Safety at Speed – S@S

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SUMMARY OF CONCEPTUAL APPROACH

Scope of the present deliverable is to compare the results obtained from the tool when the alternative configurations are adopted with the basic design results analysing also the proposed design modifications.
The major aim in the comparison of results is to demonstrate the consistency of the final results from the tool both for safety and design to cost.
As first step, a list of cut sets gathered for final consequence has been extracted by "fault tree". The first two orders of magnitude, that are the most significant in terms of risk impact, have been evaluated to lighten the analysis without loss of accuracy.
There are 6 class of severity under study:

- Catastrophic for humans
- Catastrophic for ship
- Severe for humans
- Severe for ship
- Significant for humans
- Major for ship

The analysis was performed making a comparison between the basic design and the new configuration pointing out the relevant differences.
The causes of discrepancy were investigated in a deeper analysis, to understand how the basic parameters variation influences the probability per event and the severity.
Also considering the sensitive analysis results and the usual design procedures a detailed justification has been presented at the end of the paper to validate the different run of simulations.

1 Comparison between basic and configuration 1

Hereafter are listed the differences between the basic configuration and configuration 1, for which the main characteristics are reported:

Parameters	Basic	Conf 1
L_{BP}	88 m	92,4 m
B_{WL}	14,2 m	14,2 m
T	2,63 m	2,63 m
Δ	1332t (1300 m^3)	1400 t (1365m^3)
C_b	0.396	0.396
LCG	35,20 m	36.96 m
N_{PT}	8	10
P	20550 KW	21200 KW

1.1 Catastrophic for humans

1.1.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed below, with their relative frequencies:

Basic configuration

Frequency	Event Descriptions
1.46E-04	Foundering incident*
9.16E-06	Ship in dangerous/marginal dynamic stability zones Catastrophic effect on human life considering ship being in dangerous zone
4.00E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize
3.98E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize

3.80E-06	Collision in restricted water * Striking ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
3.78E-06	Collision in open sea* Striking ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - capsize (ET)
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET) Flooding due to wave damage - stern door - capsize (ET)
1.90E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
1.89E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
1.55E-06	Ignition event Rapid self termination automatic detection system Human detection Fire extinguished manually/naturally

The extraction from "Fault tree" performed for configuration 1, even for Catastrophic for humans events, is represented here below:

Configuration 1

Frequency	Event Descriptions
3.08E-05	Foundering incident*
9.16E-06	Ship in dangerous/marginal dynamic stability zones Catastrophic effect on human life considering ship being in dangerous zone
3.95E-06	Collision in restricted water * -Struck ship (Collision ET)

	Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize
3.93E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize
3.80E-06	Collision in restricted water * Struck ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
3.78E-06	Collision in open sea* Struck ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - capsize (ET)
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET) Flooding due to wave damage - stern door - capsize (ET)
1.90E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
1.89E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
1.04E-06	Ignition event Rapid self termination automatic detection system Human detection Fire extinguished manually/naturally

1.1.2 In depth analysis

Comparing the two different results, we can note four principal critical points:

1. the value of "Foundering incident" decreases of one order of amplitude.
2. the value of "Collision in restricted water", connected with flooding, is subjected to a little decrease.
3. the value of "Collision in open sea", connected with flooding, is subjected to a little decrease.
4. the value of "Ignition event" decreases.

1.1.2.1 "Foundering incident" analysis

The differences between basic and configuration 1 events related to "Foundering incident" in fault tree are displayed below:

Basic configuration

Frequency	Event Descriptions
1.43E-04	CRITICAL LOCAL FAILURE*
3.37E-06	CRITICAL GLOBAL FAILURE*

Configuration 1

Frequency	Event Descriptions
1.18E-05	CRITICAL LOCAL FAILURE*
1.90E-05	CRITICAL GLOBAL FAILURE*

The "Critical local failure" decreases of one order of amplitude, while "Critical global failure" increases of one order of amplitude.
This is due to the developed modifies in configuration 1 for panel dimensions and space framing.

Parameters	Basic	Conf 1
tp	5 mm	6mm
b	500mm	250mm
SCF	1.5	1.3

This type of result is consistent, because a reinforcement in single plates for local strength has been inserted in the Conf 1, so the "Critical local failure" is less probable.
For what concerns the "Critical global failure", the result is justified by the increasing of the length and displacement in configuration 1: the modification will increase the load surrounded by the structure, so a global collapse is more probable in the Conf 1 than in basic configuration.
The combined result for local and global collapse in configuration 1 gives less occurrence of foundering hazard.
Despite the foundering hazard frequency is the sum of global collapse frequency and local collapse frequency, the most important component of it in the basic configuration is the local failure. In configuration 1 this item decreases, so it' s rational a decreasing of the foundering hazard frequency.

1.1.2.2 "Collision in restricted water" analysis

The differences between the basic events that lead to "Collision in restricted water" are displayed below:

Basic configuration

Frequency	Event Descriptions
3.35E-04	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in restricted water
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in restricted water
1.56E-05	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in restricted water

Configuration 1

Frequency	Event Descriptions
3.35E-04	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in restricted water
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in restricted water
1.56E-05	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in restricted water

As shown above, there isn't any changing in events probability between basic and alternative 1 configuration. So the minimal difference is imputable to the event tree, where flooding model occurs.

The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the collision event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to the remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 9: Outcomes of Collisions, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01
Remains afloat	6.81E-01	6.82E-01	6.84E-01	6.85E-01	6.86E-01	6.87E-01	6.87E-01
Slow sinking	6.60E-02	6.53E-02	6.39E-02	6.24E-02	6.14E-02	6.08E-02	6.04E-02
Rapid capsize	9.32E-03	9.27E-03	9.18E-03	9.08E-03	9.01E-03	8.97E-03	8.94E-03

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking/capsize probabilities.

1.1.2.3 "Collision in open sea" analysis

The differences between the basic events that lead to "Collision in open sea" are displayed below:

Basic configuration

Frequency	Event Descriptions
3.35E-04	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in open sea
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in open sea
1.56E-05	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in open sea

Configuration 1

Frequency	Event Descriptions
3.35E-04	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in open sea
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in open sea
1.56E-05	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in open sea

As shown above, there isn't any changing in events probability between basic and alternative 1 configuration. Like "Collision in open sea" top event, the minimal difference is imputable at the event tree, where flooding model occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the collision event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 9: Outcomes of Collisions, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01
Remains afloat	6.81E-01	6.82E-01	6.84E-01	6.85E-01	6.86E-01	6.87E-01	6.87E-01
Slow sinking	6.60E-02	6.53E-02	6.39E-02	6.24E-02	6.14E-02	6.08E-02	6.04E-02
Rapid capsize	9.32E-03	9.27E-03	9.18E-03	9.08E-03	9.01E-03	8.97E-03	8.94E-03

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking/capsize probability.

1.1.2.4 "Ignition event" analysis

Regarding this consequence, in configuration 1 there is less probability of ignition because the detection system was improved, with relevant costs added. The detector reliability increases from 0.85 to 0.90, reducing the occurrence probability of top event.
The model well defines the variation of this parameter.

1.2 Catastrophic for ship

1.2.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed below, with their relative frequencies:

Basic configuration

Frequency	Event Descriptions
2.03E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.98E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding - slow sinking
1.46E-04	Foundering incident*
1.26E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
3.35E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
1.59E-05	Collision in restricted water * Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding – rapid capsize
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings – slow sinking (ET)
1.20E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.19E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking

The extraction from "Fault tree" performed for configuration 1, even for Catastrophic for ship events, is represented here below:

Configuration 1

Frequency	Event Descriptions
1.96E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.91E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.24E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
3.29E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
3.08E-05	Foundering incident*
1.53E-05	Collision in restricted water * Striking ship (Collision ET) Collision Striking ship - ship sustained flooding Slow sinking (Collision ET)
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings – slow sinking (ET)
1.19E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.18E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking

1.2.2 In depth analysis

Comparing the two different results, we can note seven principal critical points:

1. the value of "Striking with a fixed object in restricted water", connected with flooding, has a little decrease.
2. the value of "Striking with a fixed object in open sea", connected with flooding, has a little decrease.
3. the value of "Foundering incident" has a drop of one order of magnitude.
4. the value of "Powered grounding", connected with flooding, has a little decrease.
5. the value of "Drift grounding", connected with flooding, has a little decrease.
6. the value of "Collision in restricted water", connected with flooding, has a little decrease.
7. the value of "Collision in open sea", connected with flooding, has a little decrease.

1.2.2.1 "Striking with a fixed object in restricted water" analysis

The differences between the basic events that lead to "Striking with fixed object in restricted water" in fault tree are displayed below:

Basic configuration

Frequency	Event Descriptions
2.04E-03	Internal communication failure Ship accepts striking hazard* Fixed object encountered in restricted water
1.91E-04	Encountered environment condition VTS not present External communication failure Fixed object encountered in restricted water

Configuration 1

Frequency	Event Descriptions
2.04E-03	Internal communication failure Ship accepts striking hazard* Fixed object encountered in restricted water
1.91E-04	Encountered environment condition VTS not present External communication failure Fixed object encountered in restricted water

As shown above, there isn't any changing in events probability between basic and alternative 1 configuration. So the minimal difference is imputable at the event tree, where flooding model occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the striking event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to the remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 33: Outcomes of Striking, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01
Remains afloat	7.01E-01	7.02E-01	7.04E-01	7.07E-01	7.09E-01	7.10E-01	7.10E-01
Sinking	7.92E-02	7.80E-02	7.58E-02	7.33E-02	7.16E-02	7.06E-02	6.99E-02

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking probability.

1.2.2.2 "Striking with a fixed object in open sea" analysis

The differences between the basic events that lead to "Striking with fixed object in open sea" in fault tree are displayed below:

Basic configuration

Frequency	Event Descriptions
2.04E-03	Internal communication failure Ship accepts striking hazard* Fixed object encountered in open water
1.91E-04	Encountered environment condition VTS* External communication failure Fixed object encountered in open water

Configuration 1

Frequency	Event Descriptions
2.04E-03	Internal communication failure Ship accepts striking hazard* Fixed object encountered in open water
1.91E-04	Encountered environment condition VTS* External communication failure Fixed object encountered in open water

As shown above, there isn't any changing in events probability between basic and alternative 1 configuration. So the minimal difference is imputable at the event tree, where flooding model occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the striking event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 33: Outcomes of Striking, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01
Remains afloat	7.01E-01	7.02E-01	7.04E-01	7.07E-01	7.09E-01	7.10E-01	7.10E-01
Sinking	7.92E-02	7.80E-02	7.58E-02	7.33E-02	7.16E-02	7.06E-02	6.99E-02

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking probability.

1.2.2.3 "Foundering incident" analysis

See at purpose chapter 1.1.2.1

1.2.2.4 "Powered grounding" analysis

The differences between the basic events that lead to "Powered grounding" are displayed below:

Basic configuration

Frequency	Event Descriptions
9.56E-05	Encountered environment condition Alarm not active VTS not present External communication failure
9.04E-05	Internal communication failure Navigator overconfident
9.62E-06	Encountered environment condition Alarm not active VTS fails to alert External communication failure
8.60E-06	Internal communication failure Passing too close to the other ship
4.30E-06	Internal communication failure Navigator intentionally does not change course
1.65E-06	Fire Navigator overconfident

Configuration 1

Frequency	Event Descriptions
9.56E-05	Encountered environment condition Alarm not active VTS not present External communication failure
9.04E-05	Internal communication failure Navigator overconfident
9.62E-06	Encountered environment condition Alarm not active VTS fails to alert External communication failure
8.60E-06	Internal communication failure Passing too close to the other ship

4.30E-06	Internal communication failure Navigator intentionally does not change course
1.65E-06	Fire Navigator overconfident

As shown above, there isn't any changing in events probability between basic and alternative 1 configuration. So the minimal difference is imputable at the event tree, where flooding model occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the grounding event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads and ship length.

Table 25: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.245	0.246	0.247	0.249	0.250	0.250	0.251
Sinking	0.549	0.548	0.547	0.546	0.545	0.544	0.544

Table 19: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Length

Length	**78**	**88**	**98**	**108**	**118**	**128**
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.234	0.249	0.263	0.278	0.293	0.307
Sinking	0.560	0.546	0.531	0.516	0.502	0.487

As shown above, increasing the length and adding two bulkheads, the probability to remains afloat rising against the probability of sinking.

1.2.2.5 "Drift grounding" analysis

The differences between the basic events that lead to "Drift grounding" are displayed below:

Basic configuration

Frequency	Event Descriptions
5.35E-05	Ship drifts to shore* Failure to halt drift before reaching shore*

Configuration 1

Frequency	Event Descriptions
5.35E-05	Ship drifts to shore* Failure to halt drift before reaching shore*

As shown above, there isn't any changing in events probability between basic and alternative 1 configuration. So the minimal difference is imputable at the event tree, where flooding model occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the grounding event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads and ship length.

Table 25: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.245	0.246	0.247	0.249	0.250	0.250	0.251
Sinking	0.549	0.548	0.547	0.546	0.545	0.544	0.544

Table 19: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Length

Length	**78**	**88**	**98**	**108**	**118**	**128**
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.234	0.249	0.263	0.278	0.293	0.307
Sinking	0.560	0.546	0.531	0.516	0.502	0.487

As shown above, increasing the length and adding two bulkheads, the probability to remains afloat rising against the probability of sinking.

1.2.2.6 "Collision in restricted water" analysis

See at purpose chapter 1.1.2.2.

1.2.2.7 "Collision in open sea" analysis

See at purpose chapter 1.1.2.3

1.3 Severe for humans

1.3.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed below, with their relative frequencies:

Basic configuration

Frequency	Event Descriptions
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
2.03E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.98E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding - slow sinking
1.26E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
9.16E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on human life considering ship being in dangerous zone
6.14E-05	Powered grounding* Flooding accident (Grounding ET) Remains afloat after grounding
3.35E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
1.93E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - remains afloat (ET)
1.65E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET) Flooding due to wave damage - stern door - remains afloat (ET)

1.63E-05	Drift Grounding* Flooding accident (Grounding ET) Remains afloat after grounding
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings - Remains afloat (ET)
1.20E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.19E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking

The extraction from "Fault tree" performed for configuration 1, even for Severe for humans events, is represented here below:

Configuration 1

Frequency	Event Descriptions
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
1.96E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding - remains afloat
1.91E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding - remains afloat
1.24E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
9.16E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on human life considering ship being in dangerous zone
6.35E-05	Powered grounding* Flooding accident (Grounding ET) Remains afloat after grounding
3.29E-05	Drift Grounding* Flooding accident (Grounding ET)

	Sinking
1.93E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - remains afloat (ET)
1.68E-05	Drift Grounding* Flooding accident (Grounding ET) Remains afloat after grounding
1.65E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET) Flooding due to wave damage - stern door - remains afloat (ET)
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings - Remains afloat (ET)
1.19E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.18E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking

1.3.2 In depth analysis

Comparing the two different results, we can note six principal critical points:

1. the value of "Striking with a fixed object in restricted water", connected with flooding, has a little decrease.
2. the value of "Striking with a fixed object in open sea", connected with flooding, has a little decrease.
3. the value of "Powered grounding", connected with flooding, has two branches:
   - sinking, which has a little decrease
   - remains afloat after grounding, which increases.
4. the value of "Drift grounding", connected with flooding, has two branches:
   - sinking, which has a little decrease
   - remains afloat after grounding, which increases.
5. the value of "Collision in restricted water", connected with flooding, has a little decrease.
6. the value of "Collision in open sea", connected with flooding, has a little decrease.

1.3.2.1 "Striking with a fixed object in restricted water" analysis

See at purpose chapter 1.2.2.1.

1.3.2.2 "Striking with a fixed object in open sea" analysis

See at purpose chapter 1.2.2.2.

1.3.2.3 "Powered grounding" analysis

See at purpose chapter 1.2.2.4.

1.3.2.4 "Drift grounding" analysis

See at purpose chapter1.2.2.5.

1.3.2.5 "Collision in restricted water" analysis

See at purpose chapter 1.1.2.2.

1.3.2.6 "Collision in open sea" analysis

See at purpose chapter 1.1.2.3.

1.4 Severe for ship

1.4.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed below, with their relative frequencies:

Basic configuration

Frequency	Event Descriptions
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
6.14E-05	Powered grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
4.58E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on ship considering ship being in dangerous zone
1.63E-05	Drift Grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
1.58E-05	Collision in open sea* Striking ship (Collision ET) Collision Striking ship - ship sustained flooding Remains afloat (Collision ET)

The extraction from “Fault tree” performed for configuration 1, even for Severe for ship events, is represented here below:

Configuration 1

Frequency	Event Descriptions
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
6.35E-05	Powered grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
4.58E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on ship considering ship being in dangerous zone

1.68E-05	Drift Grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
1.52E-05	Collision in open sea* Striking ship (Collision ET) Collision Striking ship - ship sustained flooding Remains afloat (Collision ET)

1.4.2 In depth analysis

Comparing the two different results, we can note three principal points:

1. the value of “Powered grounding”, connected with flooding-remains afloat, increases.
2. the value of “Drift grounding”, connected with flooding-remains afloat, increases.
3. the value of “Collision in open sea”, connected with flooding, has a little decrease.

1.4.2.1 “Powered grounding” analysis

See at purpose chapter 1.2.2.4.

1.4.2.2 “Drift grounding” analysis

See at purpose chapter 1.2.2.5.

1.4.2.3 “Collision in open sea” analysis

See at purpose chapter 1.1.2.3.

1.5 Significant for human

1.5.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed below, with their relative frequencies:

Basic configuration

Frequency	Event Descriptions
1.96E-03	Striking with a fixed object in restricted water* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
1.91E-03	Striking with a fixed object in open sea* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
4.58E-04	Ship in dangerous/marginal dynamic stability zones Significant effect on human life considering ship being in dangerous zone
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

The extraction from "Fault tree" performed for configuration 1, even for Significant for humans events, is represented here below:

Configuration 1

Frequency	Event Descriptions
1.97E-03	Striking with a fixed object in restricted water* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
1.92E-03	Striking with a fixed object in open sea* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
4.58E-04	Ship in dangerous/marginal dynamic stability zones Significant effect on human life considering ship being in dangerous zone

3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

1.5.2 In depth analysis

Comparing the two different results, we can note principally:

1. the value of "Striking with a fixed object in restricted water" has a little increase.
2. the value of "Striking with a fixed object in open sea" has a little increase.

1.5.2.1 "Striking with a fixed object in restricted water" analysis

See at purpose chapter 1.2.2.1.

1.5.2.2 "Striking with a fixed object in open sea" analysis

See at purpose chapter 1.2.2.2.

1.6 Major for ship

1.6.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed below, with their relative frequencies:

Basic configuration

Frequency	Event Descriptions
1.96E-03	Striking with a fixed object in restricted water* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
1.91E-03	Striking with a fixed object in open sea* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
2.29E-04	Ship in dangerous/marginal dynamic stability zones Major effect on ship considering ship being in dangerous zone
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

The extraction from "Fault tree" performed for configuration 1, even for Major for ship events, is represented here below:

Configuration 1

Frequency	Event Descriptions
1.97E-03	Striking with a fixed object in restricted water* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
1.92E-03	Striking with a fixed object in open sea* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
2.75E-04	Accidental flooding*

	Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
2.29E-04	Ship in dangerous/marginal dynamic stability zones Major effect on ship considering ship being in dangerous zone
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

1.6.2 In depth analysis

Comparing the two different results, we can note principally:

1. the value of "Striking with a fixed object in restricted water" has a little increase.
2. the value of "Striking with a fixed object in open sea" has a little increase.

1.6.2.1 "Striking with a fixed object in restricted water" analysis

See at purpose chapter 1.2.2.1.

1.6.2.2 "Striking with a fixed object in open sea" analysis

See at purpose chapter 1.2.2.2.

1.7 Results of risk analysis

The final results of the comparison between basic vessel and configuration 1 are summarized in the spreadsheet "results" of the DesignTool.xls, as viewable hereafter.

RISK LEVEL

Basis Vessel Alternative configuration 1

Effect on Property					Effect on Property			
Name	Weight	Frequency	Risk		Name	Weight	Frequency	Risk
Minor	0.01	1.45E-03	1.45E-05		Minor	0.01	1.45E-03	1.45E-05
Major	0.1	4.46E-03	4.46E-04		Major	0.1	4.48E-03	4.48E-04
Severe	1	5.48E-04	5.48E-04		Severe	1	5.49E-04	5.49E-04
Catastrophic	10	8.02E-04	8.02E-03		Catastrophic	10	6.68E-04	6.68E-03
			9.03E-03					7.69E-03

Effect on Human Safety					Effect on Human Safety			
Name	Weight	Frequency	Risk		Name	Weight	Frequency	Risk
Minor	0.01	1.91E-03	1.91E-05		Minor	0.01	1.91E-03	1.91E-05
Significant	0.1	4.82E-03	4.82E-04		Significant	0.1	4.83E-03	4.83E-04
Severe	1	1.06E-03	1.06E-03		Severe	1	1.04E-03	1.04E-03
Catastrophic	10	1.81E-04	1.81E-03		Catastrophic	10	6.56E-05	6.56E-04
			3.37E-03					2.20E-03

As shown above, it' s possible to see global risk, both for property and for human safety, decreases in configuration 1 in respect of basic vessel. In detail, the higher level of consequence (catastrophic) decreases in both effects, making the ship safer than basic one.

2 COMPARISON BETWEEN BASIC AND CONFIGURATION 2

Hereafter are listed the differences between the basic configuration and configuration 2, for which the main characteristics are reported:

Parameters	Basic	Conf 2
L_{BP}	88 m	88 m
B_{WL}	14,2 m	14,2 m
T	2,63 m	2,63 m
Δ	1332t (1300 m^3)	1334 t (1302m^3)
C_b	0.396	0.396
LCG	35,20 m	35,20m
N_{PT}	8	10
P	20550 KW	20550 KW

2.1 Catastrophic for humans

2.1.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.1.1.

The extraction from "Fault tree" performed for configuration 2, even for Catastrophic for humans consequence, is represented here below:

Configuration 2

Frequency	Event Descriptions
1.52E-05	Foundering incident*
9.16E-06	Ship in dangerous/marginal dynamic stability zones Catastrophic effect on human life considering ship being in dangerous zone
3.95E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize
3.93E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding

	Collision Struck ship - ship sustained flooding - capsize
3.80E-06	Collision in restricted water * Struck ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
3.78E-06	Collision in open sea* Struck ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - capsize (ET)
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET) Flooding due to wave damage - stern door - capsize (ET)
1.90E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
1.89E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
1.55E-06	Ignition event Rapid self termination automatic detection system Human detection Fire extinguished manually/naturally

2.1.2 In depth analysis

Comparing the two different results, we can note three principal critical points:

1. the value of “Foundering incident” decrease of one order of amplitude.
2. the value of “Collision in restricted water”, connected with flooding event, is subjected to a little decrease.
3. the value of “Collision in open sea”, connected with flooding event, is subjected to a little decrease.

2.1.2.1 "Foundering incident" analysis

The differences between basic and configuration 2 events related to "Foundering incident" in fault tree are displayed below:

Basic configuration

Frequency	Event Descriptions
1.43E-04	CRITICAL LOCAL FAILURE*
3.37E-06	CRITICAL GLOBAL FAILURE*

Configuration 2

Frequency	Event Descriptions
1.18E-05	CRITICAL LOCAL FAILURE*
3.37E-06	CRITICAL GLOBAL FAILURE*

The "Critical local failure" decreases of one order of amplitude, while "Critical global failure" remains constant.
This is due to the developed modifies in configuration 2 for panel dimensions and space framing.

Parameters	Basic	Conf 2
tp	5 mm	6mm
b	500mm	250mm
SCF	1.5	1.3

This type of result in the basic events is consistent, because a reinforcement in single plates for local strength has been inserted, so the "Critical local failure" in the Conf 2 is less probable than in basic configuration.
For what concern "Critical global failure", the result doesn't change respect basic vessel's one, because don't change the main dimensions of the ship. So the model assess the same structure surround the same loads than basic vessel, and of course the outcome is the same.
The combined result for local and global collapse in configuration 2 gives less occurrence of foundering hazard.
Despite the foundering hazard frequency is the sum of global collapse frequency and local collapse frequency, the most important component of it in the basic configuration is the local failure. In configuration 2 this item decreases, so it' s rational a decreasing of the foundering hazard frequency.

2.1.2.2 "Collision in restricted water" analysis

Looking at the basic configuration, the significant cut sets considered are listed in 1.1.2.2.

The basic events that lead to "Collision in restricted water" in configuration 2 are displayed below:

Configuration 2

Frequency	Event Descriptions
3.35E-04	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in restricted water
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in restricted water
1.56E-05	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in restricted water

In the fault tree development, no basic events change their values. The minimal differences displayed in the extraction for consequence are due to event tree, where the model of flooding occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the collision event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 9: Outcomes of Collisions, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01
Remains afloat	6.81E-01	6.82E-01	6.84E-01	6.85E-01	6.86E-01	6.87E-01	6.87E-01
Slow sinking	6.60E-02	6.53E-02	6.39E-02	6.24E-02	6.14E-02	6.08E-02	6.04E-02
Rapid capsize	9.32E-03	9.27E-03	9.18E-03	9.08E-03	9.01E-03	8.97E-03	8.94E-03

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking/capsize probability.

2.1.2.3 “Collision in open sea” analysis

Looking at the basic configuration, the significant cut sets considered are listed in 1.1.2.3.

The basic events that lead to “Collision in open sea” in configuration 2 are displayed below:

Configuration 2

Frequency	Event Descriptions
3.35E-04	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in open sea
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in open sea
1.56E-05	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in open sea

In the fault tree development, no basic events change their values. The minimal differences displayed in the extraction for consequence are due to event tree, where the model of flooding occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the collision event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.
The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

<u>Table 9</u>: Outcomes of Collisions, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01	2.13E-01
Remains afloat	6.81E-01	6.82E-01	6.84E-01	6.85E-01	6.86E-01	6.87E-01	6.87E-01
Slow sinking	6.60E-02	6.53E-02	6.39E-02	6.24E-02	6.14E-02	6.08E-02	6.04E-02
Rapid capsize	9.32E-03	9.27E-03	9.18E-03	9.08E-03	9.01E-03	8.97E-03	8.94E-03

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking/capsize probability.

2.2 Catastrophic for ship

2.2.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.2.1.

The extraction from "Fault tree" performed for configuration 2, even for Catastrophic for ship consequence, is represented here below:

Configuration 2

Frequency	Event Descriptions
1.96E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.91E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.26E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
3.34E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
1.53E-05	Collision in restricted water * Struck ship (Collision ET) Collision Striking ship - ship sustained flooding Collision Struck ship - ship sustained flooding – rapid capsize
1.52E-05	Foundering incident*
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings - slow sinking (ET)
1.19E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.18E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding

	Collision Struck ship - ship sustained flooding - slow sinking

2.2.2 In depth analysis

Comparing the two different results, we can note six principal critical points:

1. the value of “Striking with a fixed object in restricted water”, connected with flooding event, has a little decrease.
2. the value of “Striking with a fixed object in open sea” , connected with flooding event, has a little decrease.
3. the value of “Drift grounding” , connected with flooding event, has a little decrease.
4. the value of “Collision in restricted water” , connected with flooding event, has two branches:
   - slow sinking, which has a little decrease
   - rapid capsize, which has a little decrease.
5. the value of “Foundering incident” has a drop of one order of magnitude.
6. the value of “Collision in open sea” , connected with flooding event, has a little decrease.

2.2.2.1 “Striking with a fixed object in restricted water” analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.1.

The basic events that lead to “Striking with a fixed object in restricted water” in configuration 2 are displayed below:

Configuration 2

Frequency	Event Descriptions
2.04E-03	Internal communication failure Ship accepts striking hazard* Fixed object encountered in restricted water
1.91E-04	Encountered environment condition VTS not present External communication failure Fixed object encountered in restricted water

In the fault tree development, no basic events change their values. The minimal differences displayed in the extraction for consequence are due to event tree, where the model of flooding occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the striking event tree the branch

related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 33: Outcomes of Striking, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Minor Incidents	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01
Remains afloat	7.01E-01	7.02E-01	7.04E-01	7.07E-01	7.09E-01	7.10E-01	7.10E-01
Sinking	7.92E-02	7.80E-02	7.58E-02	7.33E-02	7.16E-02	7.06E-02	6.99E-02

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking probability.

2.2.2.2 "Striking with a fixed object in open sea" analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.2.

The basic events that lead to "Striking with a fixed object in open sea" in configuration 2 are displayed below:

Configuration 2

Frequency	Event Descriptions
2.04E-03	Internal communication failure Ship accepts striking hazard* Fixed object encountered in open water
1.91E-04	Encountered environment condition VTS* External communication failure Fixed object encountered in open water

In the fault tree development, no basic events change their values. The minimal differences displayed in the extraction for consequence are due to event tree, where the model of flooding occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the striking event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.

The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 33: Outcomes of Striking, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	-2	-1	0	1	2	3
Minor Incidents	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01	2.20E-01
Remains afloat	7.01E-01	7.02E-01	7.04E-01	7.07E-01	7.09E-01	7.10E-01	7.10E-01
Sinking	7.92E-02	7.80E-02	7.58E-02	7.33E-02	7.16E-02	7.06E-02	6.99E-02

As shown above, the probability to remains afloat has a little increase with two added bulkheads, and consequently there is a little decrease to sinking probability.

2.2.2.3 "Drift grounding" analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.5.

The basic events that lead to "Drift grounding" in configuration 2 are displayed below:

Configuration 2

Frequency	Event Descriptions
5.35E-05	Ship drifts to shore* Failure to halt drift before reaching shore*

In the fault tree development, no basic events change their values. The minimal differences displayed in the extraction for consequence are due to event tree, where the model of flooding occurs.
The presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Hence, when in the grounding event tree the branch related to remains afloat/sinking occurs, the program gives a little increase to remains afloat probability, and consequently a little decrease to sinking probability.
The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of number of transversal bulkheads.

Table 25: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Number of Transverse Bulkheads

	-3	-2	-1	0	1	2	3
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.245	0.246	0.247	0.249	0.250	0.250	0.251
Sinking	0.549	0.548	0.547	0.546	0.545	0.544	0.544

As shown above, adding two bulkheads, the probability to remains afloat rising against the probability of sinking.

2.2.2.4 "Collision in restricted water" analysis

See at purpose chapter 2.1.2.2.

2.2.2.5 "Foundering incident" analysis

See at purpose chapter 2.1.2.1.

2.2.2.6 "Collision in open sea" analysis

See at purpose chapter 2.1.2.3.

2.3 Severe for humans

2.3.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.3.1.

The extraction from "Fault tree" performed for configuration 2, even for Severe for humans consequence, is represented here below:

Configuration 2

Frequency	Event Descriptions
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
2.03E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding - slow sinking
1.98E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding - slow sinking
1.26E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
9.16E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on human life considering ship being in dangerous zone
6.14E-05	Powered grounding* Flooding accident (Grounding ET) Remains afloat after grounding
3.35E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
1.93E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - remains afloat (ET)
1.65E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET)

	Flooding due to wave damage - stern door - remains afloat (ET)
1.63E-05	Drift Grounding* Flooding accident (Grounding ET) Remains afloat after grounding
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings - Remains afloat (ET)
1.20E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.19E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking

As shown above, there are no differences between the two configurations. This leads to have not a further analysis for “Severe for humans” consequence.

2.4 Severe for ship

2.4.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.4.1.

The extraction from "Fault tree" performed for configuration 2, even for Severe for ship consequence, is represented here below:

Configuration 2

Frequency	Event Descriptions
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
6.14E-05	Powered grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
4.58E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on ship considering ship being in dangerous zone
1.63E-05	Drift Grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
1.58E-05	Collision in open sea* Striking ship (Collision ET) Collision Striking ship - ship sustained flooding Remains afloat (Collision ET)

As shown above, there are no differences between the two configurations. This leads to have not a further analysis for "Severe for ship" consequence.

2.5 Significant for human

2.5.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.5.1.

The extraction from "Fault tree" performed for configuration 2, even for Significant for humans consequence, is represented here below:

Configuration 2

Frequency	Event Descriptions
1.96E-03	Striking with a fixed object in restricted water* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
1.91E-03	Striking with a fixed object in open sea* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
4.58E-04	Ship in dangerous/marginal dynamic stability zones Significant effect on human life considering ship being in dangerous zone
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

As shown above, there are no differences between the two configurations. This leads to have not a further analysis for "Significant for humans" consequence.

2.6 Major for ship

2.6.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.6.1.

The extraction from "Fault tree" performed for configuration 2, even for Major for ship consequence, is represented here below:

Configuration 2

Frequency	Event Descriptions
1.96E-03	Striking with a fixed object in restricted water* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
1.91E-03	Striking with a fixed object in open sea* Flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
2.29E-04	Ship in dangerous/marginal dynamic stability zones Major effect on ship considering ship being in dangerous zone
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

As shown above, there are no differences between the two configurations. This leads to have not a further analysis for "Major for ship" consequence.

2.7 Results of risk analysis

The final results of the comparison between basic vessel and configuration 2 are summarized in the spreadsheet "results" of the DesignTool.xls, as viewable hereafter.

RISK LEVEL

Basis Vessel

Alternative configuration 2

Effect on Property					Effect on Property			
Name	Weight	Frequency	Risk		Name	Weight	Frequency	Risk
Minor	0.01	1.45E-03	1.45E-05		Minor	0.01	1.45E-03	1.45E-05
Major	0.1	4.46E-03	4.46E-04		Major	0.1	4.48E-03	4.48E-04
Severe	1	5.48E-04	5.48E-04		Severe	1	5.49E-04	5.49E-04
Catastrophic	10	8.02E-04	8.02E-03		Catastrophic	10	6.55E-04	6.52E-03
			9.03E-03					7.56E-03

Effect on Human Safety					Effect on Human Safety			
Name	Weight	Frequency	Risk		Name	Weight	Frequency	Risk
Minor	0.01	1.91E-03	1.91E-05		Minor	0.01	1.91E-03	1.91E-05
Significant	0.1	4.82E-03	4.82E-04		Significant	0.1	4.83E-03	4.83E-04
Severe	1	1.06E-03	1.06E-03		Severe	1	1.04E-03	1.04E-03
Catastrophic	10	1.81E-04	1.81E-03		Catastrophic	10	5.00E-05	5.00E-04
			3.37E-03					2.05E-03

As shown above, it' s possible to see global risk, both for property and for human safety, decreases in configuration 2 in respect of basic vessel. In detail, the higher level of consequence (catastrophic) decreases in both effects, making the ship safer than basic one.

3 COMPARISON BETWEEN BASIC AND CONFIGURATION 3

Hereafter are listed the differences between the basic configuration and configuration 3, for which the main characteristics are reported:

Parameters	Basic	Conf 3
L_{BP}	88 m	83.6 m
B_{WL}	14.2 m	14.2 m
T	2.63 m	2.63 m
Δ	1332t (1300 m^3)	1265 t (1234m^3)
C_b	0.396	0.396
LCG	35.20 m	33.44 m
N_{PT}	8	8
P	20550 KW	19900 KW

3.1 Catastrophic for humans

3.1.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.1.1.

The extraction from "Fault tree" performed for configuration 3, even for Catastrophic for humans consequence, is represented here below:

Configuration 3

Frequency	Event Descriptions
1.14E-05	Ship in dangerous/marginal dynamic stability zones Catastrophic effect on human life considering ship being in dangerous zone
1.09E-05	Foundering incident*
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - capsize (ET)
2.75E-06	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET)

	Flooding due to wave damage - stern door - capsize (ET)
1.27E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize
1.26E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - capsize
1.20E-06	Collision in restricted water * Striking ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
1.20E-06	Collision in open sea* Striking ship (Collision ET) Collision Striking ship - ship on Fire Collision Striking ship - ship on fire - major damage
1.04E-06	Ignition event Rapid self termination automatic detection system Human detection Fire extinguished manually/naturally
6.02E-07	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage
5.99E-07	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship on fire Collision Struck ship - ship on fire - major damage

3.1.2 In depth analysis

Comparing the two different results, we can note five principal critical points:

1. the value of “Foundering incident” decreases of one order of amplitude.
2. the value of “Ship in dangerous/marginal dynamic stability zones” increases.
3. the value of “Collision in restricted water” has two branches:
   - connected with flooding event, has a strong decreasing.
   - connected with fire event, has a strong decreasing, both for struck and striking ship.

4. the value of “Collision in open water” has two branches:
   - connected with flooding event, has a strong decreasing.
   - connected with fire event, has a strong decreasing, both for struck and striking ship.
5. the value of “Ignition event” decreases.

3.1.2.1 “Foundering incident” analysis

The differences between basic and configuration 3 events related to “Foundering incident” in fault tree are displayed below:

Basic configuration

Frequency	Event Descriptions
1.43E-04	CRITICAL LOCAL FAILURE*
3.37E-06	CRITICAL GLOBAL FAILURE*

Configuration 3

Frequency	Event Descriptions
1.01E-05	CRITICAL LOCAL FAILURE*
7.38E-07	CRITICAL GLOBAL FAILURE*

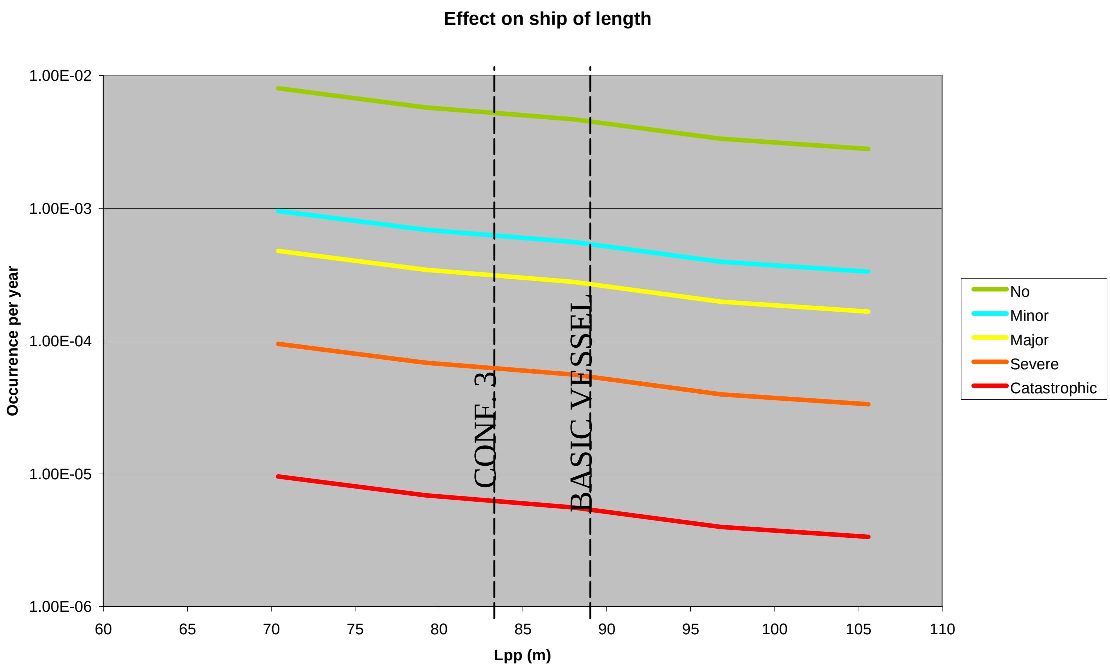
The “Critical local failure” decreases of one order of amplitude, as well as “Critical global failure”.
This is due to the developed modifies in configuration 3 for panel dimensions and space framing.

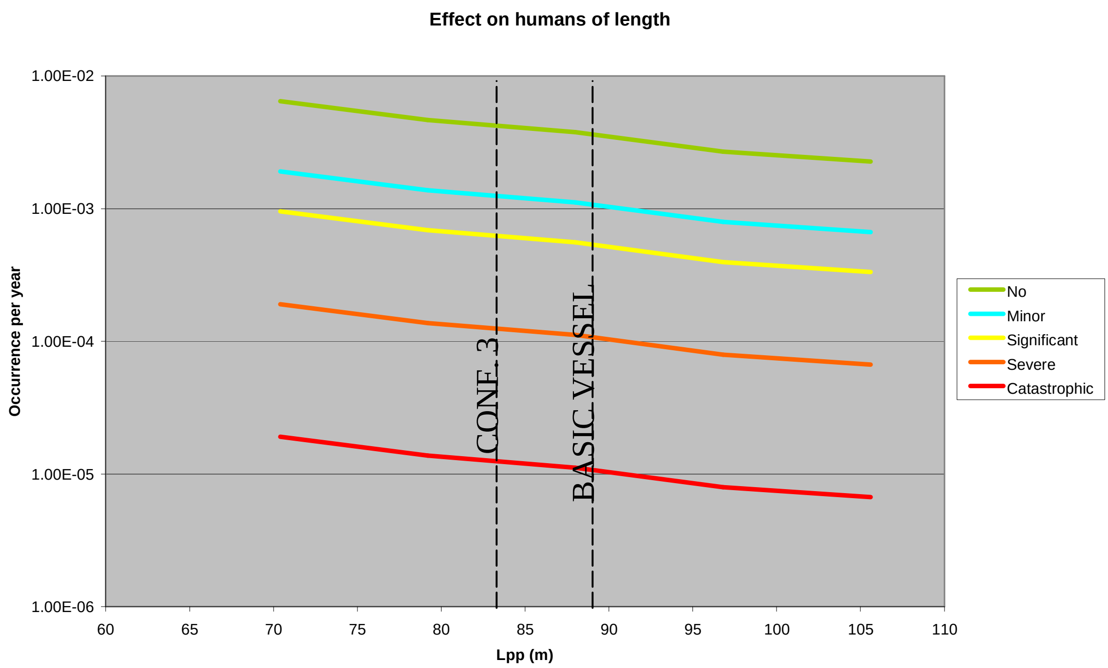
Parameters	Basic	Conf 3
tp	5 mm	6mm
b	500mm	250mm
SCF	1.5	1.3

This type of result in the basic events is consistent, because a reinforcement in single plates for local strength has been inserted, so the “Critical local failure” in the Conf 3 is less probable than in basic configuration.
For what concern “Critical global failure”, the result is justified by the decreasing of the length and displacement we made in configuration 3: the modification will decrease the load surrounded by the structure, so a global collapse is less probable in the Conf 3 than in basic configuration.
The combined result for local and global collapse in configuration 3 gives less occurrence of foundering hazard.
Despite the foundering hazard frequency is the sum of global collapse frequency and local collapse frequency, the most important component of it in the basic configuration is the local failure. In configuration 3 both item decrease, so it’ s rational a decreasing of the foundering hazard frequency.

3.1.2.2 “Ship in dangerous/marginal dynamic stability zones” analysis

This event is related with the dynamic stability model. The parameters involved in the calculation are principally the ship main dimensions like length, breadth, draft, metacentric height and roll natural period. Since the configuration 3 have smaller values of some of them, the model assess the new configuration is more dangerous from a dynamic point of view.
These results are consistent with the sensitive analysis for the dynamic stability model. Is reported here below and extract from the sensitive analysis, in which is clear how decreasing the length the probability of occurrence per year increases. This is true both for ship and for humans, and for all types of consequence considered.





3.1.2.3 "Collision in restricted water" analysis

About the basic configuration, the significant cut sets considered are listed in 1.1.2.2.

The basic events that lead to "Collision in restricted water" in configuration 3 are displayed below:

Configuration 3

Frequency	Event Descriptions
8.82E-05	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in restricted water
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in restricted water
4.10E-06	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in restricted water

For what concern fault tree, it' s possible to note how the Paging System presence has a strong influence on the internal communication failure. In fact in both branch ("Impeded by other ship" and "Navigator overconfident") the frequency values drop of one order of magnitude.
The value of "No visual detection from personnel – radar failure" remains the same than basic configuration, correctly.

In the event tree, no changes seem to exist between the two considered configuration.
Hence, the variation of consequence frequencies listed above is to be imputable only at fault tree.

3.1.2.4 "Collision in open sea" analysis

About the basic configuration, the significant cut sets considered are listed in 1.1.2.3.

The basic events that lead to "Collision in open sea" in configuration 3 are displayed below:

Configuration 3

Frequency	Event Descriptions
8.82E-05	Internal communication failure Impeded by other ship Other ship fails to avoid close quarter Other ship encountered in open sea
1.87E-05	No visual detection from personnel on bridge* Radar failure Other ship encountered in open sea
4.10E-06	Internal communication failure Navigator overconfident Other ship fails to avoid close quarter Other ship encountered in open sea

For what concern fault tree, it' s possible to note how the Paging System presence has a strong influence on the internal communication failure. In fact in both branch ("Impeded by other ship" and "Navigator overconfident") the frequency values drop of one order of magnitude.
The value of "No visual detection from personnel – radar failure" remains the same than basic configuration, correctly.

In the event tree, no changes seem to exist between the two considered configuration.
Hence, the variation of consequence frequencies listed above is to be imputable only at fault tree.

In particular, when fire event occurs, both cases of "Struck ship" and "Striking ship" are able to lead to catastrophic for humans consequences, but the top event leashed to "Struck ship" loss importance in configuration 3 because it outcomes with power –7.

3.1.2.5 "Ignition event" analysis

Regarding this consequence, in configuration 3 there is less probability of ignition because the detection system was improved, with relevant costs added. The detector reliability increases from 0.85 to 0.90, reducing the occurrence probability of top event.
The model well defines the variation of this parameter.

3.2 Catastrophic for ship

3.2.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.2.1.

The extraction from “Fault tree” performed for configuration 3, even for Catastrophic for ship consequence, is represented here below:

Configuration 3

Frequency	Event Descriptions
8.19E-05	Powered grounding* Flooding accident (Grounding ET) Sinking
6.99E-05	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
6.72E-05	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding - slow sinking
3.39E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings - Remains afloat (ET)
1.09E-05	Foundering incident*
3.81E-06	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
3.79E-06	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.27E-06	Collision in restricted water * -Struck ship (Collision ET)

	Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding – rapid capsize

3.2.2 In depth analysis

Comparing the two different results, we can note seven principal critical points:

1. the value of "Striking with a fixed object in restricted water", connected with flooding, has a significant decrease.
2. the value of "Striking with a fixed object in open sea", connected with flooding, has a significant decrease.
3. the value of "Foundering incident" has a drop of one order of magnitude.
4. the value of "Powered grounding", connected with flooding, decreases.
5. the value of "Drift grounding", connected with flooding, has a little increase.
6. the value of "Collision in restricted water", connected with flooding, has a significant decrease.
7. the value of "Collision in open sea", connected with flooding, has a significant decrease.

3.2.2.1 "Striking with a fixed object in restricted water" analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.1.

The basic events that lead to "Striking with a fixed object in restricted water" in configuration 3 are displayed below:

Configuration 3

Frequency	Event Descriptions
5.38E-04	Internal communication failure Ship accepts striking hazard* Fixed object encountered in restricted water
1.91E-04	Encountered environment condition VTS not present External communication failure Fixed object encountered in restricted water

For what concern fault tree, it' s possible to note how the Paging System presence has a strong influence on the internal communication failure. In fact the frequency values of the related event drop of one order of magnitude.
The value of "Encountered environmental condition" top event remains the same than basic configuration, correctly.

In the event tree, no changes seem to exist between the two considered configuration.
Hence, the variation of consequence frequencies listed above is to be imputable only at fault tree.

3.2.2.2 "Striking with a fixed object in open sea" analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.2.

The basic events that lead to "Striking with a fixed object in open sea" in configuration 3 are displayed below:

Configuration 3

Frequency	Event Descriptions
5.38E-04	Internal communication failure Ship accepts striking hazard* Fixed object encountered in open water
1.91E-04	Encountered environment condition VTS* External communication failure Fixed object encountered in open water

For what concern fault tree, it' s possible to note how the Paging System presence has a strong influence on the internal communication failure. In fact the frequency values of the related event drop of one order of magnitude.
The value of "Encountered environmental condition" top event remains the same than basic configuration, correctly.

In the event tree, no changes seem to exist between the two considered configuration.
Hence, the variation of consequence frequencies listed above is to be imputable only at fault tree.

3.2.2.3 "Foundering incident" analysis

See at purpose 3.1.2.1.

3.2.2.4 "Powered grounding" analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.4.

The basic events that lead to "Powered grounding" in configuration 3 are displayed below:

Configuration 3

Frequency	Event Descriptions
9.56E-05	Encountered environment condition Alarm not active VTS not present External communication failure
2.38E-05	Internal communication failure Navigator overconfident
9.62E-06	Encountered environment condition Alarm not active VTS fails to alert External communication failure
2.26E-06	Internal communication failure Passing too close to the other ship
1.65E-06	Fire Navigator overconfident
1.13E-06	Internal communication failure Navigator intentionally does not change course

For what concern fault tree, it’ s possible to note how the Paging System presence has a strong influence on the internal communication failure. In fact the only frequency values subject to change are the ones related with this to event, and the decreasing is significant.

From the event tree point of view, in the flooding branch probabilities the model assess the new configuration more dangerous than basic one: the probability value of cut set considered changes from 0.626 to 0.634. This because the model estimate configuration 3 less floatable than basic vessel, and consequently the probability of sinking increase against the probability to remain afloat.
An explanation of this could be because the model take into account the lesser reserve of buoyancy of configuration 3 in respect with basic vessel: so, when a compartment is flooded, the remaining part of hull gives less buoyancy than basic vessel one.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of ship length.

Table 19: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Length

Length	**78**	**88**	**98**	**108**	**118**	**128**
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.234	0.249	0.263	0.278	0.293	0.307

Sinking	0.560	0.546	0.531	0.516	0.502	0.487

As shown above, decreasing the length, the probability to remains afloat getting smaller than before, while the probability of sinking grows up.

3.2.2.5 "Drift grounding" analysis

About the basic configuration, the significant cut sets considered are listed in 1.2.2.5.

The basic events that lead to "Drift grounding" in configuration 3 are displayed below:

Configuration 3

Frequency	Event Descriptions
5.35E-05	Ship drifts to shore* Failure to halt drift before reaching shore*

As shown above, there isn't any changing in events probability between basic and alternative 3 configuration. So the minimal difference is imputable at the event tree, where flooding model occurs.
As previously described in the paragraph above, the flooding model take into account the lesser reserve of buoyancy of configuration 3 in respect with basic vessel: consequently, the probability of sinking increases against the probability to remain afloat.

The remarks above are in accordance with flooding model sensitive analysis, reported here below for what concerns the variation of ship length.

Table 19: Outcomes of Grounding, Probabilities per Event,
Route Distance 50 miles, Variation of Length

Length	**78**	**88**	**98**	**108**	**118**	**128**
Minor Incidents	0.206	0.206	0.206	0.206	0.206	0.206
Remains afloat	0.234	0.249	0.263	0.278	0.293	0.307
Sinking	0.560	0.546	0.531	0.516	0.502	0.487

As shown above, decreasing the length, the probability to remains afloat getting smaller than before, while the probability of sinking grows up.

3.2.2.6 "Collision in restricted water" analysis

See at purpose 3.1.2.3.

3.2.2.7 "Collision in open sea" analysis

See at purpose 3.1.2.4.

3.3 Severe for humans

3.3.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.3.1.

The extraction from "Fault tree" performed for configuration 3, even for Severe for humans consequence, is represented here below:

Configuration 3

Frequency	Event Descriptions
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
2.03E-04	Striking with a fixed object in restricted water* Flooding incident (impact ET) Striking - ship sustained flooding – slow sinking
1.98E-04	Striking with a fixed object in open sea* Flooding incident (impact ET) Striking - ship sustained flooding - slow sinking
1.26E-04	Powered grounding* Flooding accident (Grounding ET) Sinking
9.16E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on human life considering ship being in dangerous zone
6.14E-05	Powered grounding* Flooding accident (Grounding ET) Remains afloat after grounding
3.35E-05	Drift Grounding* Flooding accident (Grounding ET) Sinking
1.93E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - through hull (ET) Flooding due to wave damage - hull - remains afloat (ET)
1.65E-05	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - stern door (ET)

	Flooding due to wave damage - stern door - remains afloat (ET)
1.63E-05	Drift Grounding* Flooding accident (Grounding ET) Remains afloat after grounding
1.33E-05	Accidental flooding* Flooding through down flooding openings (ET) Flooding through Down flooding openings - Remains afloat (ET)
1.20E-05	Collision in restricted water * -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking
1.19E-05	Collision in open sea* -Struck ship (Collision ET) Collision Struck ship - ship sustained flooding Collision Struck ship - ship sustained flooding - slow sinking

As shown above, there are no differences between the two configurations. This leads to have not a further analysis for “Severe for humans” consequence.

3.4 Severe for ship

3.4.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.4.1.

The extraction from "Fault tree" performed for configuration 3, even for Severe for ship consequence, is represented here below:

Configuration 3

Frequency	Event Descriptions
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
5.70E-05	Ship in dangerous/marginal dynamic stability zones Severe effect on ship considering ship being in dangerous zone
3.82E-05	Powered grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
1.58E-05	Drift Grounding* Flooding accident (Grounding ET) -Remains afloat after grounding
5.01E-06	Collision in open sea* Striking ship (Collision ET) Collision Striking ship - ship sustained flooding Remains afloat (Collision ET)

3.4.2 In depth analysis

Comparing the two different results, we can note four principal critical points:

1. the value of "Powered grounding", connected with flooding-remains afloat, decreases.
2. the value of "Ship in dangerous/marginal dynamic stability zones" increases.
3. the value of "Drift grounding", connected with flooding-remains afloat, has a little decrease.
4. the value of "Collision in open sea", connected with flooding, has a little decrease.

3.4.2.1 "Powered grounding" analysis

See at purpose chapter 3.2.2.4.

3.4.2.2 "Ship in dangerous/marginal dynamic stability zones" analysis

See at purpose chapter 3.1.2.2.

3.4.2.3 "Drift grounding" analysis

See at purpose chapter 3.2.2.5.

3.4.2.4 "Collision in open sea" analysis

See at purpose chapter 3.1.2.4.

3.5 Significant for human

3.5.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.5.1

The extraction from "Fault tree" performed for configuration 3, even for Significant for humans consequence, is represented here below:

Configuration 3

Frequency	Event Descriptions
6.73E-04	Striking with a fixed object in restricted water* Minor and non-flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
6.48E-04	Striking with a fixed object in open sea* Minor and non-flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
5.70E-04	Ship in dangerous/marginal dynamic stability zones Significant effect on human life considering ship being in dangerous zone
3.95E-04	Accidental flooding* Flooding below vehicle deck (ET)
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

3.5.2 In depth analysis

Comparing the two different results, we can note three principal critical points:

1. the value of "Striking with a fixed object in restricted water", connected with flooding, has a significant decrease.
2. the value of "Striking with a fixed object in open sea", connected with flooding, has a significant decrease.
3. the value of "Ship in dangerous/marginal dynamic stability zones" increases.

3.5.2.1 "Striking with a fixed object in restricted water" analysis

See at purpose chapter 3.2.2.1.

3.5.2.2 "Striking with a fixed object in open sea" analysis

See at purpose chapter 3.2.2.2.

3.5.2.3 "Ship in dangerous/marginal dynamic stability zones" analysis

See at purpose chapter 3.1.2.2.

3.6 Major for ship

3.6.1 Comparison of results

About the basic configuration, the significant cut sets considered are listed in 1.6.1

The extraction from "Fault tree" performed for configuration 3, even for Major for ship consequence, is represented here below:

Configuration 3

Frequency	Event Descriptions
6.73E-04	Striking with a fixed object in restricted water* Minor and non-flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
6.48E-04	Striking with a fixed object in open sea* Minor and non-flooding incident (impact ET) -Striking - ship sustained flooding - remains afloat
2.85E-04	Ship in dangerous/marginal dynamic stability zones Major effect on ship considering ship being in dangerous zone
2.75E-04	Accidental flooding* Flooding due to wave damage (ET) Flooding due to wave damage - into bridge (ET)
1.20E-04	Accidental flooding* Flooding through down flooding openings (ET) -Flooding through Down flooding openings - Remains afloat (ET)

3.6.2 In depth analysis

Comparing the two different results, we can note principally:

1. the value of "Striking with a fixed object in restricted water", connected with flooding, decreases
2. the value of "Striking with a fixed object in open sea", connected with flooding, decreases
3. the value of "Ship in dangerous/marginal dynamic stability zones" increases.

3.6.2.1 "Striking with a fixed object in restricted water" analysis

See at purpose chapter 3.2.2.1.

3.6.2.2 "Striking with a fixed object in open sea" analysis

See at purpose chapter 3.2.2.2.

3.6.2.3 "Ship in dangerous/marginal dynamic stability zones" analysis

See at purpose chapter 3.1.2.2.

3.7 Results of risk analysis

The final results of the comparison between basic vessel and configuration 3 are summarized in the spreadsheet "results" of the DesignTool.xls, as viewable hereafter.

RISK LEVEL

Basis Vessel Alternative configuration 3

Effect on Property					Effect on Property			
Name	Weight	Frequency	Risk		Name	Weight	Frequency	Risk
Minor	0.01	1.45E-03	1.45E-05		Minor	0.01	9.07E-04	9.07E-06
Major	0.1	4.46E-03	4.46E-04		Major	0.1	1.97E-03	1.97E-04
Severe	1	5.48E-04	5.48E-04		Severe	1	5.16E-04	5.16E-04
Catastrophic	10	8.02E-04	8.02E-03		Catastrophic	10	3.20E-04	3.20E-03
			9.03E-03					3.92E-03

Effect on Human Safety					Effect on Human Safety			
Name	Weight	Frequency	Risk		Name	Weight	Frequency	Risk
Minor	0.01	1.91E-03	1.91E-05		Minor	0.01	1.48E-03	1.48E-05
Significant	0.1	4.82E-03	4.82E-04		Significant	0.1	2.36E-03	2.36E-04
Severe	1	1.06E-03	1.06E-03		Severe	1	7.25E-04	7.25E-04
Catastrophic	10	1.81E-04	1.81E-03		Catastrophic	10	3.49E-05	3.49E-04
			3.37E-03					1.33E-03

As shown above, it' s possible to see global risk, both for property and for human safety, decreases in configuration 1 in respect of basic vessel. In detail, all levels of consequence (catastrophic, severe, major/significant, minor) decrease in both effects, making the ship safer than basic one.

4 COST EVALUATION

4.1 Basic vessel costs

The costs specification for the basic vessel is reported here below:

Parameter	**unit**	**value**	
Hull material	€/ship	2 500 000	
Hull build labour	€	600 000	
Hull build overhead	€	200 000	
Hull maintenance	€	182 800	
Active Stab equipment	€	806 200	
Active Stab labour	€	120 000	
Active Stab overhead	€	60 000	
Active Stab maintenance	€ / year	20 000	
Fuel consumption electrical	gr/kWh	300	
Electrical engine relative power	%		only one parameter is required
Electrical engine designer over ride	kW	600	
Main engine cost (Designer over ride)	€		only one parameter is required
Main engine cost	€/kW	81	
Fuel price ME	€/tons	226	
Fuel price electrical	€/tons	226	
Basis net present value	€	3 905 154.2	
Required discount rate	0 - 1	0.1	
Commissioning costs	€	100 000	
Decommissioning costs	€	100 000	

Parameter	**unit**	**value**	**labour (€)**	**labour %**	**maint (€)**	**maint. %**
Diesel engines electrical	€/engine	145 000	58 000	20.0	7 830.0	2.7
Emergency engine	€	145 000	29 000	20.0	3 915.0	2.7
Water jets	€	322 800	69 724	5.4	45 192.0	3.5
3 Ghz radar	€	69 700	13 940	20.0	8 364.0	12.0

Emergency system for general alarm & PA	€	48 000	20 016	41.7	2 112.0	4.4
Talk back system	€	18 000		0.0	792.0	4.4
VTS	€	0	0	0.0	0.0	0.0
ECDIS	€	10 000	3 000	30.0	1 200.0	12.0
DGPS	€	15 000	1 995	13.3	1 800.0	12.0
Paging system	€	0	0	0.0	0.0	0.0
Emergency system for the VHF	€	72 000	14 976	20.8	3 168.0	4.4
ATA	€	40 000	Function of radar: 0	0.0	0.0	0.0
ARPA	€	35 000	Function of radar: 0	0.0	4 200.0	12.0
Identification system	€	3 500	function of ECDIS	0.0	420.0	12.0

Additional maintenance costs				
Machinery	€/year	55 700		
LSA	€/year	71 400		

Additional annual overhead				
Technical spares	€/year	566 000		
Crew costs	€/year	2 352 800	crew correction factor	1.384

Life Cycle Inputs			
Build time	Years	1	Sea Container information
Trials Time	Months	12	
Cycle Time	Days	250	
Idle Time	Days	85	
Maintenance Time	Days	30	
Maint Frequency	Years	1	
Decommission Time	Months	6	
voyages per operational cycle		250	

Fare prices		
Passengers fare price	€	20
Cars fare price	€	120
Coaches fare price	€	0
Lorries fare price	€	0

Market data			
Passengers number	per day	314	
Cars number	per day	69	
Coaches number	per day	0	
Lorries number	per day	0	

4.2 Differences in costs evaluation

The modifications performed in all 3 estimate configurations lead to a costs variation, which is showed in detail in the table below:

Cost data	Basic(€)	Conf 1(€)	Conf 2(€)	Conf 3(€)
Labour cost	1’028’000	1’080’000	1’033’000	987’000
Material cost	513’000	540’000	517’000	493’000
Overhead cost	154’000	162’000	155’000	148’000
Hull Maintenance (annual)	235’679	221’821	221’821	212’281
Additional costs due to the structural improvements	0	43’200	43’200	43’200
Additional costs due to the improvement of the detection reliability	0	5’000	0	5’000
Cost of paging system	0	0	0	40’000
Variation of internal arrangement cost	0	121’560	121’560	0
Procurement cost	6’547’616	6’751’047	6’704’443	6’479’355

Cost data	Basic(€)	Conf 1(€)	Conf 2(€)	Conf 3(€)
Voyage cost (annual)	1’916’986	1’912’618	1’910’230	1’845’064
Maintenance cost (annual)	433’160	427’479	433’160	410’082

4.2.1 In depth analysis

Comparing the different configurations, it’ s possible to perform a short analysis about the discrepancy in terms of cost with the basic vessel, analysing the different voices listed above. First of all, it should be distinguished the cost manually inputted from cost automatically calculated from the model. The first group is composed of labour cost, material cost, overhead cost, hull maintenance and additional costs due to structure improvement, fire detection system reliability improvement and presence of paging system. The costs automatically calculated are: variation of internal arrangement cost, procurement cost, voyage cost and maintenance cost.

4.2.1.1 Labour cost

The labour cost is different for different ship lengths: this is due to the methodology used by the model to evaluate this kind of costs. As input information, the model imports the panels dimensions and all the required geometric properties, the alloy and the construction type for plates and stiffeners is determined for each panel; the model can consider 4 different alloys, and 4 types of construction (plate, conventional stiffened plate, single-sided extrusion, double-sided extrusion), hence there are 16 cost constants in the model for labour cost.
The program goes panel-by-panel through the entered midship section, and for each panel, it determines the cross sectional area. It looks up the cost per kilogram constant for the particular alloy/construction combination, and multiplies it by the cross-sectional area of the panel, the length of the vessel, and the density of aluminium (to pass from volume to weight). The cost of all the panels are then added up.
It’ s now clear how the labour cost is variable among different configurations: is greater for configuration 1 where major dimensions occur, is smaller for configuration 3 where ship dimensions decreases from basic vessel. In configuration 2, the cost value remains almost the same of the basic vessel, because the main dimensions are the same, as for example the length. The minimal difference between configuration 2 and basic configuration is due to changing made in panel 1, in plate thickness and space framing.

4.2.1.2 Material cost

As labour cost, also the material cost changes in the same way.
The alloy and the construction type for plates and stiffeners is determined for each panel; the model can consider 4 different alloys, and 4 types of construction (plate, conventional stiffened plate, single-sided extrusion, double-sided extrusion), there are 16 cost constants in the model for material cost. Like described above, the program goes panel-by-panel through the entered midship section, and determines the costs of all the panels.
It' s possible to see how the material cost value is bigger in configuration 1, is smaller in configuration 3 and has a little increases in configuration 2, coherently with the explanation given above.
For the chosen values of cost per kilogram to each aluminium alloy and type of construction, it happens that material cost is assessed from the program as 50% of the labour cost.

4.2.1.3 Overhead cost

For what concern overhead costs, they vary properly with the variation of costs considered above. This voice joins generic cost voices for the vessel, different from labour and material costs, but strictly correlated with them. So its behaviour is similar to labour/material cost one.
This item is calculated from the structural model as 15% of labour cost.

4.2.1.4 Hull maintenance

The structural cost model considers the hull maintenance cost correlated with the fatigue phenomenon.
It could be possible that SSC3 had some problem from this point of view. The vibrations at which a Ro-Ro fast ferry is subjected are such high to generate some fatigue problems. This is the principal reason for what it was decided to improve the hull structure.
In all the three assessed alternative configurations, the fatigue index reported into "Foundering" spreadsheet in DesignTool.xls had a decreasing, so the structure can be considered more safe to fatigue hazard. This leads to have less needing of maintenance for the hull, and the relevant cost could decreases.
Moreover, in configuration 3 the reduced hull forms leads to a further decreasing in maintenance cost.

4.2.1.5 Additional costs

This voice rises from the choice to improve the construction quality of the basic vessel. This intention is realized decreasing in all the three assessed configurations the SCF (Stress Concentration Factor) from 1.5 to 1.3. This is a indicator that the single plates and stiffeners are subjected to less stress than basic vessel, so their strength have an improvement. This leads to an

additional cost in respect to basic vessel of about 43200 euros. This is valid for all the three alternative configurations.
Moreover, the improvement of fire detector reliability (that brings the value from 0.85 to 0.90) in configurations 1 and 3 adds 5000 euros to the basis cost.
Finally, the cost of paging system is valuated around 40000 euros, and that is computed only in configuration 3.

4.2.1.6 Variation of internal arrangement cost

The presence of two added transversal bulkheads leads also to an increasing of internal arrangement cost. This is valid for configuration 1 and 2, where added bulkheads persist.
The model assesses for each transversal bulkhead a costs of about 60000 euros, and this is consistent.

4.2.1.7 Procurement cost

The cost model calculates automatically this element, for which it takes into account several items, that are:

- Hull structure
- Propulsion units
- Electrical units
- Command and control
- Auxiliaries
- General outfitting

Hull structure gives a changing among different configurations, because it’ s the sum of “Internal arrangement cost”, “Material hull cost”, “Labour hull cost” and “Overhead hull cost”, which are described in the previous sections. Also “General outfitting” is subject to change, because it takes into account the presence of added transversal bulkheads.
Hence, this voice of cost is not a new and independent element, but it is the combination of well known components.

4.2.1.8 Voyage cost

This element is obtained from a simple calculation. The power prediction model assesses the combustible mass needle by the ship to cover the routes in one day. Once this factor is known, it is easy to multiply this value by the operative days in a year (fixed value, equal to 250 as default) and by the combustible cost (fixed value, equal to 226 euros/t as default).
The only point of discrepancy among different configurations is hence caused by the combustible mass, which depends from the power employed at the propulsion functional point.

4.2.1.9 Maintenance cost

This cost voice is the sum of a calculated cost and two additional costs, which are “Machinery cost” (equal to 55700 euros) and “LSA cost “ (equal to 71400 euros).
The calculated part of this cost is composed by four elements, which are:

- Hull maintenance
- Stabilizer maintenance
- Command and control maintenance
- Electrical maintenance

In the listed above, only the parameter “Hull maintenance” is changed among different configurations, as previously described in the above sections.
In particular, “Stabilizer maintenance” is a fixed value, equal to 20000 euros per default.
“Command and control maintenance” is the sum of a list of components of command and control devices, such as steering waterjet, 3GHz radar, ARPA, ECDIS and some others.
“Electrical maintenance” is the sum of “Diesel engines electrical maintenance” and “Emergency diesel engines electrical maintenance”, which are a percentage (equal to 2,70 as default) of the relevant cost for unit.

4.3 ICAF evaluation

The Project tool enables the designer to identify and integrate different Safety Enhancement Features to focus on the areas of high-risk contribution in the risk model, and on the main risk contributors. These measures can either be preventive, i.e. reducing the probability of an event, or mitigating, i.e. reducing the severity of the outcome.

To estimate the cost-effectiveness of the measures introduced for reducing risk, a cost benefit assessment should be carried out by re-evaluating the cost and risk of the new design. To compare the different design solution, the ICAF (Implied Cost to Avert a Fatality), which is an indicator of the cost to avert a fatality for each measure, is calculated. The recommendations and decision-making should be based on the comparison and ranking of the risk control options as a function of associated cost and benefits.

For each design solution introduced, the ICAF is calculated automatically in the 'Results' spreadsheet.
The ICAF is calculated as follow:

$$ICAF = {}^{CostIncrease}\!\big/_{RiskSaving}$$

The Cost is the change in NPV, normally a cost introduced by the SEF; it is basically the difference between the new design cost and the original design. The Risk Saving is the reduced number of fatality, which is also the difference between the new design risk level and the original design. Both figures are expressed per year.

For each different design solutions i.e. different SEF tried by the designer, the ICAF is calculated. This gives a basis to compare the cost-effectiveness of the different SEF, and to decide finally which risk control option should be implemented.

4.3.1 Basic vessel – Configuration 1

The result of ICAF calculation performed by the tool is the follow:

ICAF = 1.62 E+08

This is due to an improvement in human safety (2.20E-03 in configuration 1 against 3.37E-03 in basic vessel) and to an increase in terms of cost (the change in NPV value is –189589.42 euros).
The improvement in human safety are caused by adding of two transverse bulkheads, by the improvement of the detection reliability and by the structural improvements.
The increased costs are imputable to the major dimensions of the ship, that leads to a growing in labour, material, overhead and hull maintenance costs. Moreover, also the two added bulkheads bring to a further cost, viewable under the voice "General arrangement".

4.3.2 Basic vessel – Configuration 2

The result of ICAF calculation performed by the tool is the follow:

ICAF = 1.24 E+08

This is due to an improvement in human safety (2.05E-03 in configuration 2 against 3.37E-03 in basic vessel) and to an increase in cost (the change in NPV value is –164760 euros).
The major differences between the two configurations are related to the presence of two transverse bulkheads and to an improvement in hull structure, both for safety and costs.

4.3.3 Basic vessel – Configuration 3

The result of ICAF calculation performed by the tool is the follow:

ICAF = -3.27 E+08

This is due to an improvement in human safety (1.33E-03 in configuration 3 against 3.37E-03 in basic vessel) and to a decrease in cost (the change in NPV value is 666454.54 euros).
This type of value comes from different considerations.
First of all it should be noted a great decreasing in NPV value, because the costs decreases coherently with the ship main dimensions, but the gain assess by the model is always the same as in basic configuration. The model is not sensible to deadweight modification, but it is referred only to the market data inputted in the tool, so all the three configurations have the same assessed gain per year. This aspect is surely improbable, because the market demand is too conservative, and it doesn't consider different travelling seasons.
As second remark, the presence of paging system has a strong influence on evaluated the risk level: the event "Internal communication failure" is less important, and all the events connected with it have a drop in their frequencies of occurrence. It seems that this element is too important inside the tool functionality.
The combined effect of the above consideration leads to have minor cost than in the basic configuration, but more human safe life. This is in conflict with the reality and with the other assessed configurations.

4.4 Conclusions

The methodology performed above could be used to determine the value of the potential loss of life. It' s possible to quantify the increased cost needed to save a certain number of lives.
The analysis is based on I.M.O. methodology , which consists in a subdivision of the outcomes by severity class index, as reported in the scheme here below:

Severity Index (IMO classification)				
SI	SEVERITY	EFFECTS ON HUMAN SAFETY	EFFECTS ON SHIPS	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or sever injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

Once having determine the severity class for the outcomes of our interest , I.M.O. criteria provide a weight by what multiplier the hazard frequency, to obtain the equivalents humans fatalities.
This weight was thinking strictly connected with the definition of severity class index: for example, the "Severe" class is specific as "Single fatality" for what concern human consequence, so its weight must be surely 1.
For the purpose of our analysis, the interesting class is the "Catastrophic" one, which is defined as "Multiple fatalities" for humans consequence: I.M.O. assessed a weight of 10 for this severity class index.
From these basis, it' s possible to describe the meaning of ICAF evaluation results.

In configuration 1, there is a decreasing of human catastrophic consequence frequency of about $1.17x10^{-3}$ in respect to basic vessel. Considering a full load vessel (800 persons) and the 75% of people involved in the accident (600 people), this result means 0.702 fatalities per ship/year. This end result is obtained with an increased cost of about 189 589.42 euros, that means a human life is estimate about 270 000 euros.

In configuration 2, there is a decreasing of human catastrophic consequence frequency of about $1.32x10^{-3}$ in respect to basic vessel. Considering a full load vessel (800 persons) and the 75% of people involved in the accident (600 people), this result means 0.792 fatalities per ship/year. This end result is obtained with an increased cost of about 164 760 euros, that means a human life is estimate about 210 000 euros.

In configuration 3, there is a decreasing of human catastrophic consequence frequency of about $2.04x10^{-3}$ in respect to basic vessel. Considering a full load vessel (800 persons) and the 75% of people involved in the accident (600 people), this result means 1.224 fatalities per ship/year. This end result is obtained with a decreased cost of about 666 454 euros.
In the analysis above was explained that this configuration is not confident with the reality, so its investigation could not be performed any longer.

The above results show how it' s possible to evaluate the costs connected with saving human life. The tool provides an evaluation methodology that could be integrated, with expert experience, inside the design process. Once determined a certain number of alternative configuration, the decision making for design to cost could be performed through ICAF value. The designer has to weigh up different cost for human safety, and then choose among different solutions the most appropriate by the risk/cost effectiveness point of view.
The correct quantify of ICAF value is given by the experience of each designer.

5 GLOBAL CONCLUSION

WP6 work package has reached his goal, which is to demonstrate the reliability of results. The tool was tested through a well defined project, and the results obtained in term of risk and cost evaluation show consistency with the reality. That derives from the goodness of developed work. From these introductions, the tool constitutes an important starting point towards the fully integration process of the safety requirements into the different design phases.