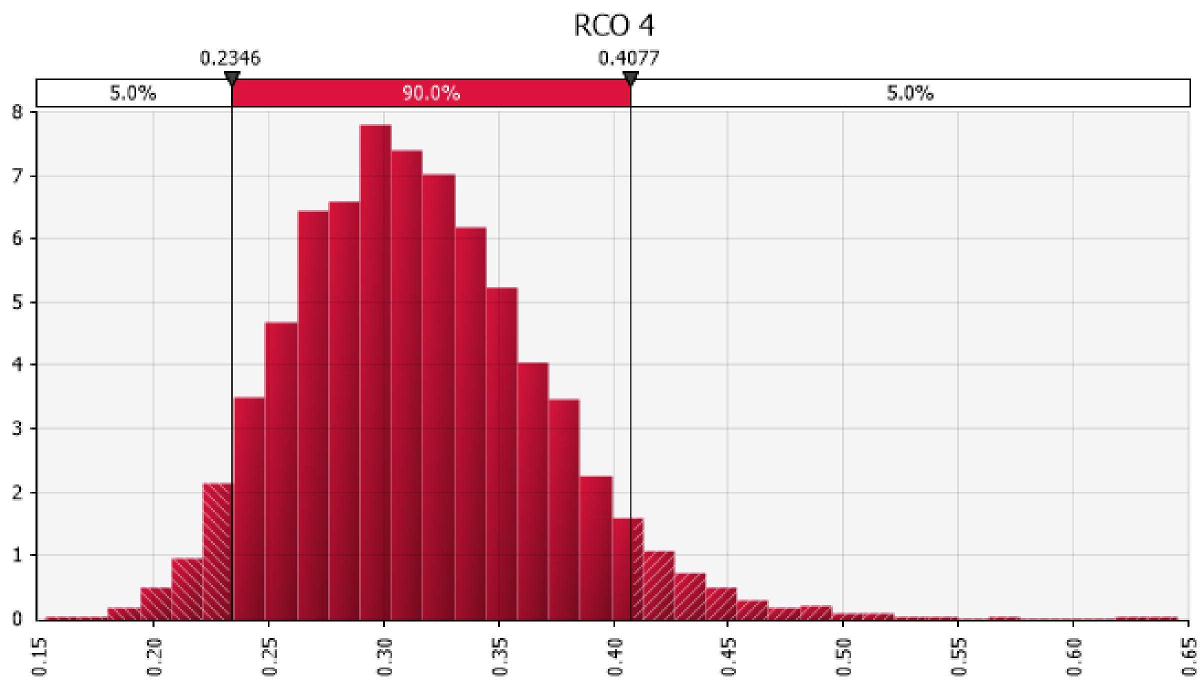

Figure 5. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO4 GCAF factor graph output.

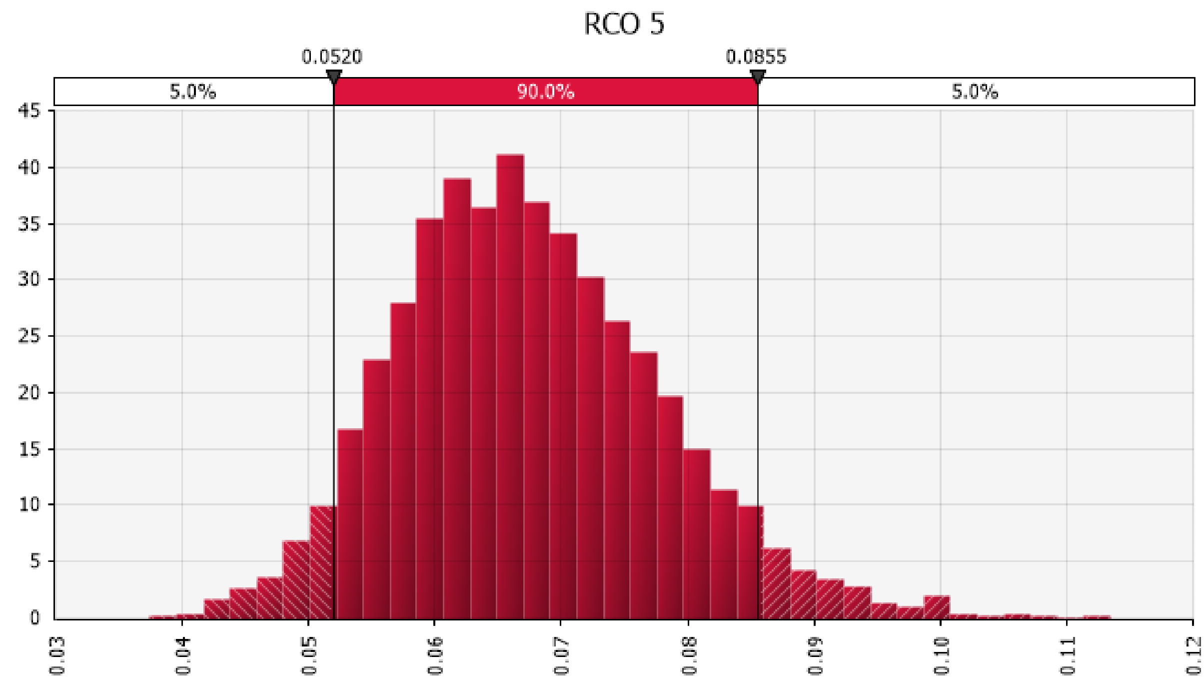

Figure 6. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO5 GCAF factor graph output.

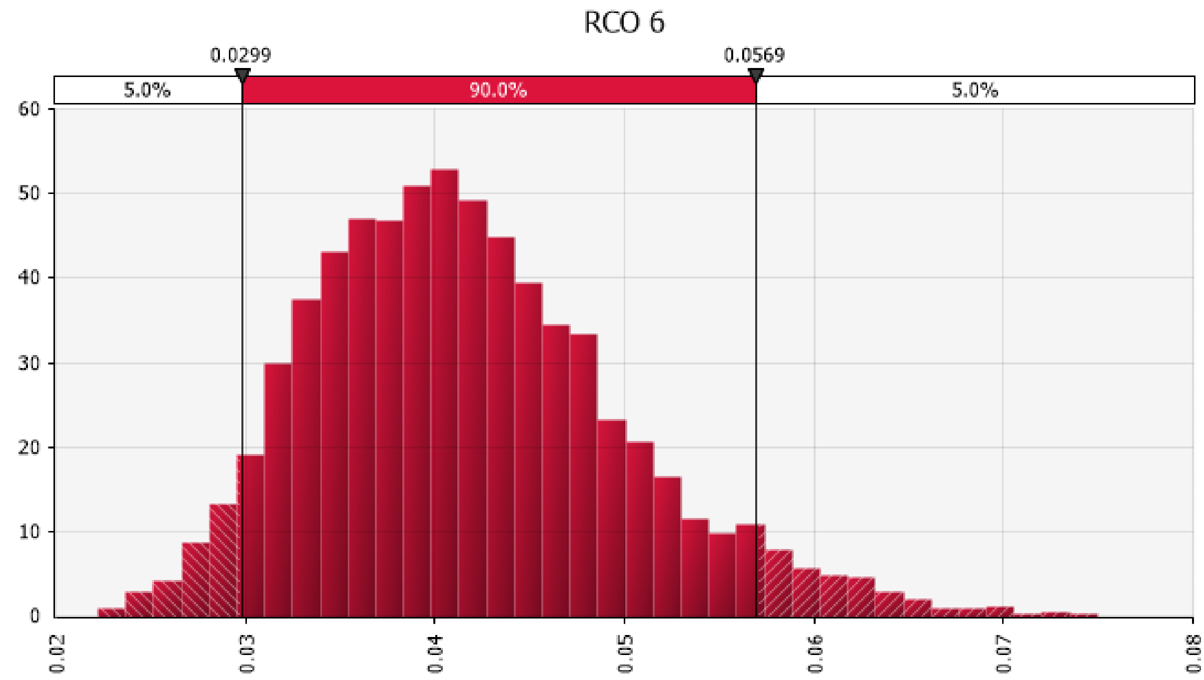

Figure 7. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO6 GCAF factor graph output.

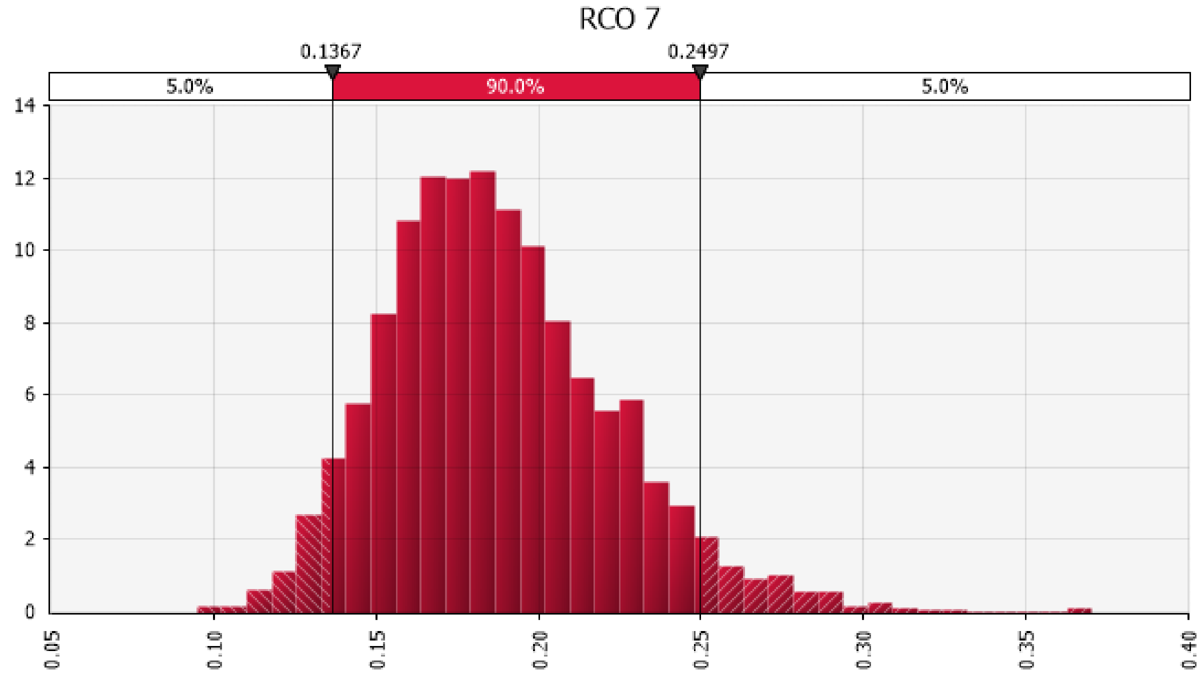

Figure 8. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO7 GCAF factor graph output.

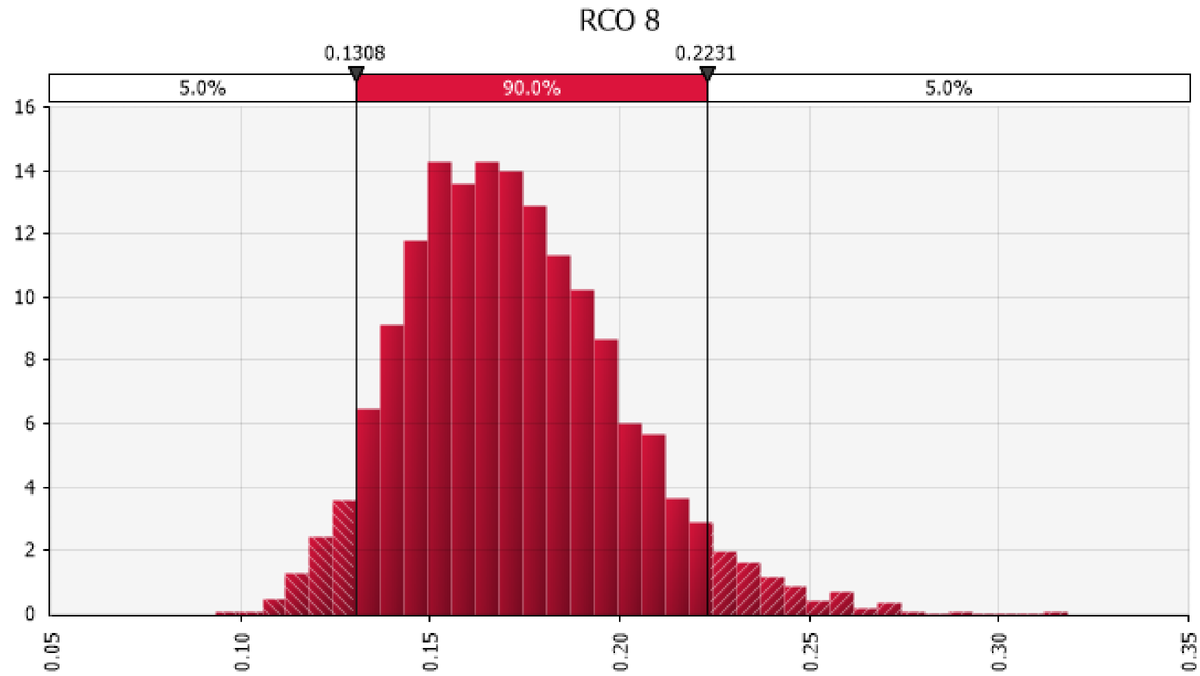

Figure 9. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO8 GCAF factor graph output.

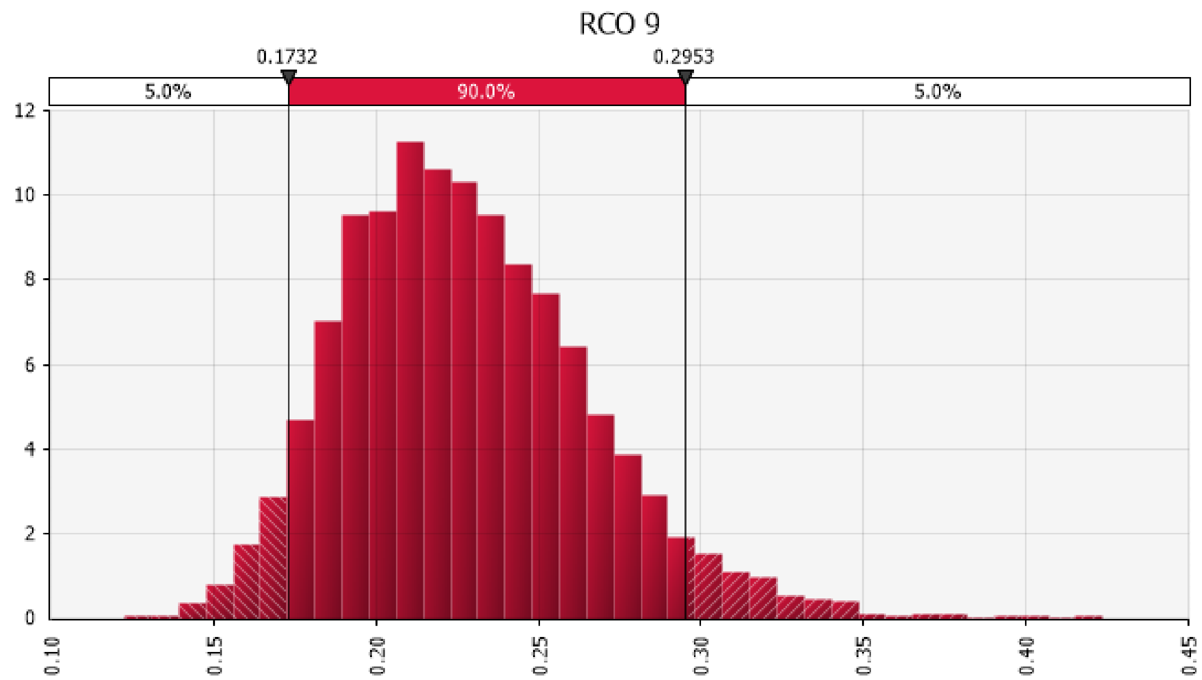

Figure 10. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO9 GCAF factor graph output.

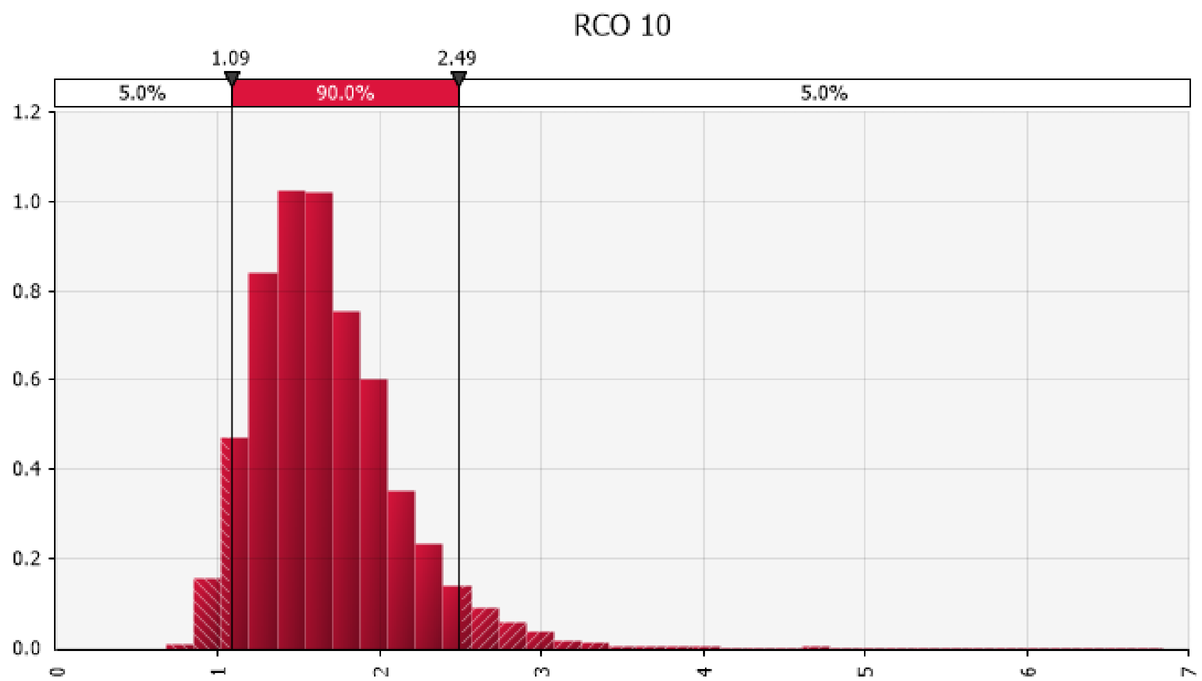

Figure 11. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO10 GCAF factor graph output.

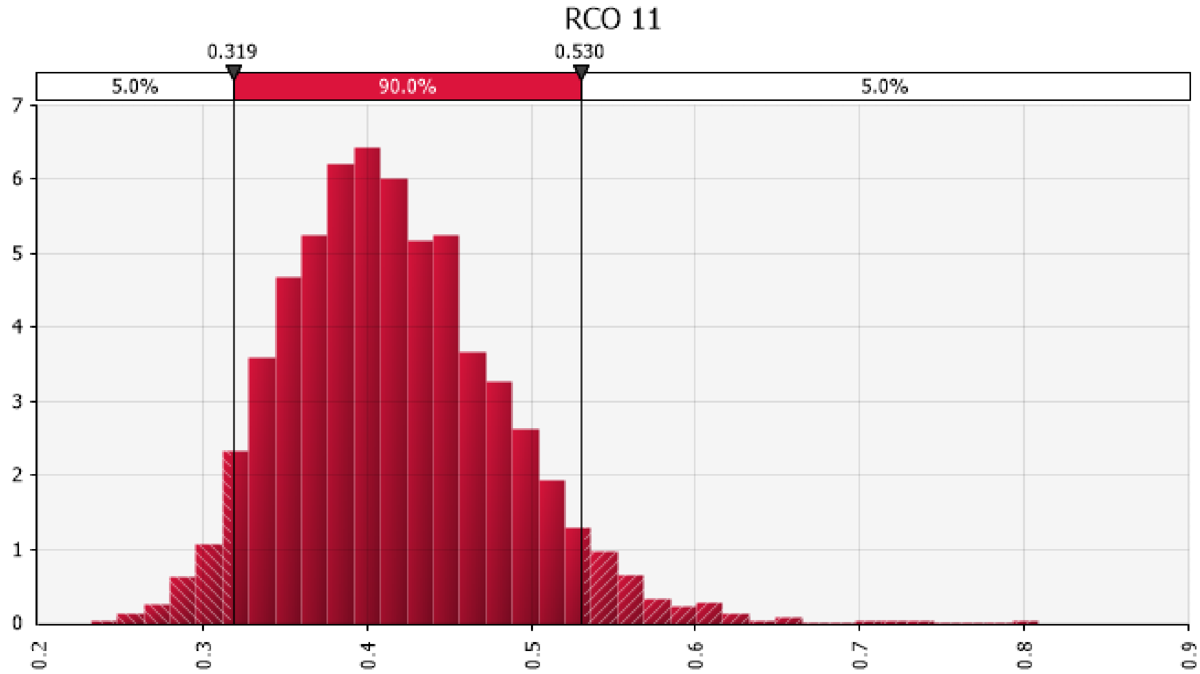

Figure 12. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO11 GCAF factor graph output.

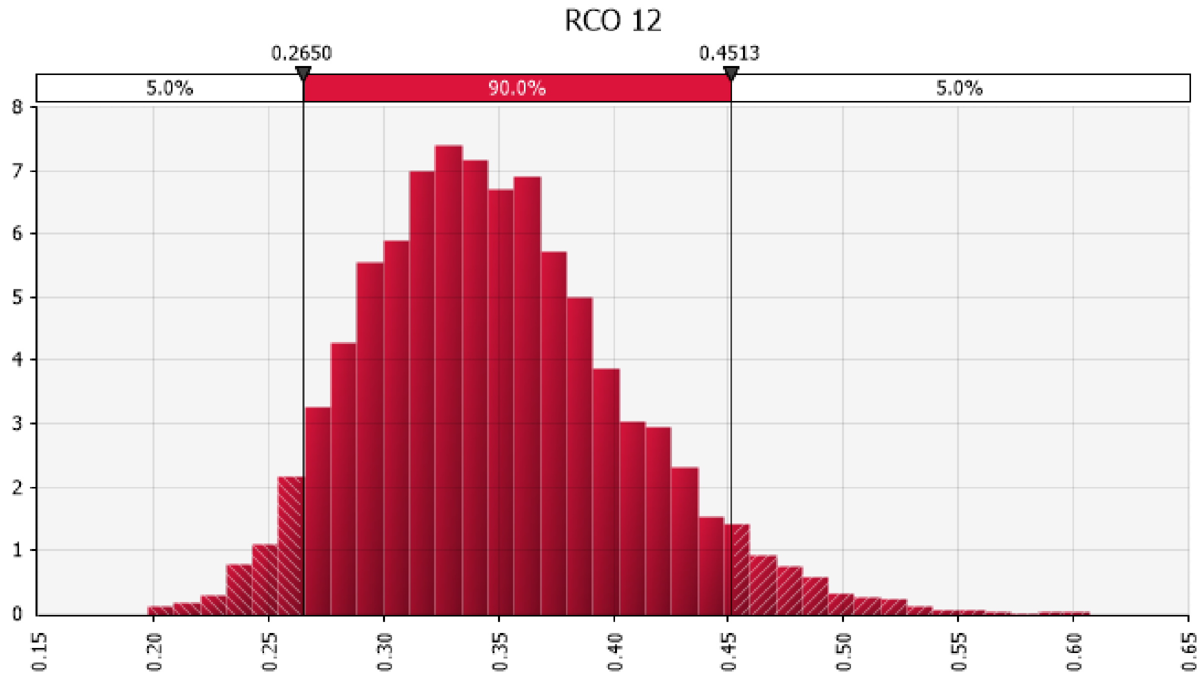

Figure 13. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO12 GCAF factor graph output.

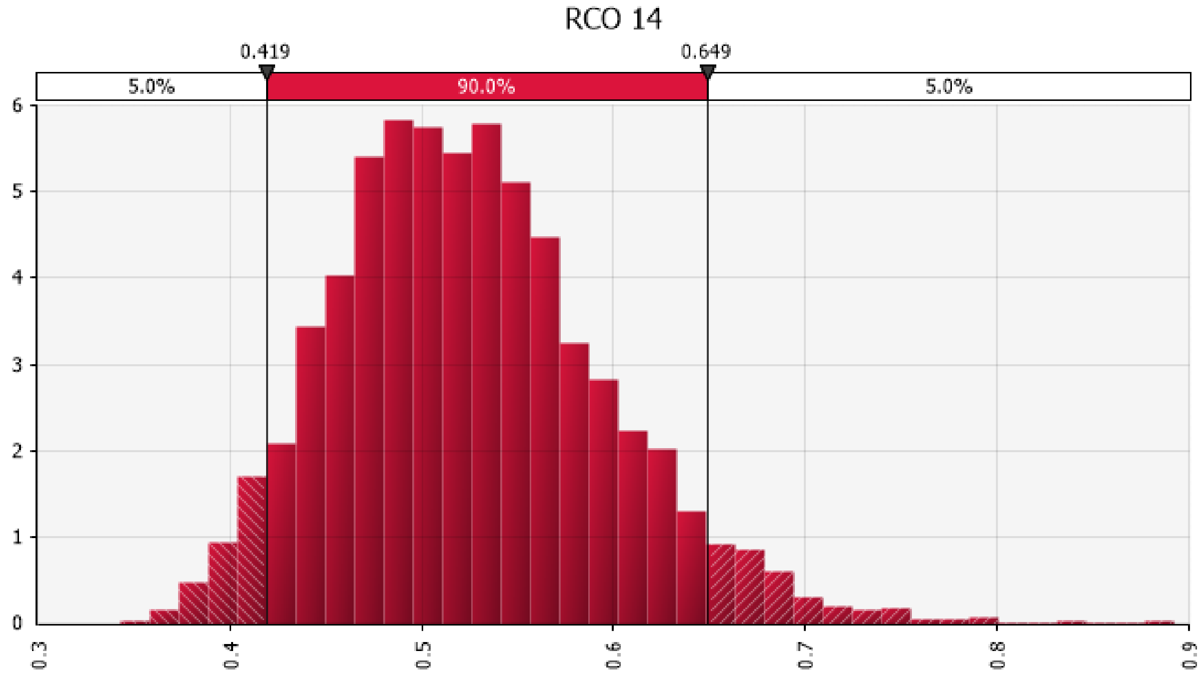

Figure 14. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO14 GCAF factor graph output.

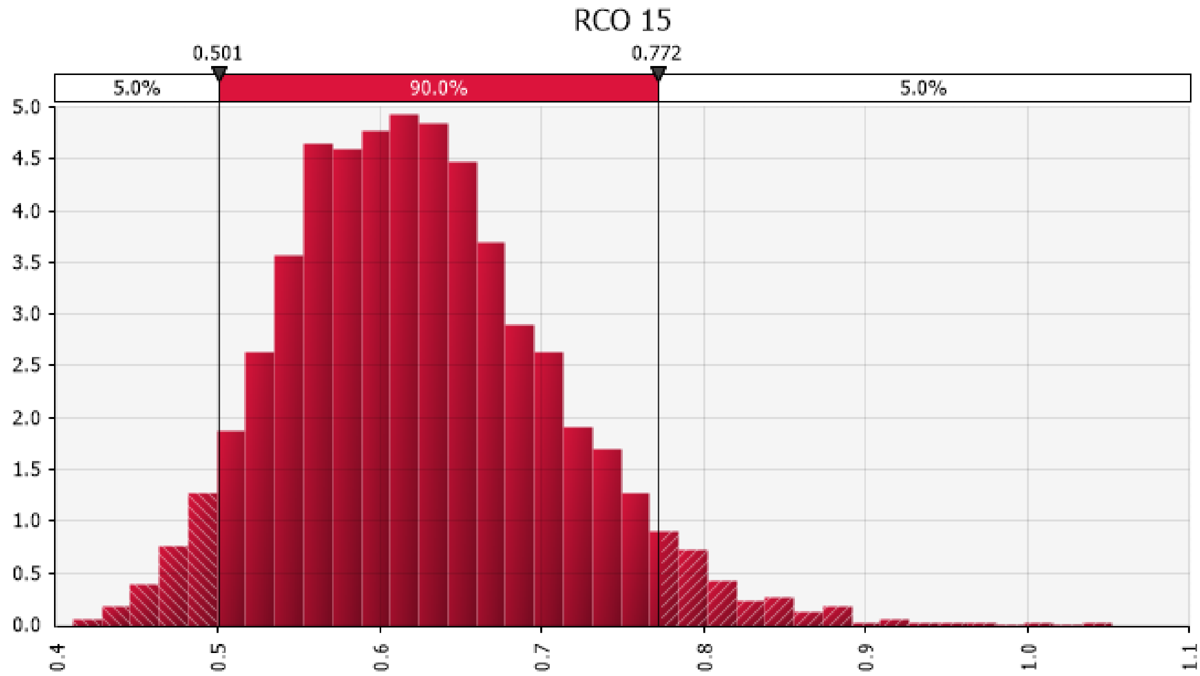

Figure 15. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO15 GCAF factor graph output.

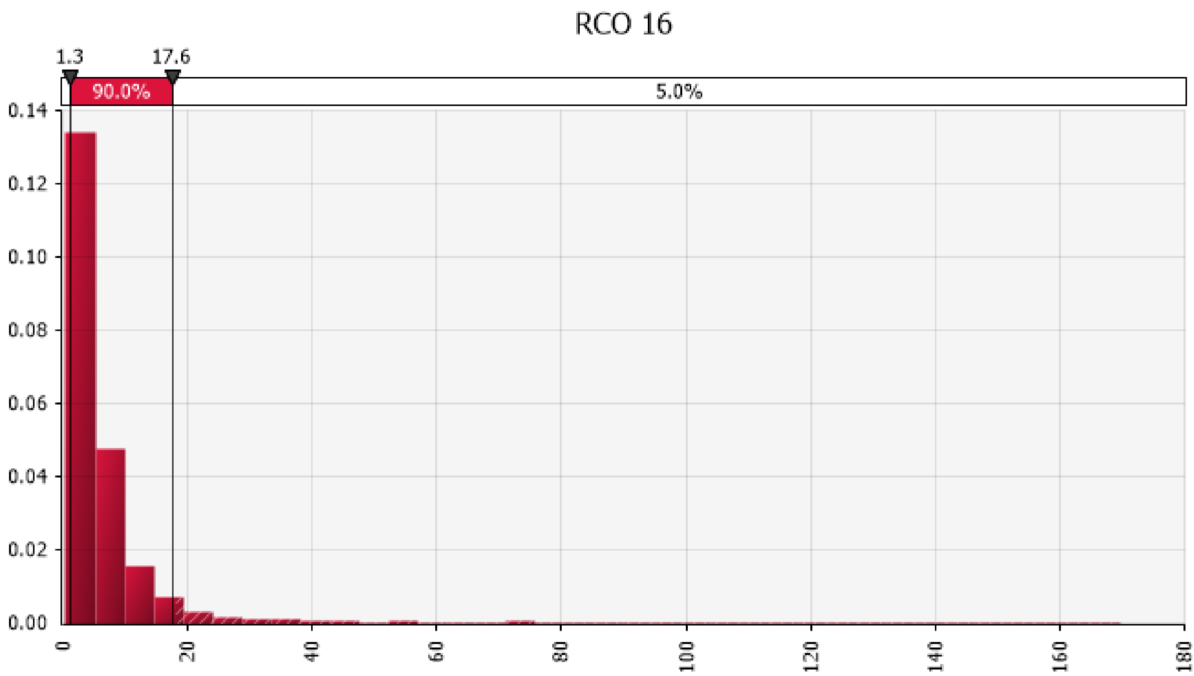

Figure 16. Uncertainty analysis for ro-ro passenger ships, newbuildings. RCO16 GCAF factor graph output.

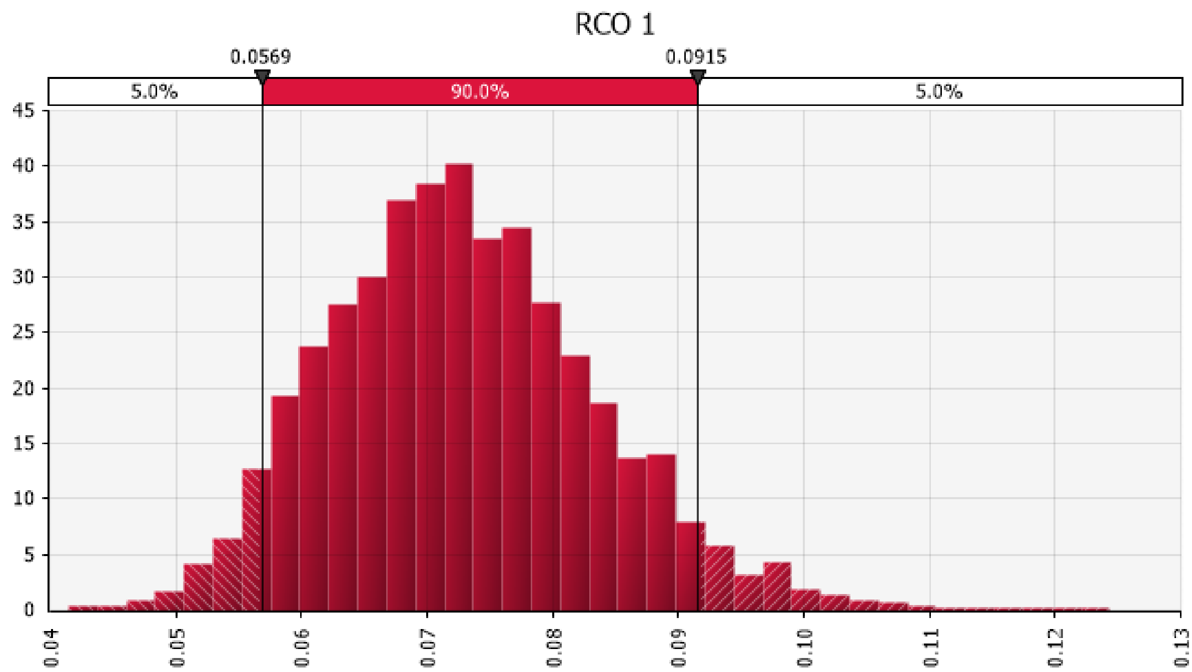

Figure 17. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO1 GCAF factor graph output.

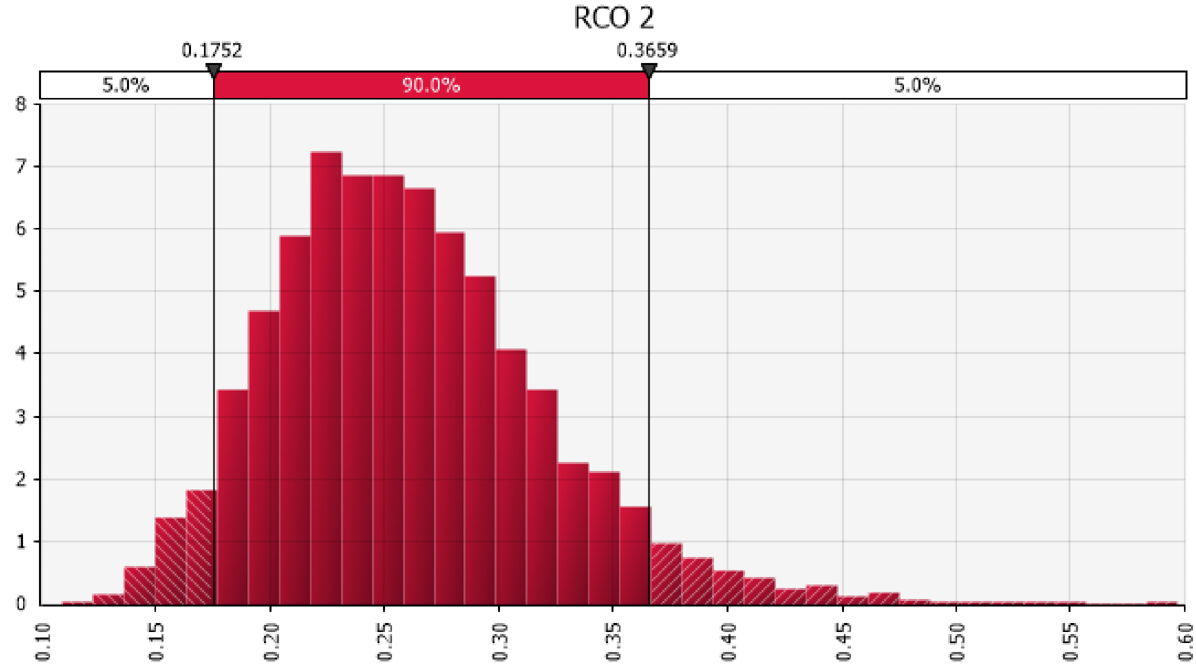

Figure 18. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO2 GCAF factor graph output.

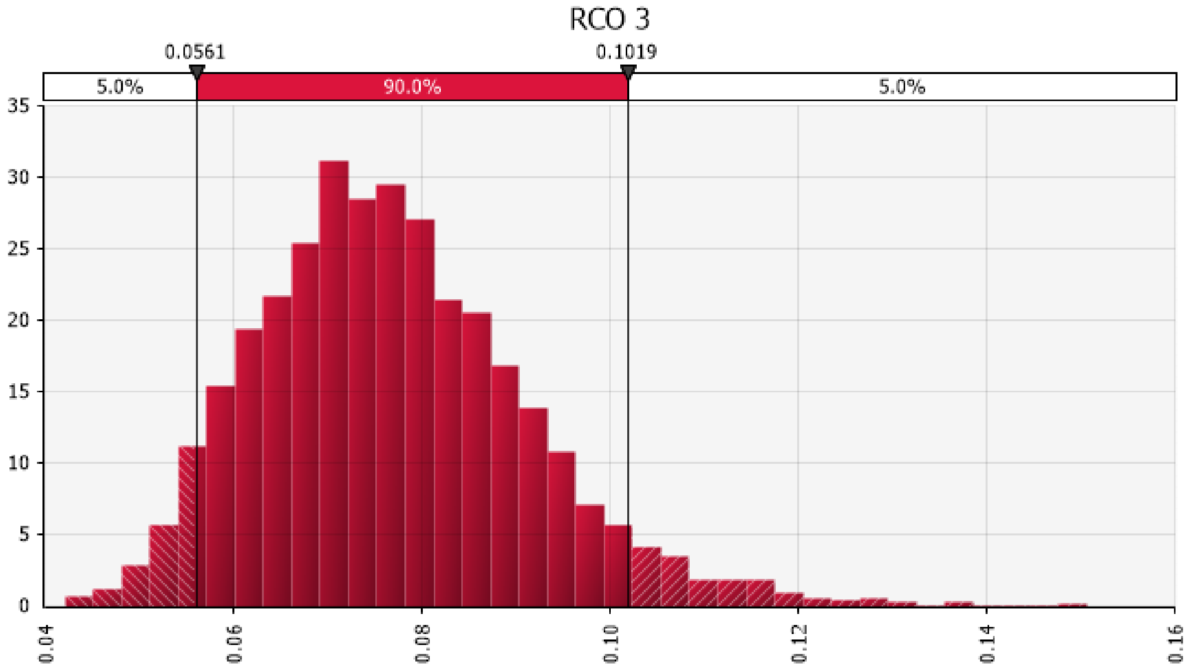

Figure 19. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO3 GCAF factor graph output.

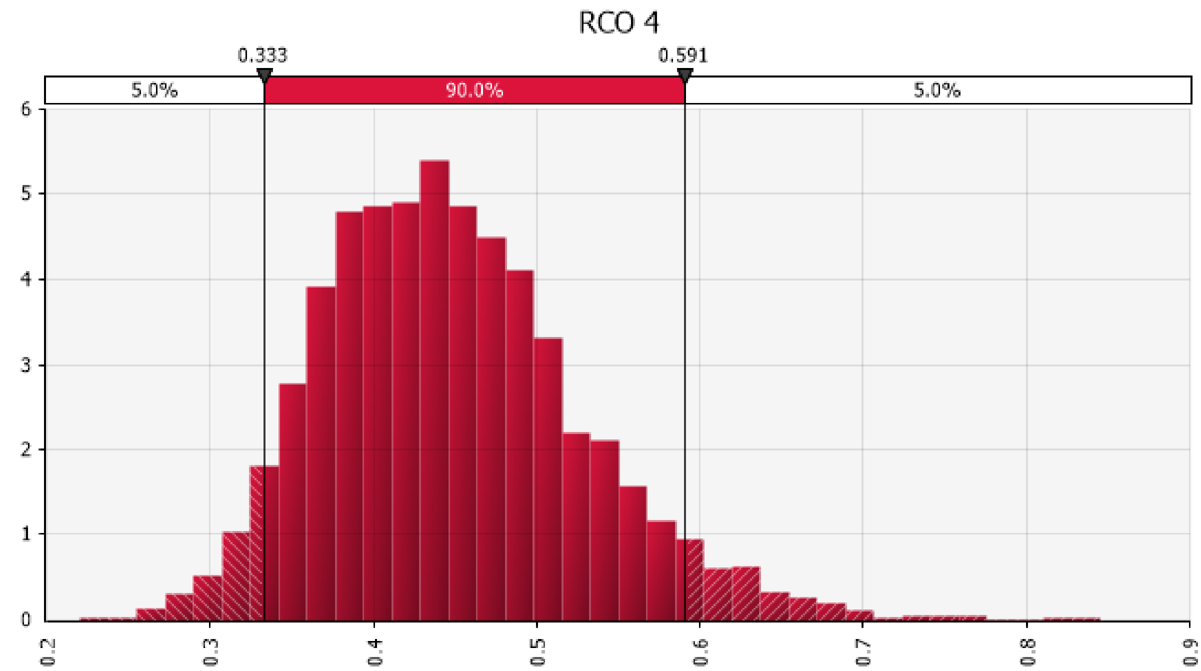

Figure 20. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO4 GCAF factor graph output.

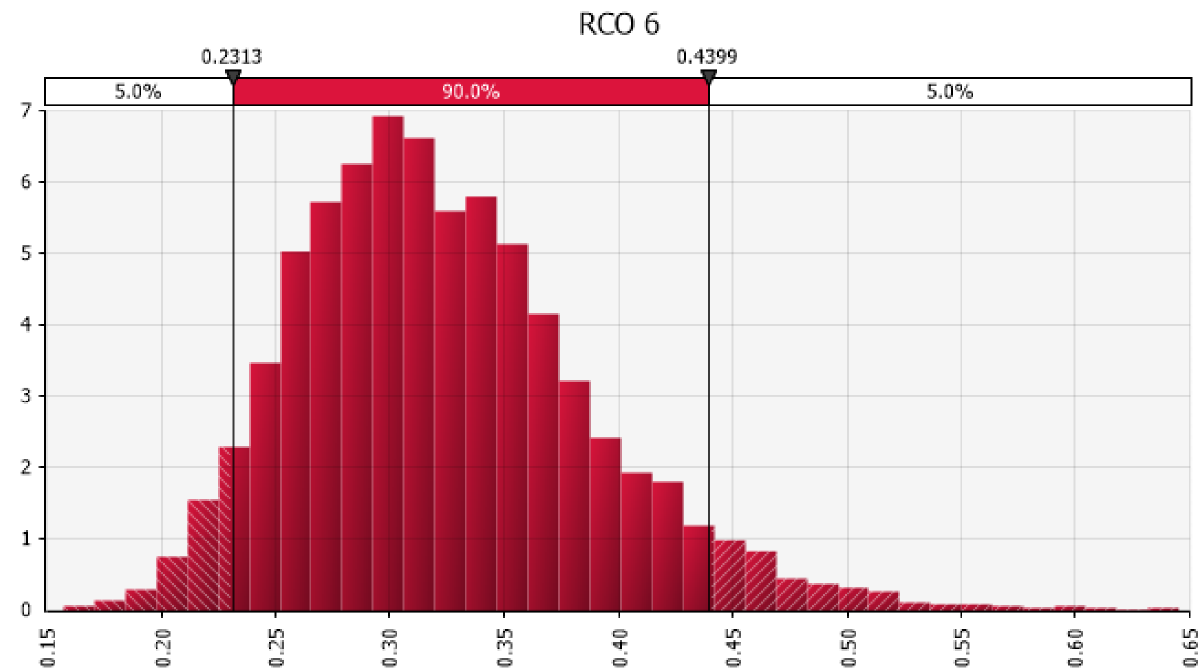

Figure 21. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO6 GCAF factor graph output.

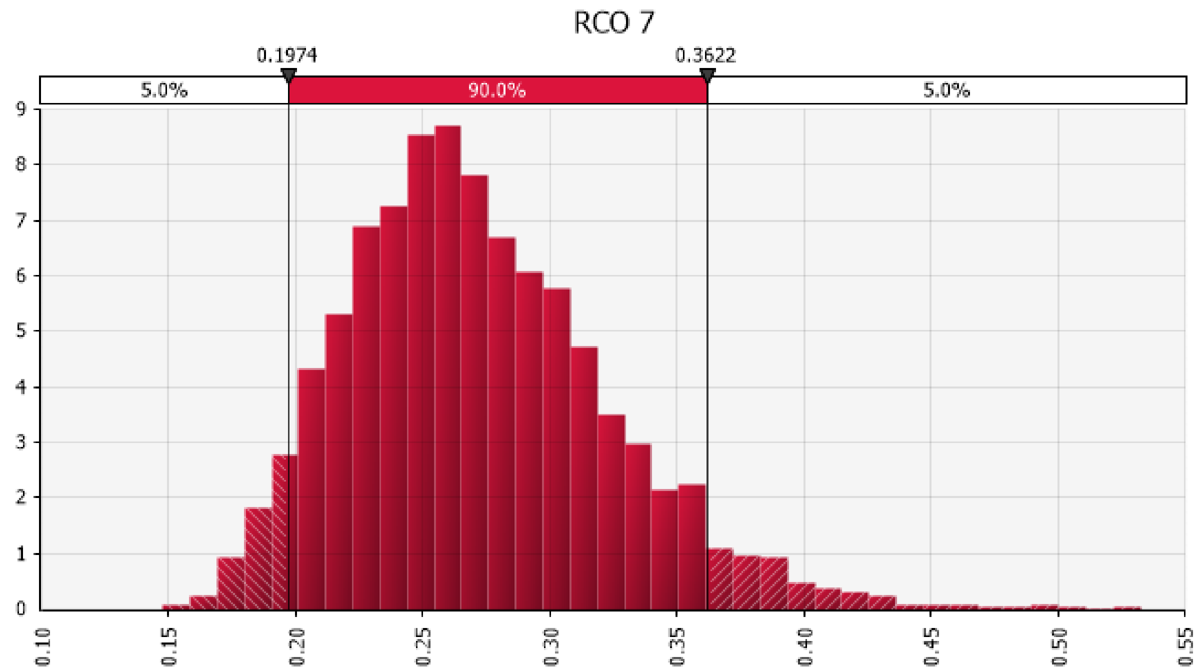

Figure 22. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO7 GCAF factor graph output.

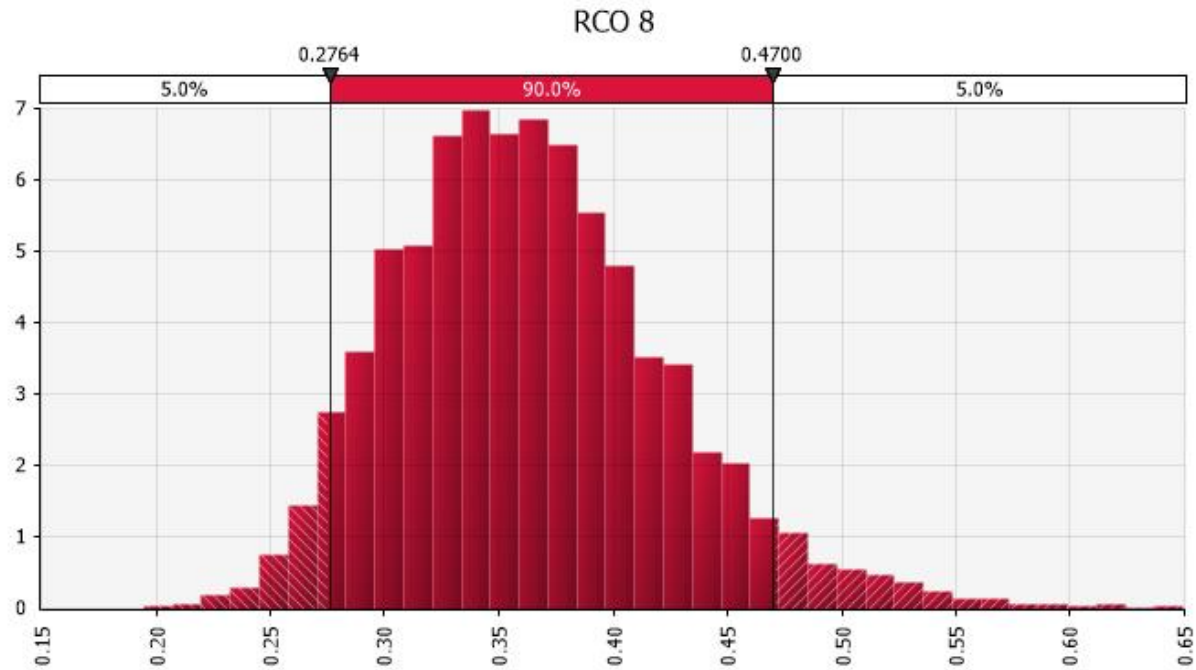

Figure 23. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO8 GCAF factor graph output.

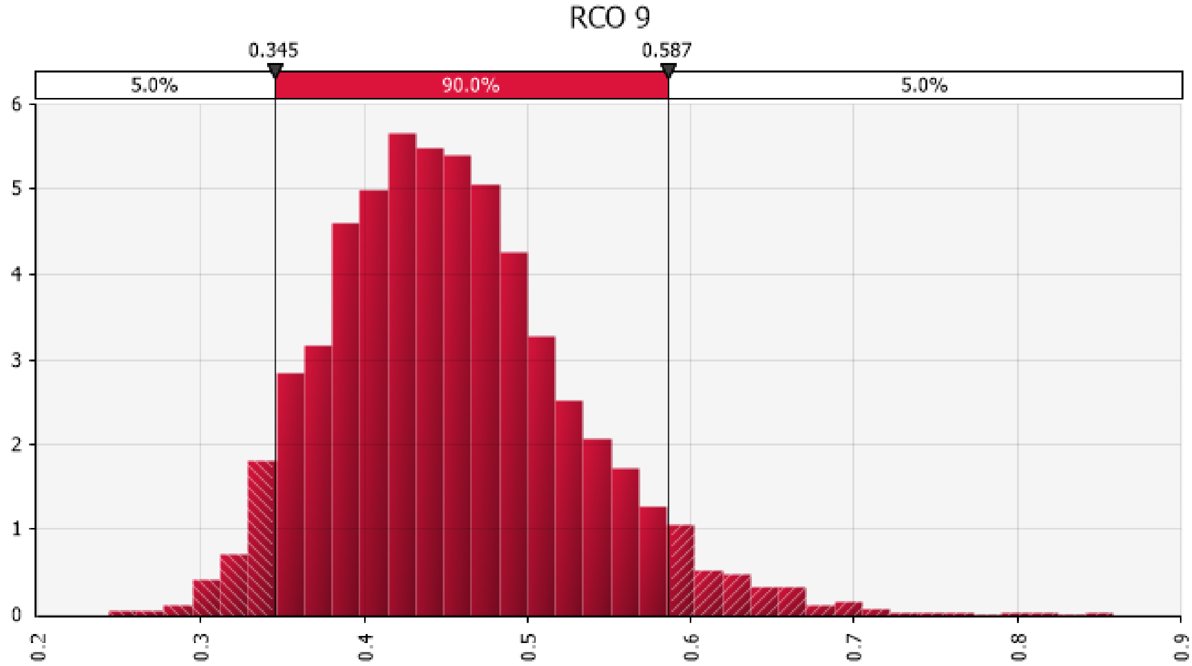

Figure 24. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO9 GCAF factor graph output.

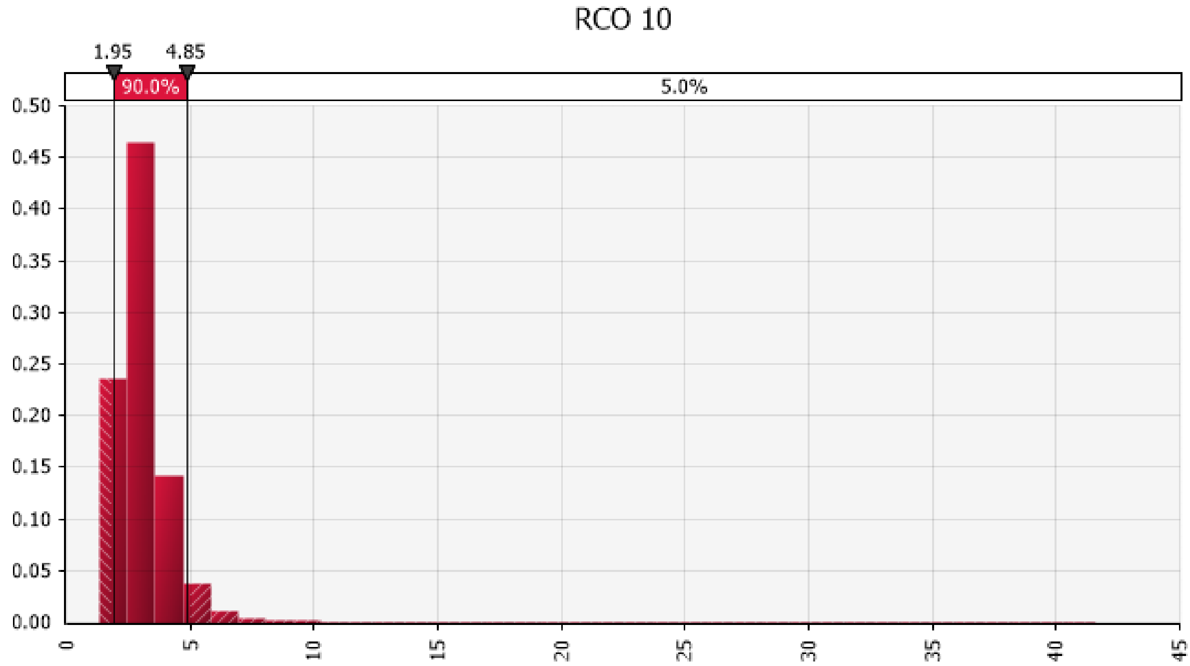

Figure 25. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO10 GCAF factor graph output.

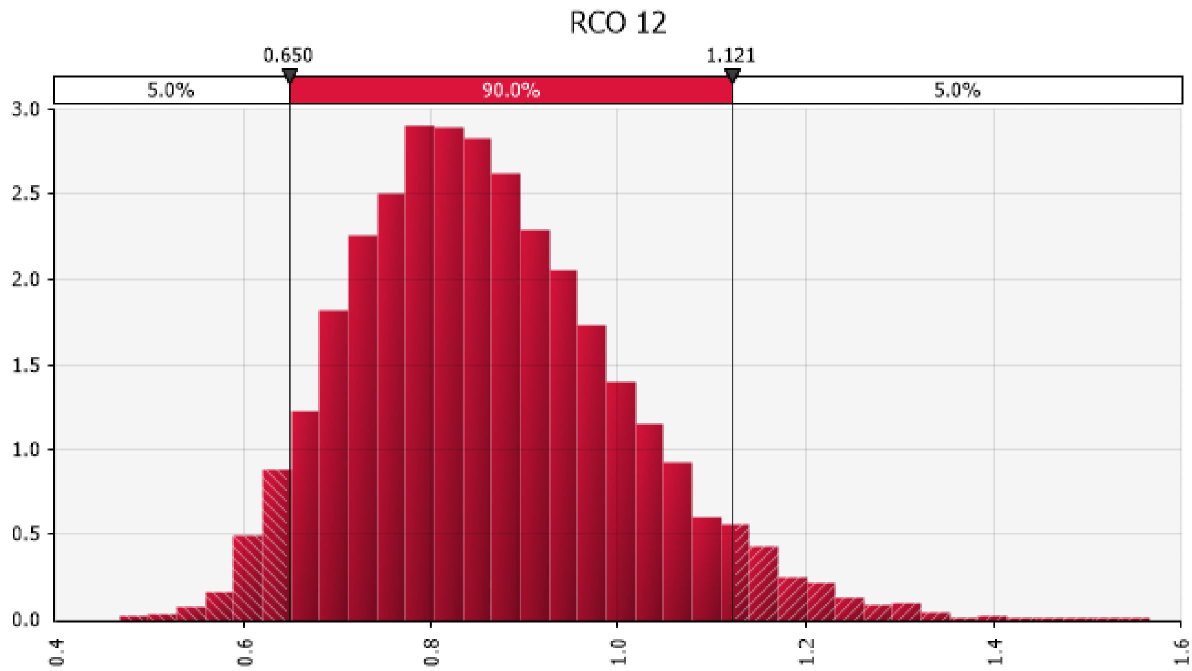

Figure 26. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO12 GCAF factor graph output.

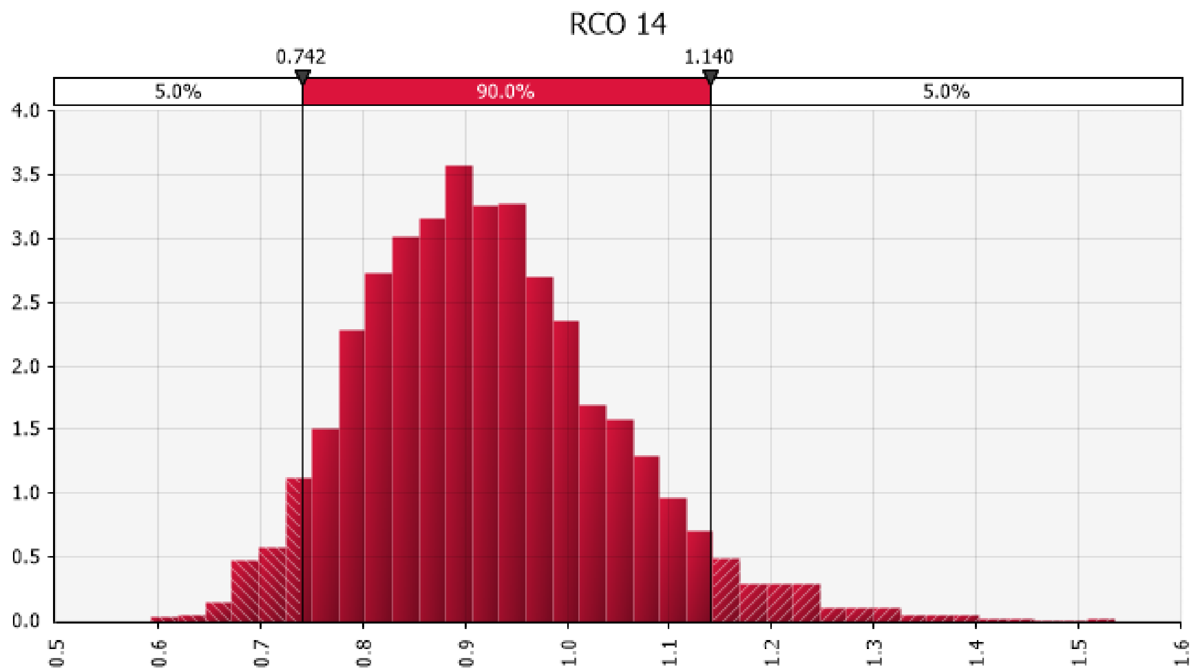

Figure 27. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO14 GCAF factor graph output.

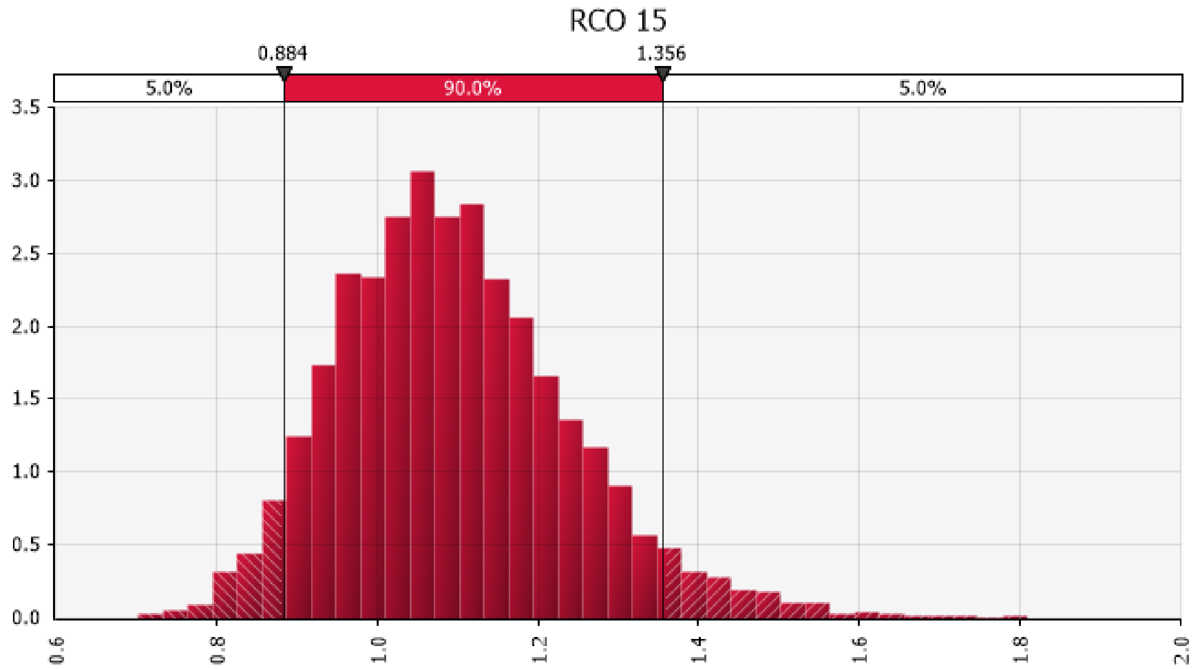

Figure 28. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO15 GCAF factor graph output.

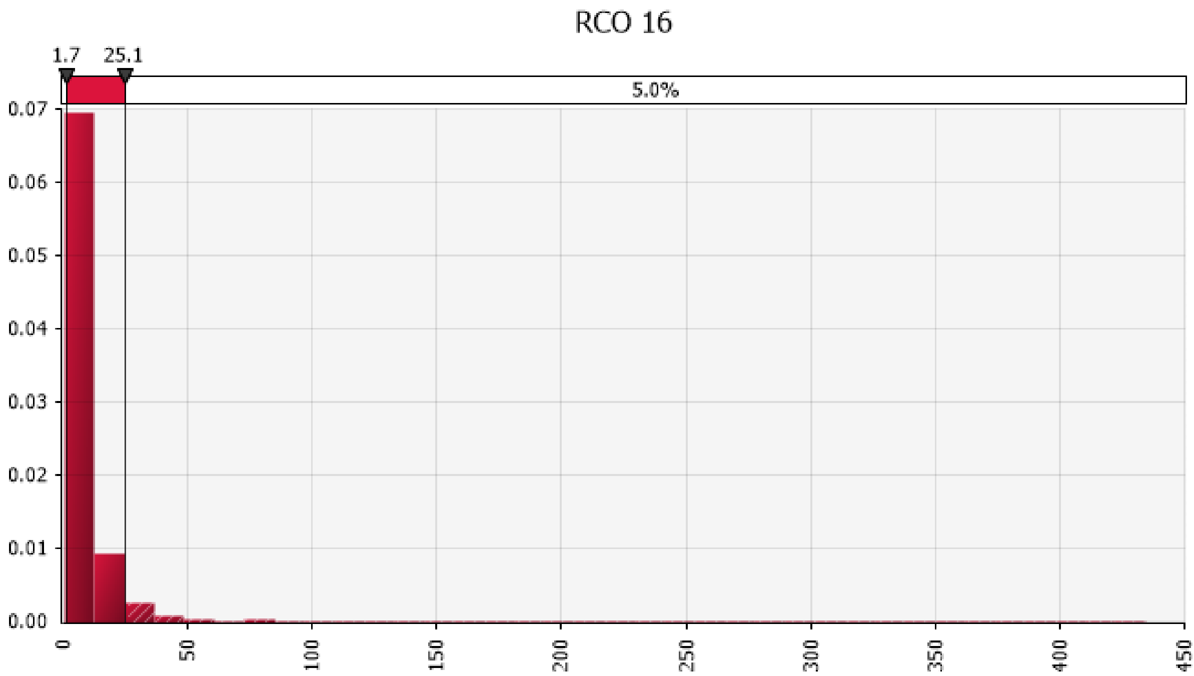

Figure 29. Uncertainty analysis for ro-ro passenger ships, existing ships. RCO16 GCAF factor graph output.

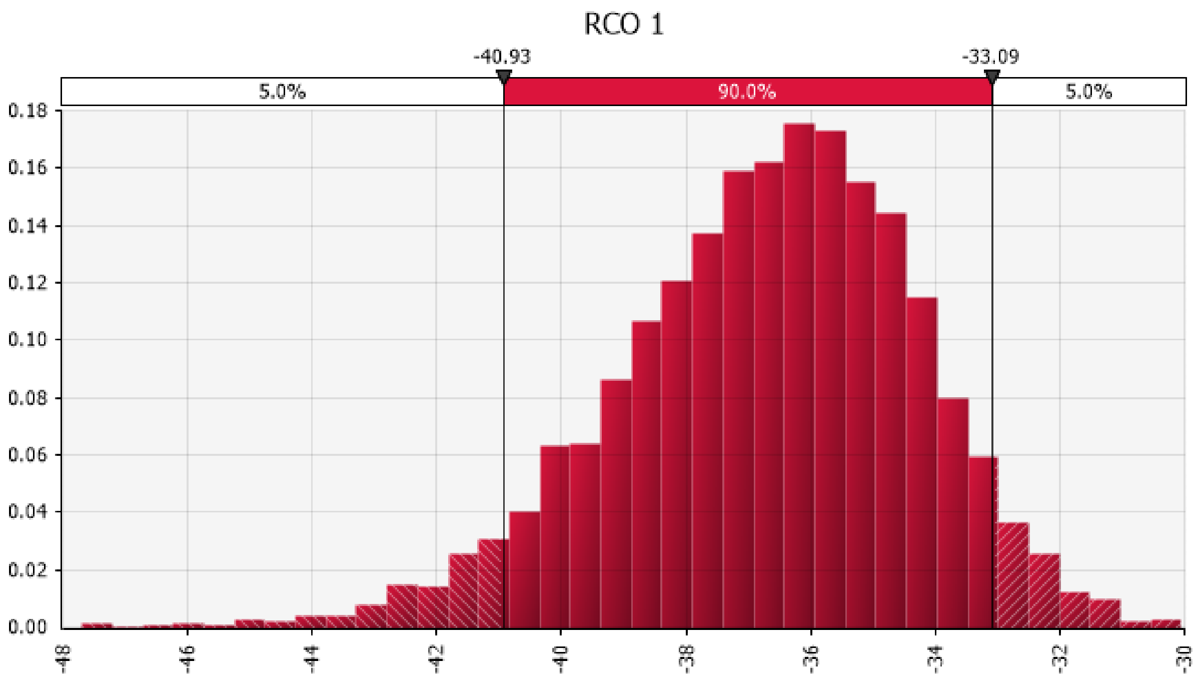

Figure 30. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO1 NCAF factor graph output.

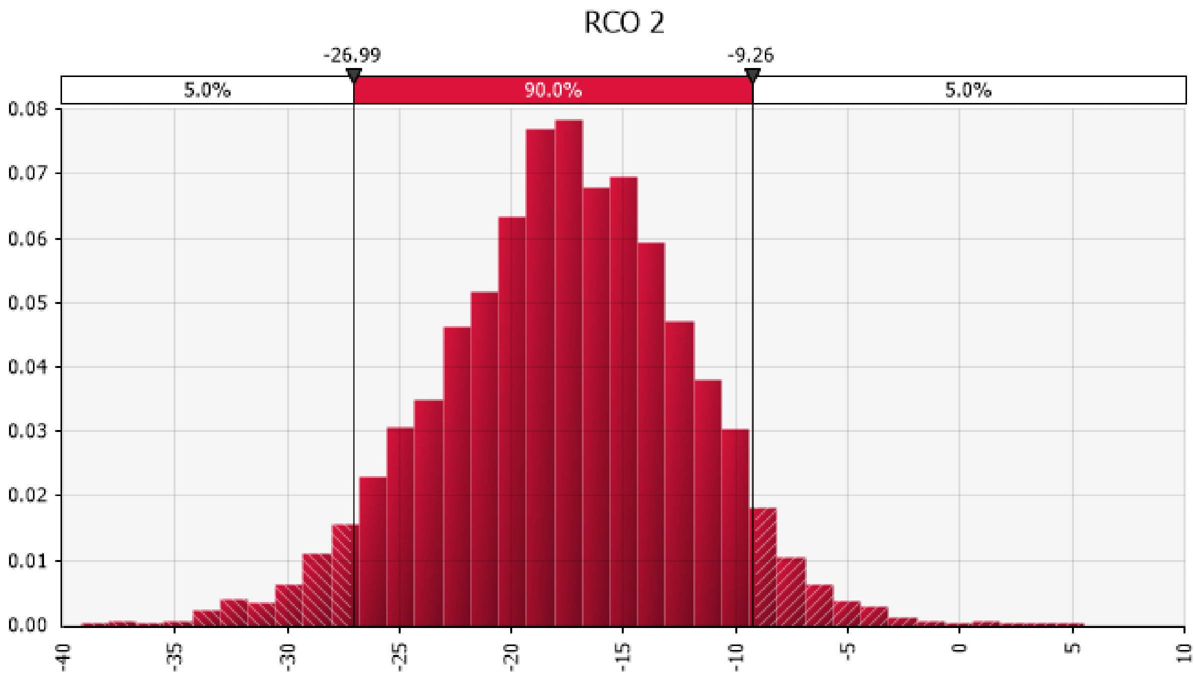

Figure 31. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO2 NCAF factor graph output.

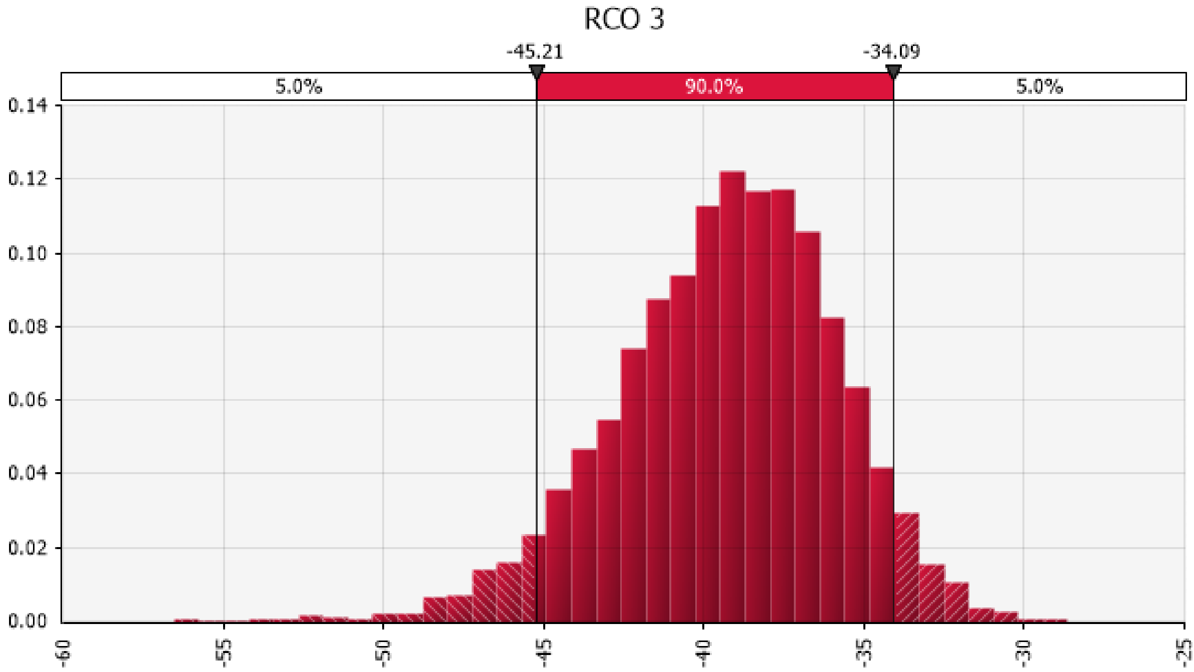

Figure 32. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO3 NCAF factor graph output.

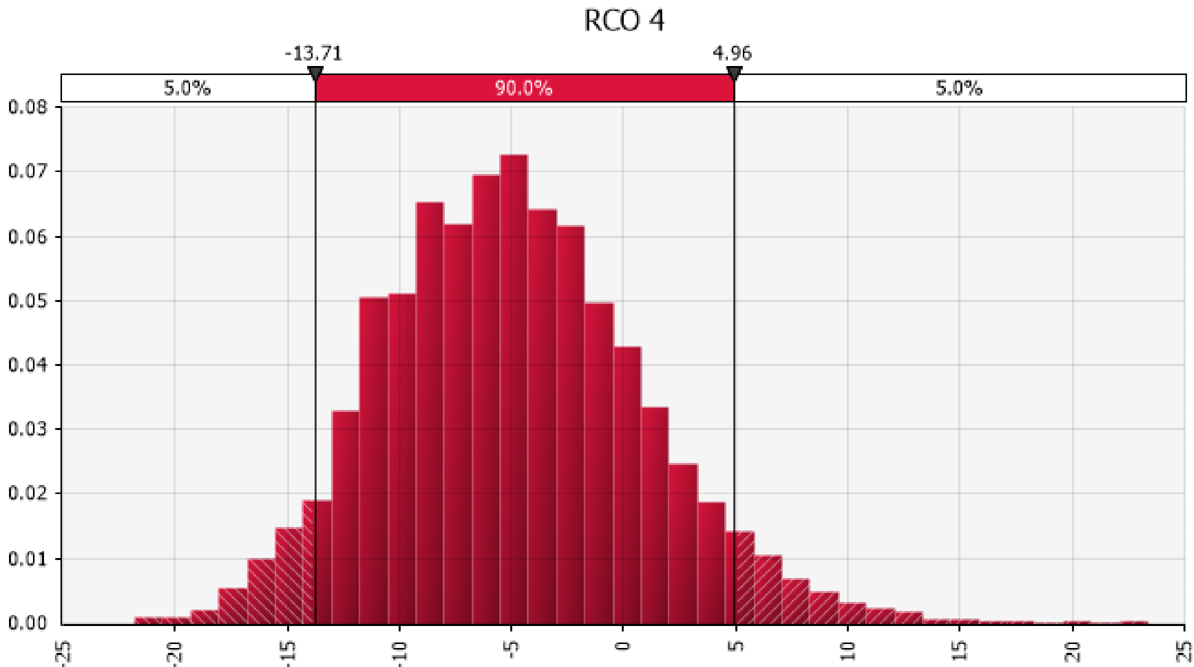

Figure 33. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO4 NCAF factor graph output.

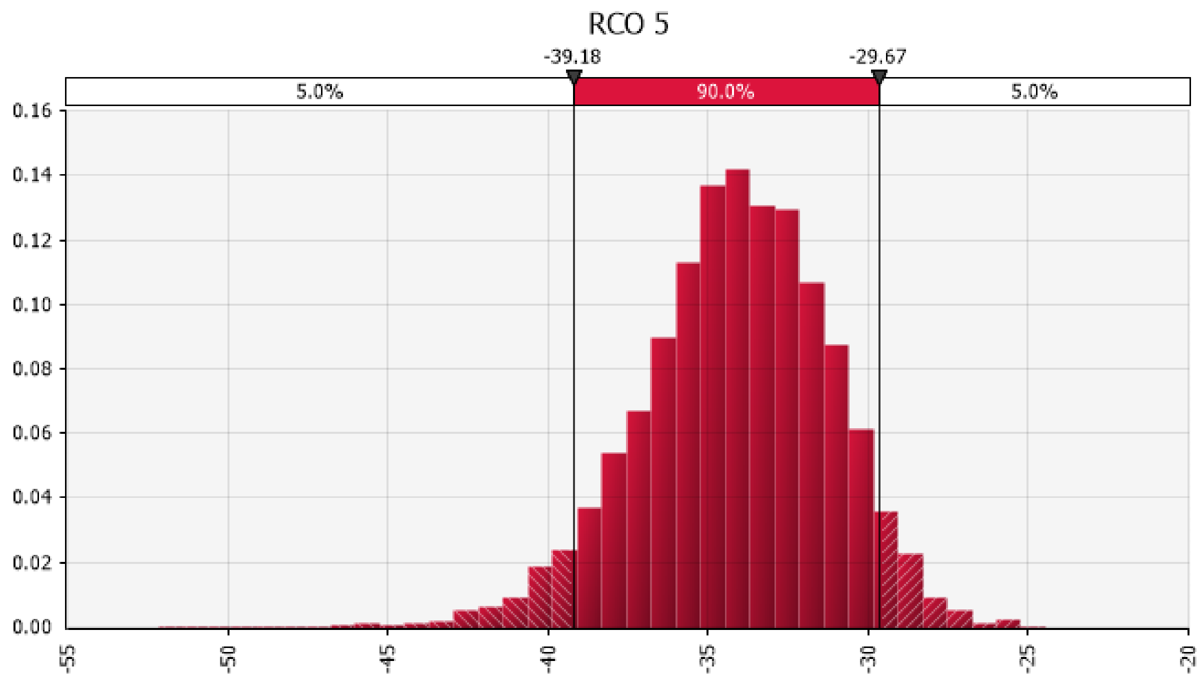

Figure 34. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO5 NCAF factor graph output.

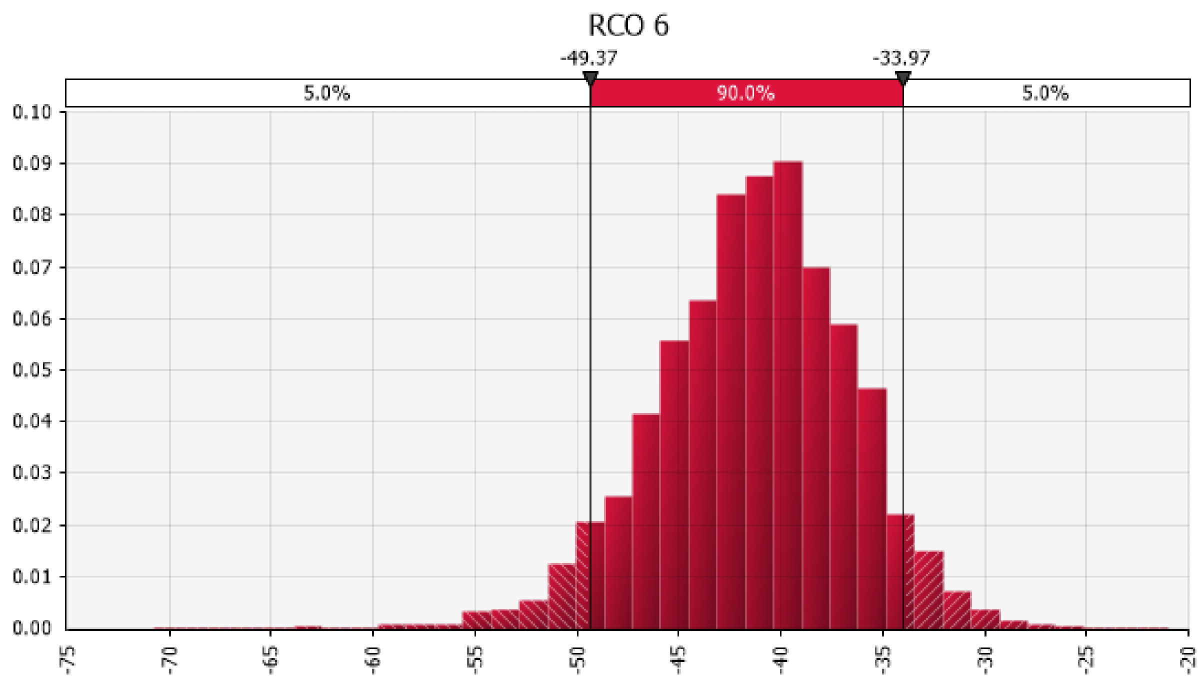

Figure 35. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO6 NCAF factor graph output.

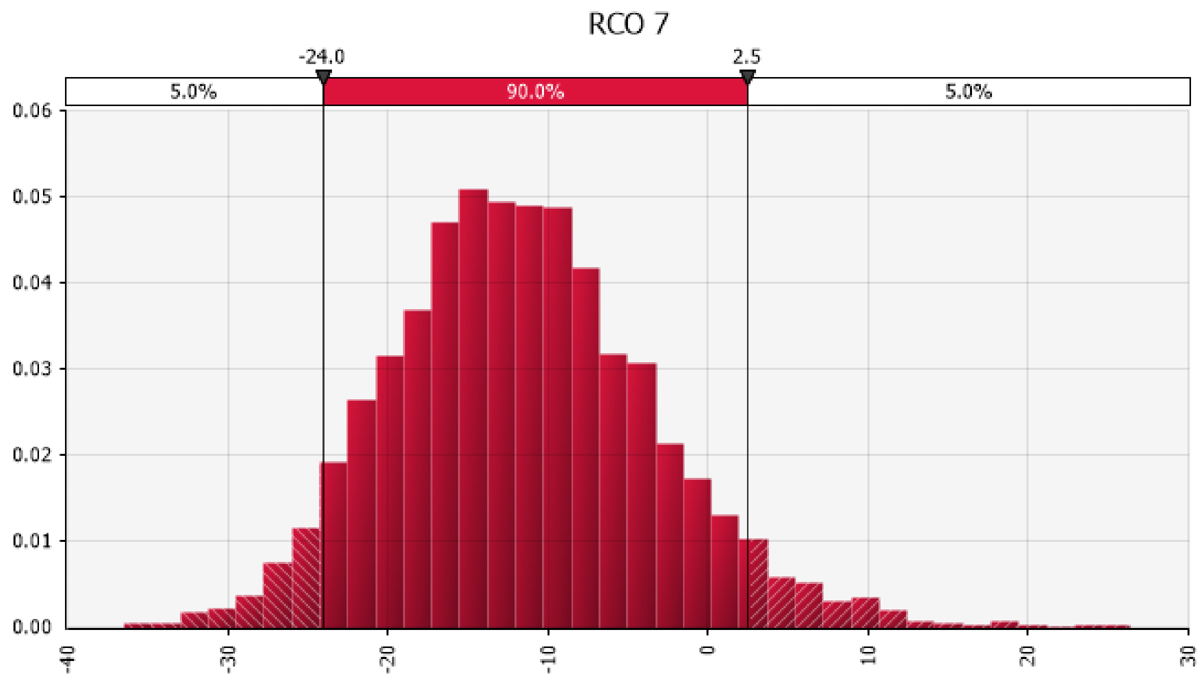

Figure 36. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO7 NCAF factor graph output.

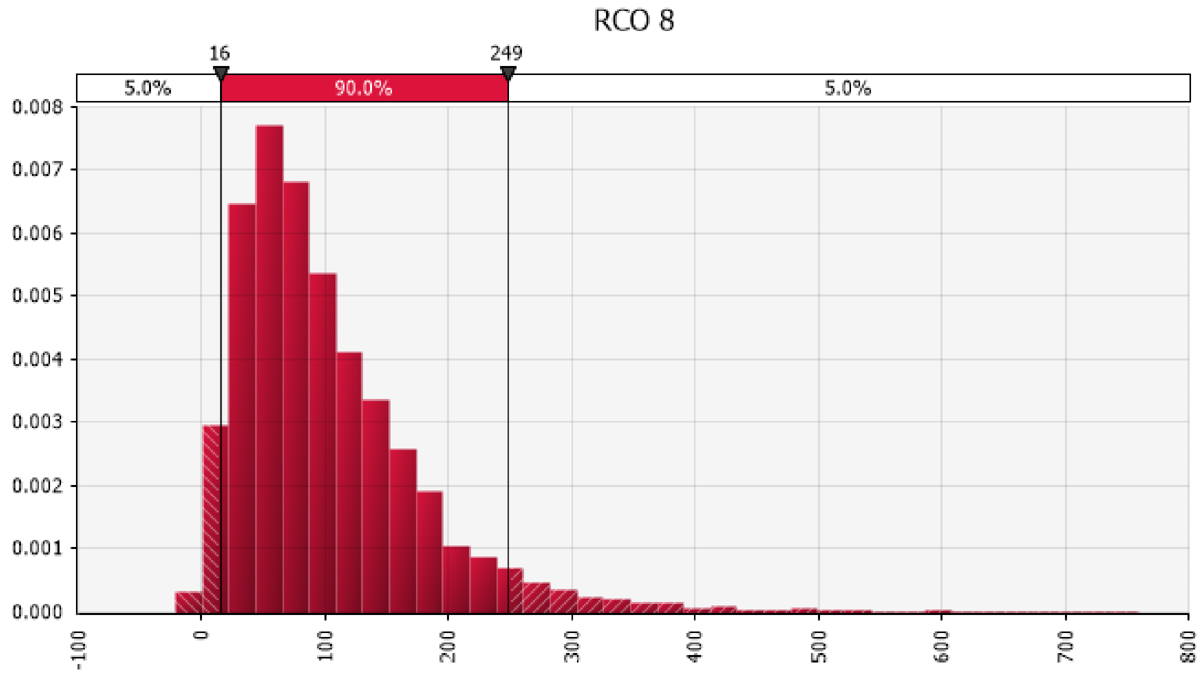

Figure 37. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO8 NCAF factor graph output.

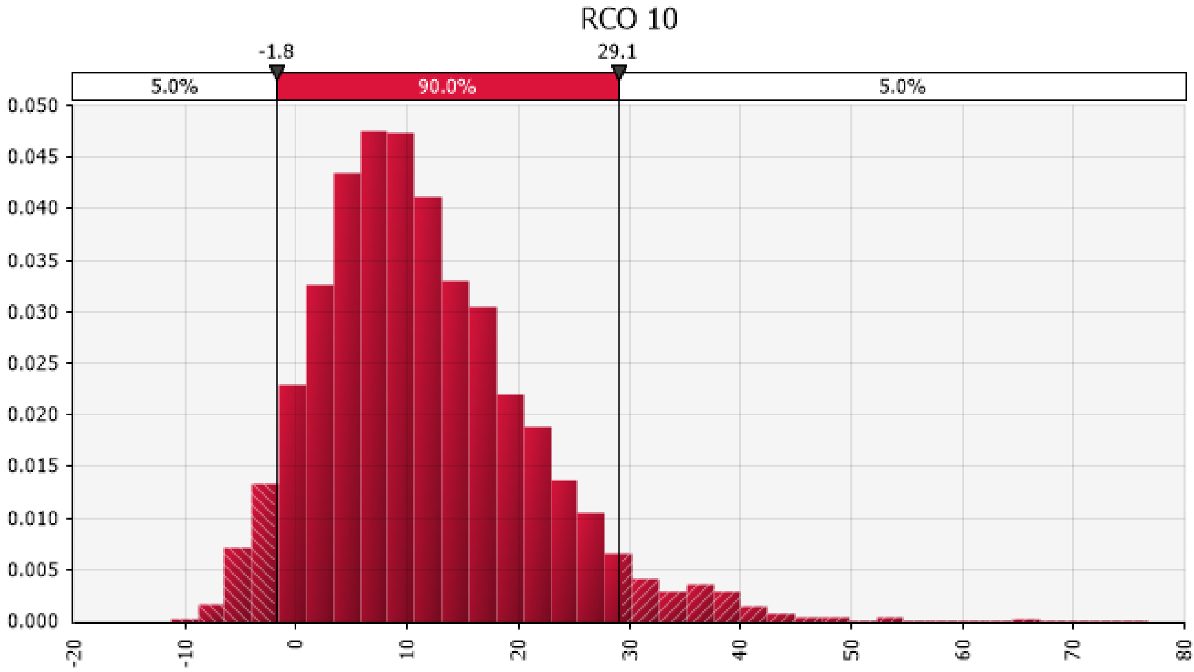

Figure 38. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO10 NCAF factor graph output.

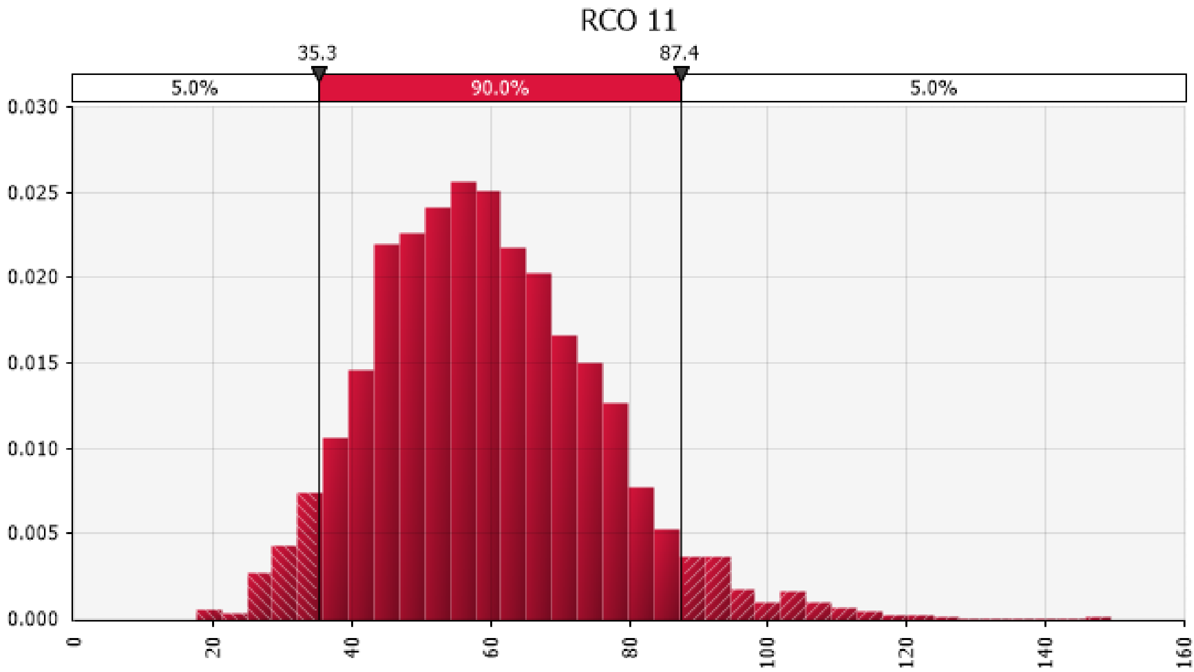

Figure 39. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO11 NCAF factor graph output.

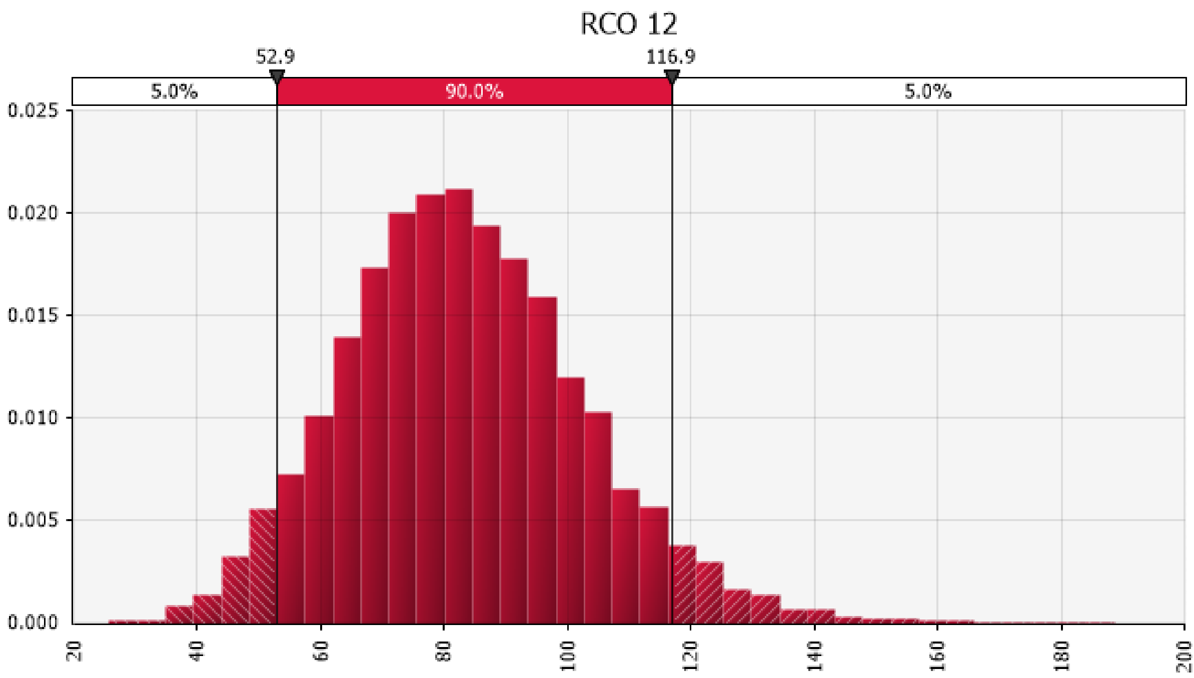

Figure 40. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO12 NCAF factor graph output.

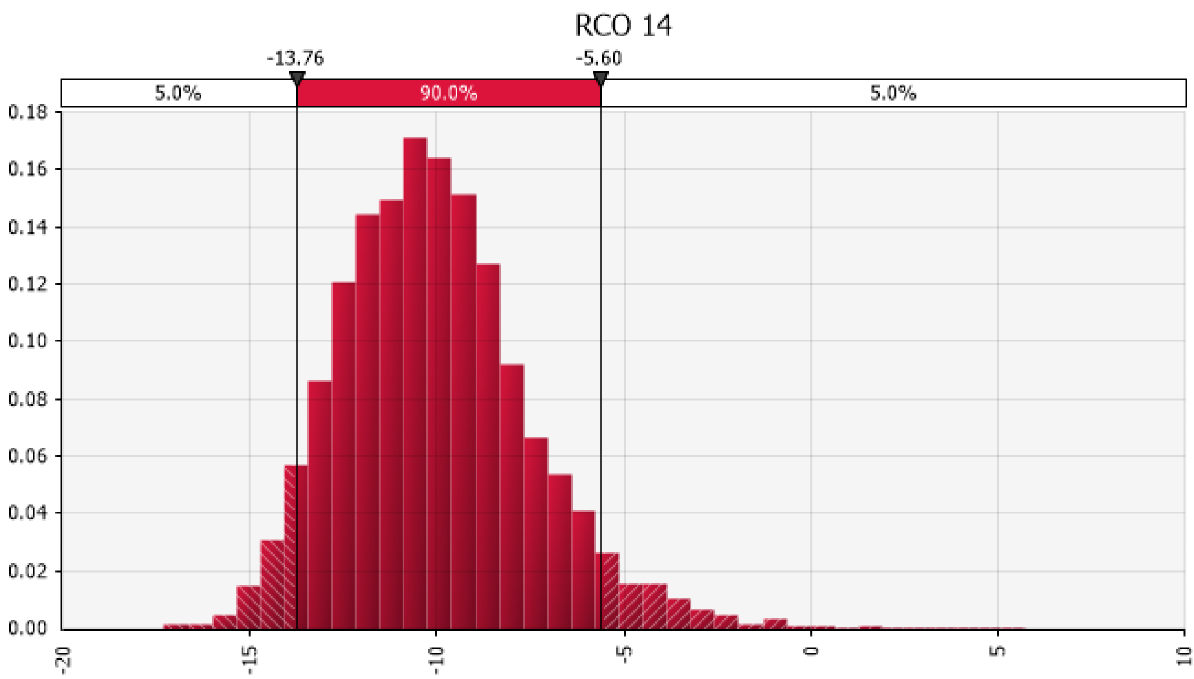

Figure 41. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO14 NCAF factor graph output.

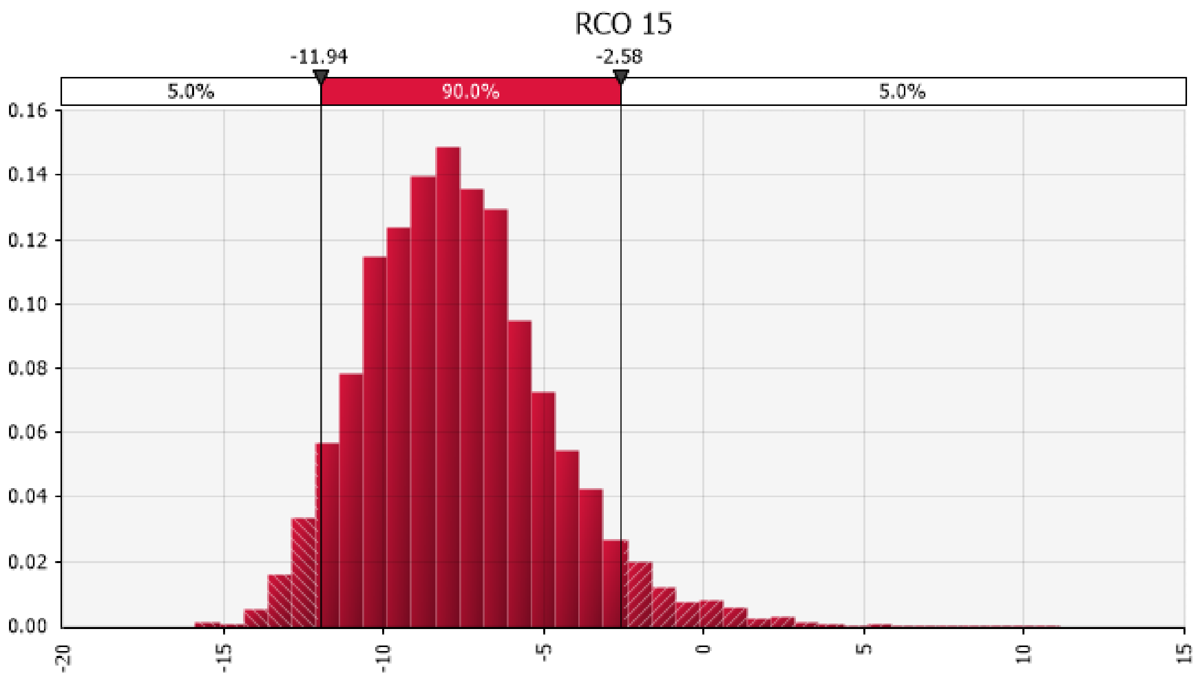

Figure 42. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO15 NCAF factor graph output.

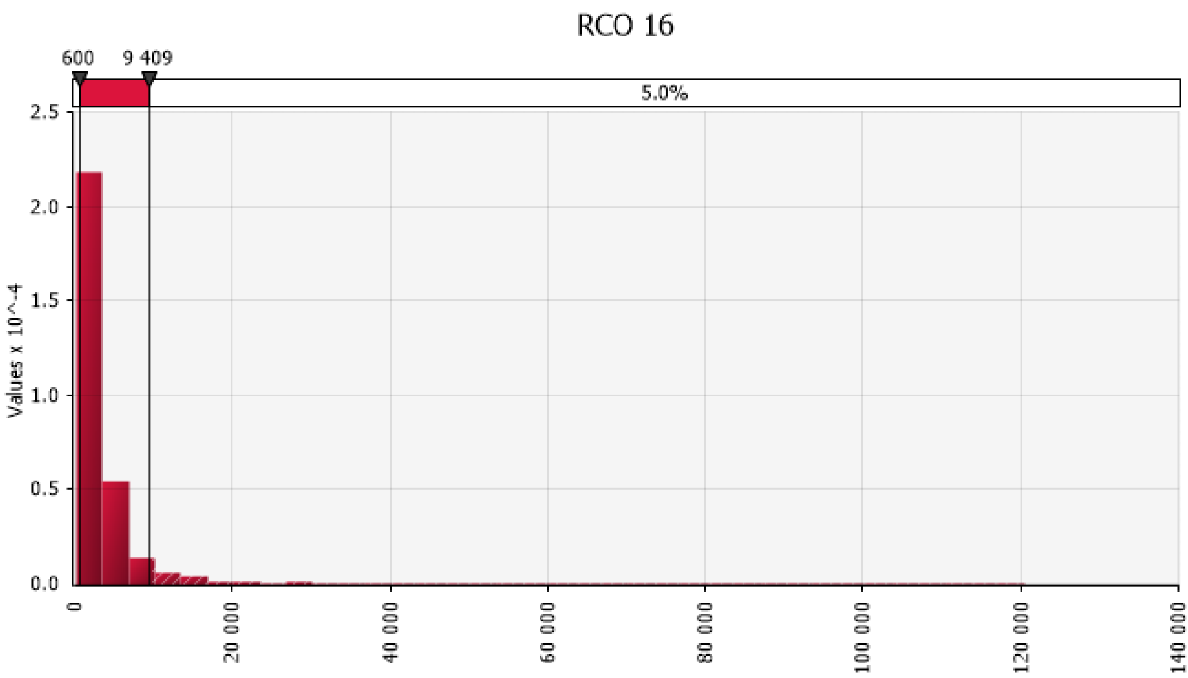

Figure 43. Uncertainty analysis for ro-ro cargo ships, newbuildings. RCO16 NCAF factor graph output.

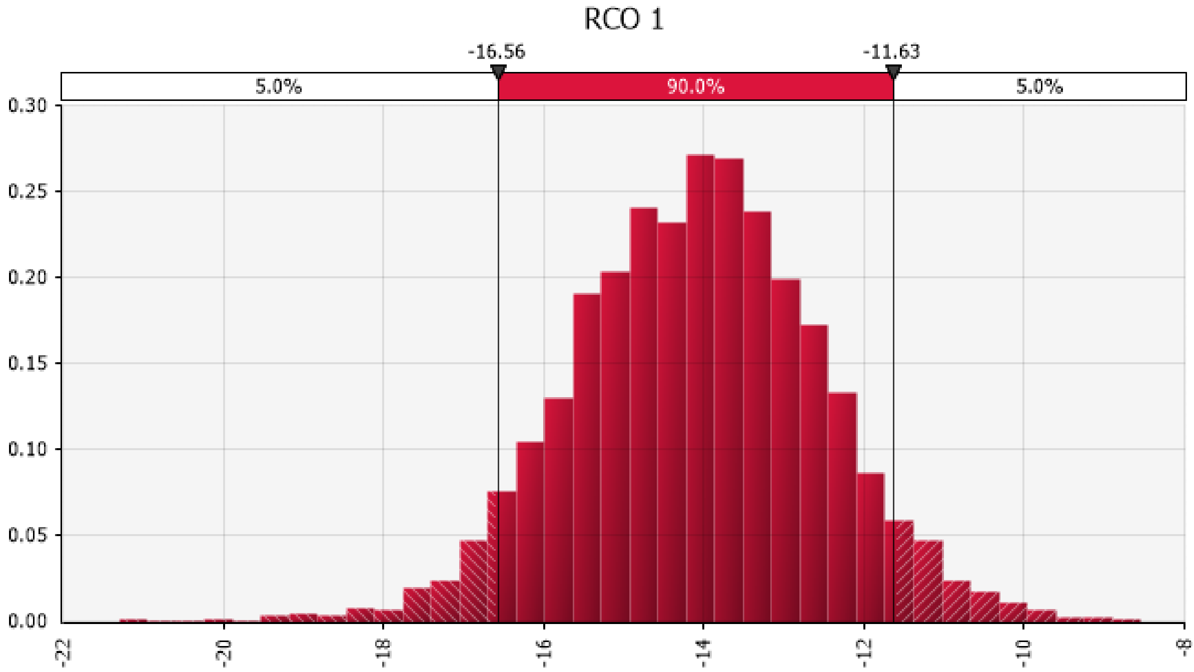

Figure 44. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO1 NCAF factor graph output.

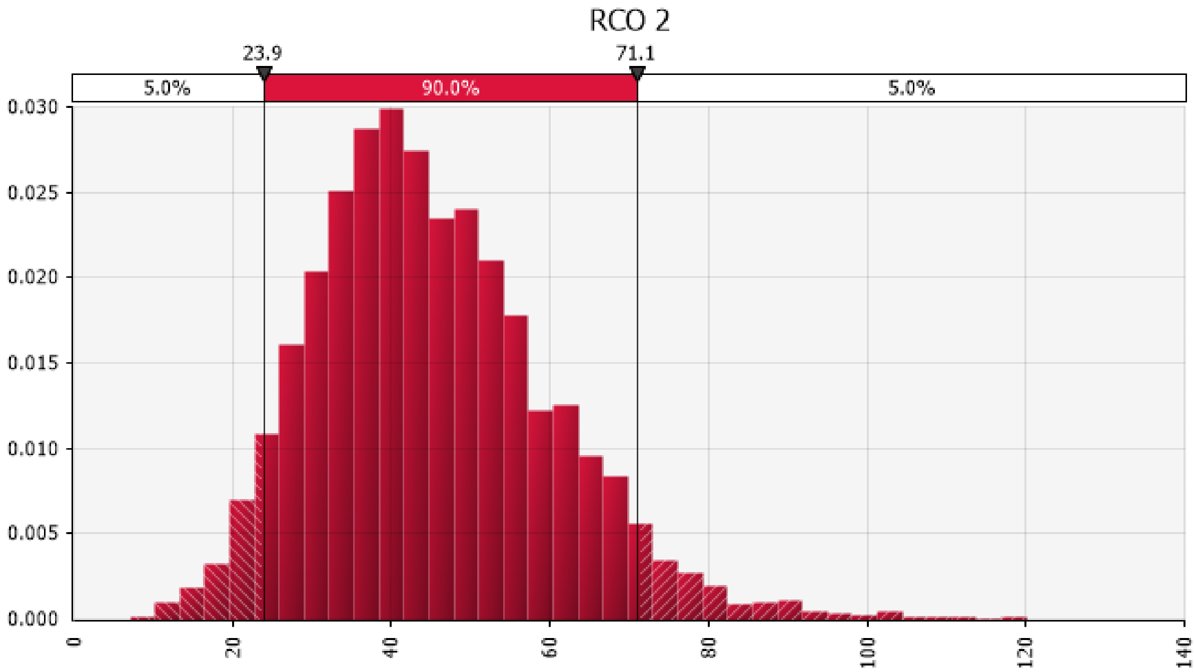

Figure 45. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO2 NCAF factor graph output.

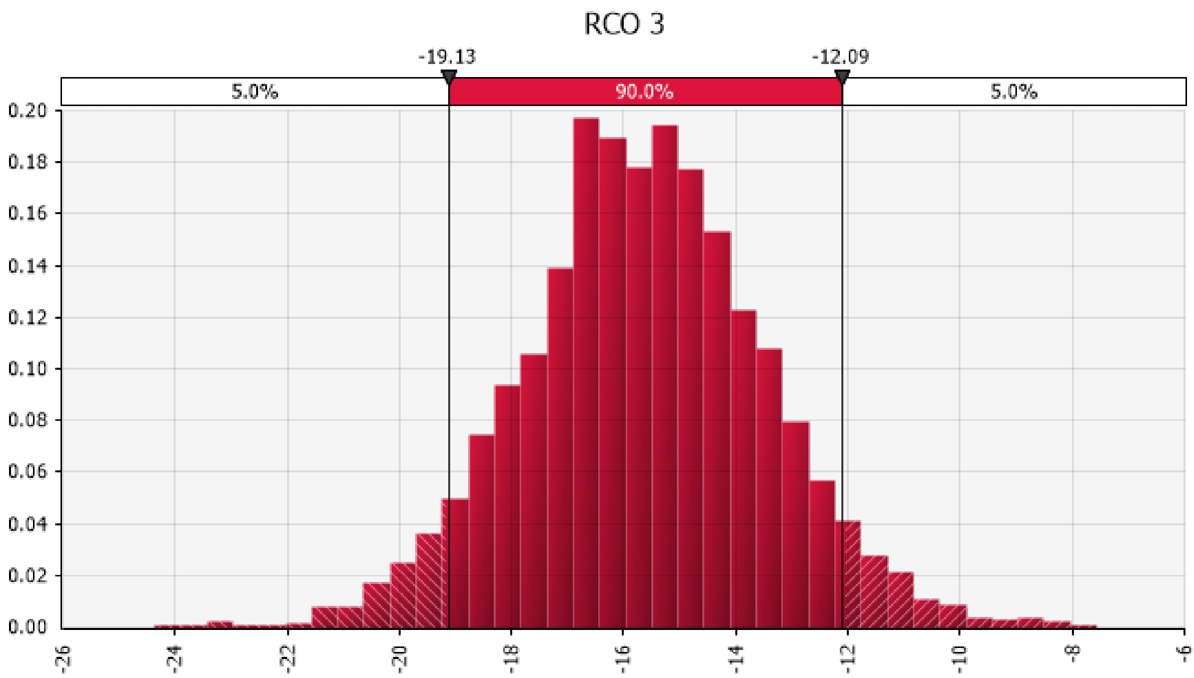

Figure 46. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO3 NCAF factor graph output.

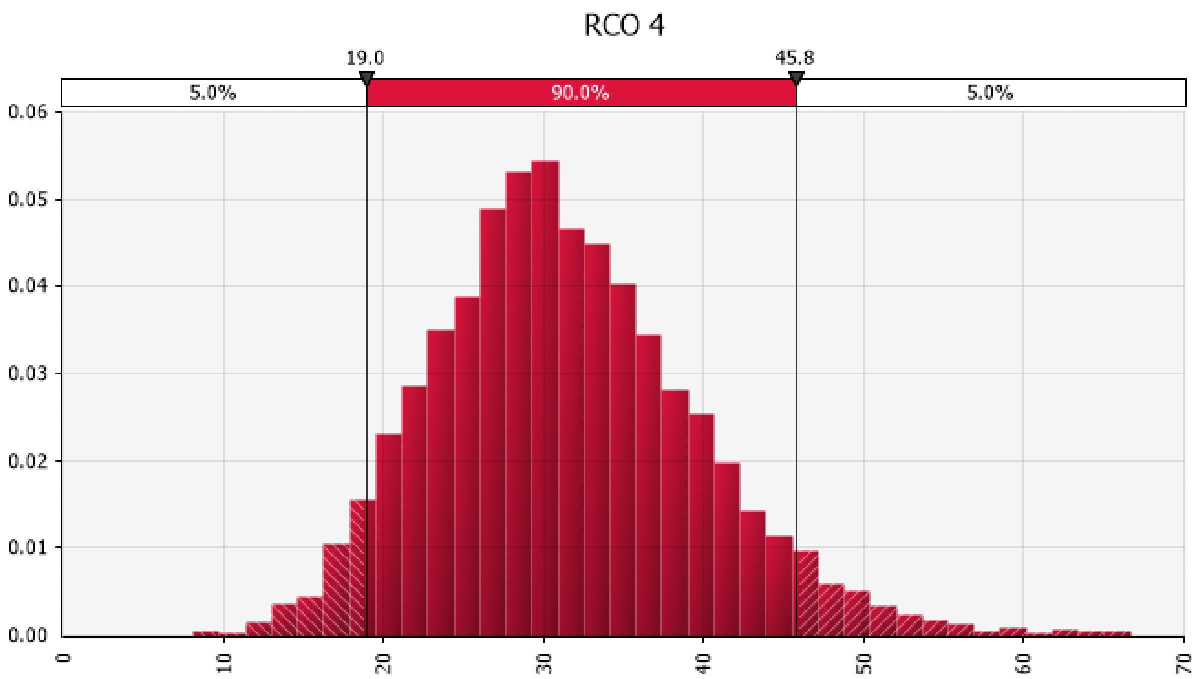

Figure 47. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO4 NCAF factor graph output.

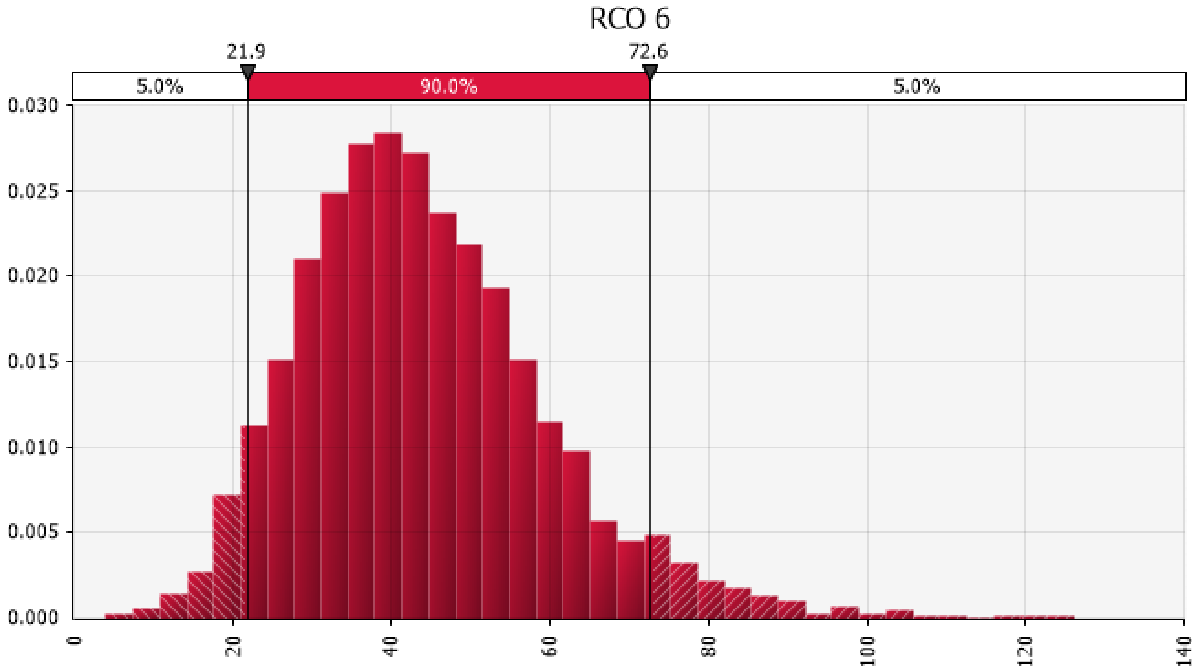

Figure 48. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO6 NCAF factor graph output.

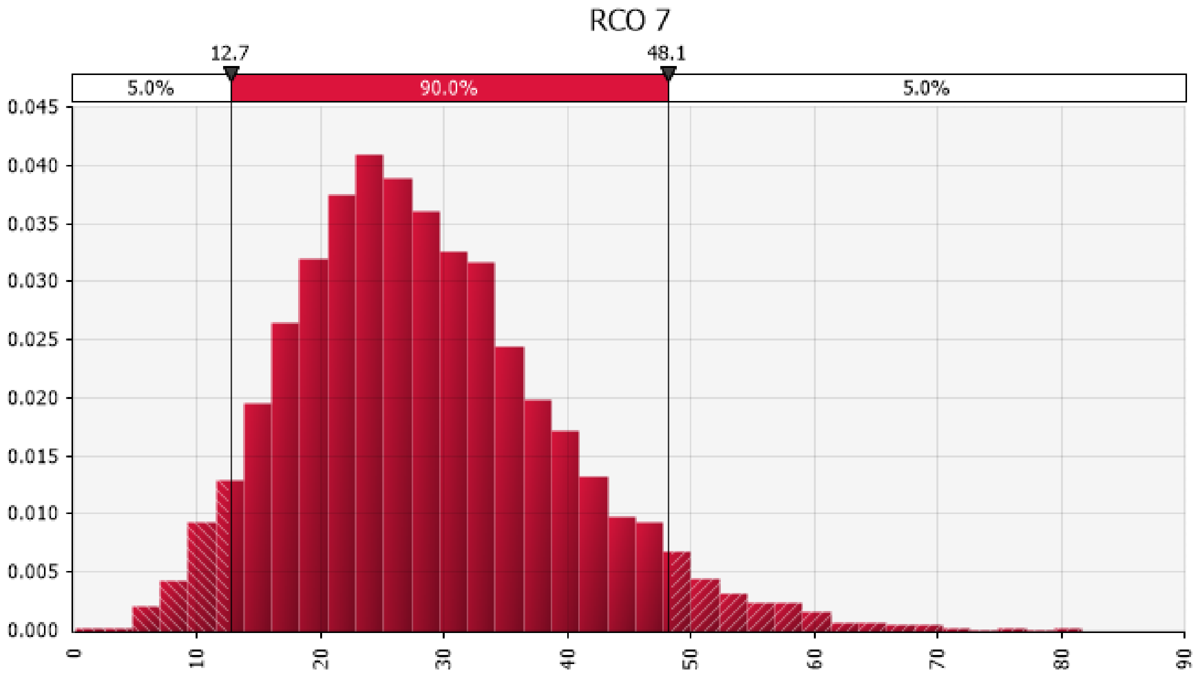

Figure 49. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO7 NCAF factor graph output.

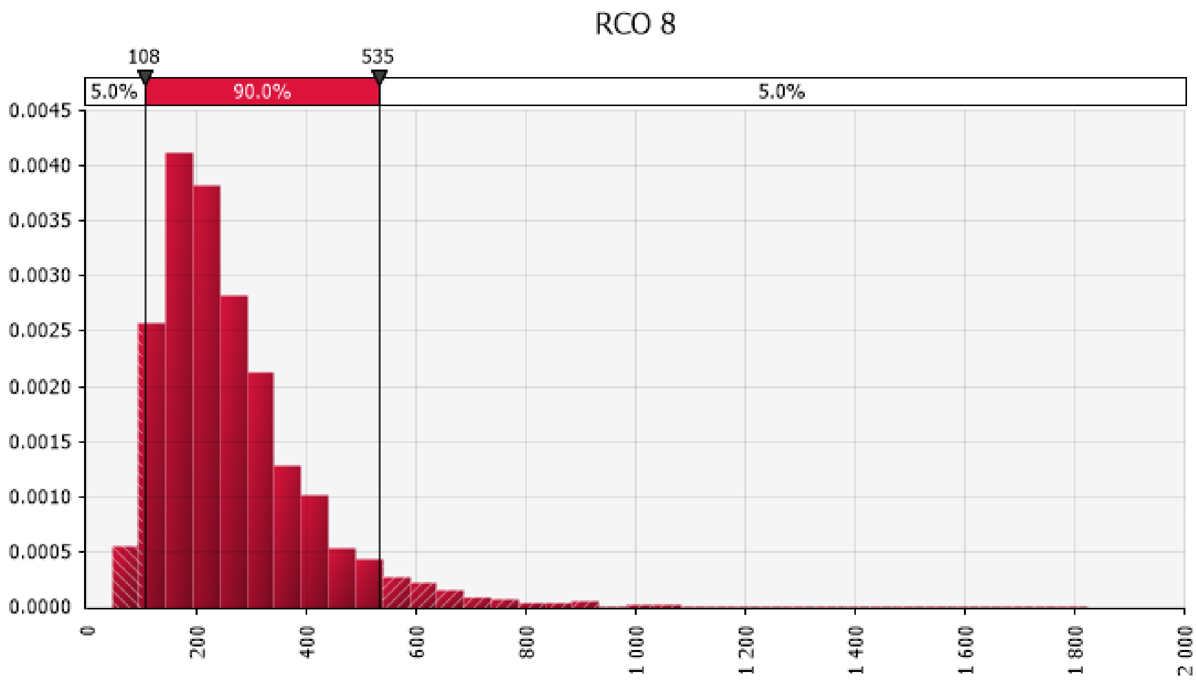

Figure 50. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO8 NCAF factor graph output.

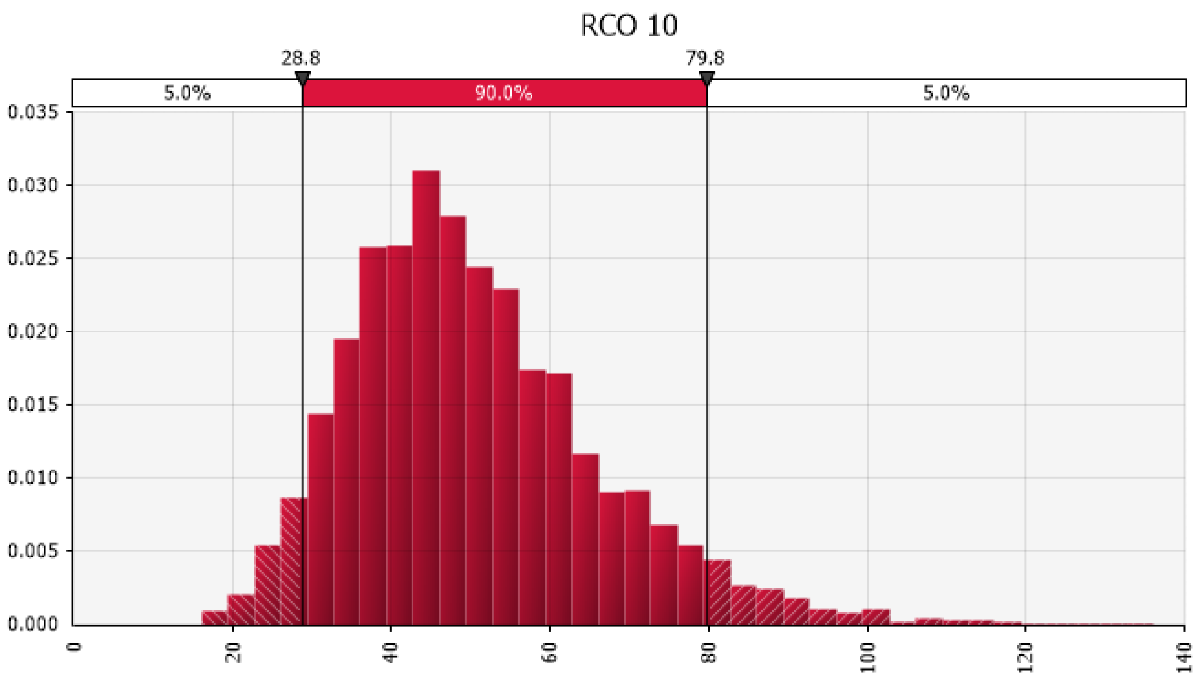

Figure 51. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO10 NCAF factor graph output.

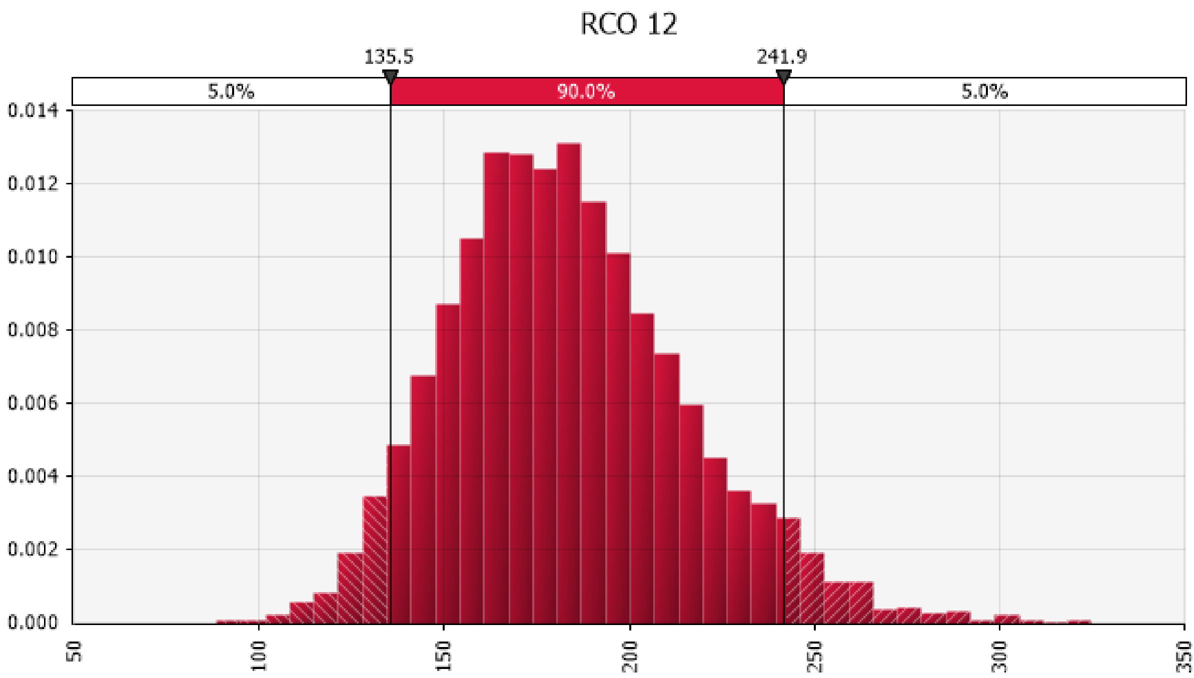

Figure 52. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO12 NCAF factor graph output.

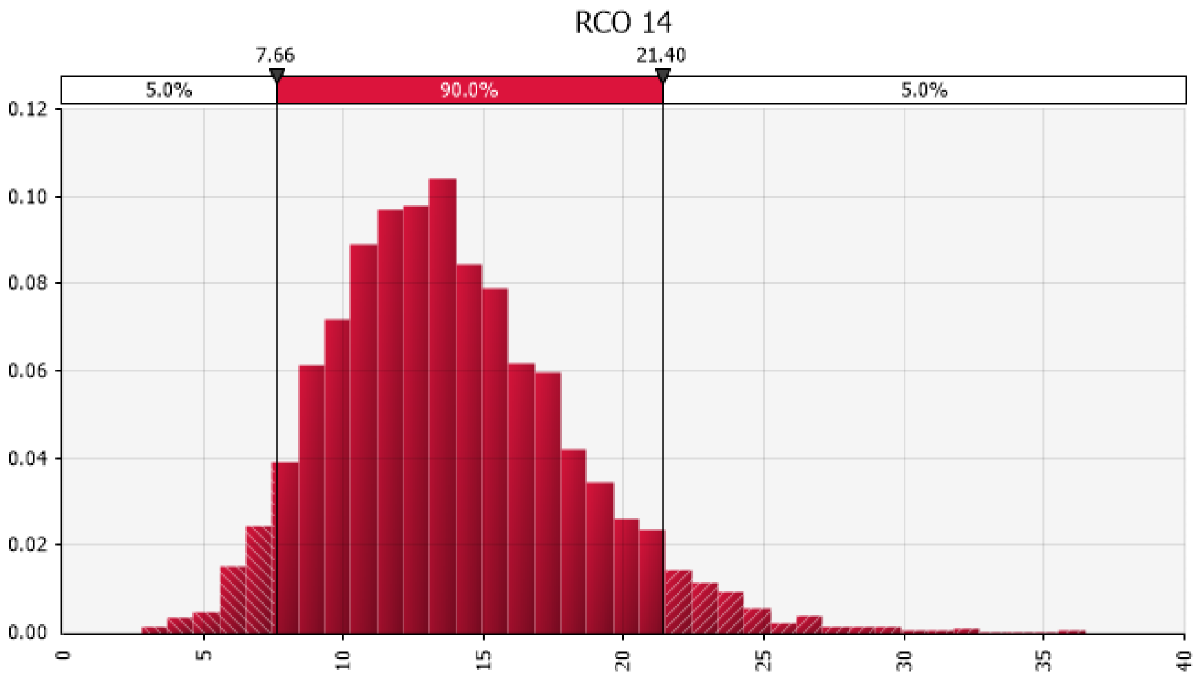

Figure 53. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO14 NCAF factor graph output.

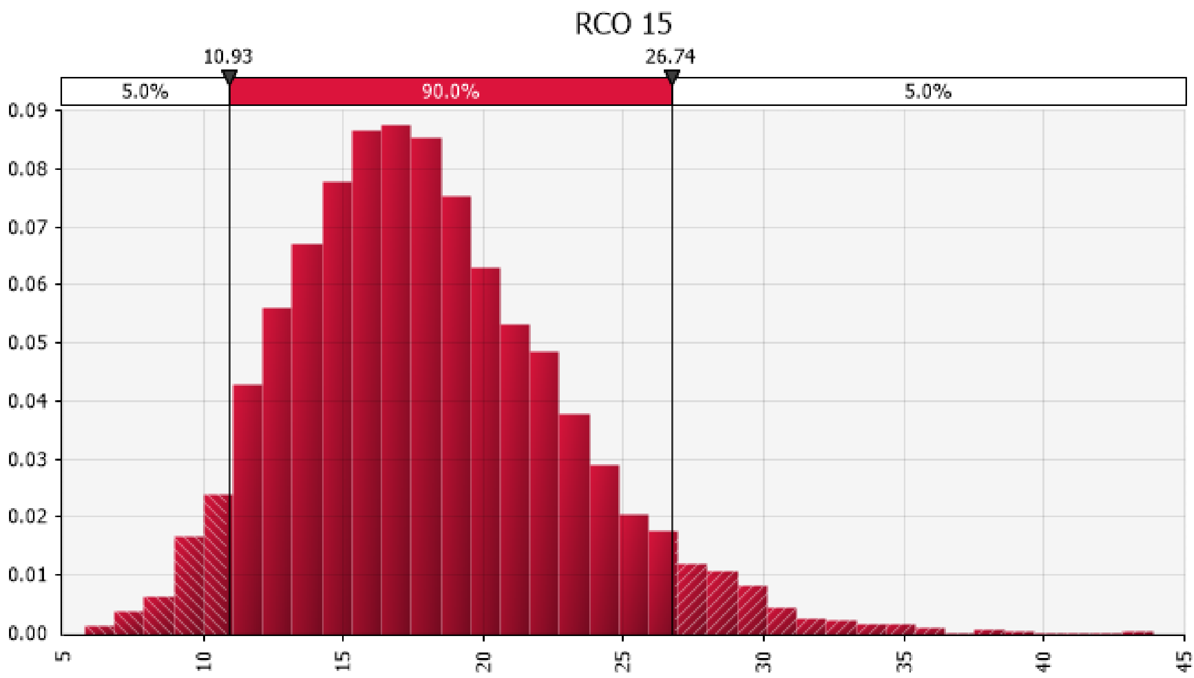

Figure 54. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO15 NCAF factor graph output.

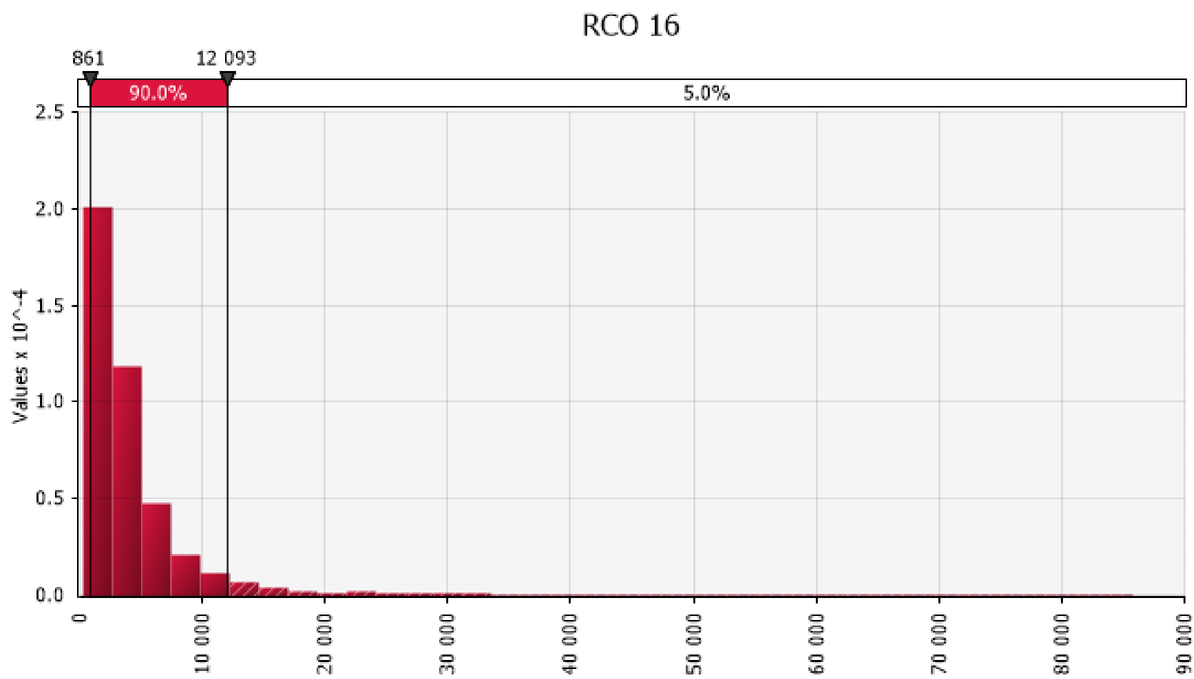

Figure 55. Uncertainty analysis for ro-ro cargo ships, existing ships. RCO16 NCAF factor graph output.

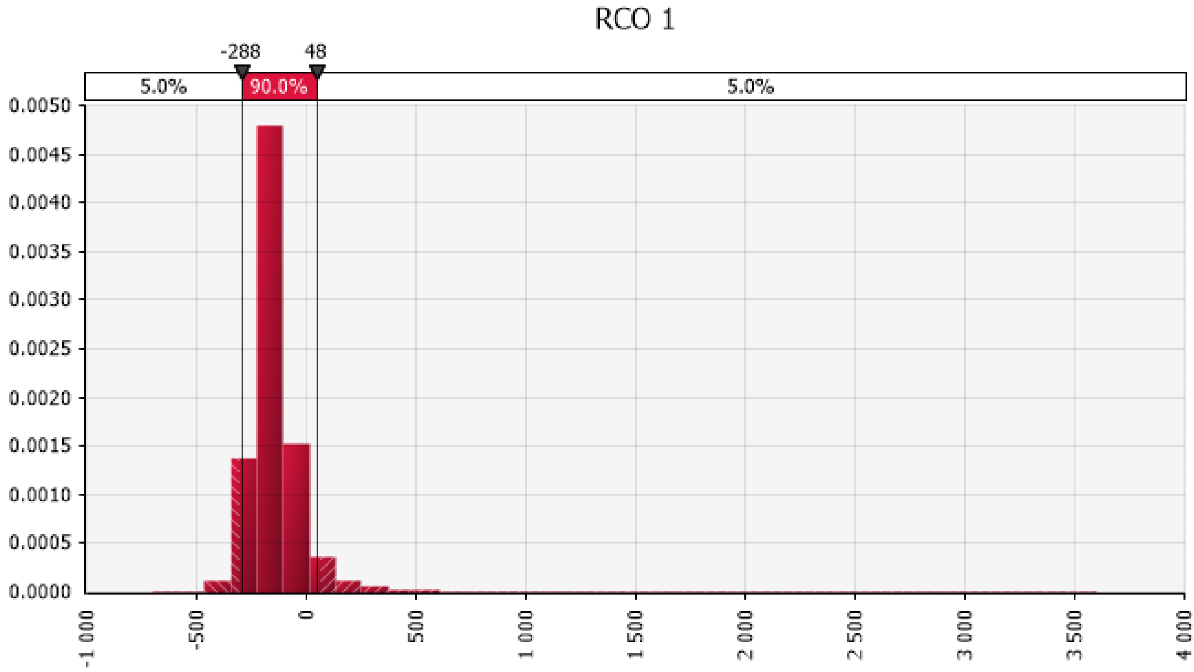

Figure 56. Uncertainty analysis for vehicle carriers, newbuildings. RCO1 NCAF factor graph output.

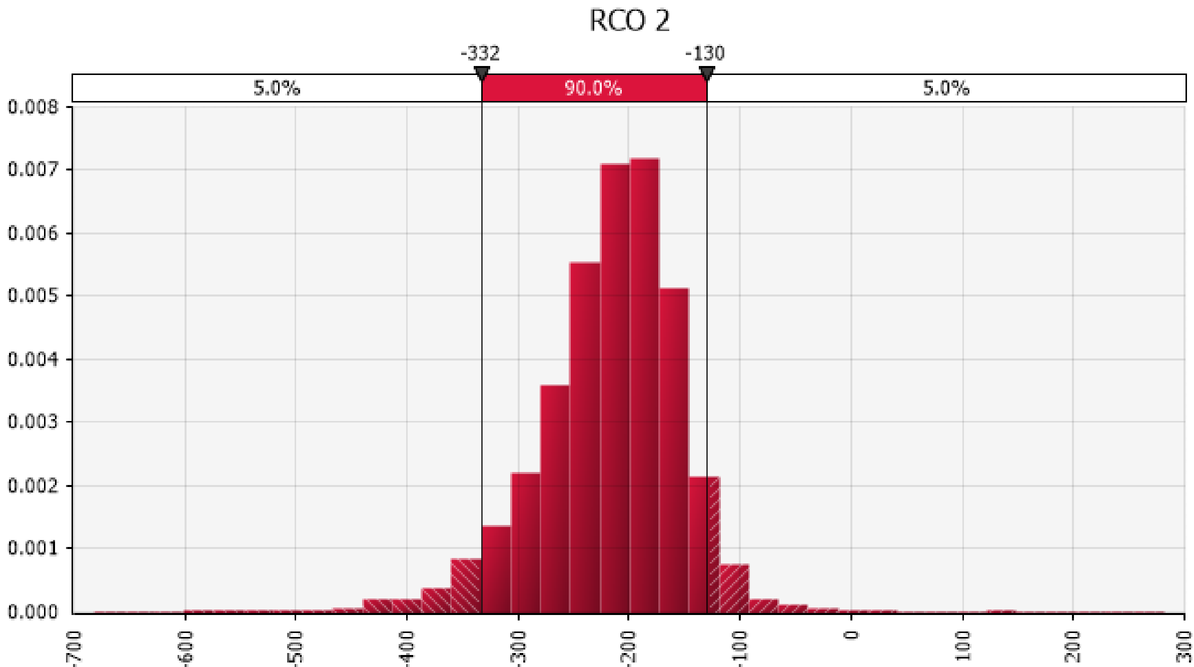

Figure 57. Uncertainty analysis for vehicle carriers, newbuildings. RCO2 NCAF factor graph output.

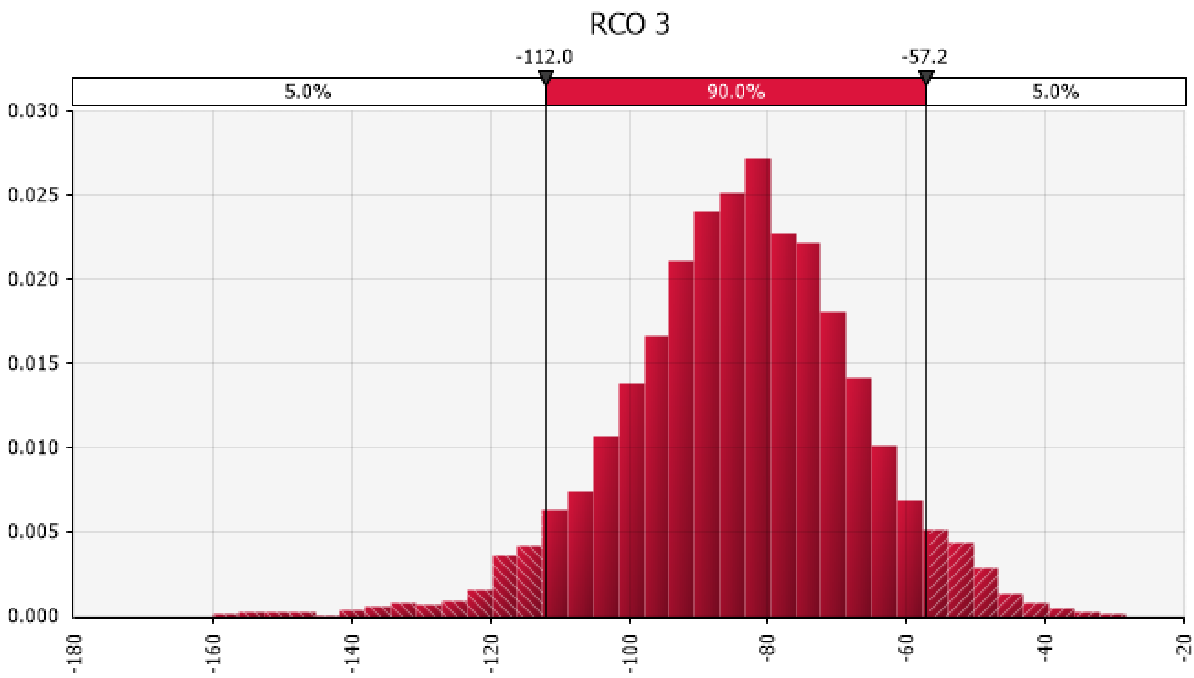

Figure 58. Uncertainty analysis for vehicle carriers, newbuildings. RCO3 NCAF factor graph output.

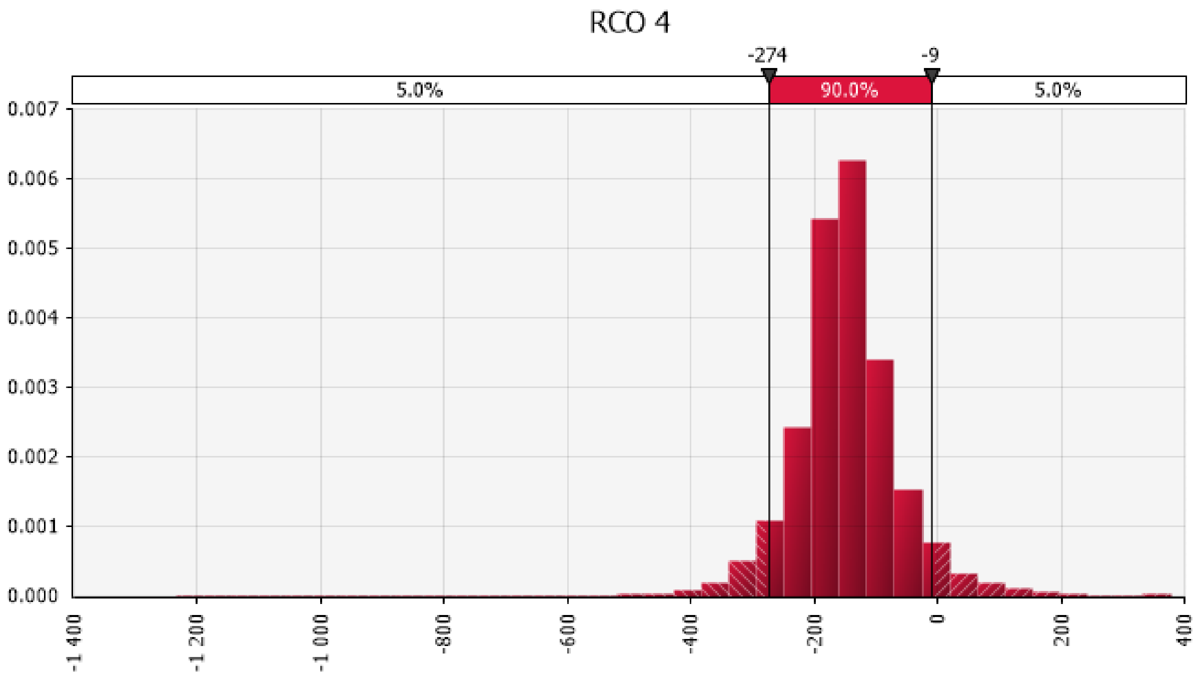

Figure 59. Uncertainty analysis for vehicle carriers, newbuildings. RCO4 NCAF factor graph output.

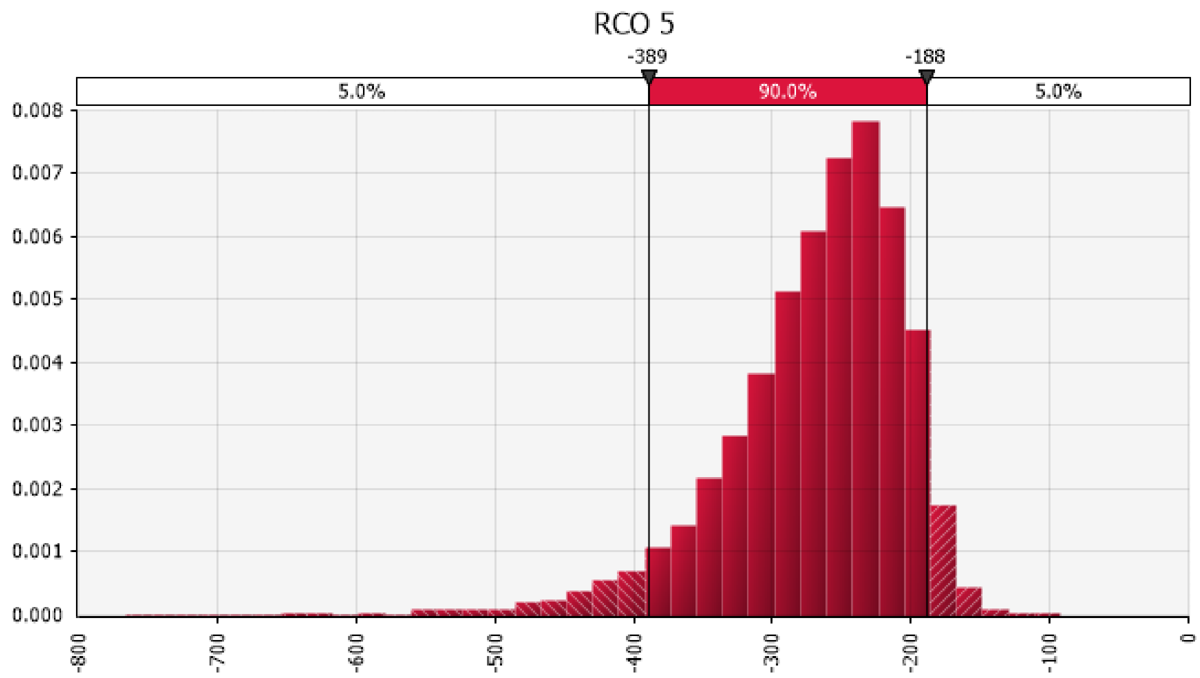

Figure 60. Uncertainty analysis for vehicle carriers, newbuildings. RCO5 NCAF factor graph output.

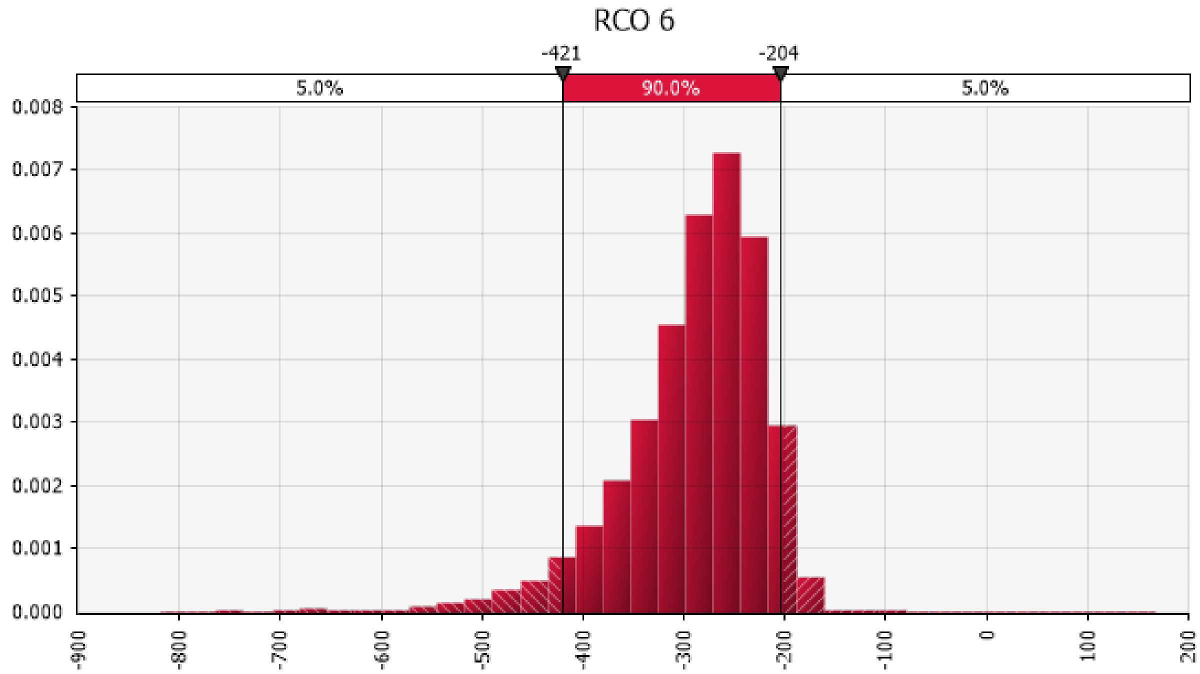

Figure 61. Uncertainty analysis for vehicle carriers, newbuildings. RCO6 NCAF factor graph output.

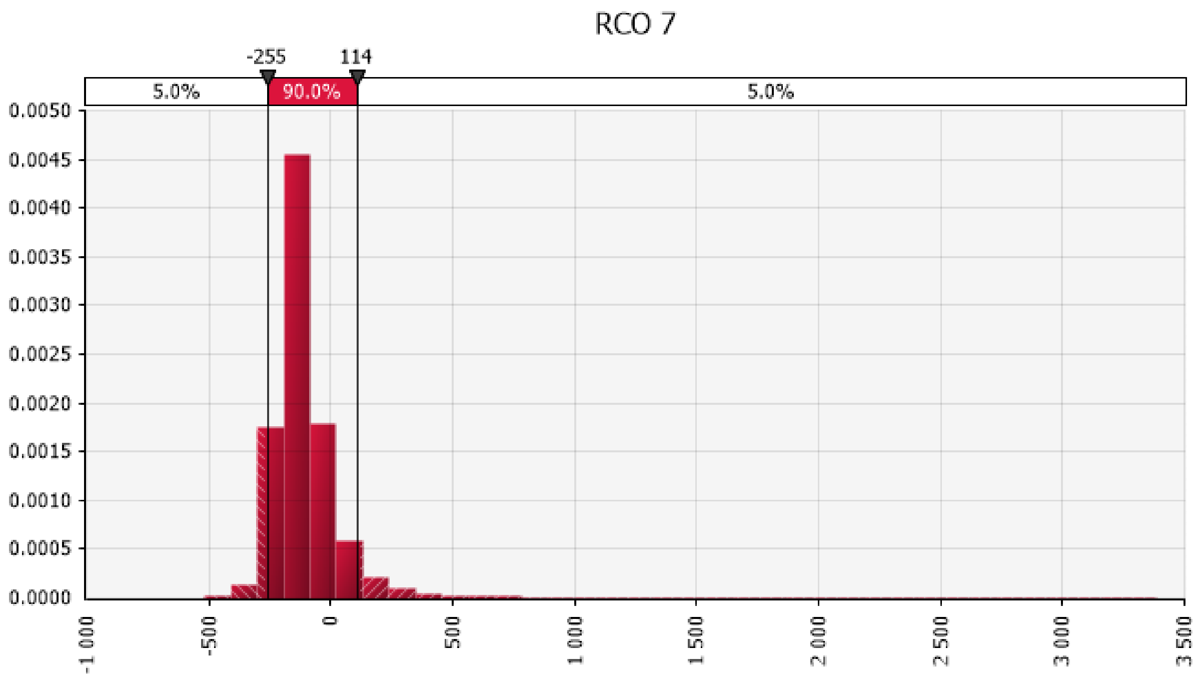

Figure 62. Uncertainty analysis for vehicle carriers, newbuildings. RCO7 NCAF factor graph output.

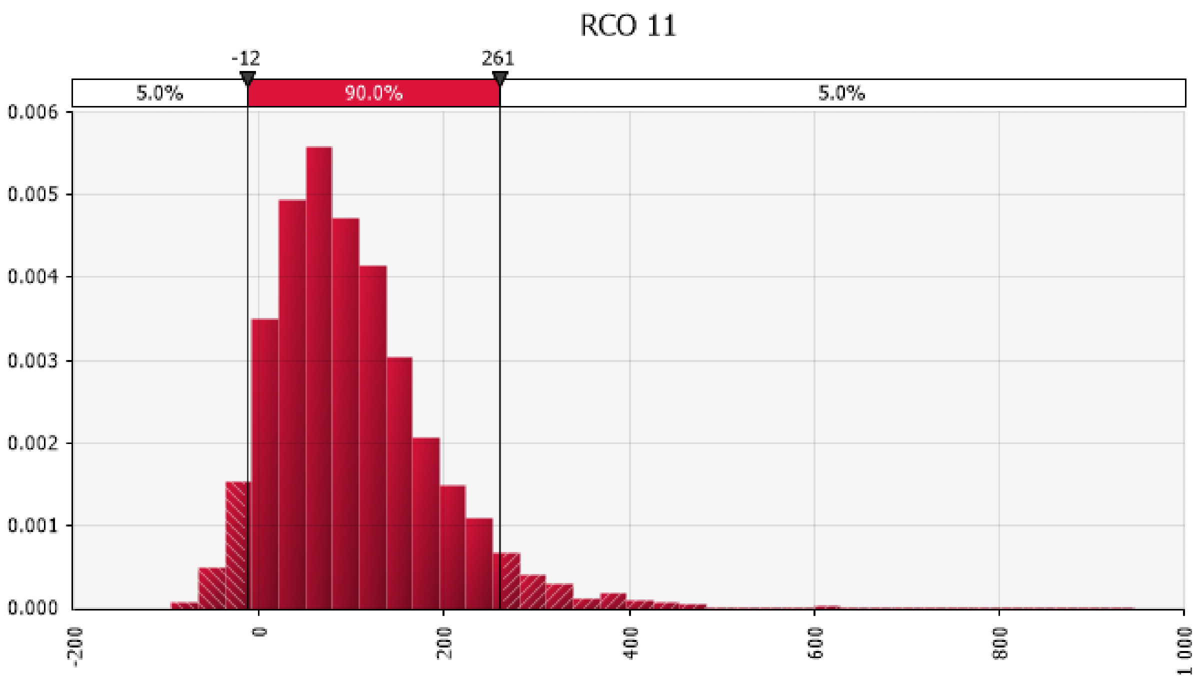

Figure 63. Uncertainty analysis for vehicle carriers, newbuildings. RCO11 NCAF factor graph output.

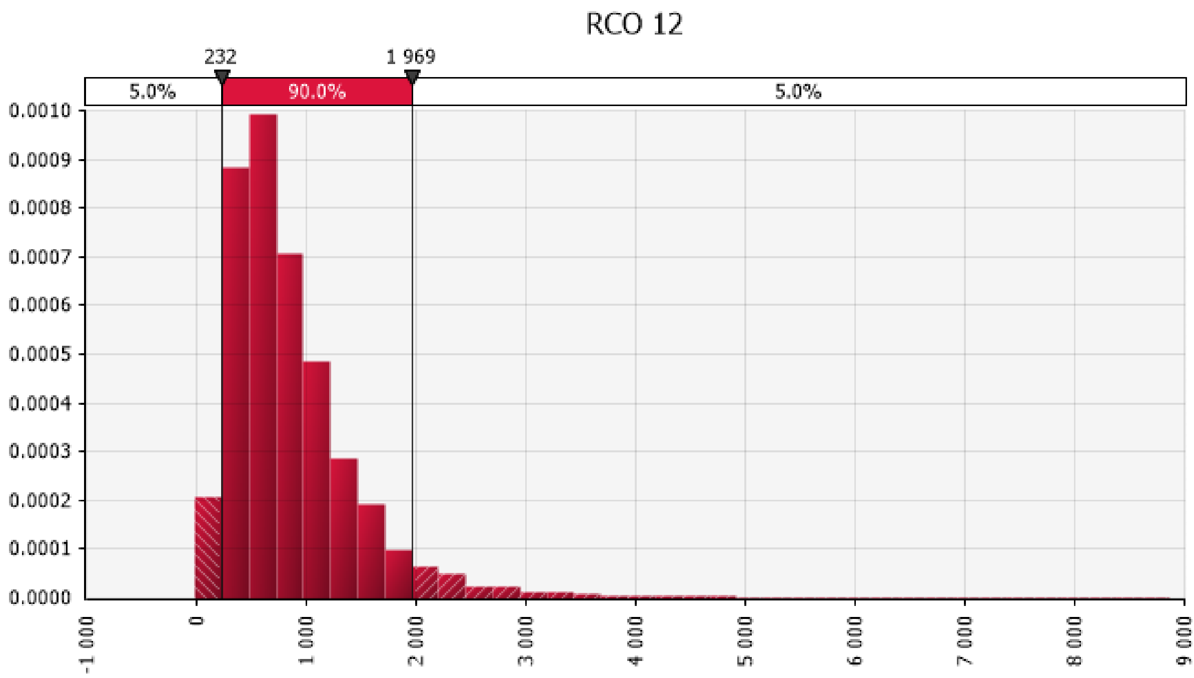

Figure 64. Uncertainty analysis for vehicle carriers, newbuildings. RCO12 NCAF factor graph output.

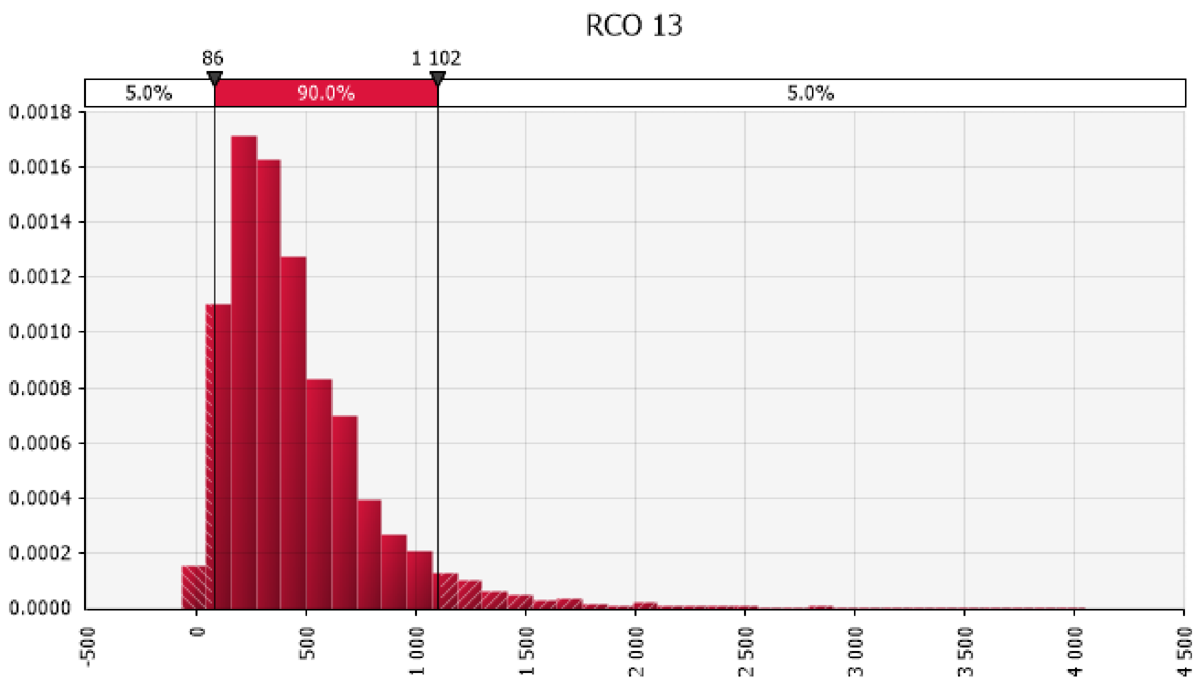

Figure 65. Uncertainty analysis for vehicle carriers, newbuildings. RCO13 NCAF factor graph output.

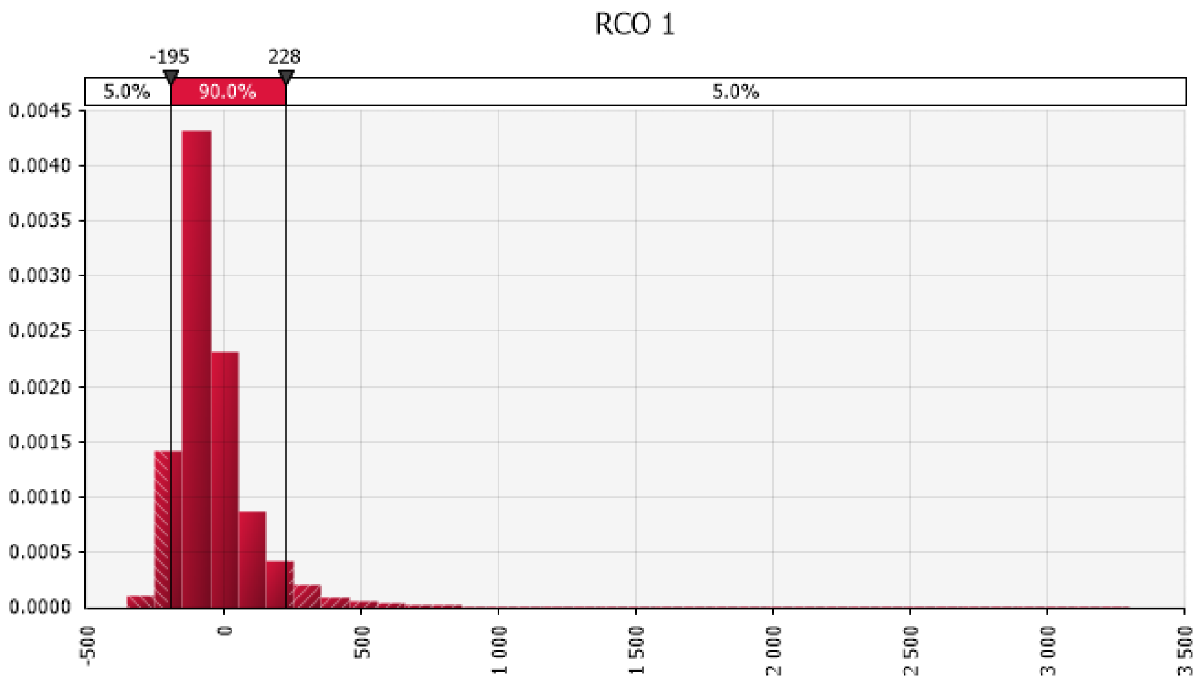

Figure 66. Uncertainty analysis for vehicle carriers, existing ships. RCO1 NCAF factor graph output.

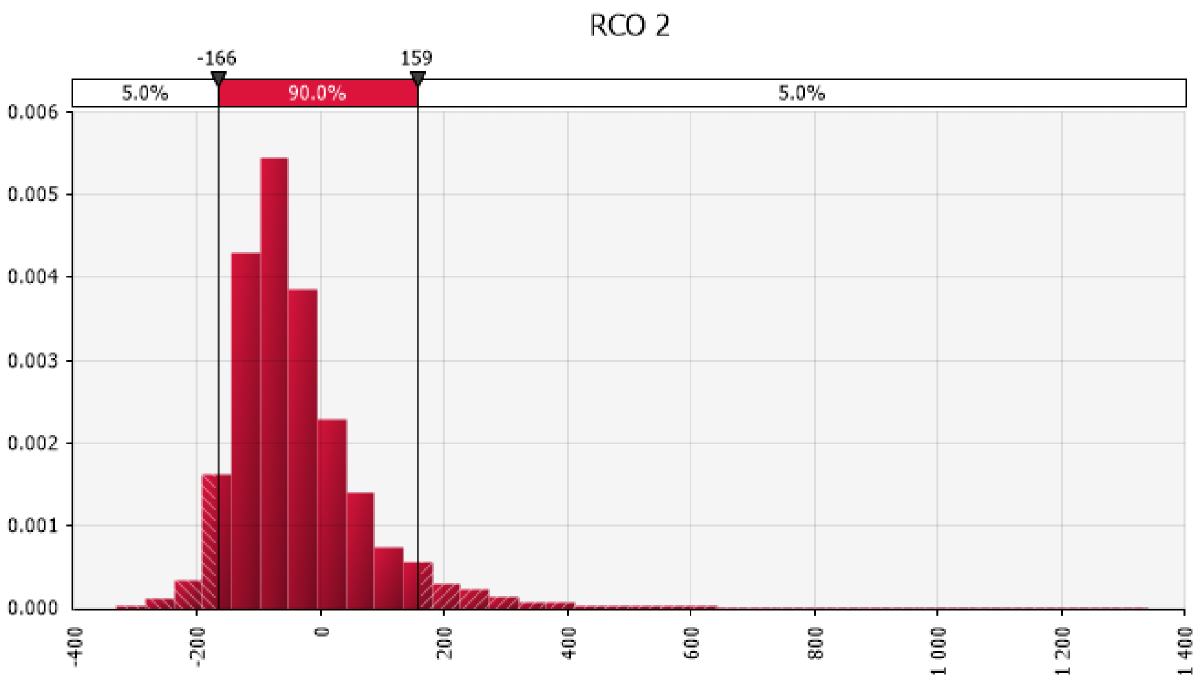

Figure 67. Uncertainty analysis for vehicle carriers, existing ships. RCO2 NCAF factor graph output.

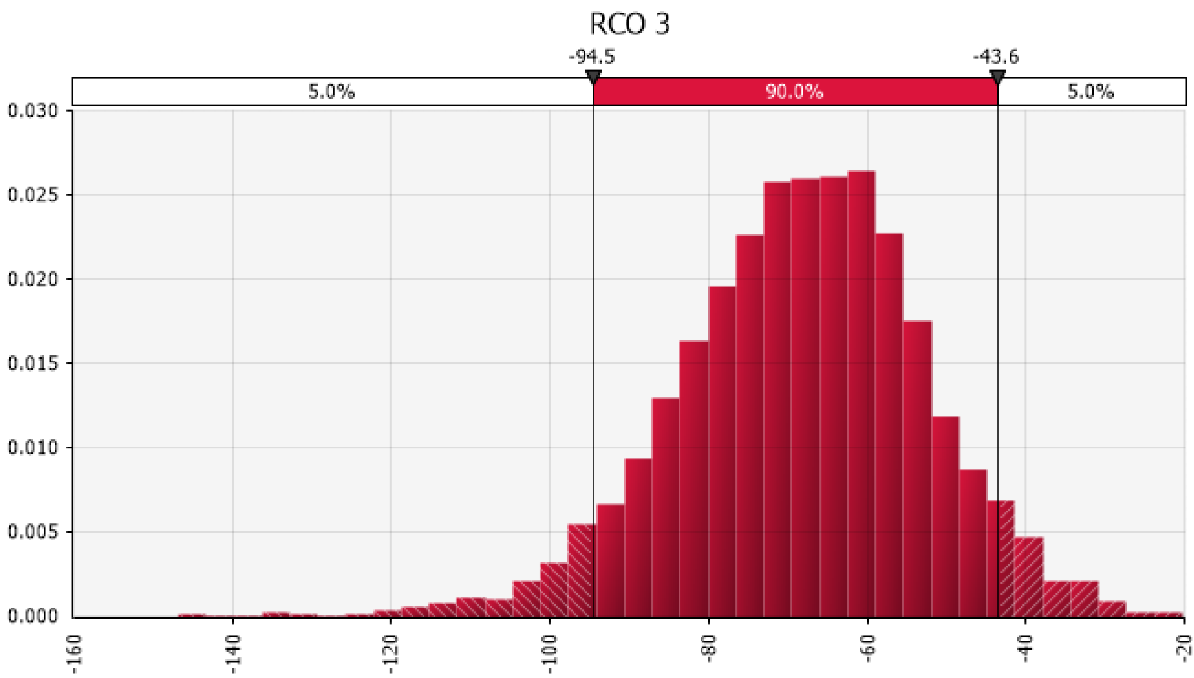

Figure 68. Uncertainty analysis for vehicle carriers, existing ships. RCO3 NCAF factor graph output.

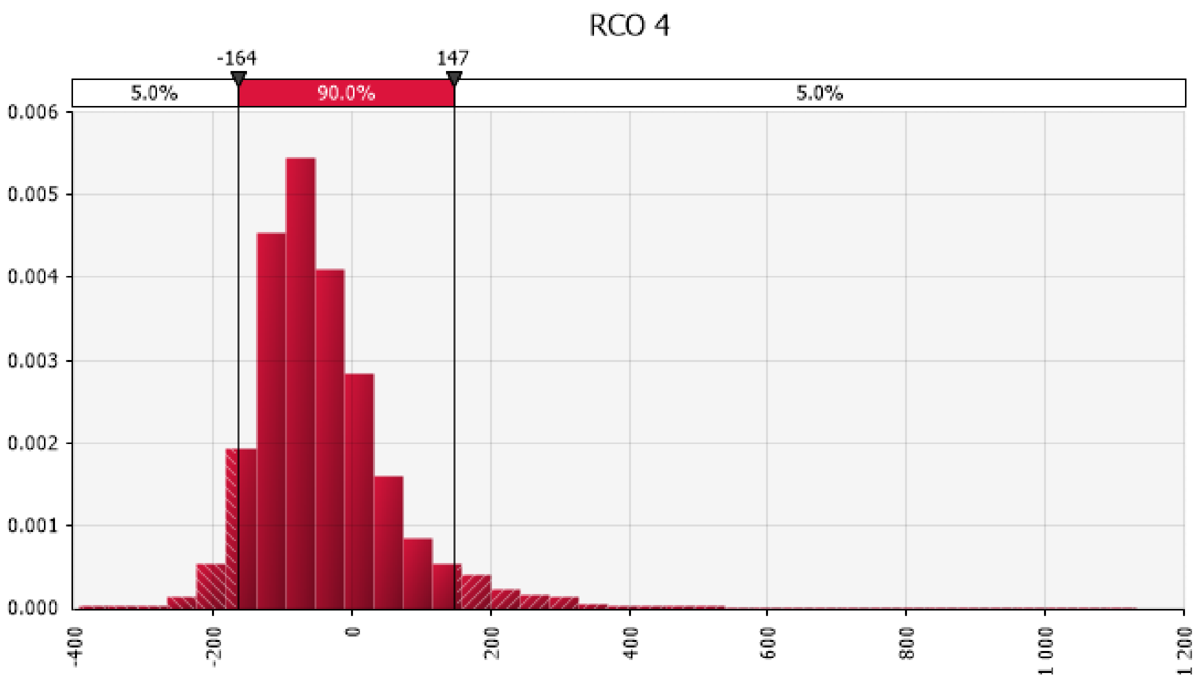

Figure 69. Uncertainty analysis for vehicle carriers, existing ships. RCO4 NCAF factor graph output.

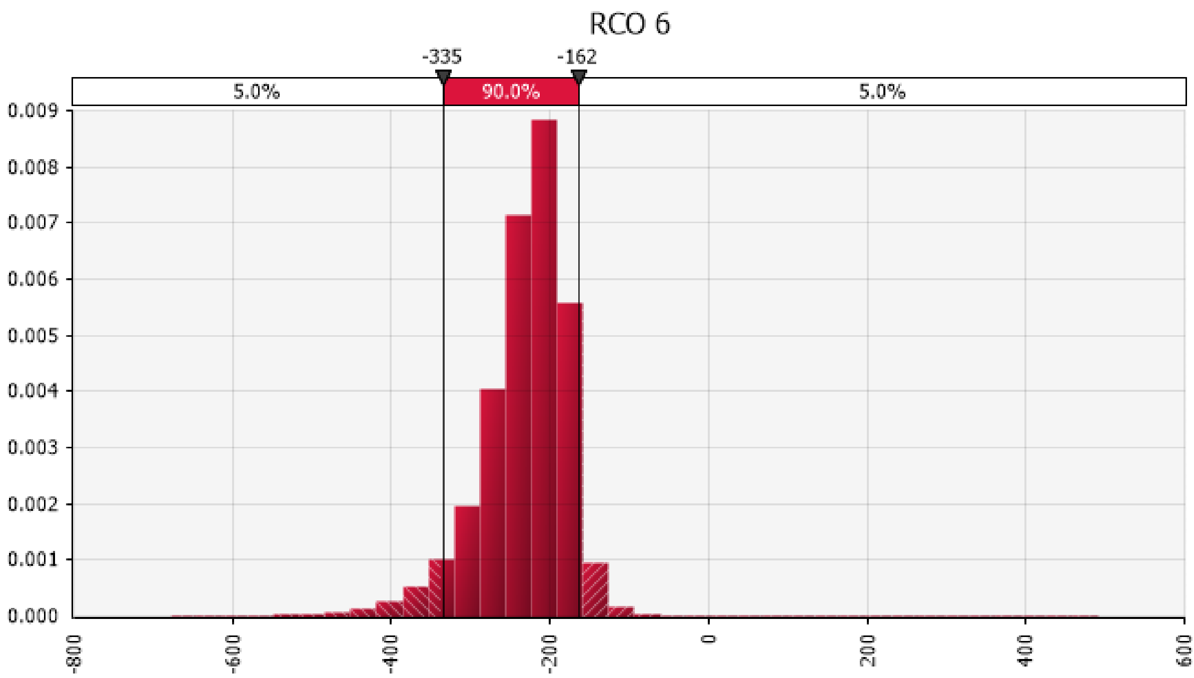

Figure 70. Uncertainty analysis for vehicle carriers, existing ships. RCO6 NCAF factor graph output.

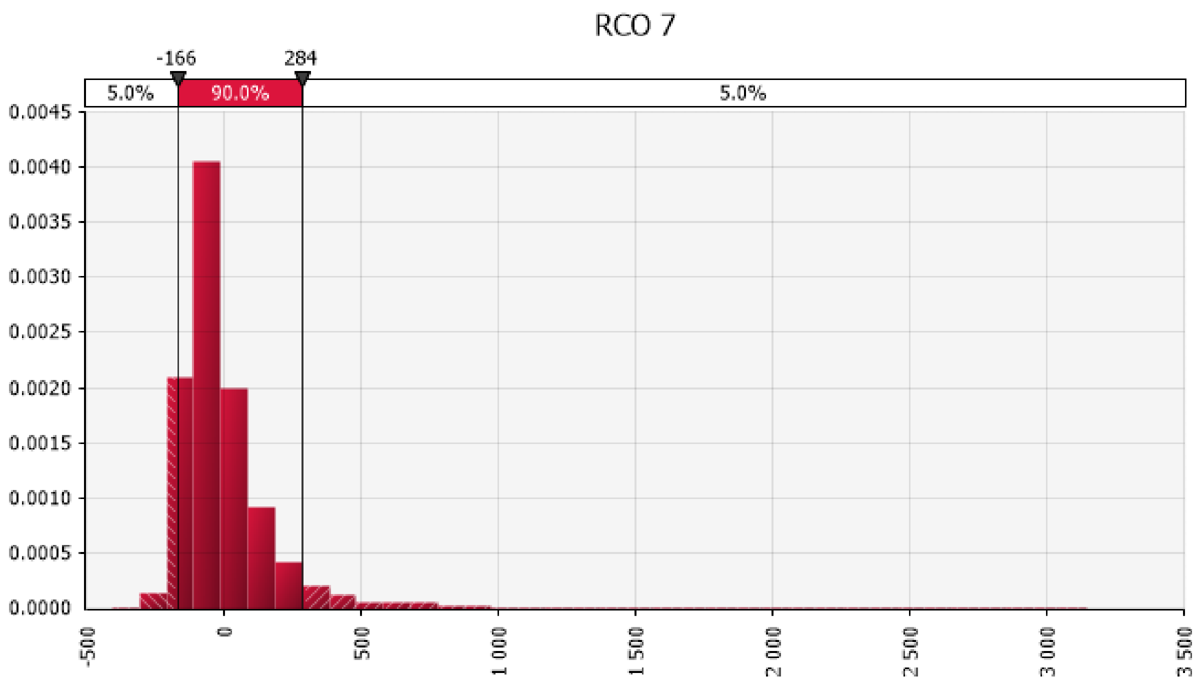

Figure 71. Uncertainty analysis for vehicle carriers, existing ships. RCO7 NCAF factor graph output.

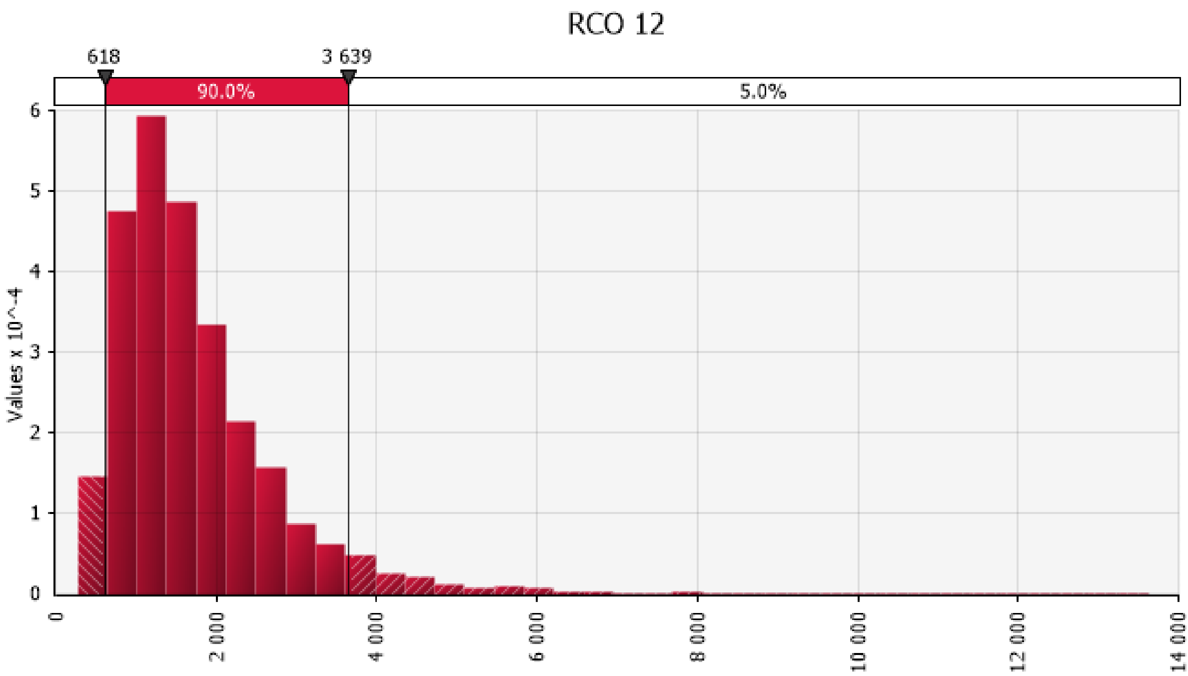

Figure 72. Uncertainty analysis for vehicle carriers, existing ships. RCO12 NCAF factor graph output.