EMSA/OP/10/2013

Combined assessment of cost-effectiveness of previous parts, FSA compilation and recommendations for decision making

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Task and objective: The report contains the results of the combined assessment of cost effectiveness based on the results from the tasks previously considered separately in this project; collision and grounding. Recommendations for decision making are included.

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3	2016-01-12	Updated and corrected tables	Rainer Hamann	Odd Olufsen	Odd Olufsen

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1 PREFACE

This report is a deliverable according to the Framework Service Contract Number EMSA/OP/10/2013. This is the third study commissioned by EMSA related to the damage stability of passenger ships. The previous studies focused on ro-ro passenger ships.

This study aims at further investigating the damage stability in an FSA framework in order to cover the knowledge gaps that have been identified after the finalisation of the previous EMSA studies and the GOALDS project.

The project is separated into 6 studies:

- Identification and evaluation of risk acceptance and cost-benefit criteria and application to risk-based collision damage stability
- Evaluation of risk from watertight doors and risk-based mitigating measures
- Evaluation of raking damages due to groundings and possible amendments to the damage stability framework
- Assessment of cost-effectiveness of previous parts, FSA compilation and recommendations for decision making
- Impact assessment compilation
- Updating of the results obtained from the GOALDS project according to the latest development in IMO.

The project is managed by DNV-GL and is established as a joint project, which includes the following organisations:

Shipyards/designer:

Euro-yards represented by: Meyer Werft, Meyer Turku, STX-France and Fincantieri

Knud E. Hansen AS

Operators:

Royal Caribbean Cruises

Carnival Cruises

Color Line

Stena Line

Universities:

National Technical University of Athens

University of Strathclyde

University of Trieste

Consultants:

Safety at Sea

Software developer:

Napa OY

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4 ABBREVIATIONS

A: Attained index calculated in accordance with SOLAS 2009. Ch.II-1
ALARP: As Low As Reasonable Practicable
CN: Collision
CT: Contact
CBA: Cost Benefit Assessment
CAF: Cost of Averting a Fatality
FSA: Formal Safety Assessment
EMSA: European Maritime Safety Agency
GOALDS: GOAL based Damage Stability
GR: Grounding
GT: Gross tonnage
IACS: International Association of Classification Societies
IMO: International Maritime Organization
NCAF: Net Cost of Averting a Fatality
NPV: Net Present Value
PLL: Potential Loss of Life
POB: Persons on board
R: Required Subdivision Index in accordance with SOLAS 2009. Ch.II-1
RCO: Risk Control Option
SAFEDOR: Design, Operation and Regulation for Safety (EU FP6 project)
VPF: Value of prevented fatality
WOD: Water on deck
WTD: Watertight door

5 EXECUTIVE SUMMARY

The focus of Task 4 is to summarise the facts and the results obtained in the EMSA III project and, on the basis of these, provide recommendations for decision making as well as highlight various discussion points, which merit further attention.

Main conclusions and recommendations for decision making

- The project does not provide any data for RoPax and passenger ships carrying less than 400 persons onboard.
- There is no data available for RoPax having more than 3,280 persons onboard.
- The Cost-Effectiveness Analysis performed in the project, supports raising the level of R for collision.
- For cruise ships, a number of RCOs have been investigated on 2 sample ships. When the assessment is based on benefits from collision only, the RCOs found to be cost effective show only limited improvement. Grounding represents a significantly higher risk than collision based on the calculations carried out in the project. There is a clear trend that RCOs improving the attained index A for collision would also improve the attained index A for grounding. When grounding is included in the risk assessment the CAF values are generally reduced and additional RCOs become cost-effective.
- Suggested levels of R are shown in two different formulations. Both formulations show a significant increase of safety level for small and medium sized ships and a moderate increase for very large ships. However, accounting for the additional cost-effective RCOs deriving from consideration of grounding (as explained above), it is concluded that the formulation with the higher level of R is deemed more appropriate, following closely the FSA process and methodology. [1]

Items for discussion and recommendations for further work.

These include recommendations by the Project Partners as a Group of Experts and as Stakeholders of the maritime/marine industry beyond the EMSA III framework.

- For large cruise ships, there is limited amount of information/data concerning their survivability in damaged conditions due to relatively small fleet and (luckily) small number of casualties, thus not attracting research focus. The limited amount that does exist (Reference 10) indicates that the current formulation of the s-factor in SOALS 2009 tends to underestimate the survivability of cruise ships. This, in turn, influences ΔPLL and cost-effectiveness.
- By contrast, there are significantly more published validation results available for damage stability of RoPax ships (s-factor) than for cruise ships, e.g., North-West European Project for Damage Stability of Ro-Ro Passenger Ships (the basis for Stockholm Agreement) and the EC-funded projects HARDER and GOALDS.

[1] Some members of the consortium have expressed their reservation wrt use of grounding in the CBA before the methods and assumptions have been further tested and validated.

- The results of EMSA III show that grounding is the dominant risk. It certainly represents a significantly higher risk than collision. However, further validation and testing is required in order to develop specific proposals.
- Presentation to and familiarisation by industry outside the consortium is also recommended before suggesting requirements such as combined collision and grounding to IMO.
- Method and software for calculation of A for collision should be developed based on the non-zonal approach as was done in the EMSA III project for grounding.

6 ABSTRACT

As specified in the tender document, the undertaking in Task 4 is to combine the results, proposals and applied RCOs from the studies described in Tasks 1, 2 and 3 and to conduct a combined CBA according to the IMO FSA Guidelines. Based on all the results provided and following an objective comparison of the alternative options, concerning potential reduction of risks and cost-effectiveness, specific recommendations for decision making are made.

7 INTRODUCTION

This report is based on the previous studies carried out within this project.

Task 1: Risk Acceptance Criteria and Risk-Based Damage Stability, Final Report, part 2: Formal Safety Assessment/1/

Task 2: Evaluation of risk from watertight doors /2/

Task 3: Evaluation of risk from raking damages due to grounding /3/

Therefor this report has to be read in conjunction with the reports from Tasks 1, 2 and 3 as referred to above in a view to consider the basis for this study as well as the assumptions made.

Additionally, the report from Task 1 /1/ includes the steps according to the IMO Formal Safety Assessment (FSA) Guidelines /4/.In the following a brief summary is given of the main findings of the investigations carried out in this study.

Step 1: Identification of Hazards.

The HAZIDs carried out in the SAFEDOR project for cruise and RoPax ships and the HAZID carried out for the Navigation Safety of Large Passenger Ships project (NAV49/INF.2) have been revisited. In addition, an examination has been carried out on accidents that occurred since these HAZIDS were carried out with a view to take onboard any relevant information and verify the validity of the HAZID studies. It was concluded from the review mentioned above that the accident databases did not reveal any new or additional causes for accidents that were not covered by the aforementioned HAZIDs.

Step 2: Risk Analysis.

Risk models were developed, respectively updated in order to identify current risk level. These risk models should adequately approximate the risk of ships complying with SOLAS 2009 (/8/) requirements. The main objective was to developed risk models considering the effect of damage stability requirements. Accident categories mainly influenced by damage stability are collision and grounding.

The risk model for collision is developed as an event tree and is based on the risk model developed in the GOALDS project but with some modifications, which are described in detail in the report. These modifications mainly concern the fatality rates when a ship sinks and the dependent probabilities updated by carefully reviewed casualty reports. Analysis of uncertainty and sensitivity are included.

The risk model for grounding is also developed in form of an event tree. This risk model considers not only grounding accidents but also accidents classified as contact but leading to hull damages below waterline that are comparable to grounding damages.

The risk analysis showed that the risk of grounding is a major risk contributor.

Step 3: Risk Control Options.

The bases for investigating the RCOs are the available sample ships; two cruise ships and 4 RoPax ships. For each sample ship various design changes developed by shipyard designers for the purpose of obtaining an increased Index-A have been investigated. The risk reduction for each RCO in the form of reduced Potential Loss of Life (PLL) is established by use of the risk model.

Step 4: Cost-Benefit Assessment.

Costs related to each design change (RCO), construction and life-cycle costs are established. The assessments are based on the assumption that the business case shall be kept constant, e.g. no change in passenger or cargo carrying capacity. The only benefit accounted for is the reduced probability for total loss of the ship when increasing the attained index A. The cost-effectiveness is assessed by considering the Net Cost of Averting a Fatality (NCAF), which is expressed by the following equation:

$$NCAF = \frac{\Delta Cost - \Delta Economic\ Benefit}{\Delta Risk}$$

In cost-benefit assessment two cost thresholds (VPF) are used, 4 million USD/fatality and 8 million USD/fatality.

Step 5: Recommendations for decision making

The results from the Cost Benefit Assessment were used to derive suggested formulation for the level of R covering collision only. A brief summary of results are included in Sec. 8 of this report. These results were obtained without considering the effects of watertight doors (Task 2) and grounding risk (Task 3).

Combining with the results from task 2 and 3:

The conclusions from Task 2 are presented in Sec. 9 of this report.

A summary of the work carried out on the evaluation of grounding risk is included in Sec. 10.

In relation to the FSA procedure the report from Task 3 includes:

- Risk analysis of grounding incidents
- Risk control options focusing on improving survivability from grounding
- Cost-benefit assessment covering grounding on two sample ships

As the title of this study and report suggests the purpose of this study is to combine the results from the three previous tasks and on this basis provide recommendations for decision making. The combined assessment is included in Sec. 12 whilst the recommendations for decision making are included in Sec. 13.

Brief introduction of Risk Control Options investigated on sample ships

In order to make the reading of this report easier an overview of the various RCOs that have been investigated for each sample ship is shown in Figure7-1.

Figure7-1 Brief description of RCOs for the sample ships

	Version	Brief description of RCO
		Cruise
Small	**00(Init)**	**Reference version**
	06	Increase breadth by 0.5 m
	09	Increase breadth by 0.1 m
Large		
	G2	**Reference version**
	G3	as G2 with wt decks
	I3	Breadth increased by 1.0 m, Freeboard increased by 0.8 m
	K3	Opt. version for collision, changed internal subdivision, freeboard increased by 0.4 m
	K4	Developed for grounding CBA, as K3 with wt decks
	M1	Developed for grounding CBA, double hull increased DB height
	M2	Developed for grounding CBA, as M1 with wt decks
		RoPax
Large	**A (Init)**	**Reference version**
	L	Increase breadth by 0.8 m
Medium	**V00**	**Reference version**
	V14	Optimized for collision: Internal subdivision (bulkheads below bulkhead deck), breadth increased by 0.2 m
	V15	Cross flooding devices + watertightness of longitudinal bulkheads
	V16	Additional watertight parts of decks
Small	**1(Init)**	**Reference version**
	2	Raising main deck by 0.3 m
Small (De)	**0(Init)**	**Reference version**
	1	Raising main deck by 0.3 m

8 RISK FROM COLLISION AND SUGGESTIONS ON LEVEL OF R

8.1 Summary of Results

For collision the results in Task 1, as documented in the final report /1/, indicated that the Attained Index A of state-of-the art designs is quite high for the small RoPax ships in comparison with the current level of Required Index R. This is due to the deterministic damage stability requirements in SOLAS (Reg. 8 - a two compartment requirement as the number of persons for all sample ships is greater than 400).

For the Mediterranean and the Baltic RoPax designs it was demonstrated that A-Index could be raised significantly while meeting the cost-effectiveness criteria (below 4 or 8 Mill USD). For the cruise ships, significant increase in A could not be shown to be cost-effective when considering collision only.

An overview of the results is shown in Figure 8-1. In this figure the Attained Index for the initial design as well as the A-Index obtained for the design modification having a NCAF value of less than 4 Mill USD, 4 Mill USD including a confidence interval of 95%, 8 Mill USD and 8 Mill USD including a confidence interval of 95%. The basis for using 4 and 8 Mill USD thresholds is explained in part 1 of the final report of Task 1, which also includes the assumptions behind the confidence limits.

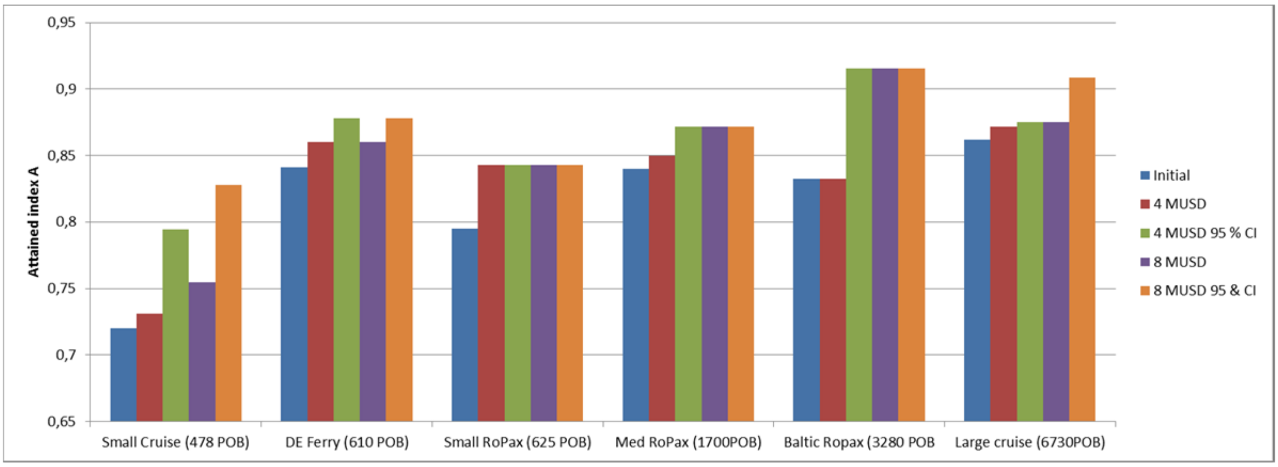

Figure 8-1 Overview of Attained Index-A for all ships wrt cost-effectiveness

An overview of the various design modifications for which cost-benefit assessments have been carried out is presented in Table 8-1 for RoPax ships and in Table 8-2 for Cruise ships.

The results shown in Table 8-1 and Table 8-2 were used as a basis for deriving alternative proposals for the level of R. The proposals are shown in Figure 8-2, and were discussed in the Task 1 report/1/.

Table 8-1 Overview of results from Cost-Benefit Assessment: RoPax, collision

Ship type	Design ident.	Index-A	<4MUSD	<4MUSD (95%)	<8MUSD	<8MUSD(95%)
Baltic RoPax	A (Initial)	0.8326				
	B	0.8703	No	Yes	Yes	Yes
	C	0.8670	No	Yes	Yes	Yes
	D	0.8824	No	Yes	Yes	Yes
	E	0.8786	No	No	no	no
	F	0.8997	No	Yes	Yes	Yes
	I	0.8494	No	No	No	no
	J	0.9184	No	No	No	No
	K2	0.9042	No	Yes	Yes	Yes
	L	0.9152	No	Yes	Yes	Yes
Mediterranean RoPax	1 (Initial)	0.8398				
	2	0.8404	no	Yes	no	Yes
	3	0.8496	no	Yes	no	Yes
	4	0.8778	No	No	No	No
	5(V14)	0.8718	No	Yes	no	Yes
Small RoPax	1 (Initial)	0.7947	Yes	Yes	Yes	Yes
	2	0.8426	Yes	Yes	Yes	Yes
De Ferry	0 (Initial)	0.8412				
	1	0.8601	Yes	Yes	Yes	Yes
	2	0.8782	No	No	No	Yes

Table 8-2 Overview of results from Cost-Benefit Assessment: Cruise ships, collision

Ship type	Design ident.	Index-A	CAF<4MUSD	CAF<4MUSD (95%)	CAF<8MUSD	CAF<8MUSD (95%)
Large cruise	G2 (Initial)	0.8621				
	H4	0.9087	No	No	No	No
	I3	0.9288	No	No	No	Yes
	J1	0.9004	No	No	No	No
	K1	0.8719	Yes	Yes	Yes	Yes
	K2	0.8777	No	No	No	No
	K3	0.8754	No	Yes	Yes	Yes
	L1	0.8774	No	No	No	Yes
Small Cruise	00 (Initial)	0.7202				
	01	0.7263	Yes	Yes	Yes	Yes
	02	0.7307	no	Yes	Yes	Yes
	03	0.7442	No	Yes	no	Yes
	04	0.7544	No	Yes	Yes	Yes
	05	0.7944	No	Yes	No	Yes
	06	0.8281	No	No	No	Yes
	07	0.8187	No	No	No	No
	08	0.8752	No	No	No	No
	09	0.7789	No	Yes	Yes	Yes

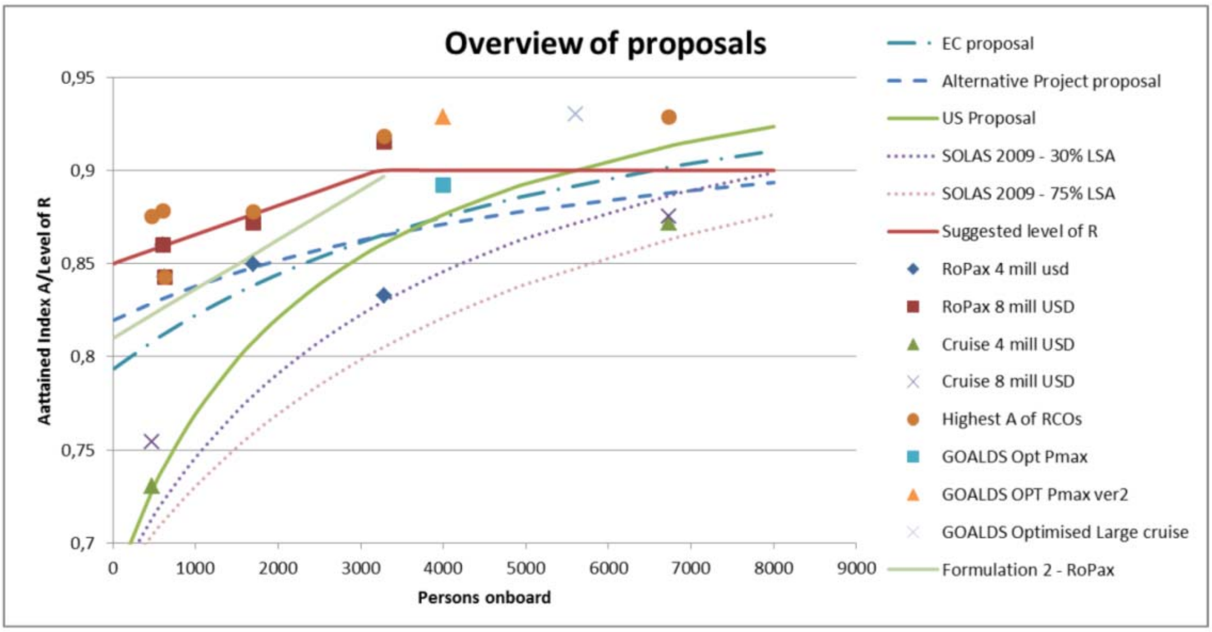

Figure 8-2 Overview of proposals for level of R as presented in the report from Task 1.

8.2 Summary of Observations and Recommendations concerning the collision risk

General

- Formulations for R covering all passenger ships (Cruise and RoPax) are suggested, as indicated in Figure 8-2.
- However, it was considered that there should be an increase in R with increasing number of persons onboard.
- The designers recommend adding a design margin of about 0.02 to 0.03 of the index. This margin is needed for practical reasons, to maintain the internal watertight integrity for a fully developed detailed design as the designs investigated here reflect a conceptual design stage only even if some of the sample ships have no margin to the required index R.

Specific

- The idea of the risk being ALARP implies that it if an option is cost-effective it is obligatory to implement it. Hence, using some sort of average of the cost-effective solutions as a basis to propose R values is inappropriate according to this methodology.
- The values derived are based on a limited solution set, meaning that if more time or resources were available, more cost-effective solutions may have been identified with still higher A-Index values.
- The observation made above offers further support that maximum achieved rather than average A-values should be considered in the decision for R values.
- The risk models for cruise ships and RoPax include outcomes where rapid capsize takes place. These relate to catastrophic accidents, which should be addressed / eliminated.
- The difference in the risk models for RoPax and Cruise ships adds also to the explanation of the differences in risk in terms of PLL. This is shown in table 14-2 in the Task 1 report./1/
- The other reason relates to how relevant the s-factor in SOLAS 2009 is for large cruise ships, Ref. /10/. It is to be noted that information related to this, however limited, represents the only recorded evidence available. This leads to two important outcomes for cruise ships: (a) the Index-A (hence Delta A and DeltaPLL) for cruise ships is underestimated, rendering RCOs non cost-effective or (b) the chosen RCOs themselves are not safety effective, which is less likely considering the level of expertise of the participating designers. The Table below portrays this very clearly.

Table 8-3 Effect of RCOs investigated (CN only, latest version of risk model)

	Version	SOLAS 2009	PLL/ship year	% comparison with reference design	Pass/Fail netCAF limit	
Small Cruise					4 mio USD	8 mio USD
	00(Init)	0.7202	0.00938	100 %		
	01	0.7263	0,00918	98%	yes	yes
	02	0.7307	0,00903	96%	no	yes
	03	0.7442	0,00858	91%	no	no
	04	0.7544	0,00823	88%	no	yes
	05	0.7944	0,00689	73%	no	no
	06	0.8281	0,00576	61%	no	no
	07	0.8187	0,00608	65%	no	no
	08	0.8752	0,00418	45%	no	no
	09	0.7789	0,00741	79%	no	yes
Large Cruise						
	G2(Init)	0.8621	0.06456	100 %		
	H4	0.9087	0.04274	66 %	no	no
	I3	0.9288	0.03333	52 %	no	no
	J1	0.9004	0.04663	72 %	no	no
	K1	0.8719	0.05997	93 %	yes	yes
	K2	0.8777	0.05726	89 %	no	no
	K3	0.8754	0.0583	90 %	no	yes
	L1	0.8774	0.05740	89 %	no	no
Baltic RoPax						
	A (Init)	0.8326	0.08829	100 %		
	B	0.8703	0.06840	77 %	no	yes
	C	0.867	0.07014	79 %	no	yes
	D	0.8824	0.06202	70 %	no	yes
	E	0.8786	0.06402	73 %	no	no
	F	0.8997	0.05290	60 %	no	yes
	I	0.8494	0.07943	90 %	no	no
	J1	0.9184	0.04304	49 %	no	no
	K2	0.9042	0.05052	57 %	no	yes
	L	0.9152	0.04472	51 %	no	yes
Mediterranean RoPax						
	V00(Init)	0.8398	0.04356	100 %		
	V1	0.8404	0.04340	100 %	yes	yes
	V12	0.8496	0.04090	94 %	no	no
	V21	0.8778	0.03323	76 %	no	no

	V14	0.8718	0.03486	80 %	no	no
Small RoPax						
	0(Init)	0.7947	0.02036	100 %		
	1	0.8426	0.01561	77 %	yes	yes
Small (De; RoPax)						
	0(Init)	0.8412	0.01514	100 %		
	1	0,8601	0.01334	88 %	yes	yes
	2	0.8782	0.01162	77 %	no	no

- In general, emphasis on stability upgrades focuses on high risk scenarios, which normally are the result of global (RoRo deck) or local (deck opening) vulnerabilities in design. Once such vulnerabilities are identified designers can address these, (normally) leading to cost-effective solutions.

- Additional thoughts relate to the RCOs being considered. For example, large RoPax are sensitive to global parameters and solutions, such as those considered in this project. For this reason cost-effective RCOs have been identified for this type of vessel because of the nature of the RCOs considered.

- Cost-effective RCOs for cruise ships, on the other hand, tend to be of local nature because of the complexity in the internal architecture. This does not mean that global design changes will not be effective, simply that local design changes will be more effective. In general, progressive flooding is key to the loss of a vessel and the complex internal architecture of a cruise ship offers many cost-effective options to curtail progressive flooding. However, this requires different tools (numerical simulations) and consideration than those being considered in SOLAS 2009 (/8/) stability calculations, used in the EMSA III study.

- Finally, an exhaustive search for cost-effective design solutions was not within the scope of the project. This would have allowed identification and focus on high risk scenarios, which normally are the result of global (RoRo deck) or local (deck opening) vulnerabilities in design.

- Notwithstanding the above, there are two cruise ship variants that could be considered in making recommendations for cruise ships, which supplemented by 3 additional points from Project GOALDS as shown in Figure 8-2 (1 large cruise ship and 2 panamax) could indicate that high indices can also be achieved for cruise ships cost-effectively. (Ref /11/)

- The assessments made in Task 1 were based on cost threshold limits(NPV) reflecting the VPF values of 4 mill and 8 mill USD as well as the upper and lower uncertainty limits of 95 and 5%, representing a 90% confidence interval. The starting points of the cost threshold limits were the level of R corresponding to the level required for the actual ship. It is to be noted that some of the initial designs of the sample ships had a level of A significantly higher than the level of R. This applies for e.g. the small cruise ship, the Mediterranean RoPax and the small RoPaxes. Figure 8-1, Table 8-1 and Table 8-2 show the results when using the threshold limits based on the level of R, while Table 8-3 shows the results when the Attained index A is used as the basis.

9 RISK FROM WATERTIGHT DOORS

9.1 Summary of Results

A summary of the work carried out in Task 2 of the project to derive a parametric formulation for quantification of contribution to risk due to WTD operation is presented in this section of the report. The complete work is documented in the final report from Task 2 /2/.

Patterns of watertight doors usage have been analysed based on data from on-board recording systems for Cruise and RoPax passenger ship types. It was observed that typically a number of one or more WTDs are in frequent use during voyages and that the majority of doors remain open in ports. It has been noted that use of WTD is affected by its category. Namely, the averaged proportion of time the C category doors remain open at sea is 11% whilst for A or B category doors it is 60%. Notably, A-category doors have been observed to remain open for 100% of the time. The average duration a C-category door remained open is 1.33 minutes, with some doors open/closed within slightly shorter and some within much longer time span.

Assessment of the impact of an open WTD on stability has led to an observation that the impact of any one single door, while varying from door to door, was found to be small relative to the impact of a combination of doors left open. Furthermore, it was noted that such impact on stability was then insensitive to category of doors comprising the combination, that is, an open door of category C or A would degrade stability to an equal extent.

A simplified mathematical model was developed to quantify this impact based on only a handful of relevant parameters. Namely, the model is based on the number of WTDs, their category, volume of connected spaces, total buoyant volume of the ship, time of the crew response to flooding situation and doors closure. Rates of WTD failures (reliability) were also accounted for. The construct of this model was a result of a compromise of simplicity, robustness and the perceived accuracy. It was found that the spread in the results derived by the simplified mathematical model was of the order of +/- 20% from the results derived through expensive direct calculations. Some of the parameters such as the location are only taken into account indirectly through the connected volume.

9.2 Summary of Observations and Recommendations concerning the risk form watertight doors

The application of this parametric model on RoPax ships needs to be further investigated as the pros and cons of the inclusion of the cargo deck in the total buoyant volume has been discussed among the partners and the impact needs to be further investigated to improve robustness of the model.

Whilst it is recommended that further study continue on possible refinements of the proposed approach, it was found during the course of the ship design and optimisation tasks that reasonable trends can be identified and viable design improvements can be put forward on the basis of calculations by the proposed approach.

For instance, the design studies have confirmed that new ships can be designed without the need for category A-doors with considerable risk reduction, a fact which also has been considered by IMO Sub-Committee SDC 2 in its decision to remove for new ships the possibility of an exemption for watertight doors to be kept open while at sea. Installation of multiples of doors of B or A category can contribute to risk to life significantly, with well over 50% increased risk. Hence this observation alone bears significant potential for tangible risk reductions.

The analysis of the existing ships also highlights that in some designs the use of doors is vital for the operation of ships. In particular for RoPax vessels it is the only way to reach other parts of the ship during normal watch keeping, as the bulkhead deck is blocked by roro cargo.

The sensitivity of the model to the input information allows stressing the importance of operational procedures on-board. Efficient and timely crew response to flooding situation can significantly reduce the risk to life of those on-board. Conversely, lack of appropriate training or inefficient operational procedures can significantly increase risk to life above levels tolerated by regulations. The mathematical model can aid disclosure of these risks for design as well as for daily ship operation, for better awareness and training.

Based on the analyses performed by a team of design offices, ship yards, class, operators and academic establishments participating in this study, the following set of recommendations is put forward for reduction of contribution to risk to life by installation and operation of watertight doors on ships.

Remove category A or B doors
This is the most cost-effective risk control option identified in this project. Type A and B door numbers need to be reduced. It is assumed that the real-life ship operation of WTDs adheres to MSC.1/Circ.1380 guidelines.

Deploy on-board monitoring of WTDs
The mathematical model proposed facilitates robust quantitative assessment of impact of opening a combination of doors on the risk. Such disclosure can be used for training on-board and measurement to facilitate and nurture development of “safety culture” for prudent use of WTDs. It is expected that significant reduction in the frequency of usage of WTD can be achieved and crew preparedness for effective management of undesirable events of flooding prioritised.

Improve design guidelines
It is recommended that guidelines to designers and operators on minimisation of the number of watertight doors on Tank Top level as well as arranging access to compartments below the bulkhead deck through upper deck levels, be developed and promoted. To achieve this, a closer cooperation between operators and designers is needed already in the conceptual design phase to avoid any design which may require the frequent usage of WTD.

10 RISK FROM GROUNDING

10.1 Introductory Remarks

While the risk from collision accidents has been the subject of extensive research and regulation over many years, the risk from grounding to conventional passenger and cargo vessels seems to have received less attention. The present SOLAS regulations for passenger and cargo ships do not address the case of grounding damages within the probabilistic framework. Safety with respect to bottom grounding is addressed by a deterministic procedure in Chapter II-1 Regulation 9: "Double bottoms in passenger ships and cargo ships other than tankers". Regulation 9 /8/, which was developed based on statistics of grounding damages /9/, provides minimum double bottom requirements and specifies deterministic bottom grounding damage characteristics to be used for survivability assessment in case of vessels with unusual bottom arrangements. Historical data, however, indicates that this design measure can be, in some cases, insufficient as demonstrated by a number of grounding accidents that resulted in ship loss and a significant number of fatalities. As a matter of fact, in case of passenger ships the impact of grounding accidents on human life seems to be more severe than that of collisions. Notably, whilst for several years there have been no records of total loss of a passenger ship due to collision accident, six passenger ships have been lost since 2000, following contact or grounding:

- The cruise ship *EXPRESS SAMINA* sunk within half an hour due to grounding while approaching the island of Paros with 80 fatalities (September 2000).
- The cruise ship *SEA DIAMOND* ran aground on a volcanic reef within the caldera of Santorini island and sunk after 27 hours with two fatalities (April 2007).
- The passenger ship *EXPLORER* sank after striking ice and sustaining damage to the hull with no fatalities (November 2007).
- The RoPax ship *PRINCESS OF THE STARS* reported engine failure and was stranded while sailing under the fierce winds and massive waves of a Typhoon in South China Sea. The ship capsized with 523 fatalities and 308 persons missing (June 2008).
- The RoPax ship *ARIAKE* developed list due to cargo shift induced by large rolling in stern quartering seas, ran aground and capsized with no fatalities (November 2008).
- The cruise ship *COSTA CONCORDIA* struck a submerged rock off the Isola del Giglio and partially capsized with 32 fatalities (January 2012).

10.2 Geometrical Modelling of Damages

Grounding accidents are traditionally associated with bottom damages. However, a common characteristic of a series of severe grounding accidents (the most recent of them is the accident of *COSTA CONCORDIA*) is that the area of the hull breach is not at the bottom, where the double bottom could offer some protection, but at the side. This is the reason why from the very beginning of the elaboration of Task 3 it was decided to take this type of damage into consideration. In this respect, two classes of damage are modelled and considered:

- damage to the ship bottom (Type 'B00'), with a principally vertical direction of penetration and

- damage to the ship side (Type ‘S00’), with a principally horizontal direction of penetration

The modelling of these two types of damage is given in detail in the Task 3 Interim Report /5/ and Final Report /3/. Two sets of parameters specifying the location and extent of the breach for each damage type are specified.

10.3 Accident Databases

One of the objectives of the EMSA III study is the identification of historical raking damages, and the modelling of damages due to grounding. Data relevant to the geometric characteristics of hull breaches resulting from accidents of Type ‘B00’ (Bottom Damages) have been extensively analysed in the GOALDS project /6/ and the corresponding distribution functions are readily available from /7/. However, data relevant to accidents of Type ‘S00’ (Side Damages), particularly for passenger ships have never been published before. It has been considered necessary, therefore, to develop a database with relevant accidents and to perform a statistical analysis of the collected data. Since the data from grounding accidents to passenger ships resulting to side damages were expected to be relatively few, it was decided to collect also data from accidents with containerships. This is a procedure that was adopted also in the GOALDS project, where the various ship types were divided in two main categories, i.e. “full ships” and “non-full ships”. The analysis of data from grounding accidents carried out in GOALDS, with emphasis on bottom damages /7/ indicated a common behaviour of the statistical properties of the grounding damage characteristics of passenger ships and containerships (non-full ships) on one hand and tankers and bulk carriers (full ships) on the other.

The accident types considered in this study included collision (CN), grounding (GR) and contact (CT). Collision accidents were included because one of the objectives of Task 1 was to revise and update the risk model for collision developed in GOALDS, considering additional information from recent accidents. Contact accidents were included because they are associated with hull breaches at the side of the ship, which are of particular interest for the present study. In total, 430 accidents to passenger ships and 866 accidents to containerships have been identified and included in the databases. Despite the significant number of accidents in the two databases, only for a relatively small number of cases it was possible to find quantitative data for the location and extent of the hull breach. The development of the probabilistic model for the hull breach geometric characteristics was based on the available data. However, it can be readily updated if or when an enhanced data sample becomes available. The structure of the databases and the collected data are described in more detail in /6/. The collected data have been also used in order to support the development/update of collision and grounding/contact Risk Models for RoPax and Cruise ships.

10.4 Probabilistic Models for Bottom and Side Damage Characteristics

Two sets of geometric characteristics were selected in Task 3 (Table 8-1) in order to uniquely define the location and extent of a hull breach due to a bottom or side damage. It should be noted that in case of multiple breaches, an artificial damage envelope is used, corresponding to the bounding region (box) enclosing all the breaches. This procedure is in line with that followed in GOALDS for the case of bottom damages. A probabilistic model for the geometric characteristics of bottom damages for passenger ships due to groundings has been developed in GOALDS and is used in this study with minor modifications. The corresponding probabilistic model for the case of side damages due to grounding or contact accidents has been developed in Task 3 and is presented in detail in /5/.

Table 10-1 Geometrical Modelling of Bottom / Side Breach

Bottom Damage	Side Damage
Longitudinal position of forward end of damage	Longitudinal position of forward end of damage
Longitudinal extent of potential damage	Longitudinal extent of potential damage
Transversal position of centre of damage	Potential damage penetration
Potential damage width	Vertical position of lower limit of damage
Potential damage penetration	Height of potential damage above its lower limit
	Indicator for Port or Starboard damage

10.5 Regulatory Framework

A proposal for a regulatory framework assessing survivability of passenger ships in damaged condition due to grounding or contact accident has been formulated, based on the probabilistic approach. The framework aims at determining an attained subdivision index associated with survivability of the ship in damaged condition. To this end, two factors are necessary: the probability of flooding a (group of) compartment(s) and the conditional probability of surviving the specified "damage case". The probability of survival (the so-called "s-factor") is calculated according to SOLAS 2009 (/8/) and/or SLF 55 (/11/). With respect to the probability of flooding a certain (group of) compartment(s), an innovative approach is developed for the evaluation of the so-called "p-factor". Combining "p-factors" with associated "s-factors" allows the determination of an attained subdivision index:

$$\mathrm{A} = \sum p_i s_i \tag{1}$$

A separate Attained Subdivision Index is calculated for each damage type: $A_{GR,B}$ and $A_{GR,S}$, corresponding to bottom and side damages due to grounding or contact accidents, respectively. Following SOLAS 2009, each one of the Attained Subdivision Indices, $A_{GR,B}$ and $A_{GR,S}$ is obtained by the summation of three partial indices, calculated for three draughts, d_s, d_p and d_l:

$$A_j = 0.4 A_{js} + 0.4 A_{jp} + 0.2 A_{jl} \tag{2}$$

In the above equation, suffix j stands for "GR,B" or "GR,S", corresponding to bottom or side damages, while A_{js}, A_{jp} and A_{jl} correspond to the partial indices at the three draughts d_s, d_p and d_l respectively, namely subdivision, partial and light draughts, as defined in SOLAS 2009 for damage stability calculations in case of collision accident. The level trim is used for stability calculations at the deepest subdivision draught and the partial subdivision draught and the actual service trim at the light service draught.

At the end, it is possible to obtain a single Attained Survivability Index for grounding and contact accidents, derived by the superposition of $A_{GR,B}$ and $A_{GR,S}$. A procedure for the appropriate superposition of the two A-indices, based on the "preservation of risk to human life”, expressed by the Potential Loss of Life is presented in /3/. The term *Attained Survivability Index* is introduced for this combined index instead of the well-known *Attained Subdivision Index*, in order to emphasize the fact that its calculation is based on data within the Risk Model regarding the depended probabilities of the various events, which is beyond the subdivision characteristics of each particular design.

10.6 Calculation of the p-factor

The probability of flooding a particular group of compartments p_i is calculated according to an innovative procedure, the so called “direct approach”, which is different from the traditional “zonal approach” used in SOLAS 2009. The “zonal approach” is based on the development of formulae/procedures for the calculation of the probability of flooding of a specific compartment or group of compartments. In addition, the development of software tools for the identification of all possible damage cases is required.

According to the “direct approach”, a large number of hull breaches are generated along the hull, each one with an associated probability of occurrence. For each defined hull breach, the corresponding watertight compartments open to the sea are identified. By grouping different hull breaches leading to the same (set of) compartments open to the sea, it is possible to define a limited set of flooding conditions, i.e. the called “damage cases”. Summing up the probabilities associated with all breaches leading to the same damage case, it is possible to determine the probability associated with this damage case, i.e. the “p-factor”. The probabilities of occurrence of the hull breaches must be properly linked with the underlying damage characteristics probability distributions. The generation of the hull breaches can be either random (e.g. Monte Carlo sampling) or deterministic (systematic discretisation).

10.7 Zonal vs. Direct Approach

Each of the two methods has advantages and disadvantages:

1. <u>Zonal Approach:</u>

    - The traditional zonal approach is already used in SOLAS. Therefore, it is already familiar to both designers and regulators (and also to software developers) and could be easily adopted for the calculation of the p-factors of grounding accidents.
    - The zonal approach requires the development of adequate formulae for the calculation of the p-factors. New formulae need to be developed, whenever improved damage statistics are available.
    - Damaged stability calculations based on the zonal approach require developing of software tools for the identification of the damage cases, i.e. all possible combinations of watertight compartments that may become open to the sea as a result of a hull breach.
    - The zonal approach is based on some crude simplifying assumptions (i.e. both the hull form and the damaged compartments are assumed to be box-shaped). As a result, its accuracy is questionable in case of realistic hull forms. In case of collision accidents, the errors introduced by this approximation were considered to be acceptable.

However, in case of grounding, such errors can be much larger, thus inhibiting the use of the zonal approach.

2. Direct Approach:

- The direct approach is relatively new and scarcely used. Therefore, it might take additional effort to introduce it to the designers and regulators.
- On the other hand, the direct approach is very flexible and can be readily adapted whenever new and improved damage statistics are made available in the future.
- No simplifications are required regarding the shape of the hull or the damaged compartments. Due to the inherent simplicity of the direct approach, there will be no need for lengthy and complicated explanatory notes to specify the appropriate treatment of complex, or unconventional internal geometries. Of course, additional effort will be needed to introduce the method. In some way, internal watertight integrity should also be proven in the cases developed with the direct approach.
- If the direct approach is selected, then the development of software for the analysis of grounding accidents is straightforward, since the damage cases are 'automatically' developed during the process. Therefore, there will be no need for developing additional software tools that would be otherwise necessary, in order to identify the full set of damage cases.

Based on the above, the direct approach was selected for the calculation of the p-factors, for the cases of bottom and side damages due to grounding and contact accidents.

10.8 Development of the Software Tool

A dedicated Software Tool has been developed within the NAPA package in the course and for the purpose of this study. The tool can treat both type of damages (bottom damages and side damages). These two types of damages are treated sequentially, resulting in two different A-indices. An option has been added, allowing the use of SLF 55 (/11/) proposal for the calculation of the "s-factor" for the case of RoPax ships. Two different alternatives have been implemented: the software tool generates automatically the required number of hull breaches or reads them from a special input file. User instructions and modelling considerations including alternative ways of using damage stages, openings, cross-flooding connections, up-flooding connections and A-class bulkheads are presented in /5/.

10.9 Risk Model

High-level event sequences and risk models for the various accident types have been already discussed in the first interim report of Task 1 of the EMSA III study. In Task 3, the high-level event sequence and the risk model for grounding accidents have been revisited, in order to take into account an additional parameter that was introduced in Task 3, with decisive impact on the survivability of passenger ships, i.e. the type of damage: (a) bottom damage (type B00) and (b) side damage (type S00). The corresponding Risk Models have been subsequently developed: (a) Risk Model for Grounding Accidents to cruise ships, (b) Risk Model for Grounding Accidents to RoPax ships, (c) Combined Risk Model for Grounding and Contact

Accidents to cruise ships, (d) Combined Risk Model for Grounding and Contact Accidents to RoPax ships. The combined Risk Model for Grounding and Contact Accidents to cruise ships and RoPax ships is presented in /3/.

10.10 Application of the Framework and Assessment of Risk Control Options

The developed procedure and software tool have been applied for the damaged stability evaluation of a series of passenger ships. More specifically, two cruise ships and four RoPax ships, developed in Task 1 (reference designs) along with a series of variants of these designs, developed to maximize safety in damaged condition have been assessed and the attained indices corresponding to bottom and side damages due to grounding accidents have been calculated. On the basis of the results obtained in Subtask 3.c, a Cost Benefit Assessment (CBA) has been performed according to the IMO FSA Guidelines. The RCOs for a large cruise ship and for a medium size RoPax ship have been compared on the bases of the obtained reduction of risk and the associated lifetime cost. The details of the calculations and the obtained results are summarized in /3/.

10.11 Risk to Human Life due to Grounding and Contact Accidents

For all variants of the six passenger ships that were assessed, the A-indices for bottom and side damage were quite large, larger than the A-index for collisions. The $A_{GR,S}$ index, calculated for grounding accidents resulting to side damage was larger than A_{GN} (the A-index for collision damages) by a difference ranging from 0.03 to 0.12, with the exception of one design variant where the two indices were practically equal. With the exception of three design variants, the $A_{GR,B}$ index, calculated for grounding accidents resulting to bottom damage was even larger than $A_{GR,S}$. This is partly due to the protection offered by the double bottom. For bottom damages it is relatively easy to achieve a very high attained index cost-effectively by reducing or eliminating upflooding openings, to protect higher spaces in case of damages with a penetration exceeding the double bottom height.

Design variants with improved survivability in case of collision accidents, generally exhibit improved survivability in case of grounding and contact accidents as well.

The quite high values of the $A_{GR,S}$ index may be to some extend attributed to the fact that the probabilistic model for the geometric characteristics of the hull breaches has been developed using data from grounding and contact accidents. Since contact accidents are expected to lead to breaches of reduced length, if a new probabilistic model could be developed based only on grounding accidents, it is reasonable to expect that this would lead to an increase in the relative frequency of longer damages and hence to a reduction of the corresponding A-index. At the same time however, the initial frequency of accidents would be much smaller and the overall result would be a reduction of the calculated risk to human life.

Despite the increased A-index associated with grounding and contact accidents, the resulting risk to human life (the PLL calculated by the corresponding risk models) is higher than that for collision accidents**.** The main reason for this is the higher initial frequency of grounding and contact accidents in comparison with that of collisions both for RoPax and Cruise ships while, in addition, the dependent probability of having a hull breach and water ingress in case of an accident is found to be higher in case of grounding and contact accidents than for collisions.

The risk to human life in case of grounding and contact accidents is mainly associated with the side damages, while the contribution from bottom damages is much smaller. The main reasons for this behaviour are:

- The smaller A-Index in case of side breaches. As already mentioned this is partly because of the protection offered by the double bottom in case of bottom damages.
- Bottom groundings are quite often associated with a soft bottom, resulting in no hull breach and therefore to zero fatalities. On the other hand, in case of side grounding or contact, there is no chance of soft bottom, therefore the probability of a hull breach and water ingress is increased accordingly.
- In case of bottom grounding, even with a hard bottom, there is a quite significant probability that the ship remains aground, in which case there is no sinking or capsizing and no fatalities are calculated by the risk model. The corresponding probability that the ship remains aground is much smaller in case of a side damage.

10.12 Observations and Recommendations concerning the risk from grounding

- The probability of survival (the so-called "s-factor") is calculated according to SOLAS 2009 (/8/) and/or SLF 55 (/11/), which addresses collision. Although this might be considered as a rough approximation, the use of SOLAS 2009 and SLF 55 procedure for the s-factor was discussed in detail and agreed between the partners, given that there were no resources in order to develop a more suitable procedure within this study.
- Given that the s-factor is based on probability of capsize within half an hour following collision (Ref. /10/), raises further questions concerning the validity of such formulation for cruise ships (safe side uncertainty).
- More research activities are needed to achieve a robust procedure, which may be acceptable by the maritime community.

11 SENSITIVITY AND UNCERTAINTY

11.1 ΔPLL and Cost Values for collision and grounding

For evaluating cost efficiency of designs with increased damage stability, cost thresholds were calculated by multiplying the risk reduction achieved by increased A-Indices with two CAF values of 4 million USD and 8 million USD. If the additional costs of a novel design are below such a threshold it is regarded to be cost effective. For these calculations the risk models for collision and grounding/contact were used.

The risk models were developed considering accident statistics and casualty reports for the development of the scenarios as well as for accident frequencies and dependent probabilities. The uncertainty in all these values depends on the available information, i.e. sample size. As mentioned in Appendix D of the report of Task 1 this uncertainty can be considered via distributions for initial accident frequencies as well as for most of dependent probabilities. The risk models were realised using the software tool Palisade© that allows the consideration of the uncertainty via distributions. For all nodes in the risk models for which uncertainty was considered, a distribution was specified and a static value used for calculation without uncertainty. The details of the approximation of the uncertainty were explained in the above mentioned report. This allowed calculating cost threshold not only for the static values (the values given in the event trees) but also for mean as well as for the percentiles[2] 5%, 50% and 95%. The cost thresholds for the different percentiles allow conclusions on the soundness of the result of CBA because they indicate the probability that the cost threshold is higher or lower. In particular the interval 5% - 95% provides a good indication of the uncertainty in the cost efficiency evaluation, i.e. small interval shows low uncertainty.

In the following tables (Table 11-1, Table 11-2, Table 11-3 and Table 11-4) the results (cost thresholds) for the various design options are summarised calculated with the risk models and separately for collision and grounding/contact. Each of the tables summarise the values for one accident category and one CAF value (4 or 8 million USD). In the first row of each ship size category, e.g. Large Cruise, the values for A-Index and PLL of the reference design are given, e.g. G2. For each of the designs investigated, the A-Index, PLL, ΔPLL for 30 years and the cost thresholds are given.

[2] A percentile (or a centile) is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations fall. For example, the 5% percentile is the value (or score) below which 5% percent of the observations may be found. (Wikipedia)

Table 11-1 VPF Values Collision (4 million USD)

	Vers.	A-Index	PLL	ΔPLL	4 m$				
		SOLAS 2009	1/ship year	(30 a)	Static	Mean	50%	5%	95%
Small	00 (Init)	0.7202	0.00938						
	06	0.8281	0.00576	1.08E-01	4.34E+05	5.43E+05	4.34E+05	8.3E+04	1.4E+06
	09	0.7789	0.00741	5.90E-02	2.36E+05	2.95E+05	2.28E+05	4.5E+04	7.4E+05
Large									
	G2	0.8621	0.06456						
	G3	0.8643	0.06353	3.09E-02	1.24E+05	1.54E+05	1.23E+05	2.3E+04	3.9E+05
	I3	0.9288	0.03333	9.37E-01	3.75E+06	4.66E+06	3.68E+06	6.9E+05	1.2E+07
	K3	0.8754	0.05833	1.87E-01	7.47E+05	9.34E+05	7.32E+05	1.5E+05	2.3E+06
	K4	0.8792	0.05655	2.40E-01	9.61E+05	1.21E+06	9.60E+05	1.8E+05	3.0E+06
	M1	0.8529	0.06887	-1.29E-01	-5.17E+05	-6.41E+05	-5.13E+05	-1.6E+06	-1.0E+05
	M2	0.8747	0.05866	1.77E-01	7.08E+05	8.87E+05	6.98E+05	1.3E+05	2.2E+06
Baltic	A (Init)	0.8326	0.08829						
	L	0.9152	0.04472	1.31E+00	5.23E+06	6.39E+06	5.13E+06	8.3E+05	1.6E+07
Mediterranean	V00	0.8398	0.04356						
	V14	0.8718	0.03486	2.61E-01	1.04E+06	1.27E+06	1.03E+06	1.7E+05	3.2E+06
	V15	0.8717	0.03489	2.60E-01	1.04E+06	1.27E+06	1.02E+06	1.7E+05	3.3E+06
	V16	0.88086	0.0324	3.35E-01	1.34E+06	1.63E+06	1.32E+06	2.2E+05	4.1E+06
Small	1(Init)	0.7947	0.02036						
	2	0.8426	0.01561	1.42E-01	5.70E+05	6.96E+05	5.65E+05	9.0E+04	1.8E+06
Small (De)	0(Init)	0.8412	0.01514						
	1	0.8601	0.01334	5.40E-02	2.16E+05	2.65E+05	2.15E+05	3.6E+04	6. 6E+05

Table 11-2 VPF Values Collision (8 million USD)

	Vers.	A-Index	PLL	ΔPLL	8 m$				
		SOLAS 2009	1/ship year	(30 a)	Static	Mean	50%	5%	95%
Small	00 (Init)	0.7202	0.00938						
	06	0.8281	0.00576	1.0850E-01	8.68E+05	1.08E+06	8.65E+05	1.7E+05	2.7E+06
	09	0.7789	0.00741	5.9012E-02	4.72E+05	5.85E+05	4.7E+05	9.1E+04	1.5E+06
Large									
	G2	0.8621	0.06456						
	G3	0.8643	0.06353	3.0898E-02	2.47E+05	3.09E+05	2.45E+05	4.7E+04	8.0E+05
	I3	0.9288	0.03333	9.3678E-01	7.49E+06	9.31E+06	7.37E+06	1..4E+06	2.4E+07
	K3	0.8754	0.05833	1.8680E-01	1.49E+06	1.87E+06	1.46E+06	3.0E+05	4.7E+06
	K4	0.8792	0.05655	2.4017E-01	1.92E+06	2.41E+06	1.92E+06	3.6E+05	6.0E+06
	M1	0.8529	0.06887	-1.2921E-01	-1.03E+06	-1.28E+06	-1.03E+06	-3.3E+06	-2.0E+05
	M2	0.8747	0.05866	1.7696E-01	1.42E+06	1.77E+06	1.40E+06	2.6E+05	4.4E+06
Baltic	A (Init)	0.8326	0.08829						
	L	0.9152	0.04472	1.3069E+00	1.05E+07	1.28E+07	1.03E+07	1.7E+06	3.2E+07
Mediterranean	V00	0.8398	0.04356						
	V14	0.8718	0.03486	2.6090E-01	2.09E+06	2.53E+06	2.06E+06	3.4E+05	6.4E+06
	V15	0.8717	0.03489	2.6009E-01	2.08E+06	2.54E+06	2.04E+06	.3.4E+05	6.5E+06
	V16	0.88086	0.0324	3.3478E-01	2.68E+06	3.28E+06	2.66E+06	4.5E+05	8.3E+06
Small	1(Init)	0.7947	0.02036						
	2	0.8426	0.01561	1.4246E-01	1.14E+06	1.40E+06	1.13E+06	1.8E+05	3.5E+06
Small (De)	0(Init)	0.8412	0.01514						
	1	0.8601	0.01334	5.3989E-02	4.32E+05	5.31E+05	4.30E+05	7.1E+04	1.3E+06

Table 11-3 VPF Values Grounding (4 million USD)

Ship type		Grounding			PLL	Bottom damage			Side damage				4 m$				
		A_{bottom}	A_{side}	$A_{grounding}$		ΔA	PLL	ΔPLL	ΔA	PLL	ΔPLL	ΔPLL (total)	Static	Mean	50%	5%	95%
Large cruise	Ref G2	0.9171	0.9135	0.9142	0.334048		1/ship year	1/ship year		1/ship year	1/ship year	30 a					
	I3	0.9483	0.952	0.9513	0.189599	0.0312	3.84E-02	2.32E-02	0.0385	1.51E-01	1.21E-01	4.33E+00	1.73E+07	1.57E+07	1.50E+07	7.00E+06	2.64E+07
	K3	0.9625	0.9522	0.9543	0.178424	0.0454	2.78E-02	3.37E-02	0.0387	1.51E-01	1.22E-01	4.67E+00	1.87E+07	1.67E+07	1.60E+07	7.91E+06	2.78E+07
	G3	0.9264	0.9354	0.9336	0.258153	0.0093	5.47E-02	6.91E-03	0.0219	2.03E-01	6.90E-02	2.28E+00	9.11E+06	8.33E+06	7.94E+06	3.70E+06	1.43E+07
	K4	0.9621	0.9534	0.9551	0.174941	0.045	2.81E-02	3.34E-02	0.0399	1.47E-01	1.26E-01	4.77E+00	1.91E+07	1.71E+07	1.64E+07	8.01E+06	2.85E+07
	M1	0.9406	0.9818	0.9736	0.101442	0.0235	4.41E-02	1.75E-02	0.0683	5.73E-02	2.15E-01	6.98E+00	2.79E+07	2.56E+07	2.44E+07	1.13E+07	4.46E+07
	M2	0.9416	0.978	0.9707	0.11267	0.0245	4.34E-02	1.82E-02	0.0645	6.93E-02	2.03E-01	6.64E+00	2.66E+07	2.43E+07	2.31E+07	1.08E+07	4.11E+07
Small Cruise	Ref 00	0.8799	0.8312	0.8409	0.044609												
	06	0.9192	0.8897	0.8956	0.029273	0.0393	4.30E-03	2.09E-03	0.0585	2.50E-02	1.32E-02	4.60E-01	1.84E+06	1.67E+06	1.60E+06	7.61E+05	2.79E+06
	09	0.9159	0.8589	0.8703	0.036422	0.036	4.47E-03	1.92E-03	0.0277	3.19E-02	6.27E-03	2.46E-01	9.82E+05	8.76E+05	8.34E+05	4.16E+05	1.47E+06
Baltic RoPax	Ref A	0.9707	0.9351	0.9422	0.203074												
	L	0.9737	0.9697	0.9705	0.10436	0.003	1.99E-02	2.27E-03	0.0346	8.45E-02	9.64E-02	2.96E+00	1.18E+07	1.07E+07	1.02E+07	4.88E+06	1.80E+07
Mediterannean RoPax	Ref 1	0.9811	0.9475	0.9542	0.082807												
	5(V14)	0.9829	0.9519	0.9581	0.075775	0.00182	6.67E-03	7.10E-04	0.0044	6.91E-02	6.32E-03	2.11E-01	8.44E+05	7.58E+05	7.33E+05	3.63E+05	1.26E+06
	V15	0.9823	0.9584	0.9632	0.066671	0.00122	6.91E-03	4.76E-04	0.0109	5.98E-02	1.57E-02	4.84E-01	1.94E+06	1.76E+06	1.69E+06	8.02E+05	2.93E+06
	V16	0.9948	0.9680	0.9734	0.048002	0.01372	2.03E-03	5.35E-03	0.0205	4.60E-02	2.95E-02	1.04E+00	4.18E+06	3.71E+06	3.59E+06	1.86E+06	6.02E+06
Small RoPax	Ref SRoPax1	0.9789	0.9171	0.9295	0.046639												
	SRoPax2	0.9767	0.8852	0.9035	0.06372	0.00223	3.32E-03	-3.18E-04	0.03186	6.04E-02	-1.68E-02	-5.12E-01	-2.05E+06	-1.86E+06	-1.79E+06	-3.11E+06	-8.56E+05
De Ferry	Ref 0	0.9987	0.9165	0.9329	0.042337												
	De1	0.9982	0.9098	0.9275	0.045804	0.00053	2.46E-04	-7.25E-05	0.00672	4.56E-02	-3.39E-03	-1.04E-01	-4.16E+05	-3.77E+05	-3.60E+05	-6.31E+05	-1.70E+05

Table 11-4 VPF Values Grounding (8 million USD)

Ship type		Grounding			PLL	Bottom damage			Side damage				8 m$				
		A_{bottom}	A_{side}	$A_{grounding}$		ΔA	PLL	ΔPLL	ΔA	PLL	ΔPLL	ΔPLL (total)	Static	Mean	50%	5%	95%
							1/ship year	1/ship year		1/ship year	1/ship year	30 a					
Large cruise	Ref G2	0.9171	0.9135	0.9142	0.334048												
	I3	0.9483	0.952	0.9513	0.189599	0.0312	3.84E-02	2.32E-02	0.0385	1.51E-01	1.21E-01	4.33E+00	3.47E+07	3.13E+07	3.01E+07	1.40E+07	5.28E+07
	K3	0.9625	0.9522	0.9543	0.178424	0.0454	2.78E-02	3.37E-02	0.0387	1.51E-01	1.22E-01	4.67E+00	3.73E+07	3.34E+07	3.20E+07	1.58E+07	5.57E+07
	G3	0.9264	0.9354	0.9336	0.258153	0.0093	5.47E-02	6.91E-03	0.0219	2.03E-01	6.90E-02	2.28E+00	1.82E+07	1.67E+07	1.59E+07	7.40E+06	2.86E+07
	K4	0.9621	0.9534	0.9551	0.174941	0.045	2.81E-02	3.34E-02	0.0399	1.47E-01	1.26E-01	4.77E+00	3.82E+07	3.42E+07	3.29E+07	1.60E+07	5.71E+07
	M1	0.9406	0.9818	0.9736	0.101442	0.0235	4.41E-02	1.75E-02	0.0683	5.73E-02	2.15E-01	6.98E+00	5.58E+07	5.13E+07	4.87E+07	2.26E+07	8.92E+07
	M2	0.9416	0.978	0.9707	0.11267	0.0245	4.34E-02	1.82E-02	0.0645	6.93E-02	2.03E-01	6.64E+00	5.31E+07	4.86E+07	4.63E+07	2.16E+07	8.22E+07
Small Cruise	Ref 00	0.8799	0.8312	0.8409	0.044609												
	06	0.9192	0.8897	0.8956	0.029273	0.0393	4.30E-03	2.09E-03	0.0585	2.50E-02	1.32E-02	4.60E-01	3.68E+06	3.34E+06	3.20E+06	1.52E+06	5.58E+06
	09	0.9159	0.8589	0.8703	0.036422	0.036	4.47E-03	1.92E-03	0.0277	3.19E-02	6.27E-03	2.46E-01	1.96E+06	1.75E+06	1.67E+06	8.32E+05	2.95E+06
Baltic RoPax	Ref A	0.9707	0.9351	0.9422	0.203074												
	L	0.9737	0.9697	0.9705	0.10436	0.003	1.99E-02	2.27E-03	0.0346	8.45E-02	9.64E-02	2.96E+00	2.37E+07	2.14E+07	2.04E+07	9.76E+06	3.60E+07
Mediterannean RoPax	Ref 1	0.9811	0.9475	0.9542	0.082807												
	5(V14)	0.9829	0.9519	0.9581	0.075775	0.00182	6.67E-03	7.10E-04	0.0044	6.91E-02	6.32E-03	2.11E-01	1.69E+06	1.52E+06	1.47E+06	7.25E+05	2.51E+06
	V15	0.9823	0.9584	0.9632	0.066671	0.00122	6.91E-03	4.76E-04	0.0109	5.98E-02	1.57E-02	4.84E-01	3.87E+06	3.51E+06	3.37E+06	1.60E+06	5.86E+06
	V16	0.9948	0.9680	0.9734	0.048002	0.01372	2.03E-03	5.35E-03	0.0205	4.60E-02	2.95E-02	1.04E+00	8.35E+06	7.43E+06	7.18E+06	3.72E+06	1.20E+07
Small RoPax	Ref SRoPax1	0.9789	0.9171	0.9295	0.046639												
	SRoPax2	0.9767	0.8852	0.9035	0.06372	-0.00223	3.32E-03	-3.18E-04	-0.03186	6.04E-02	-1.68E-02	-5.12E-01	-4.10E+06	-3.71E+06	-3.59E+06	-6.21E+06	-1.71E+06
De Ferry	Ref 0	0.9987	0.9165	0.9329	0.042337												
	De1	0.9982	0.9098	0.9275	0.045804	-0.00053	2.46E-04	-7.25E-05	-0.00672	4.56E-02	-3.39E-03	-1.04E-01	-8.32E+05	-7.54E+05	-7.21E+05	-1.26E+06	-3.39E+05

11.2 Sensitivity Analysis

The uncertainty in several of the parameters of the risk model was approximated by distributions. The risk models were used to calculate cost thresholds for the evaluation of the cost of RCOs. For these cost thresholds the uncertainty was expressed in terms of the 90% confidence interval, i.e. giving the cost thresholds relating to 5% and 95% percentile.

Additionally, in this section the sensitivity of the cost thresholds with respect to variation in the parameters of the risk model were investigated using the data for the designs developed in EMSA III project and focusing on increased damage stability in collision as well as grounding/contact accidents. For this sensitivity analysis the parameters were changed and the impact on the cost thresholds was determined.

These sensitivity analyses were carried out for the ship types and ship size under consideration, the risk models collision and grounding-contact and the following parameters:

- Initial accident frequency;
- Operational area (terminal or other waters);
- Fast or slow sinking.

First, sensitivity was investigated in terms of what is the effect of one additional or less accident:

- Initial accident frequency: ±1 accident;
- Operational area (terminal or other waters): moving one accident between both categories;
- Fast or slow sinking: ±1% in the rate of fast sinking.

However, the results for grounding/contact showed so small influence and therefore the variation was increased to 10 for both risk models.

The results were graphically summarised in the following by plotting the sensitivity as error bars around the result of the risk model.

Collision

The results for the sensitivity with respect to initial accident frequency are summarised in the following. The variation in initial accident frequency by ±10 accidents is equal to a relative change in initial accidents frequency of ±59% for Cruise and ±20% for RoPax. The sensitivity of the cost thresholds with respect to the variation in parameter values depends also on the ΔRisk achieved by the design variant, i.e. risk control option with new damage stability.

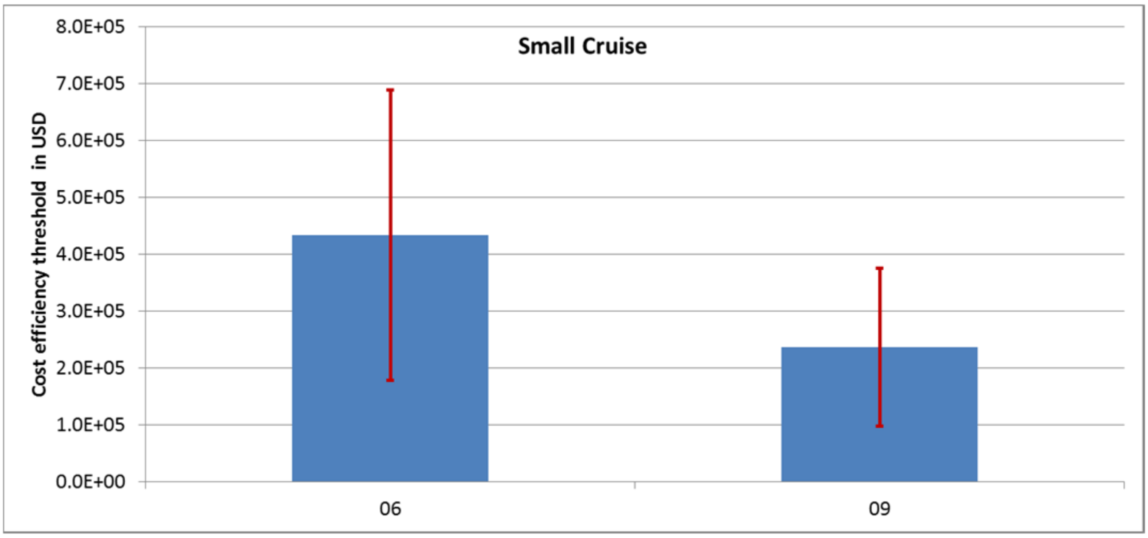

Figure 11-1 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for small Cruise.

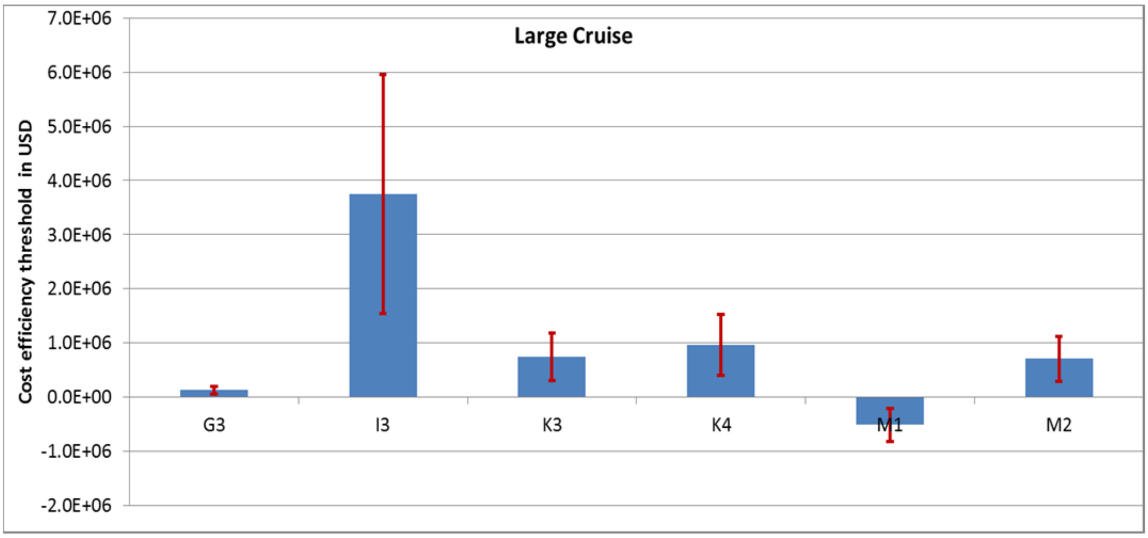

Figure 11-2 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for large Cruise.

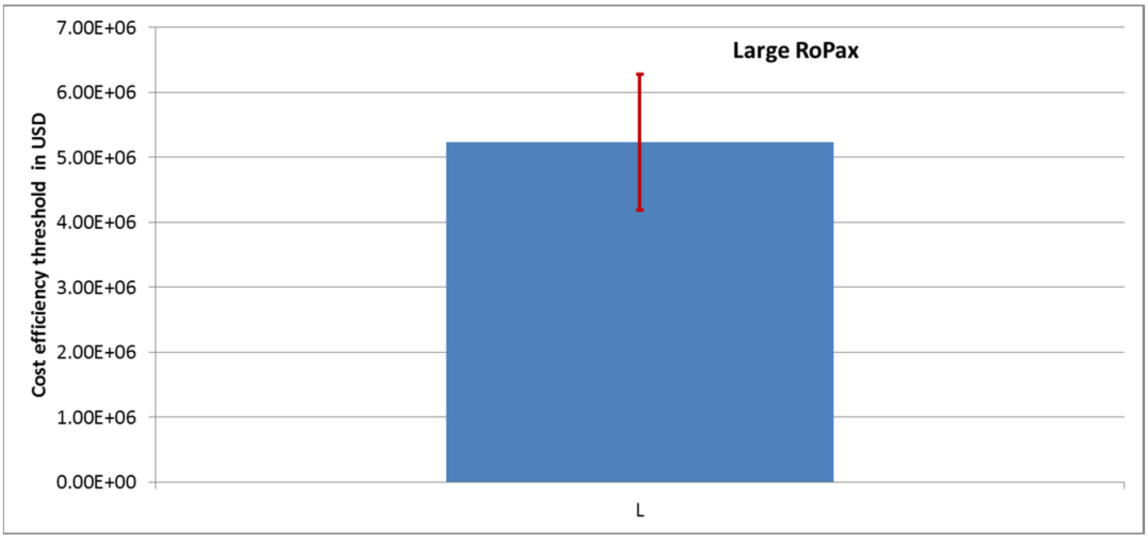

Figure 11-3 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for large RoPax.

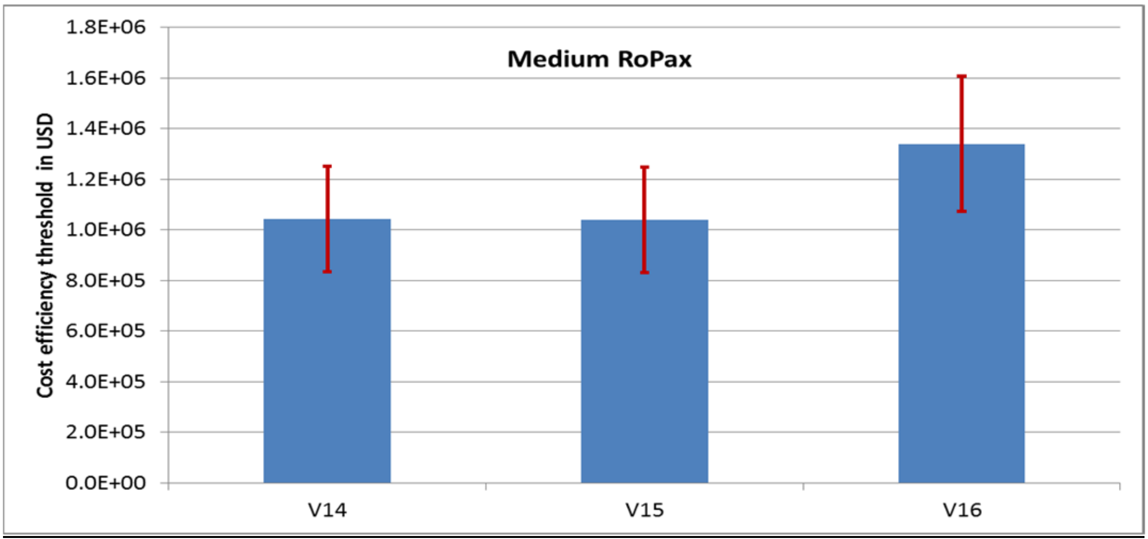

Figure 11-4 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for medium RoPax.

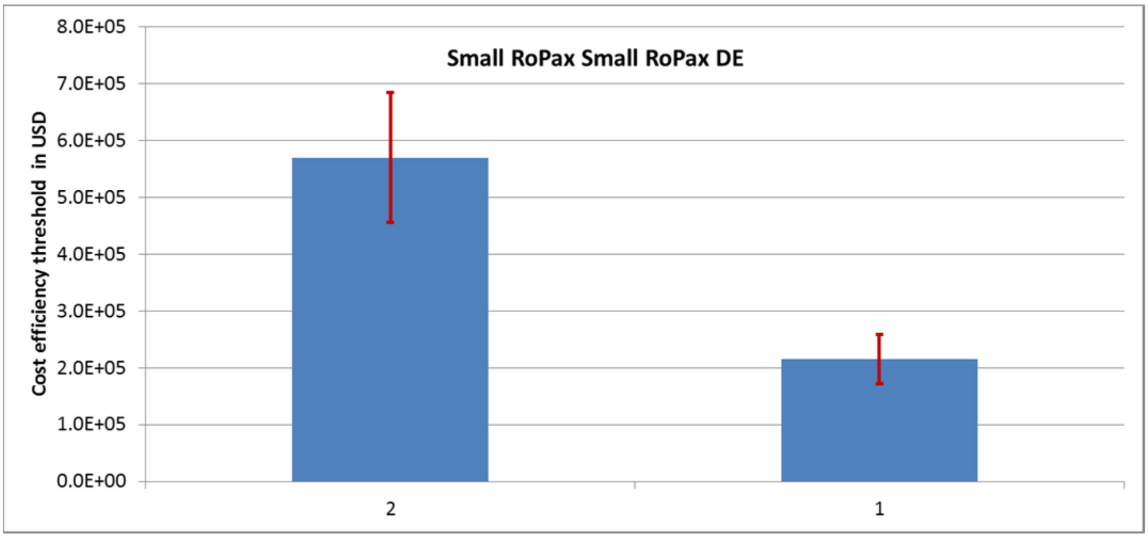

Figure 11-5 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for small RoPax.

The variation in dependent probability for operational area (terminal – other waters) (±10 accidents in terminal area, total number of accidents kept constant) is equal to a relative change in the probability of having an accident in terminal area of ±48% for both ship types. As shown by the figures the impact on the cost threshold and subsequently on the cost-benefit assessment is significant.

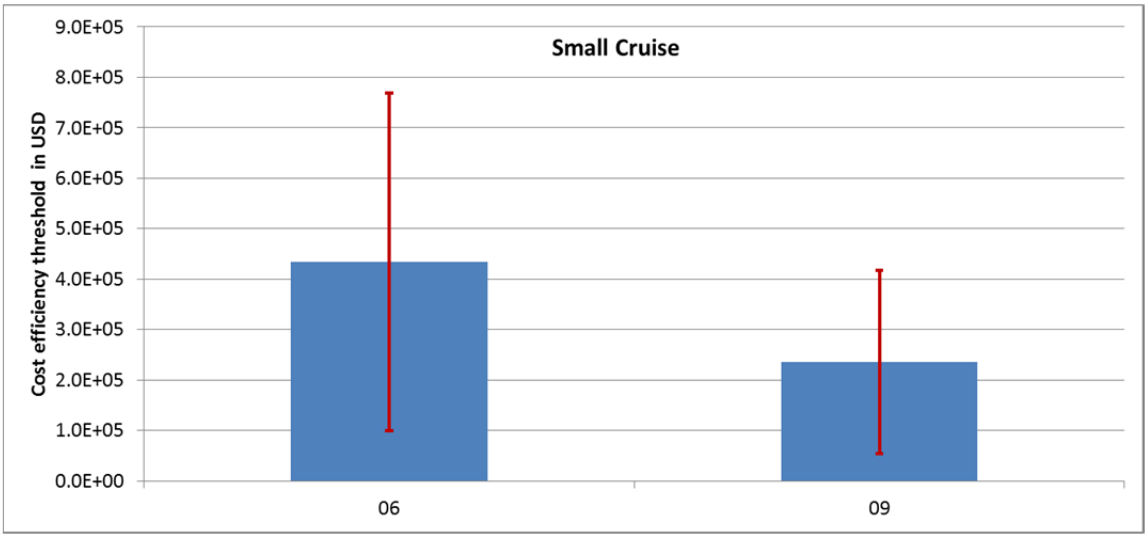

Figure 11-6 Sensitivity of cost threshold for CAF of 4 million USD with respect to operational area and for novel designs for small Cruise.

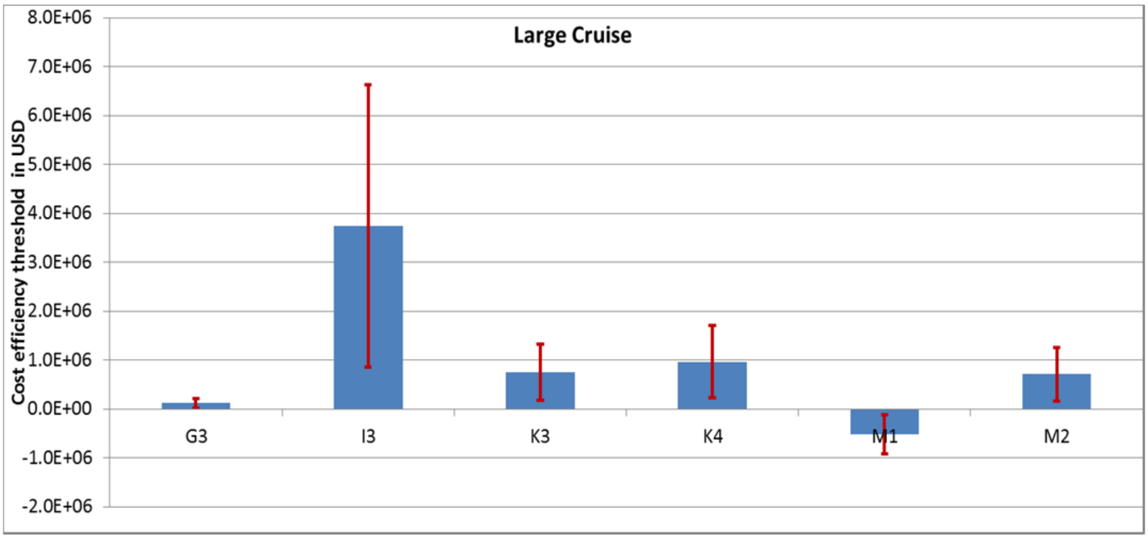

Figure 11-7 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for large Cruise.

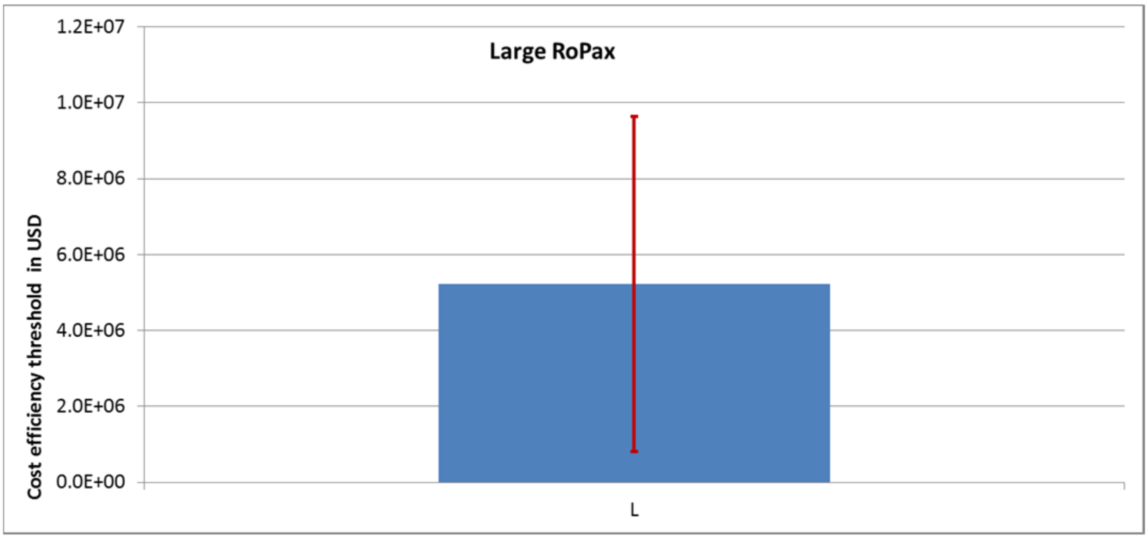

Figure 11-8 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for large RoPax.

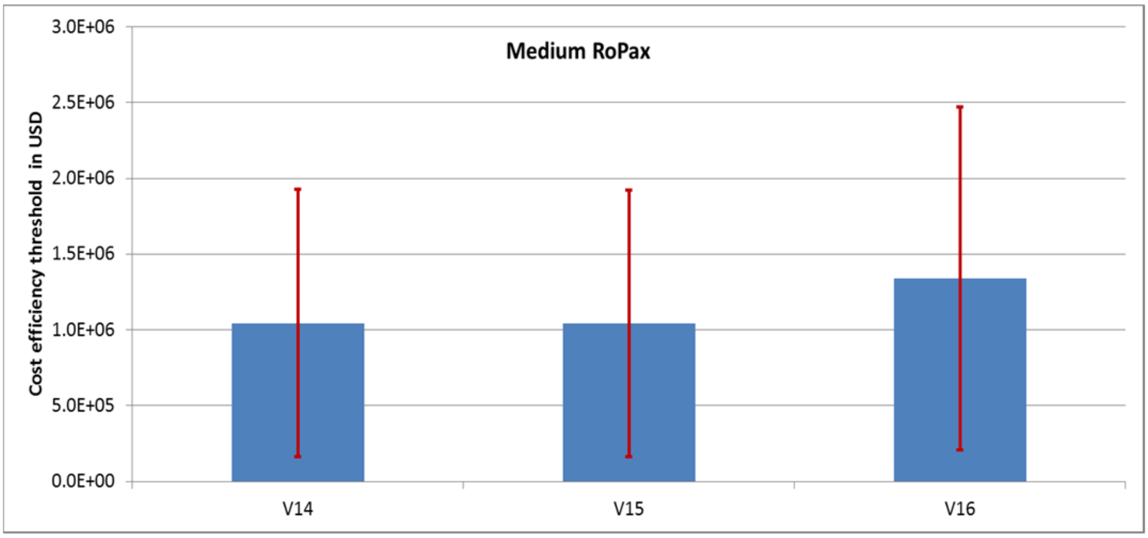

Figure 11-9 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for medium RoPax.

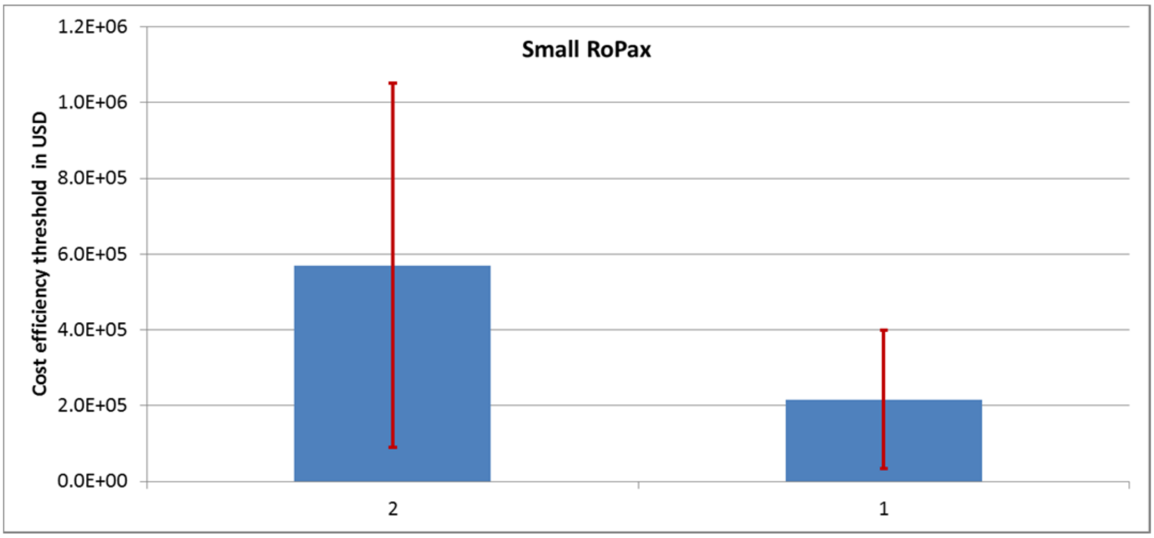

Figure 11-10 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for small RoPax.

The results for variation in dependent probability for fast sinking (±10% probability of fast sinking) were summarised below.

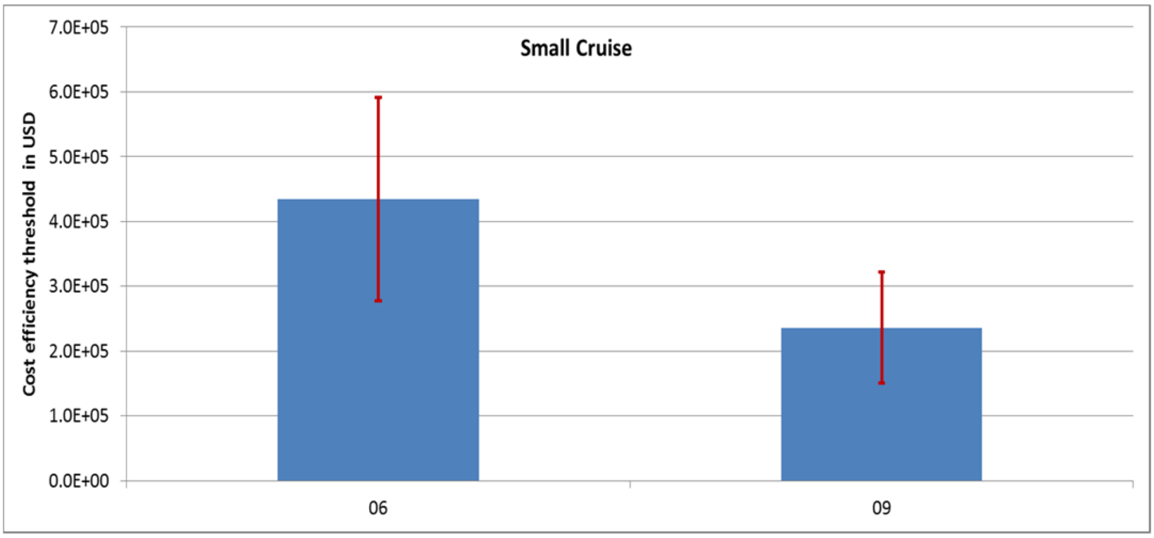

Figure 11-11 Sensitivity of cost threshold for CAF of 4 million USD with respect to fast/slow sinking and for novel designs for small Cruise.

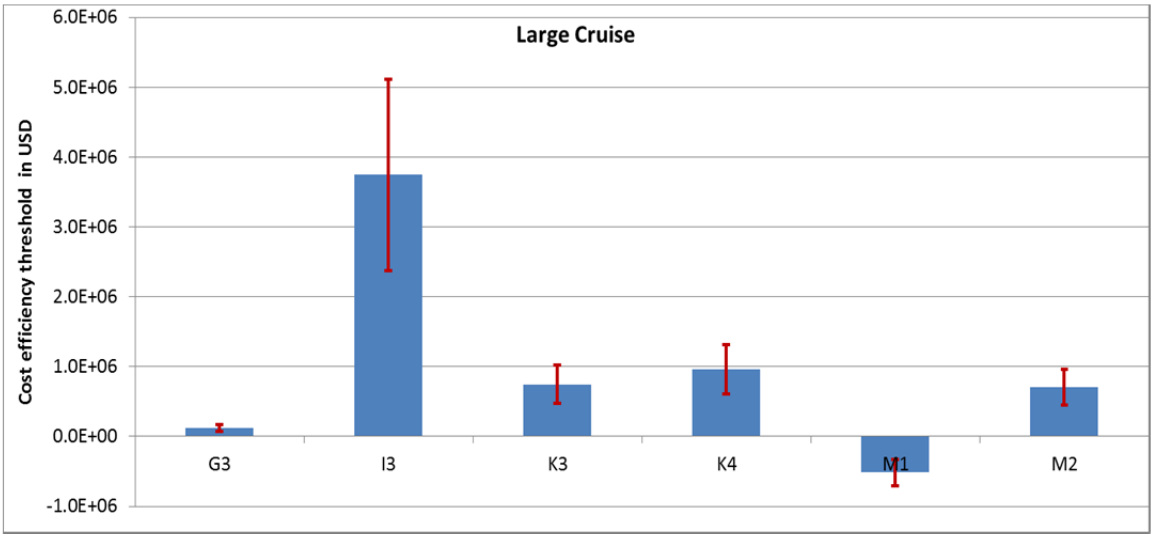

Figure 11-12 Sensitivity of cost threshold for CAF of 4 million USD with respect to fast/slow sinking and for novel designs for large Cruise.

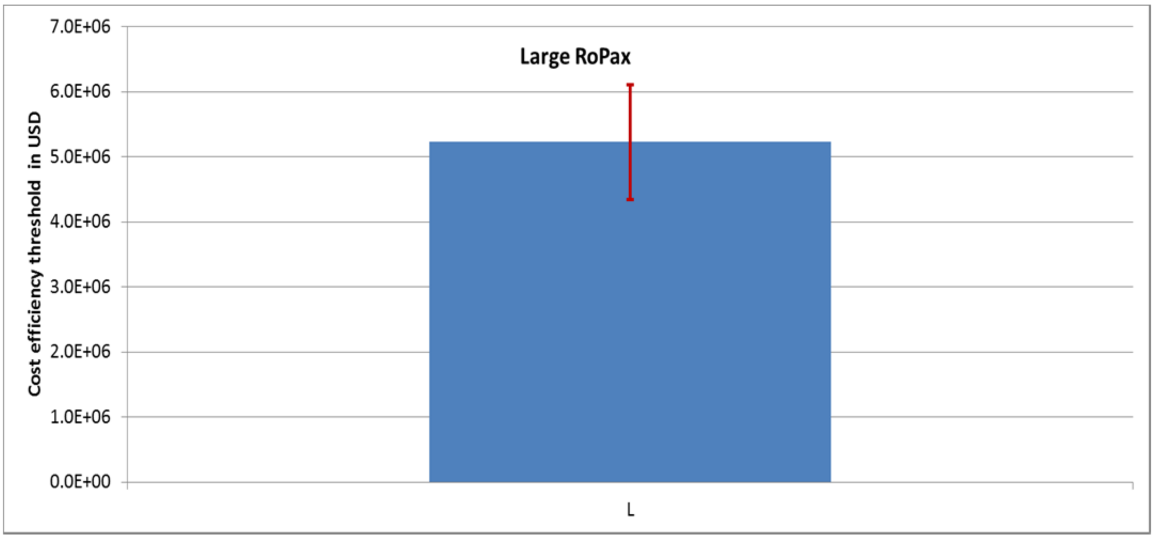

Figure 11-13 Sensitivity of cost threshold for CAF of 4 million USD with respect to fast/slow sinking and for novel designs for large RoPax.

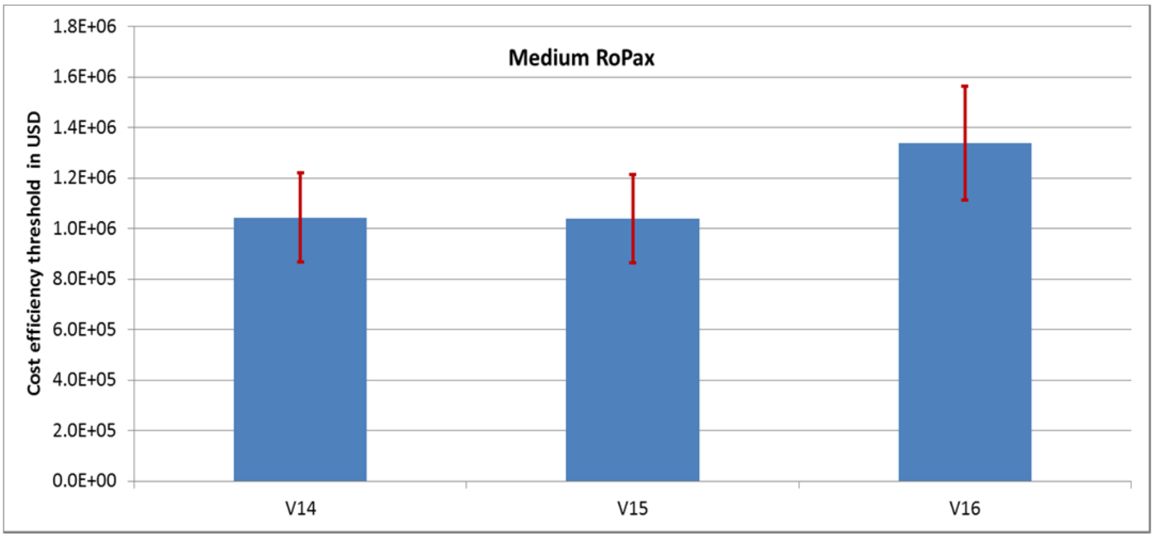

Figure 11-14 Sensitivity of cost threshold for CAF of 4 million USD with respect to fast/slow sinking and for novel designs for medium RoPax.

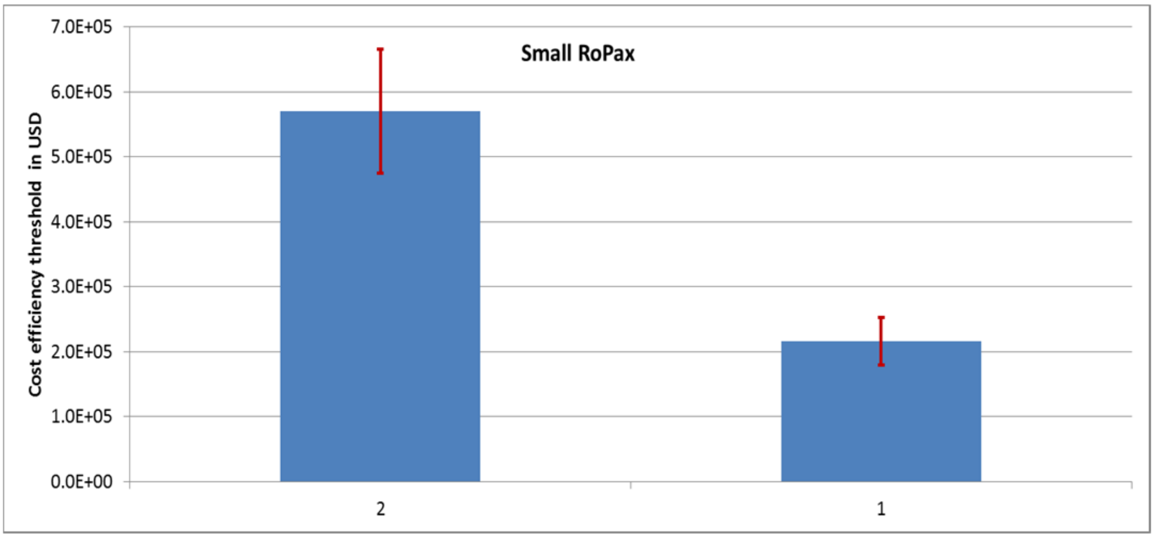

Figure 11-15 Sensitivity of cost threshold for CAF of 4 million USD with respect to fast/slow sinking and for novel designs for small RoPax.

Grounding/Contact

The variation in initial accident frequency (±10 accidents) is equal to a relative change in accident frequency of ±24% for Cruise and ±9% for RoPax. Due to the linearity of the risk model the effect on cost thresholds is of the same value. The figures in the following summarise the results graphically in a view to provide easier access to the results.

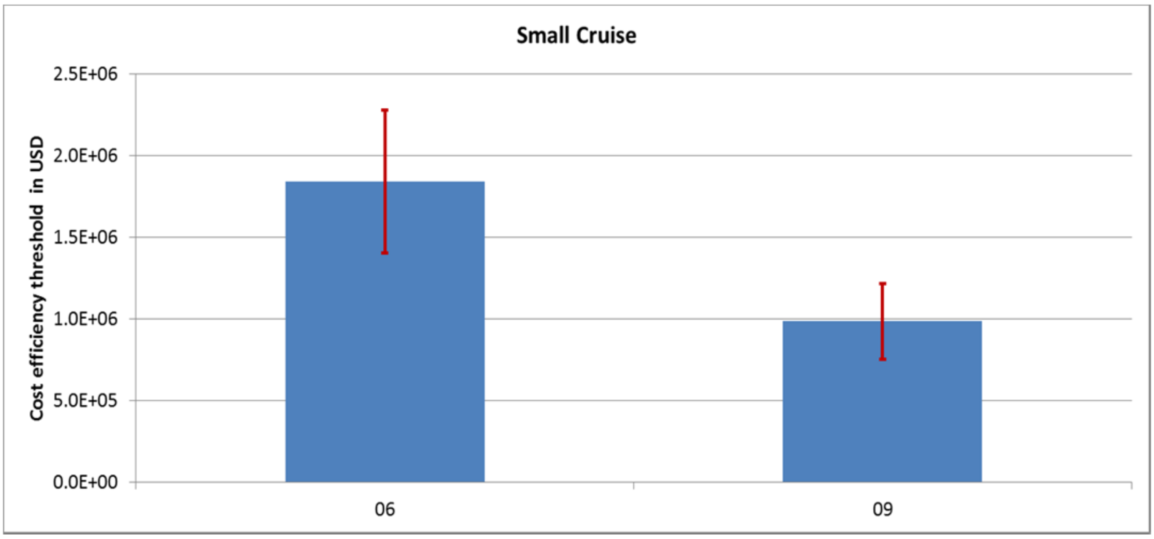

Figure 11-16 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for small Cruise.

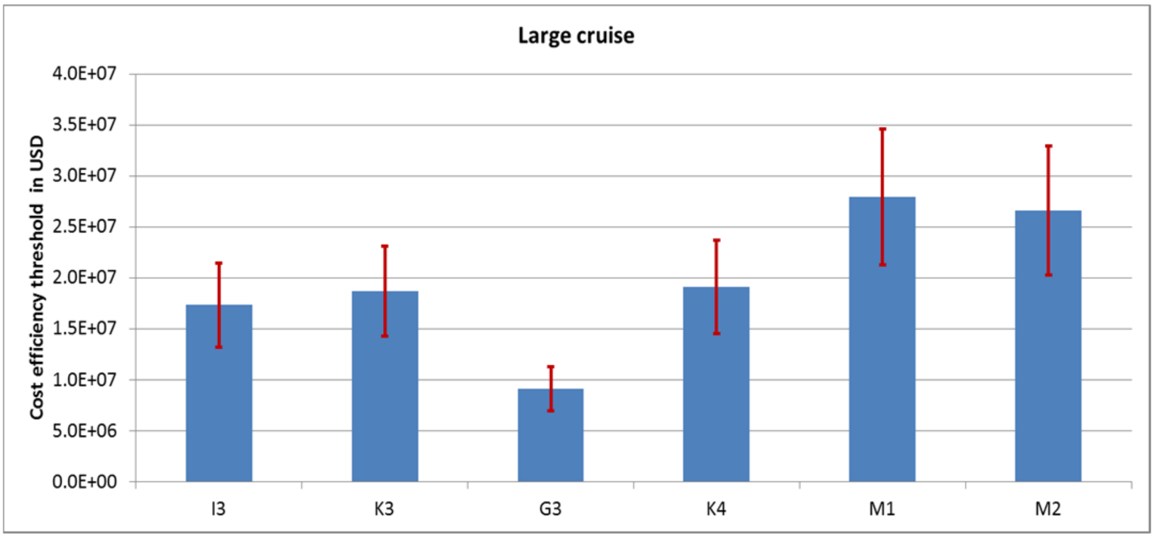

Figure 11-17 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for large Cruise.

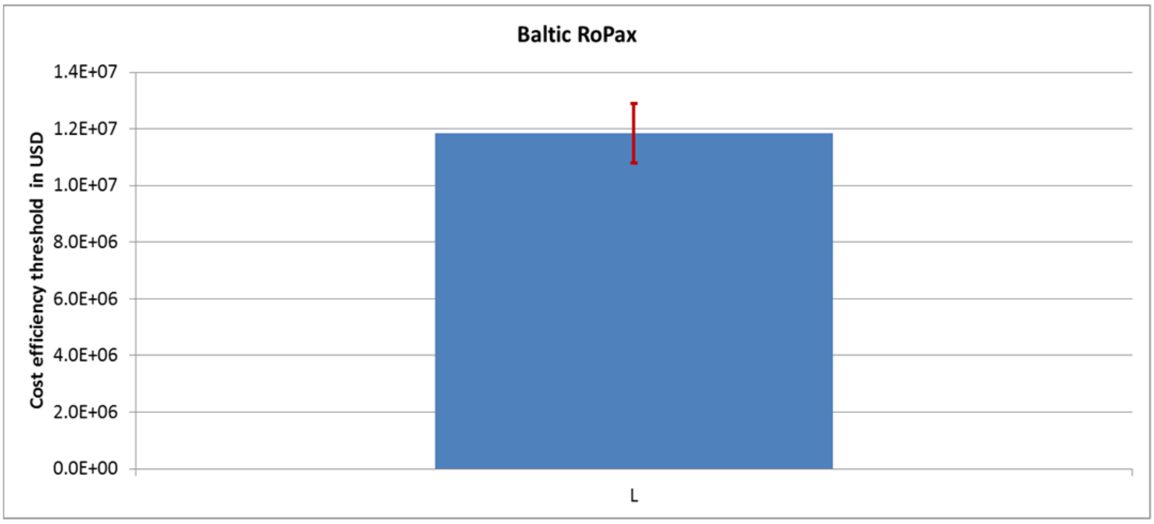

Figure 11-18 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for large RoPax.

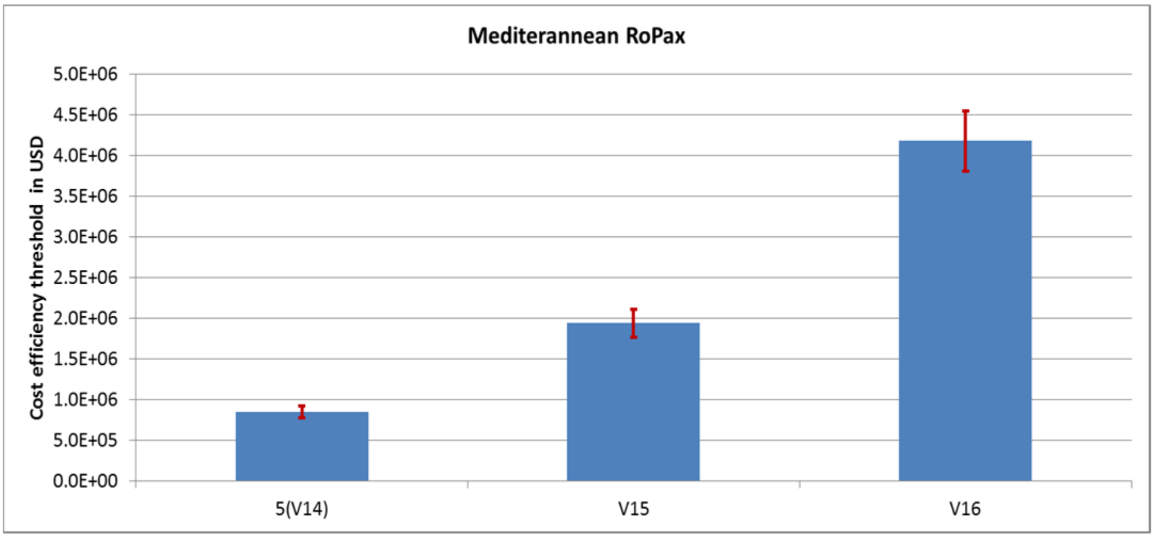

Figure 11-19 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for medium RoPax.

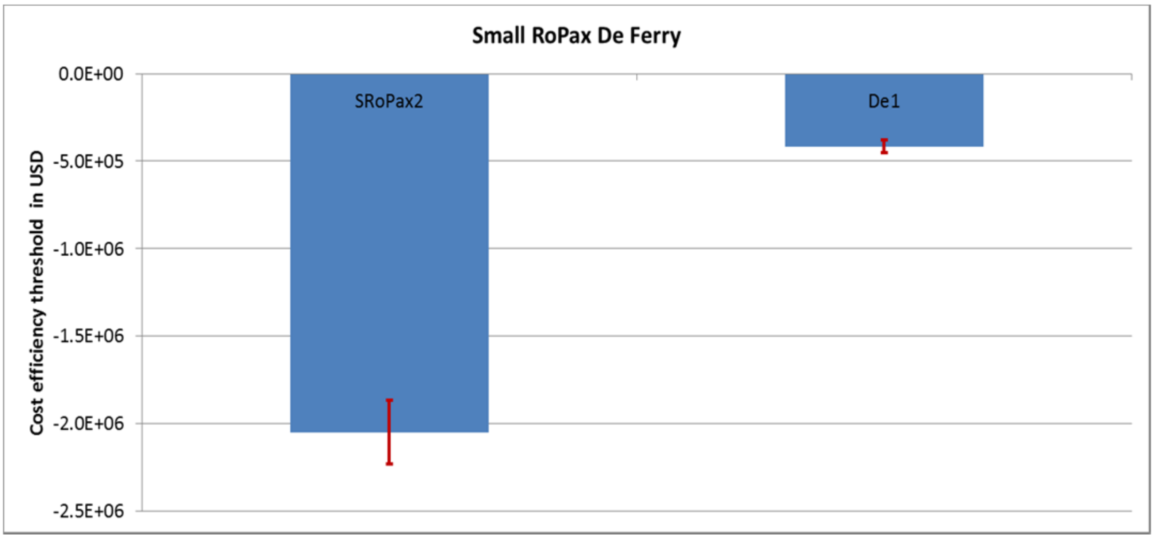

Figure 11-20 Sensitivity of cost threshold for CAF of 4 million USD with respect to *initial accident frequency* and for novel designs for small RoPax.

The variation in dependent probability for operational area (terminal – other waters) (±10 accidents in terminal area, total number of accidents kept constant) is equal to a relative change in the probability of having an accident in terminal area of ±8% for both ship types.

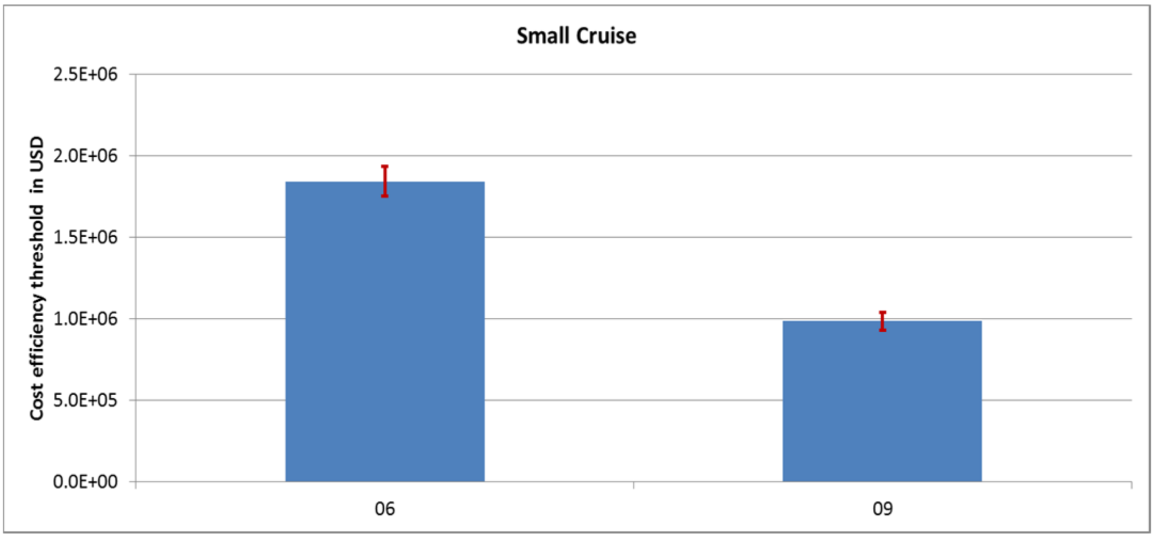

Figure 11-21 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for small Cruise.

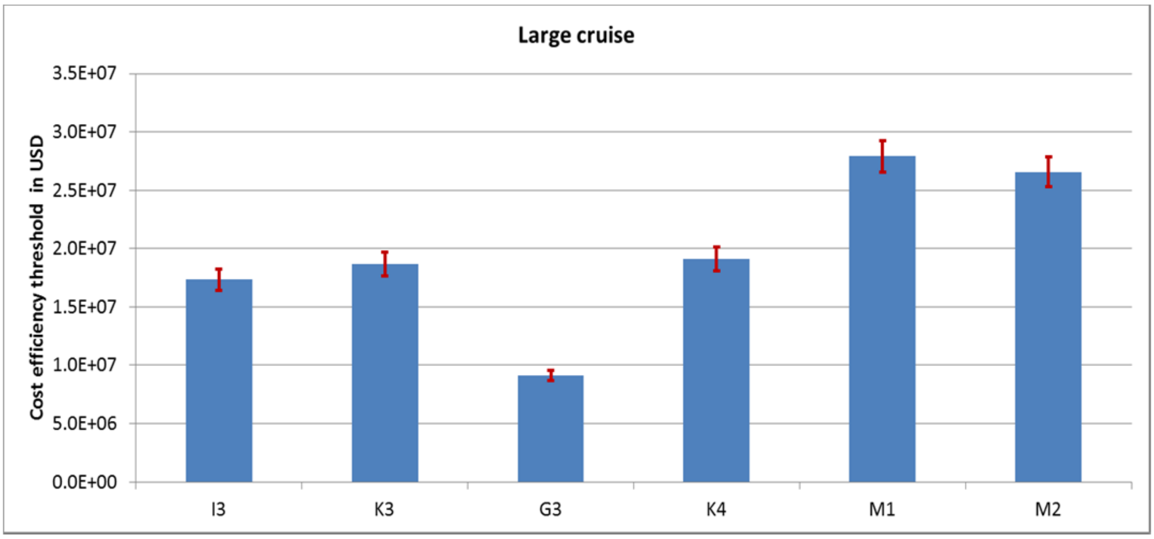

Figure 11-22 Sensitivity of cost threshold for CAF of 4 million USD with respect *operational area* and for novel designs for large Cruise.

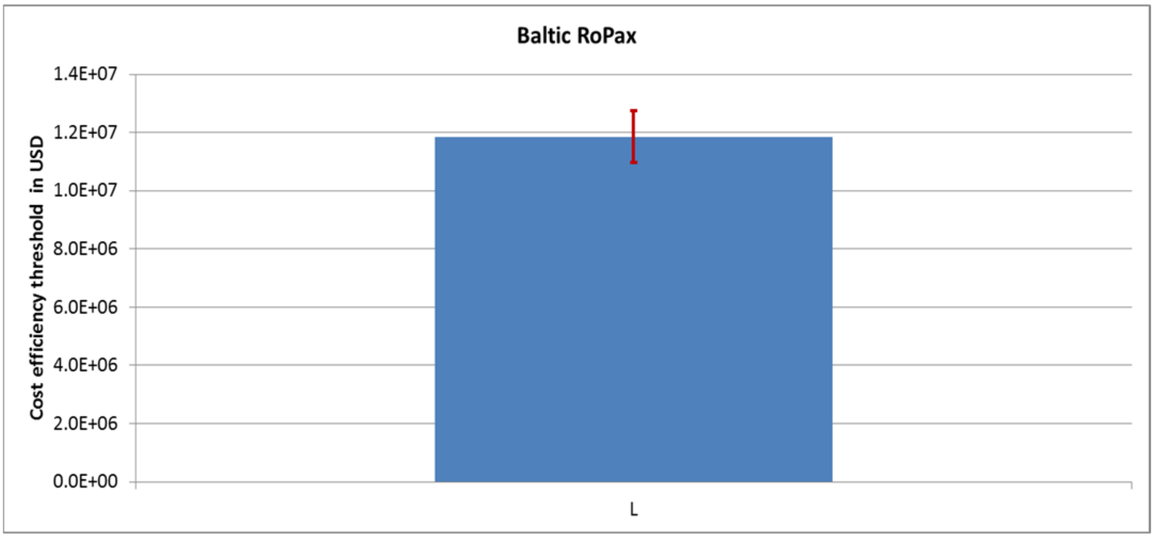

Figure 11-23 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for large RoPax.

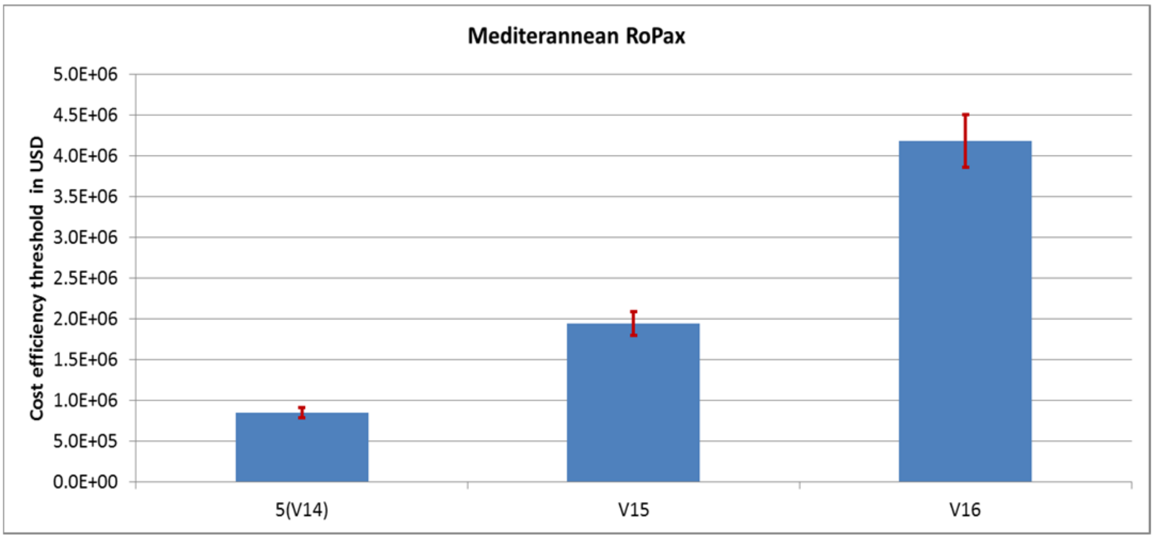

Figure 11-24 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for medium RoPax.

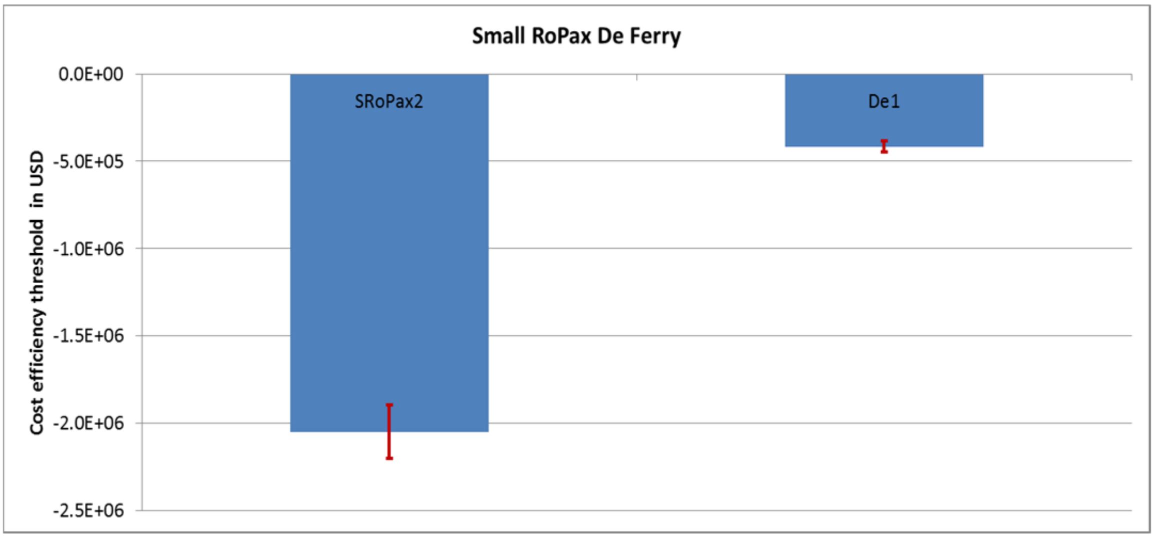

Figure 11-25 Sensitivity of cost threshold for CAF of 4 million USD with respect to *operational area* and for novel designs for medium RoPax.

The results for variation in dependent probability for fast sinking (±10% probability of fast sinking) were summarised below.

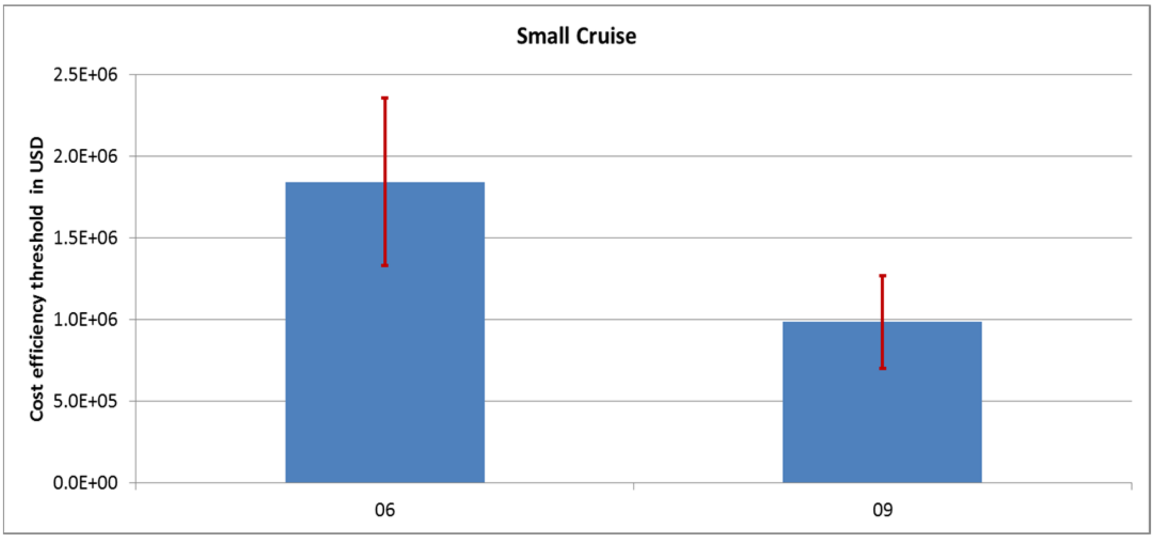

Figure 11-26 Sensitivity of cost threshold for CAF of 4 million USD with respect to *fast/slow sinking* and for novel designs for small Cruise.

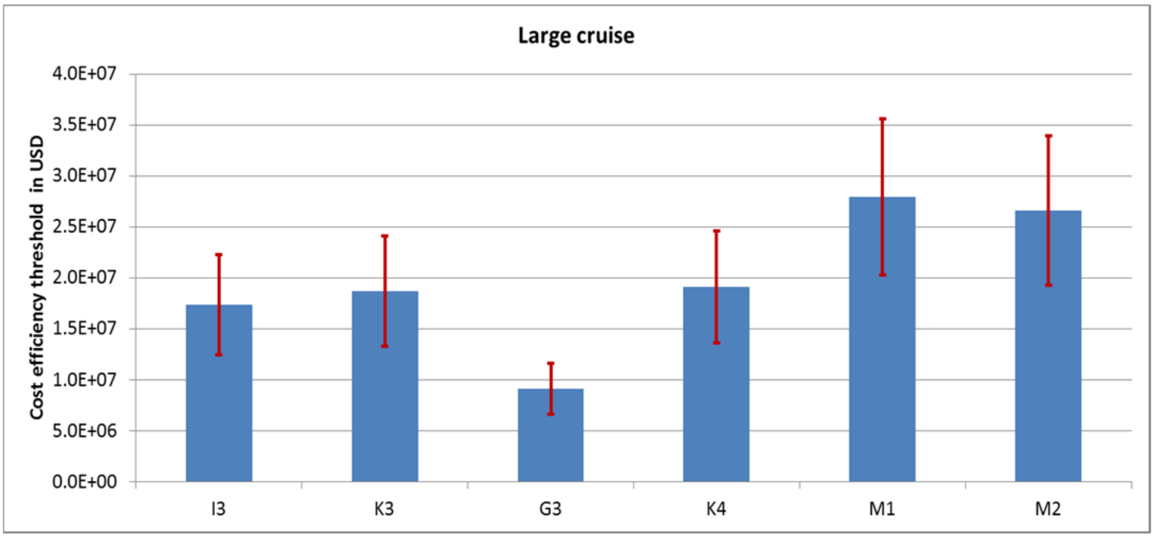

Figure 11-27 Sensitivity of cost threshold for CAF of 4 million USD with respect *fast/slow sinking* and for novel designs for large Cruise.

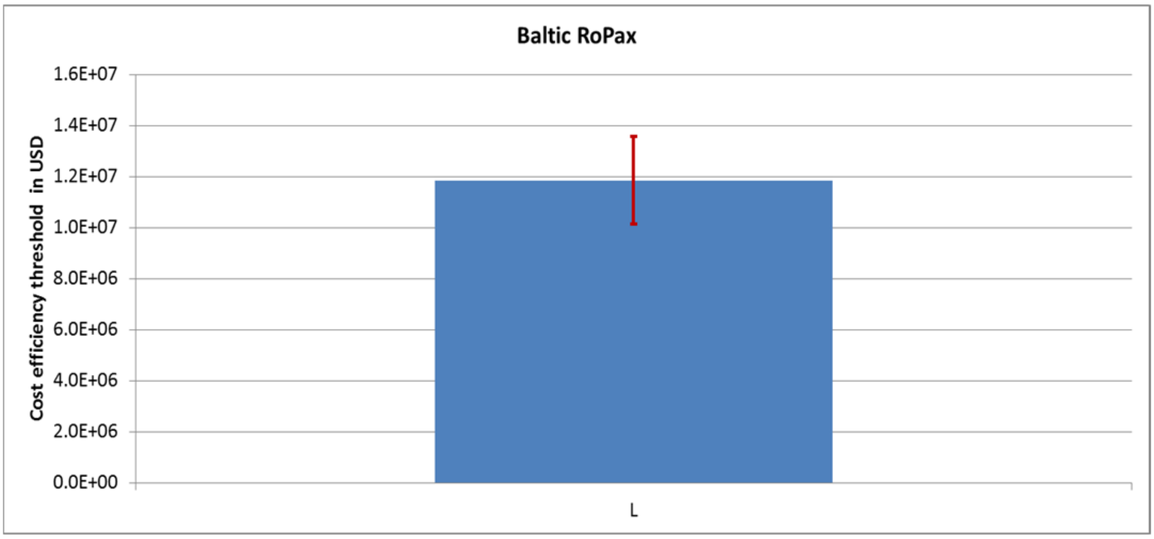

Figure 11-28 Sensitivity of cost threshold for CAF of 4 million USD with respect to *fast/slow sinking* and for novel designs for large RoPax.

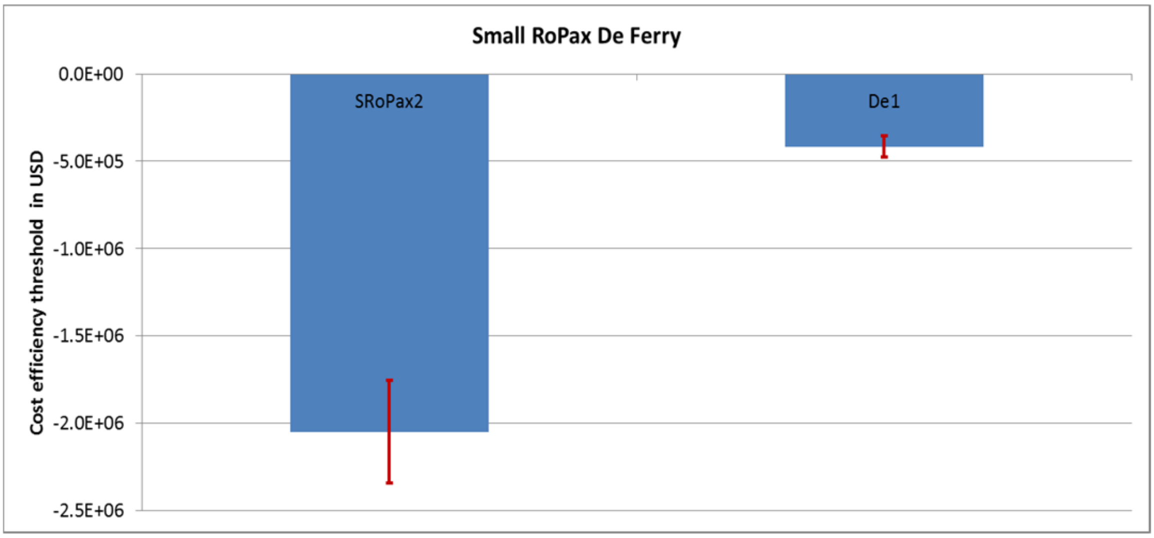

Figure 11-29 Sensitivity of cost threshold for CAF of 4 million USD with respect to *fast/slow sinking* and for novel designs for medium RoPax.

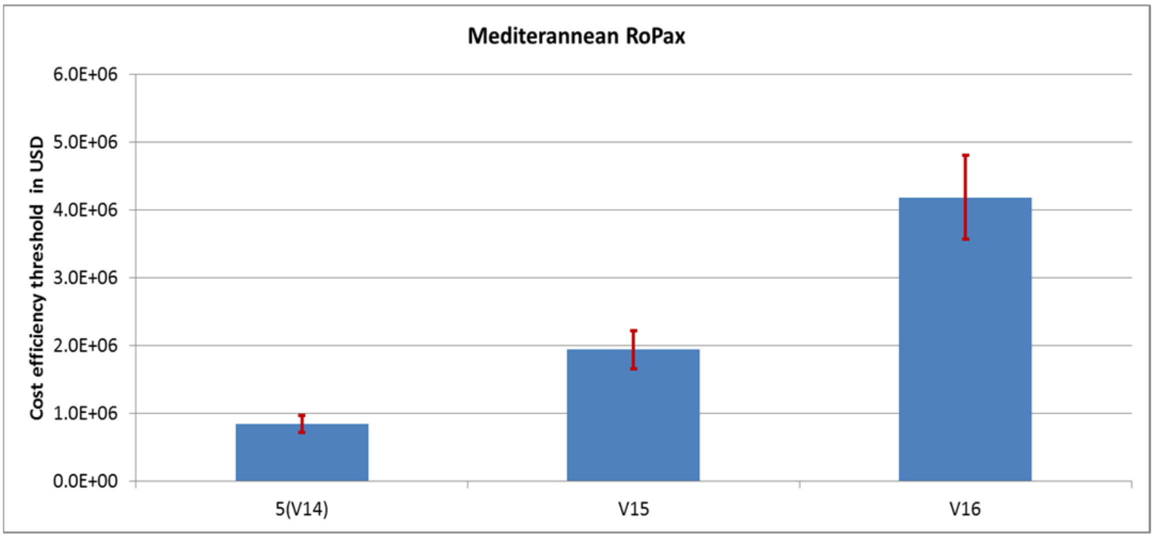

Figure 11-30 Sensitivity of cost threshold for CAF of 4 million USD with respect to *fast/slow sinking* and for novel designs for medium RoPax.

12 COMBINING COLLISION AND GROUNDING

12.1 Superposition of A Indices (Combined C&G Risk Model)

The assessment of damage stability of passenger ships considering along with collisions also grounding and contact accidents, according to the probabilistic framework developed in Task 3, results in calculating three A-Indices:

- A collision A-Index A_{CN}, calculated according to SOLAS 2009
- An index for grounding and contact accidents resulting in bottom damages $A_{GR,B}$ and
- An index for grounding and contact accidents resulting in side damages, $A_{GR,S}$.

In the final report of Task 3 /3/, a procedure has been presented for the derivation of a single Attained Survivability Index[3] for grounding and contact accidents, based on the "preservation of risk to human life", expressed herein in terms of the Potential Loss of Life (PLL). This procedure can be easily extended to include also collision accidents, in order to calculate one single Attained Survivability Index for all three kinds of accidents considered in Task 1 and Task 3 of this study, leading to a hull breach and flooding of watertight compartments:

In this respect, it is possible to express the potential loss of life associated with accident type *i* by a formula of the following form:

$$PLL_i = POB \cdot c_i \cdot (1 - A_i) \qquad (3)$$

Where:

- *POB* is the number of persons on board (considering assumptions with respect to occupancy),
- *i* stands for collision accidents (CN), bottom grounding and contact accidents (GR-B), or side grounding and contact accidents (GR-S),
- c_i is an appropriate coefficient, depending on the type of accident and the type of ship (RoPax or Cruise ship) that may be calculated from the corresponding risk model.

In this respect, the potential loss of life associated with each type of accident may be expressed as follows:

$$PLL_{CN} = POB \cdot c_{CN} \cdot (1 - A_{CN}) \qquad (4)$$

$$PLL_{GR,B} = POB \cdot c_{GR,B} \cdot (1 - A_{GR,B}) \qquad (5)$$

3 The term Attained Survivability Index was introduced for the combined index instead of the well-known Attained Subdivision Index, in order to emphasize the fact that its calculation is based on data within the Risk Model regarding the depended probabilities of the various events, which is beyond the subdivision characteristics of each particular design.

$$PLL_{GR,S} = POB \cdot c_{GR,S} \cdot (1 - A_{GR,S}) \tag{6}$$

Summing up the above equations, it is possible to express the total PLL resulting from the three types of accidents as follows:

$$PLL_{TOT} = POB \cdot \sum_i [c_i \cdot (1 - A_i)] \tag{7}$$

A combined Attained Survivability Index *A* for all three types of accidents may be calculated by setting:

$$PLL_{TOT} = POB \cdot c_T \cdot (1 - A) \tag{8}$$

Where:

$$c_T = \sum_i c_i \tag{9}$$

From the above equations, it follows directly that:

$$(1 - A) = \frac{PLL_{TOT}}{POB \cdot c_T} = \frac{POB \cdot \sum_i [c_i (1 - A_i)]}{POB \cdot \sum_i c_i} \Rightarrow A = 1 - \frac{\sum_i [c_i (1 - A_i)]}{\sum_i c_i} \Rightarrow A = \frac{\sum_i [c_i A_i]}{\sum_i c_i} \tag{10}$$

Finally:

$$A = \frac{c_{CN}}{c_{CN} + c_{GR,B} + c_{GR,S}} A_{CN} + \frac{c_{GR,B}}{c_{CN} + c_{GR,B} + c_{GR,S}} A_{GR,B} + \frac{c_{GR,S}}{c_{CN} + c_{GR,B} + c_{GR,S}} A_{GR,S} \tag{11}$$

Coefficients c_i have been calculated from the corresponding risk models, resulting in the following equations:

a. <u>For RoPax ships</u>

$$A = 0.171\, A_{CN} + 0.155\, A_{GR,B} + 0.674\, A_{GR,S} \tag{12}$$

b. <u>For Cruise ships</u>

$$A = 0.143\, A_{CN} + 0.141\, A_{GR,B} + 0.716\, A_{GR,S} \tag{13}$$

It is to be noted that the above formulations are based on the risk models and accident frequencies for the fleet at risk used in this study. If this is repeated in 5 or 10 years from now the distributions may appear differently.

12.2 Combined CBA of collision and grounding

The suggestions for the level of R worked out in Task 1 and presented in Figure 8-2 are based on the results from cost-benefit assessment available for collision only. However, it is shown in the previous section that when a design modification (RCO) is considered for the purpose of increasing the A-Index for collision, there is a positive effect on the survivability for grounding as well. In this section the assessment of cost and benefits when taking into account the effect in terms of reduced PLL from both collision and grounding is included.

Table 12-1 provides the overview of all the results for both collision and grounding available in this study.

This table includes the following information:

On the left hand side of the table the sample ships and design variants are identified with the respective attained indices A for collision and grounding. The sample ships and the design variants are described in the final report from Task 1 /1/ and in some cases also in the final report from Task 3, /3/. The latter applies for the large cruise ship and the Mediterranean RoPax for which separate cost-benefit assessments were carried out in Task 3.

The column DPLL GR+CN shows the change in PLL for the design variants taking into account both collision and grounding.

The columns NPV(M$) show the Net Present Value of the costs related to the modification carried out, which includes capital cost, construction costs and operational costs. The assumptions are described in the report of Task 1 /1/. The revenue from reduced probability for loss of ship is included.

The column NCAF(GR+CN)(M$/fat) shows the values obtained whilst accounting for the uncertainties related to the costs. In comparison with the medium, the cost estimates for low and high represent a decrease or increase in cost parameters of 20%.

For the small RoPax and the De Ferry the results for grounding have not been taken into account. This is because in the grounding calculations a reduced GM value compared with the design modified to obtain the highest possible attained Index-A for collision has been applied.

Table 12-1 CAF Values Collision and Grounding

Ship type	Design ident	A-Index				ΔRisk	NPV (M$)			NCAF (GR+CN) (M$/fat)		
		Collision	Grounding			ΔPLL GR+CN	Low	Mean	High	Low	Mean	High
		A_{CN}	A_{bottom}	A_{side}	A_{GR}							
Large cruise	Ref G2	0.8621	0.9171	0.9135	0.9142							
	I3	0.9288	0.9483	0.952	0.9513	5.27	22.24	31.20	37.53	4.22	5.92	7.12
	K3	0.8754	0.9625	0.9522	0.9543	4.86	3.28	5.27	7.37	0.68	1.10	1.52
	G3	0.8643	0.9264	0.9354	0.9336	2.31	-1.20	-0.88	-0.56	-0.52	-0.38	-0.24
	K4	0.8792	0.9621	0.9534	0.9551	5.01	3.49	5.61	7.74	0.70	1.12	1.54
	M1	0.8529	0.9406	0.9818	0.9736	6.85	6.44	10.97	14.32	0.94	1.60	2.09
	M2	0.8747	0.9416	0.978	0.9707	6.82	6.96	11.51	14.90	1.02	1.69	2.19
Small Cruise	I	0.7202	0.8799	0.8312	0.8409							
	06	0.8281	0.9192	0.8897	0.8956	0.57	1.53	2.11	2.50	2.69	3.72	4.40
	09	0.7789	0.9159	0.8589	0.8703	0.30	0.46	0.62	0.75	1.50	2.03	2.45
Baltic RoPax	Ref A	0.8326	0.9707	0.9351	0.9422							
	L	0.9152	0.9737	0.9697	0.9705	4.27	6.28	8.44	9.95	1.47	1.98	2.33
Med RoPax	Ref 1	0.8398	0.9811	0.9475	0.9542							
	5(V14)	0.8718	0.9829	0.9519	0.9581	0.47	3.76	5.17	6.08	7.97	10.95	12.89
	V15	0.8717	0.9823	0.9584	0.9632	0.74	3.69	5.12	6.06	4.96	6.88	8.14
	V16	0.8809	0.9948	0.9680	0.9734	1.38	3.66	5.19	6.21	2.65	3.76	4.50

By using the results obtained, also taking grounding into account the picture changes significantly:

- For the large cruise ship, the design option I3 having an attained index A for collision of 0.9288 has a mean NCAF of 5.92 million USD and meets the threshold of 8 mill USD
- For the small cruise ship the design option 06 having an attained index A for collision of 0.8281has a mean NCAF of 3.7 million USD and meets the threshold of 4 million USD.
- The Mediterranean RoPax design option V16 with the attained index A for collision of 0.8809 has a mean NCAF value of 3.76 million USD.
- The Baltic RoPax having an attained index A for collision of 0.9159 has a mean NCAF value of 1.98 million USD. These results are illustrated in Figure 12-1. The cases where the recommended RCOs are based on collision only are marked by red(Ref. Task 1). The cases where the benefits from grounding have been considered are marked by blue. The small RoPax and the DE Ferry are not included here due to lack of relevant data.

It is concluded that despite the fact that collision and grounding are different accidents, there are clear indications from the calculations carried out that when improving ship survivability for collision, there is also a positive effect on the survivability of grounding. The NCAF values are therefore considerably less than if collision only is taken into account.

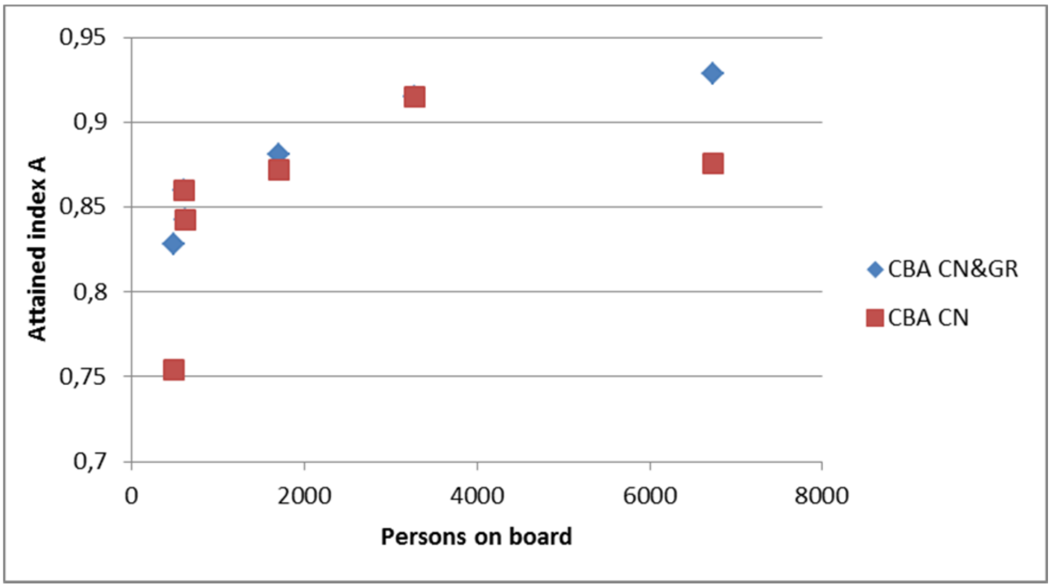

Figure 12-1 Effect of taking grounding into account in the CBA

13 SUGGESTED FORMULATIONS FOR THE LEVEL OF R

13.1 Recommendations from task 1

In task 1, several proposals were made regarding the level of R. The bi-linear function was preliminarily recommended while awaiting the results from the grounding assessment. Having revisited the results and carried out a new cost-benefit assessment and also having had further discussion it has become clear that a smooth curve representing an increased R with increasing number of persons onboard should be the basis for any recommendation.

As shown in task 1 an alternative proposal was also made by the designers participating in EMSA III, based on thoughts discussed among the EU member states prior to SDC1:

$$R = 1 - C1 * \frac{5000}{2{,}5 * N + 15225} \quad (14)$$

Where

N = total persons on board

C1 = reduction factor for the risk

Such proposal suggests that a large increase for smaller ships may seem suitable, while keeping a moderate increase for larger ships.

Based on this the factor C1 could be varied with the number of persons on board

$$C1 = 0.8 - \frac{0.25}{10{,}000} * (10{,}000 - N) \quad (15)$$

The C1 factor may also be used for the purpose of adjusting the level of R to special ship types like SPS ships or ships in domestic trade.

The level of R following this suggestion is plotted in Figure 13-1 together with the corresponding A for the RCOs found cost-effective when considering collision only.

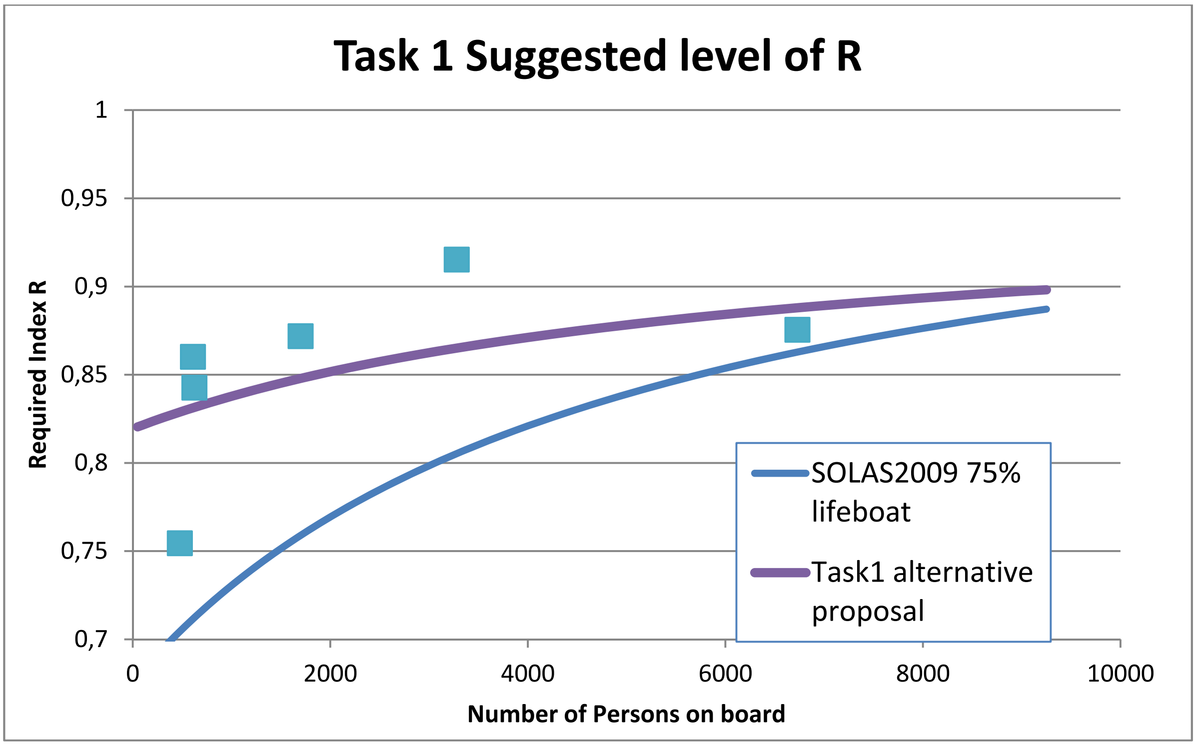

Figure 13-1 Recommendations from Task 1

13.2 Suggestion for level of R (collision) based on combined CBA

Based on the Cost Benefit Assessment shown in Table 12-1, described in Section 12.2 and shown in Figure 12-1, additional RCOs for the small and the large cruise ship as well as the Mediterranean RoPax are found to be cost-effective. It is generally seen that an RCO that has a positive effect on collision has a positive effect of grounding as well. Therefore, it can be supported to suggest that the level of R is based on those RCOs that meet the CAF criteria, in accordance with the IMO FSA guidelines.

In this respect, the formulation shown below for R is suggested for collision. This is based on the assumption described in Section 8.2 that an allowance for design margin in the range of 0.02 and 0.03 is accounted for.

Therefore the following formulation is suggested:

$$R = 1 - \frac{C1 * 6200}{4 * N + 20000} \qquad (16)$$

Where:

$$C1 = 0.8 - \frac{0.25}{10000} * (10000 - N) \qquad (17)$$

N is the number of Persons On Board

The suggested formulation is shown in Figure 13-2.

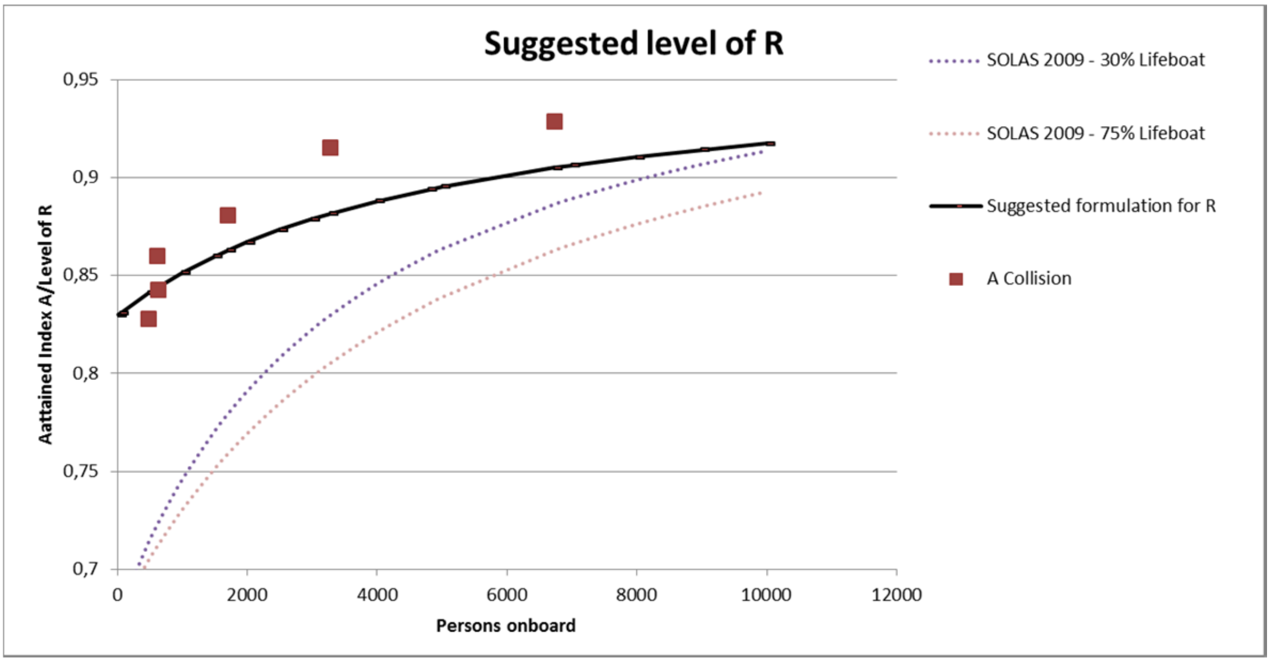

Figure 13-2 Suggested level of R – combined CBA

13.3 Summary of Observations and Recommendations concerning suggestions for the level of R

- The sample ships do not cover ships under 100m or less than 400 POB. There is no data or justification within this project to propose a formulation of R below the smallest sample vessel. Furthermore, small passenger ships represent a far more diverse range of vessels than the simple RoPax and cruise ship division we have adopted here, with more restrictions on the range of RCOs.

- Figure 13-2 clearly shows that increasing the level of R for collision is justified when the additional risk reduction from grounding is taken into account in the CBA for the selected RCOs. Of the 6 points inserted in this figure – 4 are well above the recommended R threshold (especially for the ships with large number of passengers on-board), 1 exactly on the proposed threshold, and 1 below the proposed threshold, with the points on or below the threshold being for small numbers of persons on-board. Put differently, there are still unspent money for improving safety, which is considered as a good margin considering the various uncertainties in the calculations and lack of details in the design.

- Considering the risk levels for collision and grounding as seen from the comparison of PLL per ship-year values in Table 11-1, Table 11-2, Table 11-3 and Table 11-4 the following comparative table is put together:

Table 13-1 Comparative tables PLL (all values per ship year)

Ship	Alt.	PLL (collision)	PLL (grounding, bottom)	PLL (grounding, side)	PLL (total)	% PLL (grounding, side) / PLL (total)
Large cruise						
	I3	3.33E-02	3.84E-02	1.51E-01	2.23E-01	67.8%
	K3	5.83E-02	2.78E-02	1.51E-01	2.37E-01	63.7%
	G3	6.35E-02	5.47E-02	2.04E-01	3.26E-01	63.8%
	K4	5.66E-02	2.81E-02	1.47E-01	2.32E-01	63.4%
	M1	6.89E-02	4.41E-02	5.73E-02	1.70E-01	33.6%
	M2	5.87E-02	4.34E-02	6.93E-02	1.71E-01	40.4%
Small cruise						
	09	7.41E-03	4.47E-03	3.19E-02	4.38E-02	72.9%
Baltic RoPax						
	L	4.47E-02	1.99E-02	8.45E-02	1.49E-01	56.7%
Med. RoPax						
	5 (V14)	3.49E-02	6.67E-03	6.91E-02	1.11E-01	62.4%
	V15	3.49E-02	6.91E-03	5.98E-02	1.02E-01	58.9%
	V16	3.24E-02	2.03E-03	4.60E-02	8.04E-02	57.2%
Small RoPax						
	2	1.56E-02	3.32E-03	6.04E-02	7.93E-02	76.1%
De Ferry						
	De1	1.33E-02	2.46E-04	4.56E-02	5.91E-02	77.1%

From this comparison it can be clearly seen that the risk due to "grounding, side" is the largest risk contributor between the collision, grounding (bottom) and grounding (side). For the alternatives considered, "grounding, side" typically represents around 60% of the total risk calculated, with cases as high as 77%, and only for two alternatives (large cruise, M1 and M2) being reduced to 33% and 40% respectively. As it can be clearly seen, with collision being regulated and attended through the rule making for over 60 years, the risk from collision/flooding has been drastically reduced in comparison to the grounding. This observation provides strong support for a focused approach to derive a suitable formulation for R concerning grounding or indeed combined collision and grounding, ref. also Sec.12.2.

14 CONCLUSIONS AND RECOMMENDATIONS

Based on many rounds of discussion among the participants and the wider organisations involved in this project, the following conclusions and recommendations are put forward, grouped in two categories.

14.1 Main conclusion and recommendations for decision making

- The project does not provide any data for RoPax and passenger ships carrying less than 400 persons onboard.
- There is no data available for RoPax having more than 3,280 persons onboard.
- The Cost-Effectiveness Analysis performed in the project, supports raising the level of R for collision.
- For cruise ships, a number of RCOs have been investigated on 2 sample ships. When the assessment is based on benefits from collision only, the RCOs found to be cost effective show only limited improvement. Grounding represents a significantly higher risk than collision based on the calculations carried out in the project. There is a clear trend that RCOs improving the attained index A for collision would also improve the attained index A for grounding. When grounding is included in the risk assessment the CAF values are generally reduced and additional RCOs become cost-effective.
- Suggested levels of R-Index are shown in two different formulations. Both formulations show a significant increase of safety level for small and medium sized ships and a moderate increase for very large ships. However, accounting for the additional cost-effective RCOs deriving from consideration of grounding (as explained above), it is concluded that the formulation with the higher level of R is deemed more appropriate, following closely the FSA process and methodology. [4]

14.2 Items for discussion and recommendations for further work

These items include recommendations by the Project Partners as a Group of Experts and as Stakeholders of the maritime/marine industry beyond the EMSA III framework.

- For large cruise ships, there is limited amount of information/data concerning their survivability in damaged conditions due to relatively small fleet and (luckily) small number of casualties, thus not attracting research focus. The limited amount that does exist (Reference 10) indicates that the current formulation of the s-factor in SOLAS 2009 tends to underestimate the survivability of cruise ships. This, in turn, influences ΔPLL and cost-effectiveness.

[4] Some members of the consortium have expressed their reservation wrt. use of grounding in the CBA before the methods and assumptions have been further tested and validated.

- By contrast, there are significantly more published validation results available for damage stability of RoPax ships (s-factor) than for cruise ships, e.g., North-West European Project for Damage Stability of Ro-Ro Passenger Ships (the basis for Stockholm Agreement) and the EC-funded projects HARDER and GOALDS.
- The results of the EMSA III study show that grounding is the dominant risk. It certainly represents a significantly higher risk than collision. However, further validation and testing is required in order to develop specific proposals.
- Presentation to and familiarisation by industry outside the consortium is also recommended before suggesting requirements such as combined collision and grounding to IMO.
- Method and software for calculation of A for collision should be developed based on the non-zonal approach as was done in the EMSA III project for grounding.

REFERENCES

/1/ DNVGL Report No.: 2015-0166 Risk Acceptance Criteria and Risk Based Damage Stability, Final Report, part 2: Formal Safety Assessment

/2/ DNVGL Report No.:2015-0167 Evaluation of risk from watertight doors

/3/ DNVGL Report No.:2015-0168 Evaluation of risk from raking damages due to grounding, Final report

/4/ IMO MSC-MEPC.2/Circ.12 Revised Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Process

/5/ DNVGL Report No. PP090623/3-1 Evaluation of risk from raking damages due to grounding - Sub-task a & b.

/6/ Mains, C., Bulian, G., "GOALDS-D3.2-GL-Grounding Damage Characteristics", 02 February 2011

/7/ Bulian, G., Francescutto, A., "Exploratory data analysis of grounding data from the updated GOALDS database and assessment of requirements and assumptions in SOLAS Ch. II-1 Part B-2 Regulation 9", Rev.02, 30 August 2010

/8/ IMO, "International Convention for the Safety of Life at Sea (SOLAS)"

/9/ IMO SLF47/INF.4, "Bottom damage statistics for draft regulation 9", Submitted by Germany and Norway, London, UK, 9 June 2004

/10/ Vassalos, D: "Damage Stability of Cruise Ships – Evidence and Conjecture", STAB 2015, Glasgow, June 2015, Vol. II, pp 1155-1166.

/11/ IMO SLF55/INF.9 The GOAL based Damage Stability project (GOALDS) – Development of a new risk-based damage stability requirement for passenger ships based on Cost-Benefit Assessment.

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