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ENTREPRENEURSHIP, BUSINESS ENGINEERING AND MANAGEMENT DOCTORAL SCHOOL

RISK BASED DESIGN CONCEPT IMPLEMENTATION IN SHIP RETROFITTING PROCESS

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Acronime

AHP – Analytic Hierarchy Process

BWTS – Ballast Water Treatment System

DBP – Disinfection Byproducts

FMEA – Failure Modes and Effects Analisys

FTA – Failure tree analysis

HiP-HOPS - Hierarchically Performed Hazard Origin & Propagation Studies

IMO – International Maritime Organization

LNG / LPG – Liquefied natural gas / Liquefied petroleum gas

PHA – Preliminary Hazard Analysis

PSI – Preventing and extinguishing fire

PSS - Product – Service – System

RBD – Risk Based Design

SSM - Operational security and health

TDW – Deadwight tons

TEU – Twenty foot equivalent unit

TRO – Total residual oxidants

USCG- United States Coast Guard

UV – Ultraviolet radiation

Key words

Risk analysis, Ship design, Ballast water treatment, Risk based design, Multicriterial hierarchy, Ship – System association compatibility, Eco-inovative re-design

SUMMARY

INTRODUCTION

The PhD Thesys `` Risk Based Design Concept Implementation in Ship Retrofitting Process``, is part of the industial engineering field and has a multidisciplinary approach. There are technical, procedural, managerial aspects that must be taken into consideration.

The reason for choosing this topic is based on the following:

First of all, there were made few and superficial studies in this field untill now, speaking about the international scale, by this, offering the possibility of following the proposed metodology resulted from this study.

Also, it was taken into consideration the new pollution standards which demands a decrease of the environmental influence, together with the energy efficiency increasing.

An other aspect would be the fact that, due to the financial crisis, shipbuiding decreased. Correlated with this, decreased the new technology development which should have been provided from the design.

As an alternative solution is the maintain of actual ship for an extra period of time. The problem is that most of them has moral and physical degradation, being compulsory a retrofitting by which to install the nedeed system (ballast water treatment system).

This kind of job needs new materials and inovative technologies, which has not been used until now onboard, being possible to appear a large sort of operational or technical risks.

That is why, it is compulsory to find new sollutions as an answer for the mentioned risk factors and for achieving the new standards.

The final target and also the inovative part of these studies is represented by the methodology that helps the development of new solutions, regarding old ships retrofitting. These solutions must give realistic answers to the new International Maritime Organisation standards, together with economical efficiency and operational safety maintain.

I followed the idea that the proposed methodology should not have a local or restrictive state. That is why there were chosen 10 different examples of treatment systems, covering a large area of treatment process.

After the hierarchycal analysis and incompatibilities highlight, it resulted the fact that for most of the chosen ships, only 2 – 3 type of systems are proper to install onboard. It exist also, the situation in which none of the treartment systems is compatible with a certain ship. That is why, in Chapter 7, it was developed a study assuming different ways of improving the treatment systems.

As Risk Based Design concept sugest, any change of the design structure or function of a system assumes a large scale of unknown. In order to establish if the improvements has also some side effects, I developed a risk analysis. The main used methods are FTA and FMA.

It can be observed that, after reevaluating the existent situation (by implementing the improvements), through Risk Based Design method, the resulted advantages are apparent little (only 6 systems out of 100 possible combination ship – system).

However, for that 6 ships, oboard of which the sugested improvements can be made, the savings are significant if we take into consideration the fact that the system lifecycle costs are on the order of million of dollars.

CAP. I CURRENT STAGE ANALYSIS OF RISK METHODOLOGIES IN SHIP DESIGN AND RE-DESIGN

Risk management represents the collecting data process and information synthesizing, focusing the development of an obvious understanding regarding the risks existing in a certain system. It supose probabilities and consequences maximization for the positive events and minimization for the adverse ones.

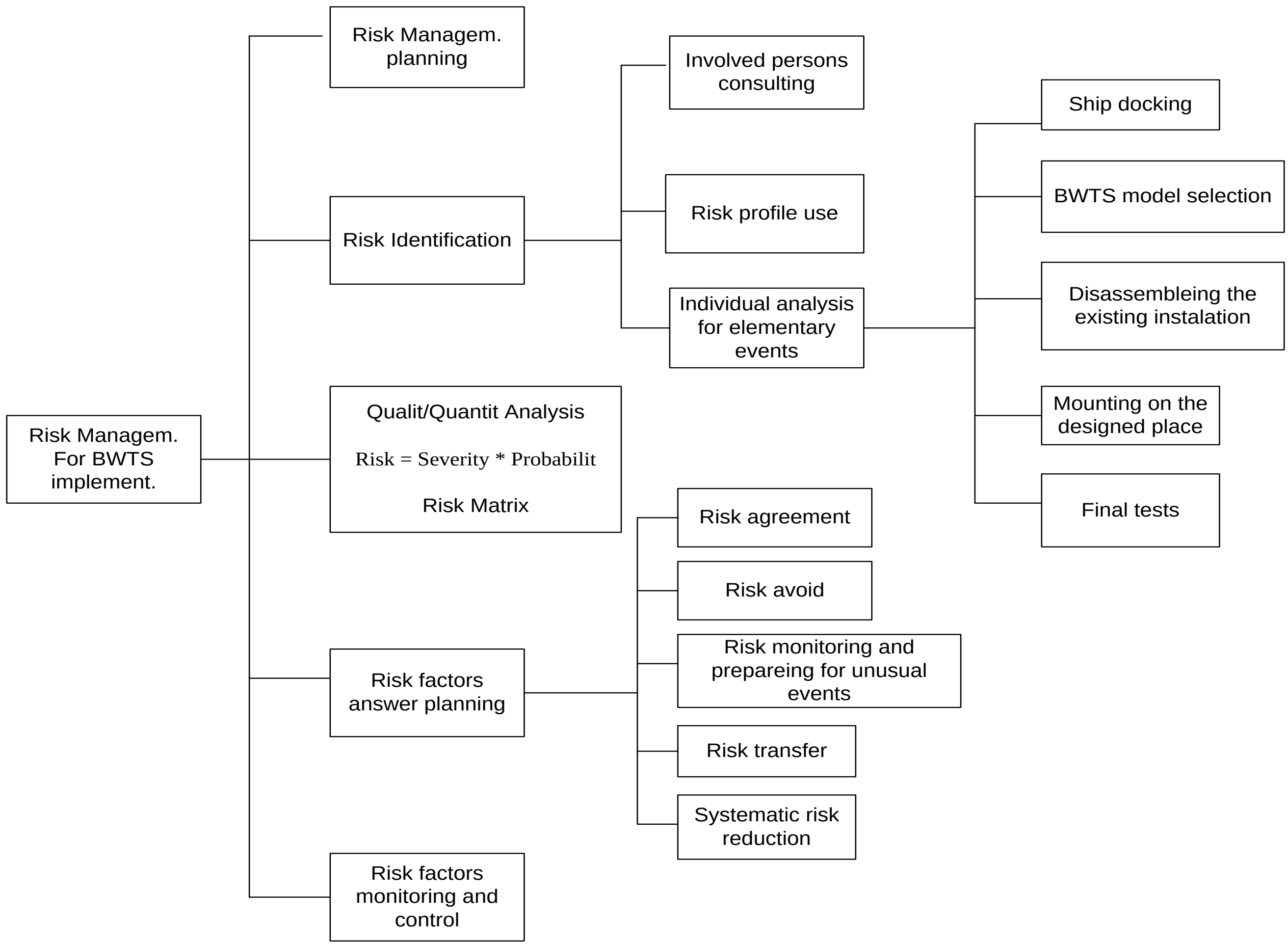


Fig. 1.1 Risk Management application for a Ballast water treatment system

Risk analysis regarding design parameters and system technical performance

Risk analysis process in naval and aerospace field is developed at the highest performance level due to the huge costs, involved in the specific systems. Some of the usual analysis used are: PHA (preliminary hazard analysis), Risk trees and Fault trees, FMEA (Failure modes and effect analysis).

On the following it will be illustrated an example of Risk tree, regarding a ship running, focusing on the shell cracks occurrence. Because the below tree is given only as a simple example, it was choosen a single cause for the subsequent analysis. This is represented by vibration factors, being shown also possible sollutions for risk avoidance or decreasing.

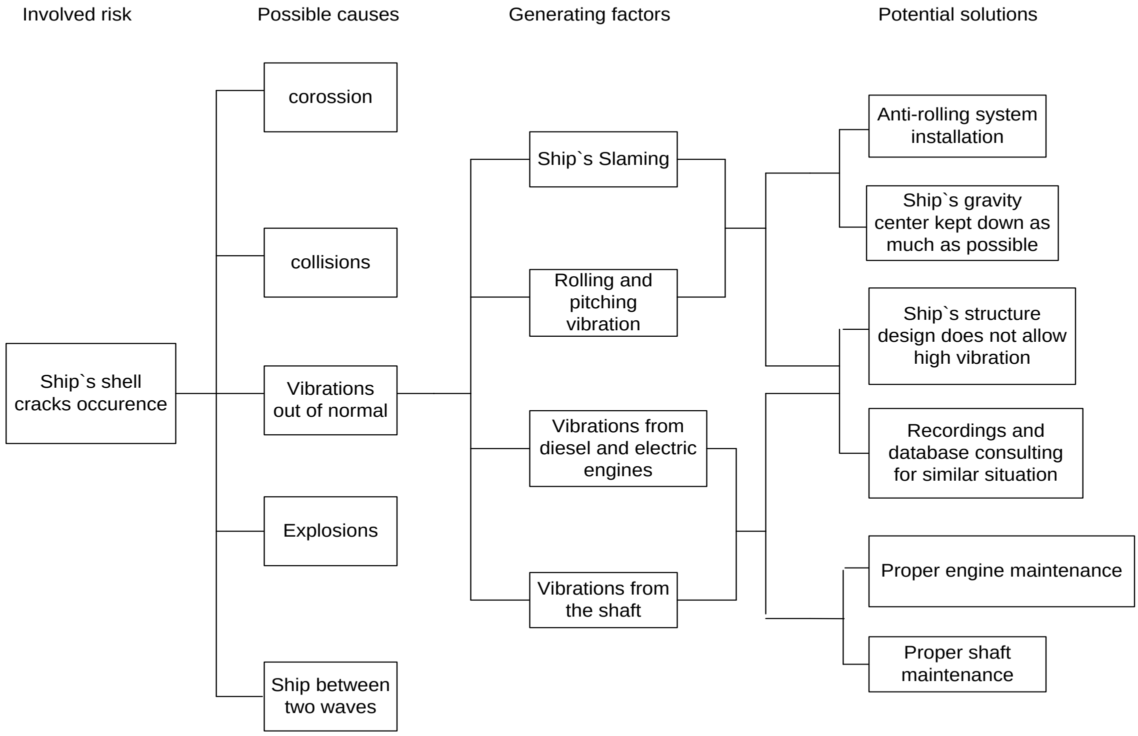


Fig. 1.2 Risks tree for ships shell early frazzle

Failure tree analysis (FTA) of an unjustified investment

Failure tree is a graphical model which represents the connetions between the failure events and the simultaneous human errors that can happen in the system. The calculation of the main event probability is possible only evaluating the failure probabilities for each basic component. [4]

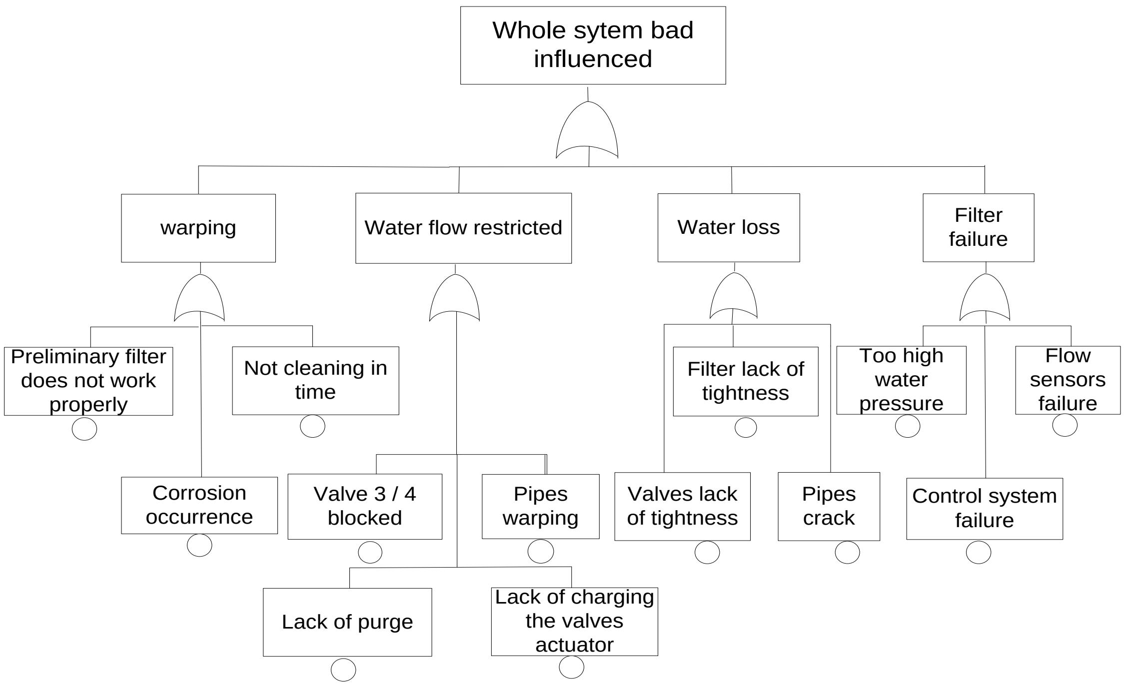


Fig. 1.3 Failure tree (FTA) for the system functioning with an extra filter

CAP. II DIFFERENT WAYS OF ANALYSING RISK BASED DESIGN METHODOLOGY

2.1 Risk Based design concept preview

Risk management integration in design process leads to "Risk Based Design" concept. Science and technical improvements gave the opportunity for inovation in the naval field. The main targets are: bigger, faster and more economical ships. Also, an other interest regards the environmental pollution decrease.

The fact is that, together with this technological improvements, risk level is rising. Obviously it is not enough any more only to follow the standards an reglementation. That is why, it is compulsory to adopt some predictive analysis, to be integrated in design process. This risk analysis must be considered at the same level of importance with economic efficiency or environmental pollution.

A definition for RBD is: risk management integration in the design process, aiming to reach a high as possible performance level, by implementing inovative technology (reffering to speed, transport capacity, comfort, environmental pollution, efficiency) at a low cost, maintaining the operational risk at the normal limitation. [10]

2.2 Ship Design Process

The role of the specific used instruments

At the moment, in ship design process, the safety aspects are restricted only to existing standards and regulations, taking into consideration, the expense decrease interest.

An additional budget and deeper risk analysis and safety level could stimulate inovative design implementation. [11]

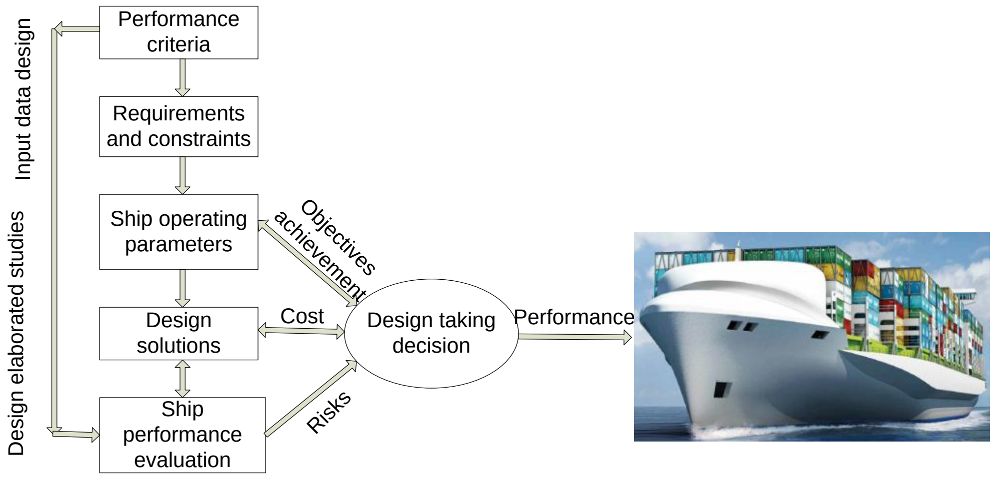


Fig. 2.1 Design process [12]

``Design Safety Level`` concept relies on the possibility of evaluating the existing risks from the entire ship lifetime, taking into consideration all possible safety measures (passive and active).

This evaluation must be developed within the design stage. Although it represents a complex objectiv, the obtained benefits are substantially.

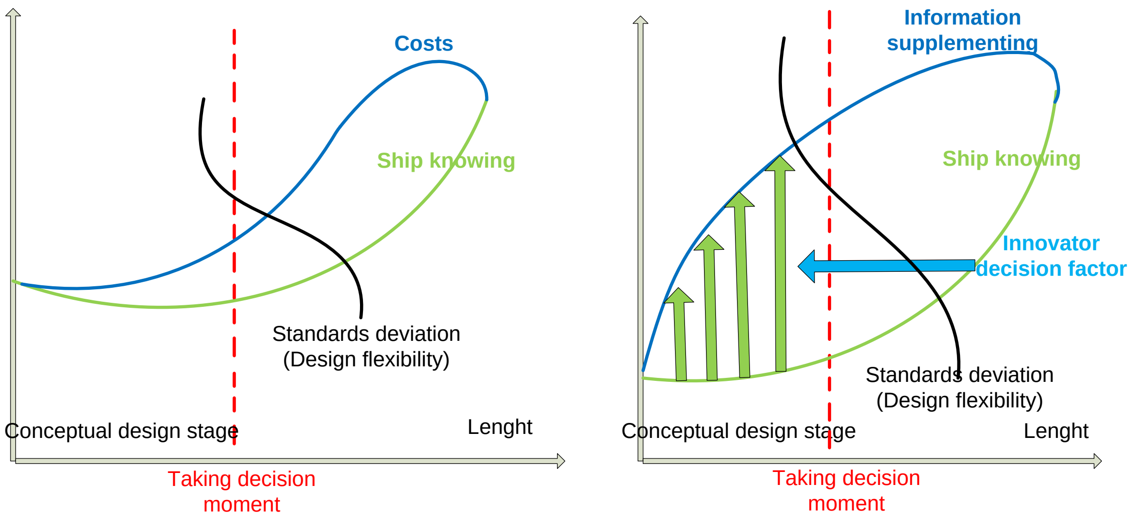


Fig. 2.2 Classic Design vs. Risk Based Design

One of the most important features of RBD is the implementation of safety measures at a high level, with a low cost.

In order to reach the safety level, it is compulsory the implementation of some procedures for measuring the risk analysis. It must be take into consideration the fact that, due to analysis complexity, some clues must be followed, as: historical data from previous major accidents, experts opinions, software simulations.

This kind of instruments (clues) must be integrated into the design process to facilitate the conections between safety and other factors (economic, performance, environmental).

2.3 Critical scenarios identification (potential risks or incidents)

The fact that facilitates the use of RBD onboard ships is the fact that ship`s safety is influenced only by a small number of factors (hazards). This factors, individual or associated, leads to a number of unfavorable scenarios. Below is graphically represented, in a simple example, the interconections between different scenarios, that can happen onboard a ship.

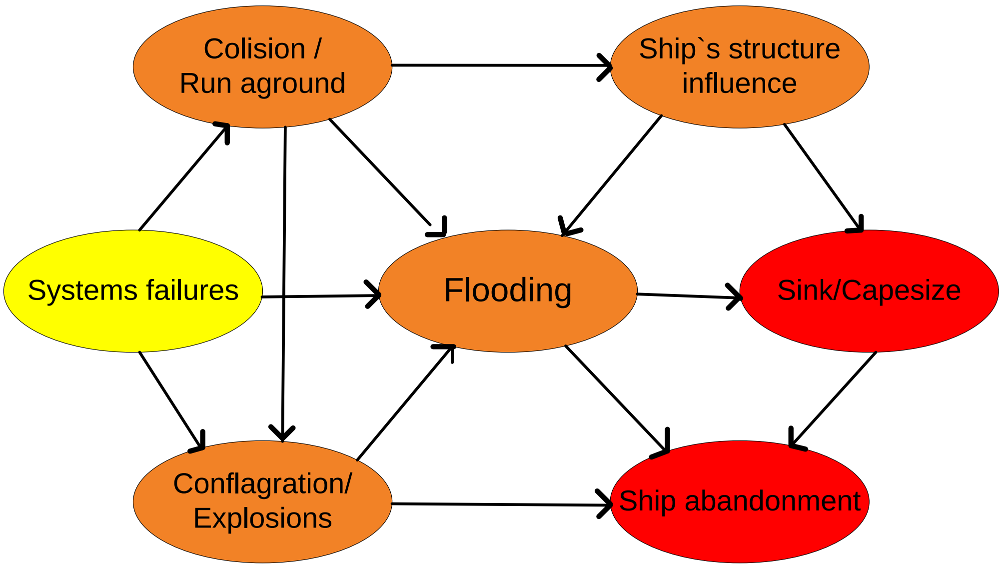


Fig. 2.3 Different scenarios interconections onboard a ship

2.4 Risk Based Design concept way of implementation

Safety management or risk management is a process that can be achieved through a multitude of ways. The steps are represented in the below graphic.

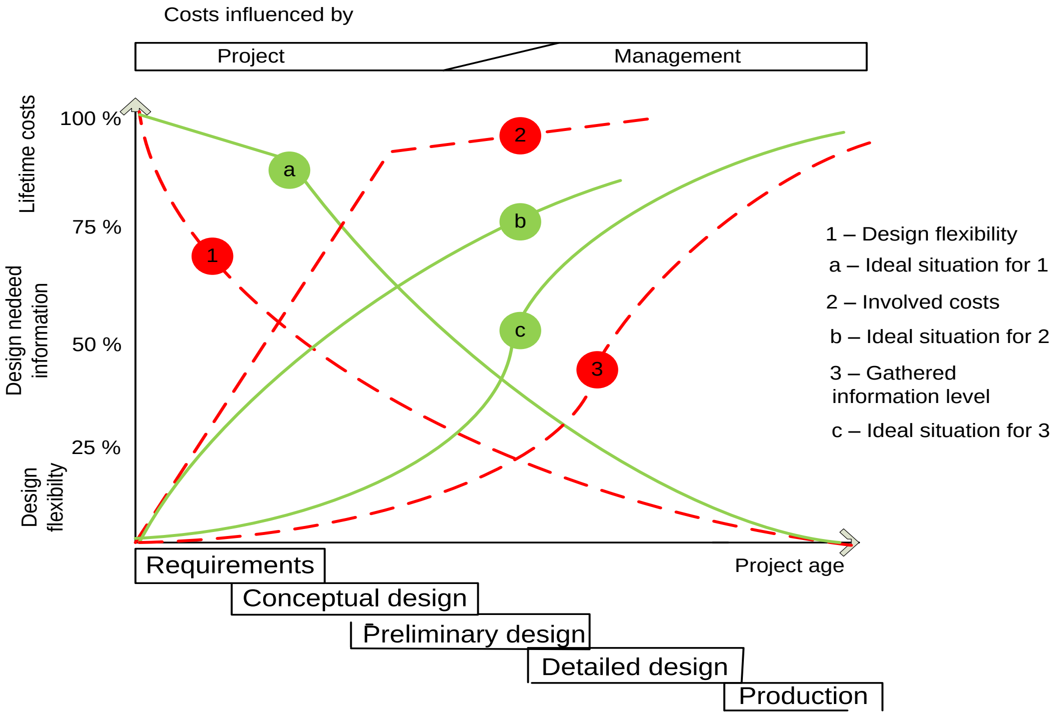


Fig. 2.4 Design process factors[15]

2.5 Instruments used in Risk Based Design concept

RBD requires advanced instruments for developing Risk Management analysis in a certain project. This instruments facilitates consequences analysis for a variety of hazards: technical failures, conflagrations, explosions, floodings, capesize, and so on.

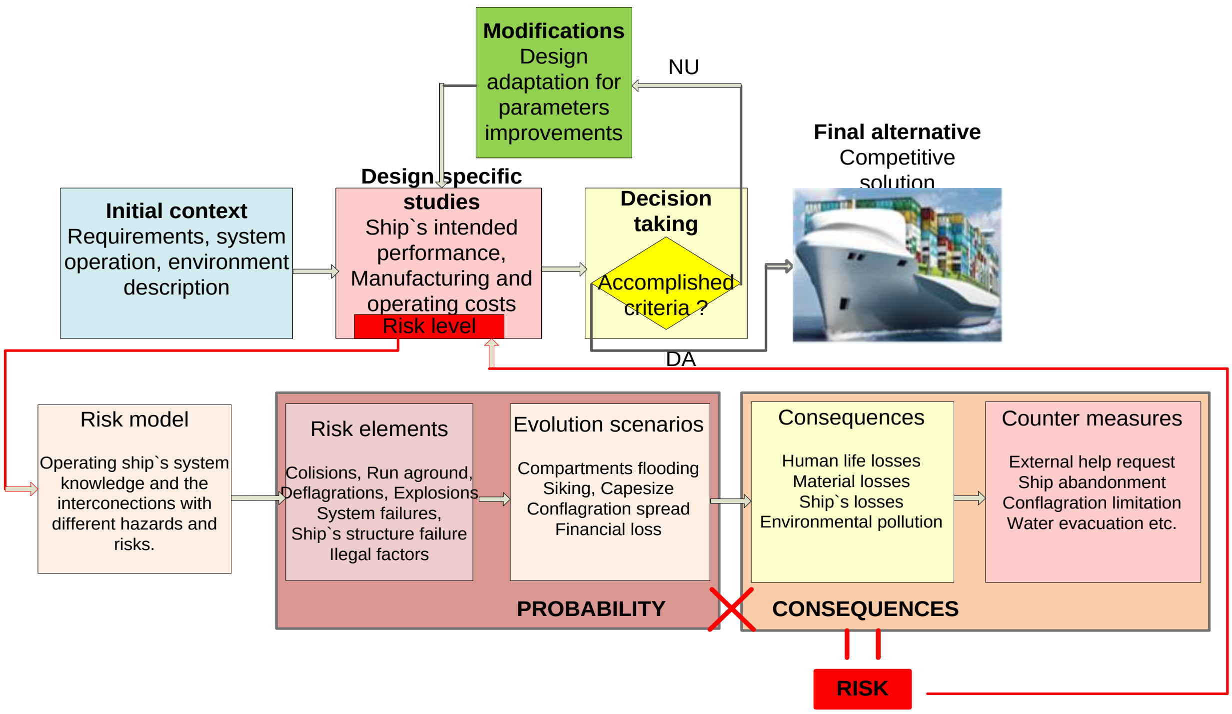


Fig. 2.5 RBD algorithm implementation

As it can be seen in the previous diagram, there are mentioned the most important risk elements, which are vital to be considerd within the RBD process.

Two of the most used methods for predicting risks as the ones already mentioned, are FTA (Failure tree analysis) and FMEA(Failure mode and effect analysis).

Recently there was implemented an other software model, which extends the interest area, from risk predicting to design optimization.

HiP-HOPS model has three main phases:
1. System modeling and potential failures counting
2. Failure trees analysis
3. FMEA analysis

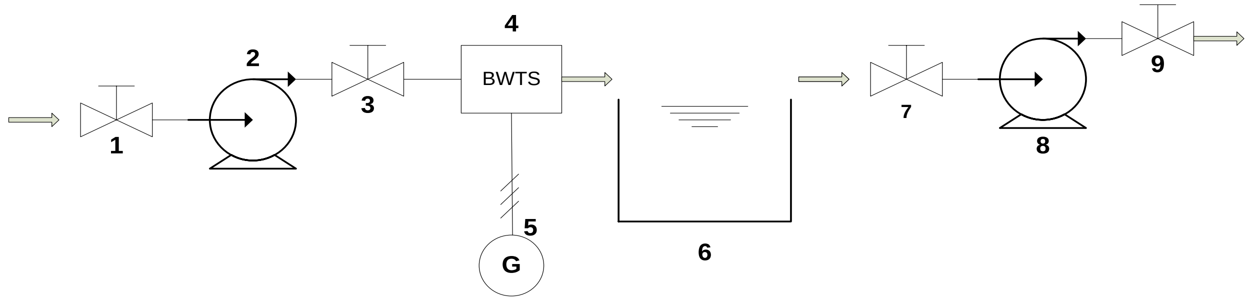


Fig. 2.6 Elementary design of the analysed system

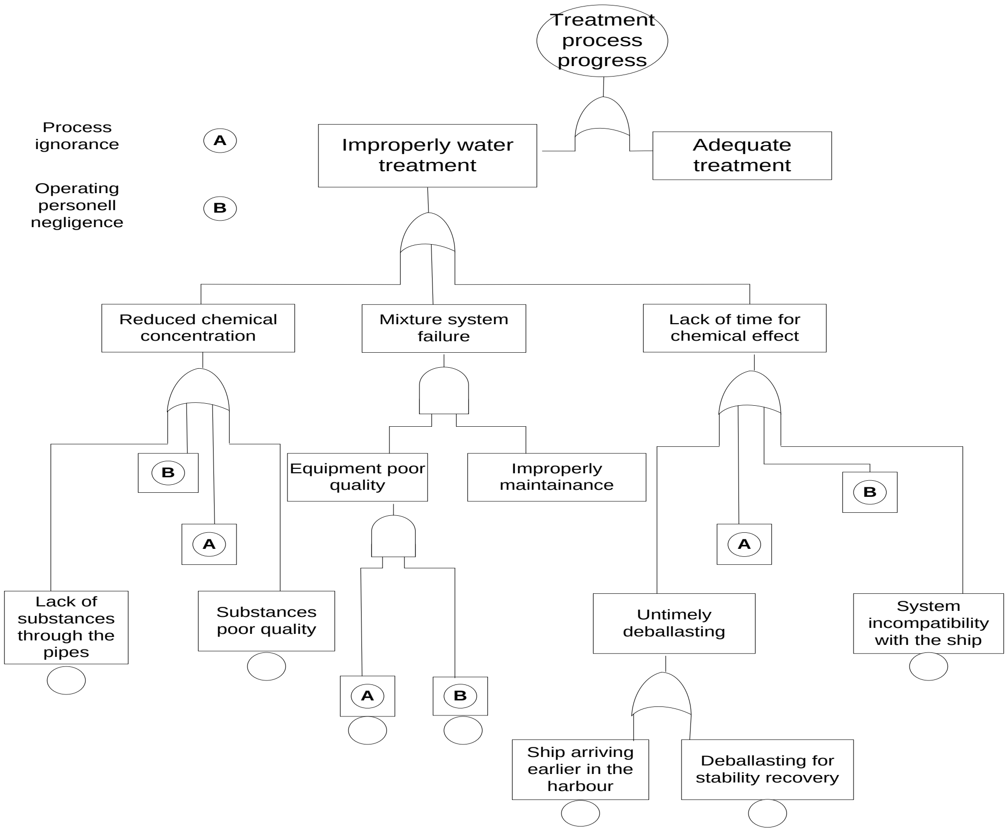


Fig. 2.7 Failure tree coresponding with the previous system diagram

Within the third stage, all failure trees, corresponding with each component of the system, will be analysed, the information being centralised in the tabular structure created in FMEA. In this way, for each component will be visible all possible corespondence with the others from the system, generating the probability for unfavorable events.

Analysis process

In the following, will be ilustrated an elementary example of a failure tree conversion in a FMEA structure. The example is based on the previous FTA diagram. All the initial components failures were symbolized with $D_1 – D_{13}$ and the effects on the system with $E_1 – E_7$.

Tab. 2.1 Results for FMEA

Multiple system failures		
Component 1 – 13 failure	**Immediate system effect**	**Interconnection with other components effects**
D_1	E_1	
D_2	E_3, E_2, E_1 (chronological)	
D_3	E_3, E_2, E_1	
D_4	E_3, E_2, E_1	
D_5	E_3, E_2, E_1	
D_6		E_6 (in association with D_7) şi E_4, E_2, E_1 (in association with D_7 şi D_8)
D_7		E_6 (în asociere cu D_7) şi E_4, E_2, E_1 (in association with D_7 şi D_8)
D_8		E_4, E_2, E_1 (in association with D_6 şi D_7)
D_9	E_7, E_5, E_2, E_1	
D_{10}	E_7, E_5, E_2, E_1	
D_{11}	E_5, E_2, E_1	
D_{12}	E_5, E_2, E_1	
D_{13}	E_5, E_2, E_1	

An elementary example, to prove the importance for this algorithm in RBD process, for Ballst water tretment system, can be analysed in the bellow diagram.

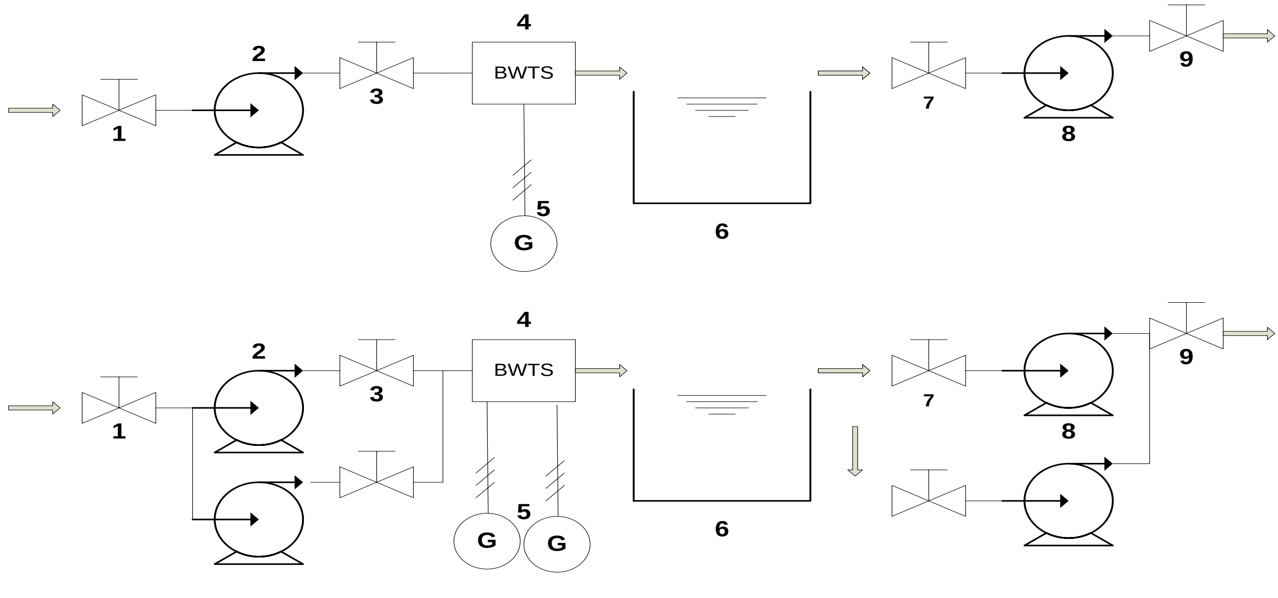


Fig. 2.8 BWTS before and after improvement

CAP. III WATER BALLAST TREATMENT SYSTEM REQUIREMENTS

3.1 Technical details for the today systems

Wartsila – Aquarius Electroclorination [21]

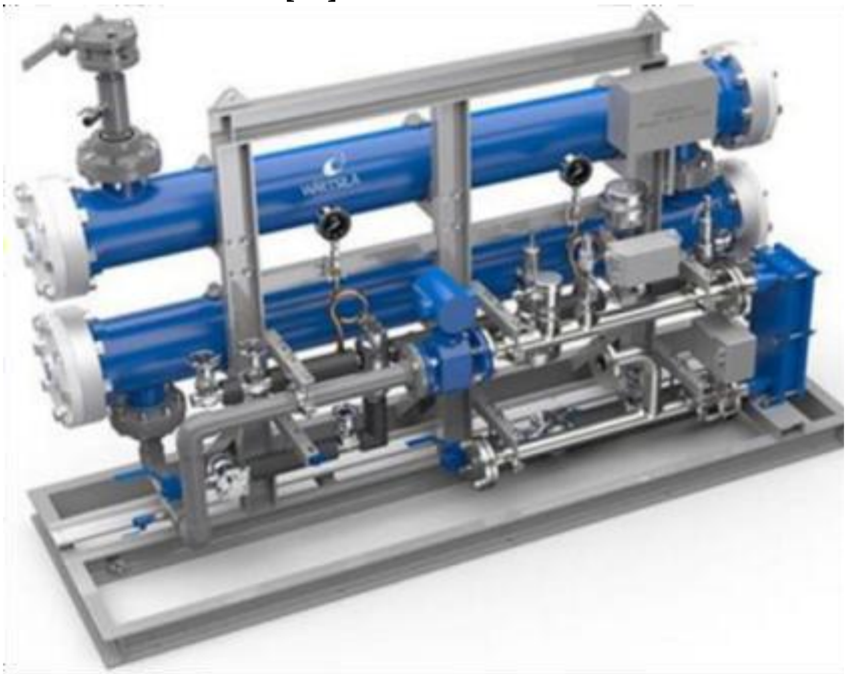


Fig. 3.1 Overview of the Wartsila – Aquarius Electroclorination system

This treatment system process relies on filtration as first stage, within are eliminated the microparticles biotic or mineral, up to 40 µm.

The second treatment stage relies on electroclorination. The sodium hypochlorite, produced in the process is injected in the water feed pipe, mixing with the sea water flow. For preventing chemical substances concentration fluctuation, the process is permanently monitorized.

3.2 Ecoinvative ballast water treatment [23]

The proposed sollutions for achieving this target can be: Shore treatment base, Fresh water supply in the aride areas.

3.2.1 Shore treatment base

Small shipping companies or oldest ships, which does not afford the investition in a BWTS (the implementation cost may not be payed off during the remaining lifetime of the ship), has an alternative sollution in ballasting (surecharge) from the shore treatment base or existing on a ship-base with treatment role. Also, it exists the alternative that the ship to ballast from open sea, but to deballast at a shore system.

A big disadvantage of the shore treatment is represented by the difficulty to supply with this system all the harbours around the world, taking into consideration a series of aspects. A main aspect is the cost – much biggerr than for a ship system. An other element would be the interest level and the developped policy by the local investors and other decisional factors. Also, probably the most difficult aspect, is the location and specific conditions required for system correct operating.

The main advantages of installing the shore treatment system:
- money saving for aquisition, onboard installing and operating
- risks decreasing regarding system operating
- the use of extra power for other purposes
- it rises the rentability of the system operation

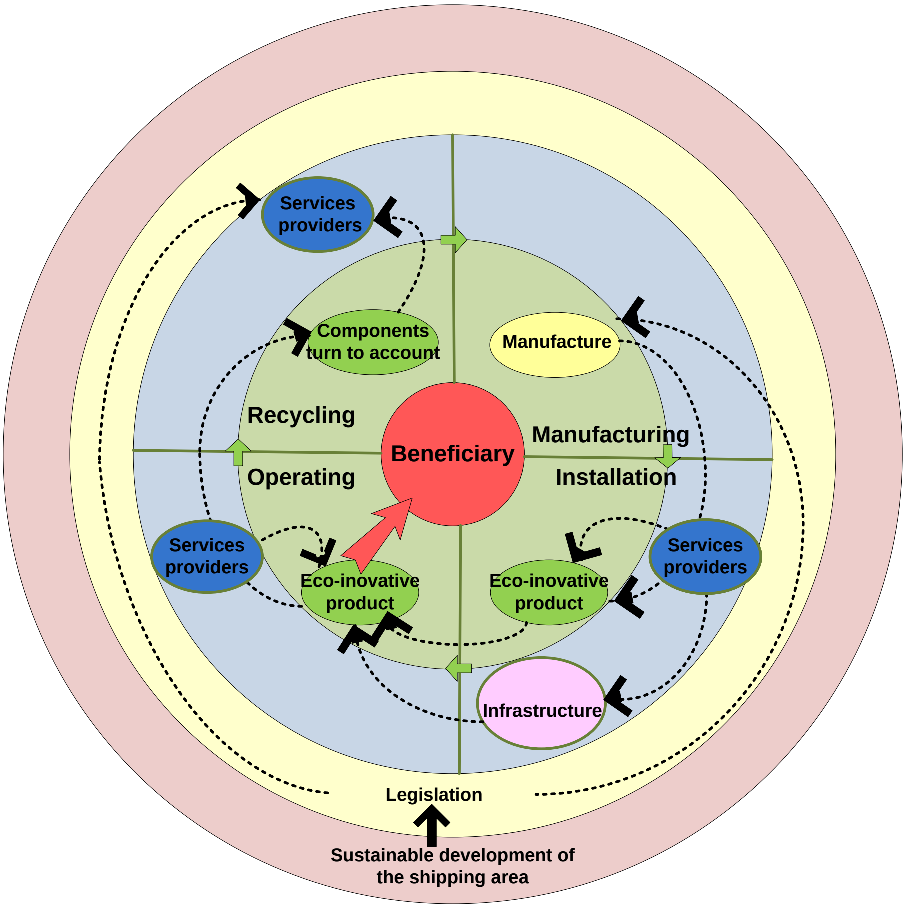


Fig 3.2 Shore treatment system implementation as eco-inovative technology

3.2.2 Fresh water supply in aride areas [24] [25]

This method is reffering to a series of particular cases, that can`t be applied in any context. More exactly, is about high aride areas where for irrigating is used very expensive water supply.

The idea is that, the ships coming to take aboard oil, or other type of raw materials, need to deballast. If, instead of using sea water, that must be treated through an expensive process, will be used fresh water, this can be delivered to supply the irrigating system.

The biggest problem in this context is represented by the voyage planning, that must be done in so as to exist a direct rute between the fresh water supply harbour and the aride area harbour.

There is possible that any consecutive harbours to have the same specific (either an excess of fresh water, either with lack of water). It is well known also, the fact that a ship, often does not unload whole merchandise in a harbour, but fractionated, according to the market are. From this reason, also the ballast water unloaded in a certain harbour, won`t be equal with the maximum tanks capacity.

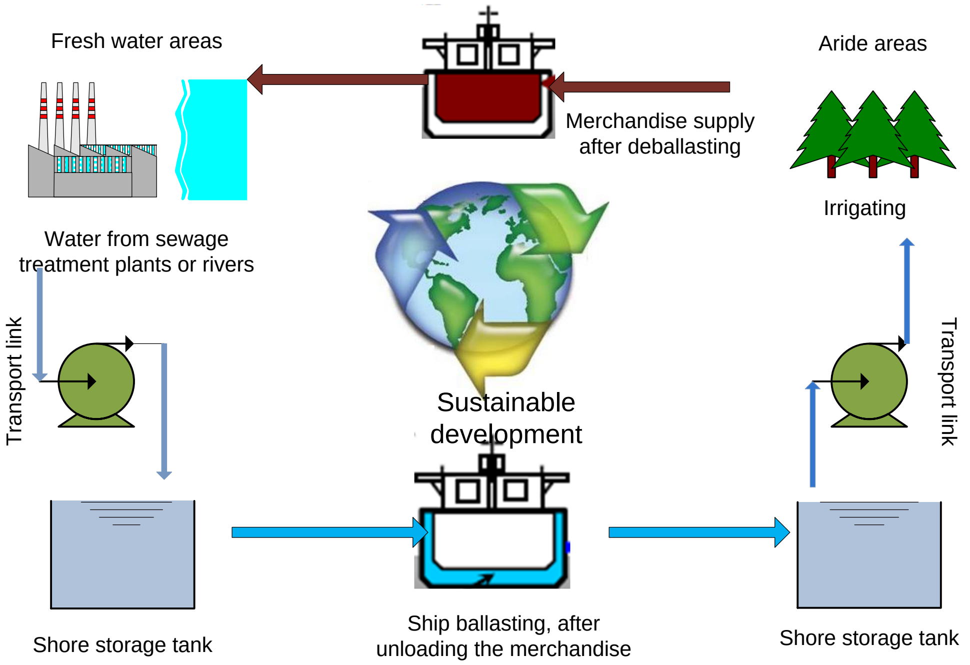


Fig. 3.3 Ballast water management and fresh water transfer to aride areas

3.3 Analysis selection for the representative systems

Power consumption

For the most representative type of systems, will be realised the association with the most common ships, oboard of which is supposed to be installed. At the end, the most favorable combination ship - system will be shown.

Tab. 3.1 Power consumption calculation regarding the flow

Flow / Model	Aquarius EC	HiBallast	Aquarius UV	Balpure	Ecochlor	Crystal Ballast	Hyde Guardian	Mitsui	NK O3	Hitachi
500	56	126	106	46	26	99	66	22	76	56
1000	102	232	142	92	51	197	107	42	132	112
1500	157	331		136	74	296	160	62	190	166
2000	214	434		184	100	394	214	84	254	229
2500	265	539		230	124	495	270	106	320	289
3000	316	626		276	146	596	331		386	346
3500	373	713		323	170		393		463	415

3.4 Representative ship selection

To be mentioned the fact that the ships took into consideration, are the ones older than five years. That is because the new ships are provided with ballast treatment system from the design stage. [36]

Tab. 3.2 Basic features for the considered ships

Type of ship	Displacement [TDW]	Ballast tank capacity [m^3]	Ballast pumps flow [m^3 / h]	Gen-set [kW]
Oil Tanker	9200	2620	2 x 250	3 x 780
	24 000	11 900	2 x 750	3 x 850
	65 000	26 100	2 x 1500	4 x 950
	166 000	52 300	4 x 1500	4 x 1630
Bulk-carrier	41 000	14 000	2 x 1500	4 x 740
	60 000	20 000	2 x 2000	3 x 1150
Containership	2420TEU	12 000	2 x 500	3 x 800

CAP. IV TREATMENT SYSTEMS COMPATIBILITY WITH THE SELECTED SHIPS AND HIERARCHICAL PROCESS

4.1 Power supply compatibility

To verify any system compatibility with the counted ships, will be taken into consideration the percent that represents the nedeed power supply for system operation, from the gen-set available power.

An important criteria for removing from potential to be used system list, is the fact that the nedeed power supply exceeds 10 % from the gen-set available power.

To obtain all possible combinations between the systems and the selected ships (10 examples of each), was realised the below matrix:

Tab. 4.1 Possible combinations matrix, between the systems and selected ships, preliminary phase

Treat system / Ship	Treatment flow [mc/h]	Aquarius EC [kWh]	HiBallast [kWh]	Aquarius UV [kWh]	Balpure [kWh]	Ecochlor [kWh]	Crystal Ballast [kWh]	Hyde Guard [kWh]	Mitsui [kWh]	NK O3 [kWh]	Hitachi [kWh]
T 9200	500	56	126	106	46	26	99	66	22	76	56
T 24 000	1500	157	331	248	136	74	296	160	62	190	166
T 40 700	2000	214	434	284	184	100	394	214	84	254	229
T 65 000	3000	316	626	-	276	146	596	331	128	386	346
T 95 000	4500 (3500 + 1000)	475	945	-	415	221	892	500	190	598	527
T 125 000	4000 (2x2000)	428	868	-	398	200	788	428	168	508	458
T 166 000	6000 (2x3000)	632	1252	-	552	192	1192	662	-	772	692
V 41 000	3000	316	626	-	276	146	596	331	128	386	346
V 60 000	4000 (2x2000)	428	868	-	398	200	788	428	168	508	458
2420TEU	1000	102	232	142	92	51	197	107	42	132	112

4.2 Ship – System compatibility from treatment duration point of view

It must be take into consideration the fact that treatment process duration, fluctuates depending to the system type, as ca be seen in the below table. Generally speaking, when it is about small ships (T 9400, T 24000, 2420 TEU), the distance between two consecutive harbours is relative small, implicitly the voyage duration and the treatment duration. That is why, it must be analysed which type of system has efficacy for a short treatment duration.

4.3 Systems ranking according to the fuel consumption

Based on the system power consumption will be estimated also the oil consumption and the quantity of air pollutants.

In the below table is represented the specific oil consumption for each type of ship. [44] [45] [46]

Tab. 4.2 Oil consumptions, specific to the considered ships gen-set

Ship	Gen-Set [kW]	Type and model of Gen-Set	Specific oil-consumption [g / kWh]
T 9200	3 x 780	BAUDOUIN 12M26C1100-18	209
T 24 000	3 x 850	MAN 9L16/24 – HFO	198
T 40 700	3 x 900	CATERPILLAR 3512B	211
T 65 000	4 x 950	MAN 5L21/31 - HFO	205
T 95 000	4 x 1200	CATERPILLAR3516B - HFO	195
T 125 000	4 x 1170	CATERPILLAR M20C - HFO	201
T 166 000	4 x 1630	MAN 8L21/31 - HFO	193
V 41 000	4 x 740	BAUDOUIN 12M26C1100-18	209
V 60 000	3 x 1150	CATERPILLAR M20C - HFO	201
2420TEU	3 x 800	MAN 9L16/24 - HFO	198

Based on this table, on the treatment duration during a voyage, combinated with the yearly voyages (all the calculations can be find in the thesys), it resulted the yearly oil consumption, correspondingt with the treatment system power consumption.

Tab. 4.3 Yearly oil consumption matrix

Treat system / Type of ship	Aquarius EC [kg]	HiBallast [kg]	Aquarius UV [kg]	Balpure [kg]	Ecochlor [kg]	Crystal Ballast [kg]	Hyde Guard [kg]	Mitsui [kg]	NK O3 [kg]	Hitachi [kg]
T 9200	9828	22120	37212	8072	4561	17381	23170	3864	13342	9828
T 24 000	20515	-	12832	17774	9669	-	41818	8096	24827	21692
T 40 700	13545	-	-	11646	6330	-	27090	5315	16077	14495
T 65 000	19434	-	-	16975	8979	-	40710	7872	-	21280
T 95 000	27786	-	-	24276	12927	-	-	11115	-	-

4.4 Systems ranking according to the operating cost

In total annual cost are included the supplies, the maintance and the consumed oil cost.

Tab. 4.4 Operating cost matrix, specific to each system, according to the needed water flow

Treatment system		Aquarius EC [$x1000]	HiBallast [$x1000]	Aquarius UV [$x1000]	Balpure [$x1000]	Ecochlor [$x1000]	Crystal Ballast [$x1000]	Hyde Guard [$x1000]	Mitsui $x1000	NK O3 $x1000	Hitachi [$x1000]
Ship	Flow										
T 9200	500	15	15	9	14	14	9	9	7		
T 24 000	1500	18	-	12	17	17	13,5	14	9		
T 40 700	2000	18	-	-	17	17	-	14	9		
T 65 000	3000	20	-	-	19	19	-	15,5	11	-	
T 95 000	4500	20	-	-	19	19	-	-	11	-	-
V 60 000	4000	-	-	-	-		-	-		-	-
2420TEU	1000	18	18	12	17	17	13,5	14	9		

4.5 Systems ranking according to aquisition cost

Regarding the aquisition cost must be counted some references: Severn Trent De Nora[58], BALPURE[56] , AURAMARINE[59] financial offerts for Constanta Shipyard. I was allowed to use this information through the ECOREFITEC Project, that analysed the possibility of installing a BWTS onboard of a 38 000 TDW tanker.

CAP. V ANALYTIC HIERARCHY PROCESS METHODOLOGY FOR RISING SYSTEMS PERFORMANCE

5.1 Multicriterial ranking

In the following there is made an analyse of the systems, in order to select the compatible ones with the choosen ten ships.
Due to the fact that the diferences regarding oil consumption, operating or aquisition costs, installing area, are pretty small, theoreticaly, any of the ten systems can be installed onboard of any ship.

That is why will be required a ranking, based on criterial hierarchy, the criteria being the represented by the previous calculated parameters.

In the following I will mention the choosen parameters (criteria) to be followed in the analysis, for each ship separately, and, at the end, will be proposed the best treatment system, according to the selected ship. Fig.5.1:

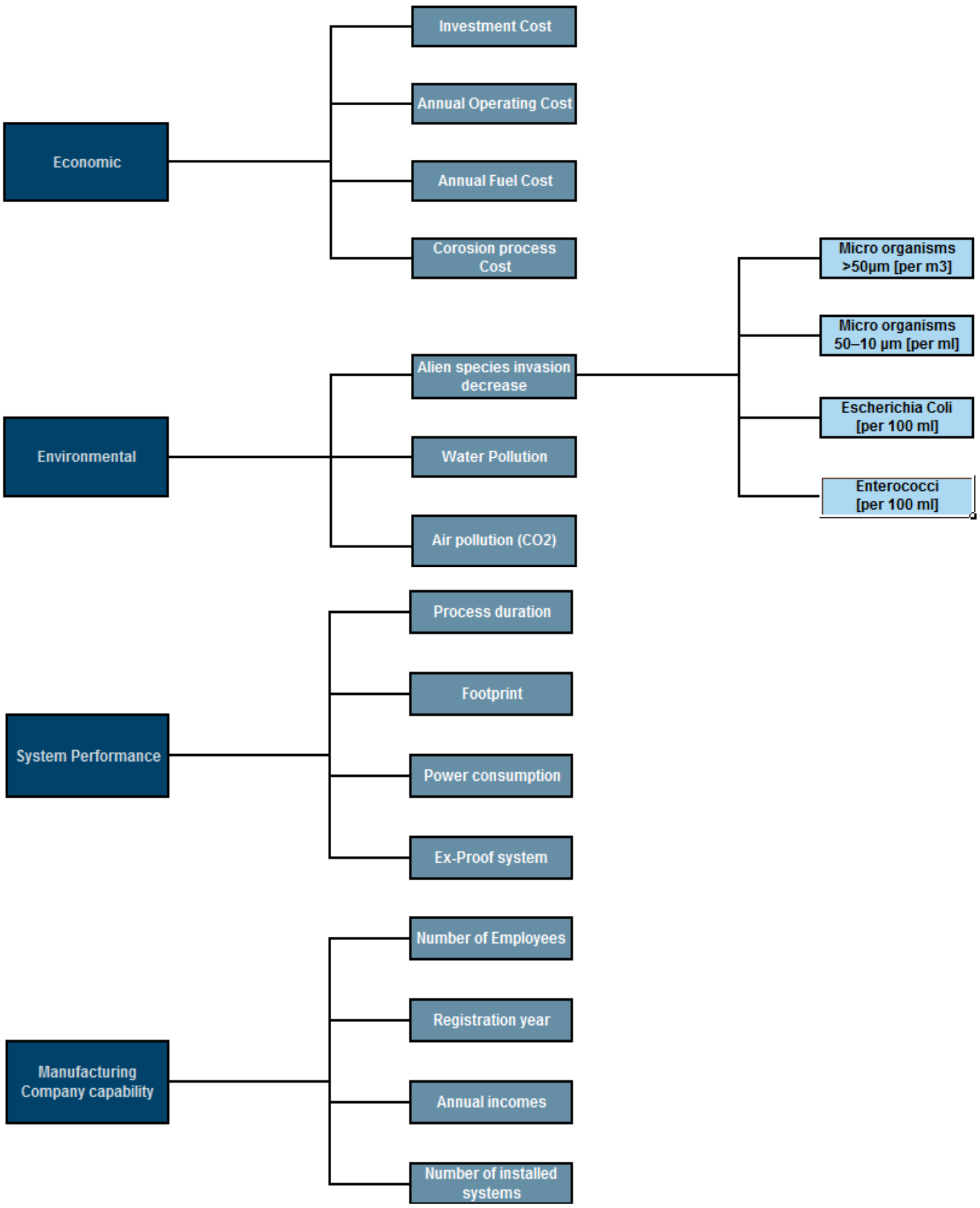


Fig. 5.1 Criteria parameters clasification

5.2 Weights calculation

In the following diagrams there are represented the rankings for each of the four main criteria. The specific values are based on the literature [72] [73].

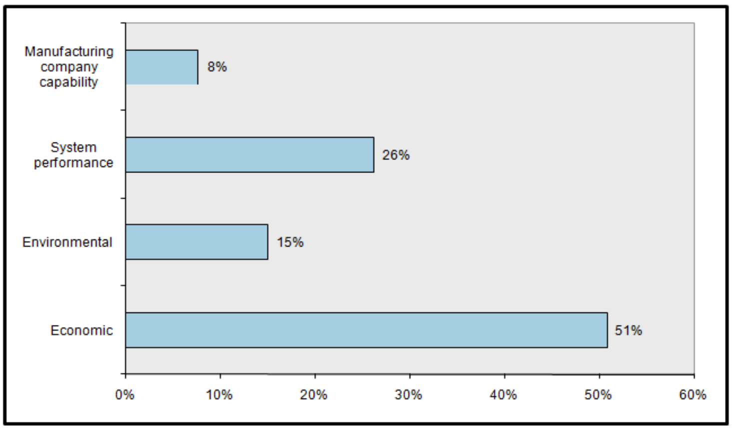


Fig. 5.2 Systems specific criteria ranking

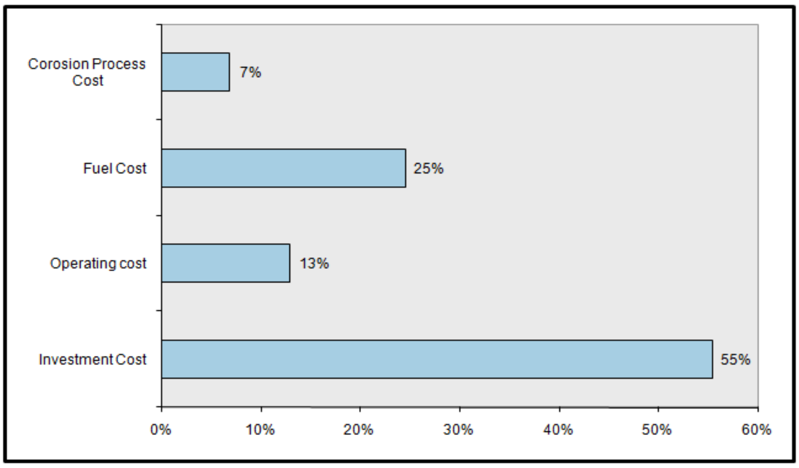


Fig. 5.3 Economical criteria parameters ranking

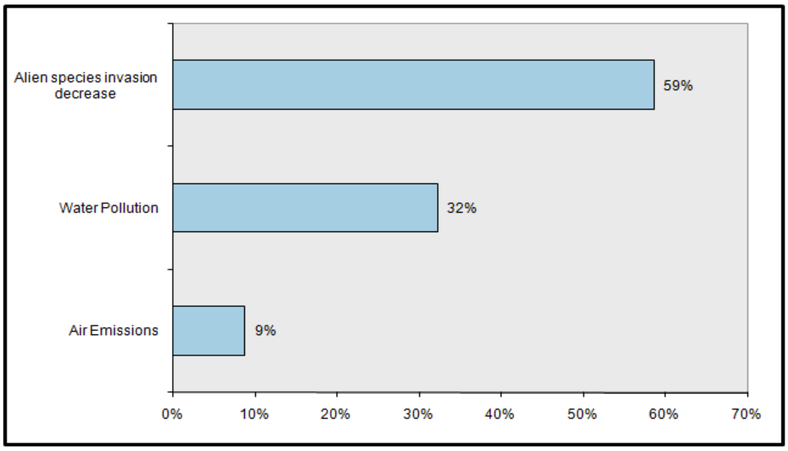


Fig. 5.4 Environmental criteria parameters ranking

In the final annexes, (at the end of the thesys), there are centralised the values corresponding to the technical parameters of the treatment systems and the ships.

CAP. VI LIFETIME RISKS IDENTIFICATION FOR TREATMENT SYSTEMS

6.1. Treatment system selection and aquisition specific risks

There is the risk that the shipyards to be overcrowded, being unable to achieve installing operation in time, causing high financial loss.

Also, is expected a rise of the costs, both for the systems and for the installing operations. An other reason would be the one that a slow management in the environmental protection could turn in a bad light the entire company.[76]

1. Lack of methodologies based on real databases and recordings [78]

There is a divergence between the systems manufacturers and the beneficiary. If the first, consider unjustified any tarry in applying the proposed measures, the last ones does not know whom to adress for obtaining some relevant answers.

2. Harbours, areas and sea transited

It must be taken into consideration the fact that physico-chemical water properties varies from a harbour to an other, on a very large scale. Not only that few systems can treat both sea and fresh water, but also the turbulence or solid particles can create serious problems to the unsustainable systems.

3. Type of ships, 4. Maintanance

6.2. Onboard installing risks

The previous mentioned stages, are taken from the project "Eco innovative refitting technologies and processes for shipbuilding industry promoted by European Repair Shipyards", EcoREFITEC-D-4.1-2012-12-01-SSA, in partnership with Constanta Shipyard.

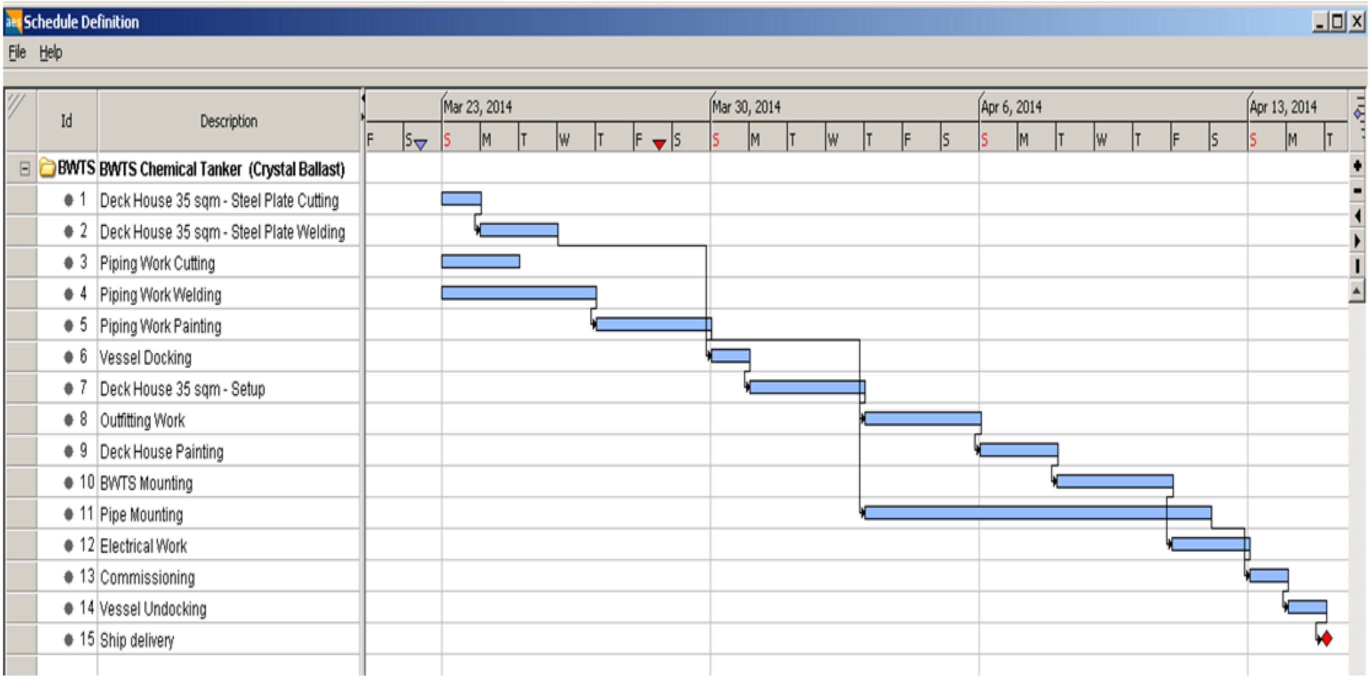


Figura 6.1 Gant graphic for the system onboard installing operations

Tab. 6.1 Potential risks centralization, regarding the system instalation onboard

Nr.	Initiating elements	Produced risk factor
1	Aquisition delay up to the moment of Standard implementation, consequently the demand will exceed the offer	Shipyard overcrowded – very long waiting time, very expensive services
2	Insufficient personnel, qualified in BWTS onboard instalation	Weak quality, expensive services
3	Shipyard selection based on other criteria than the performance or cost	Weak quality, expensive services
4	Very long duration for the operations	Expensive docking
5	Improperly use of the oxyacetylene device - failure to comply fire prevention - fire work in forbidden areas - electrical broken device that can produce flame	Fire braking
6	- Lack of knowledge - Diminshed work performance - Not following operational rules	Operational risks

6.3. Specific risks for system operating

Chemical treatment risks [88]

- the ones with short delay effect (due to strong oxidants ballasted to sea)
- the ones with long delay (due to by-products)

Ozonation treatment risks

Ozone decomposition in sea water creates a strong oxidants that neutralize the aquatic invasive organismes. The risk is that this oxidants (hypo-bromic acid) is poisonous also for the operators.

UV treatment risks

UV treatment efficiency depends on the water turbidity and solid suspensions, that makes harder the radiation propagation.

Deoxygenation treatment risks

Sediments management risks

Solid wastes after treatment, representing the remains of the aquatic organismes, is forbidden to be overboard discharged. That is why is compulsory that all the systems to be fitted with rough preliminary filter, retaining the over 50 μm particles

CAP. VII RISK BASED DESIGN ANALYSIS FOR A BALLAST WATER TREATMENT SYSTEM

7.1 Possible improvements for a BWTS [80]

On this chapter is analysed the incompatibilities between some treatment systems with the considered ships, by following RBD methodology.

There are proposed a series of solutions, some of them already implemented, and others not even in design phase.

This analysis intend to avoid, or at least to reduce the potential risks, that can appear when is about to implement an incompatible system with a certain ship.

At the end of the thesys will be indicated how much the proposed solutions can be take into profit regarding financial, environmental or safety, compared with the previous solutions, specific for the classical analysis.

7.2 Feasibility system re-analysing and analytical process ranking

7.2.1 Improving filtration

The main disadvantages, specific for filtration improvement, are the extra-space nedeed for installing suplementary filters, and also, an extra power consumption, due to the pressure drop rise. It must be mentioned the aquisition cost increase.

After introducing the new values, specific for ClearBallast system (from 7.8 table) in the AHP software model, the ranking value changed from 3 to 9, placing this system on the second position, regarding the treatment performance.

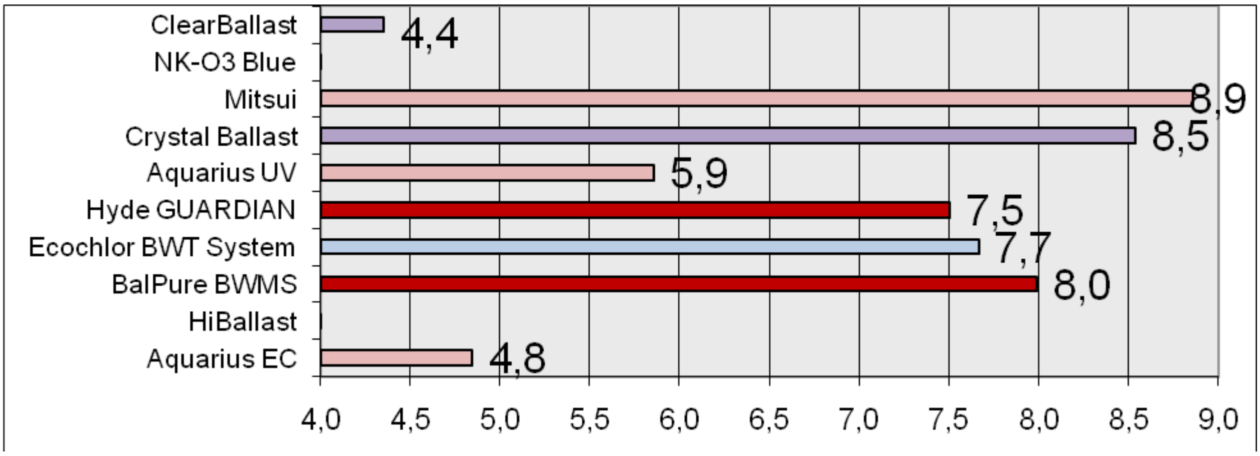


Fig. 7.1 Ranking values before improvements

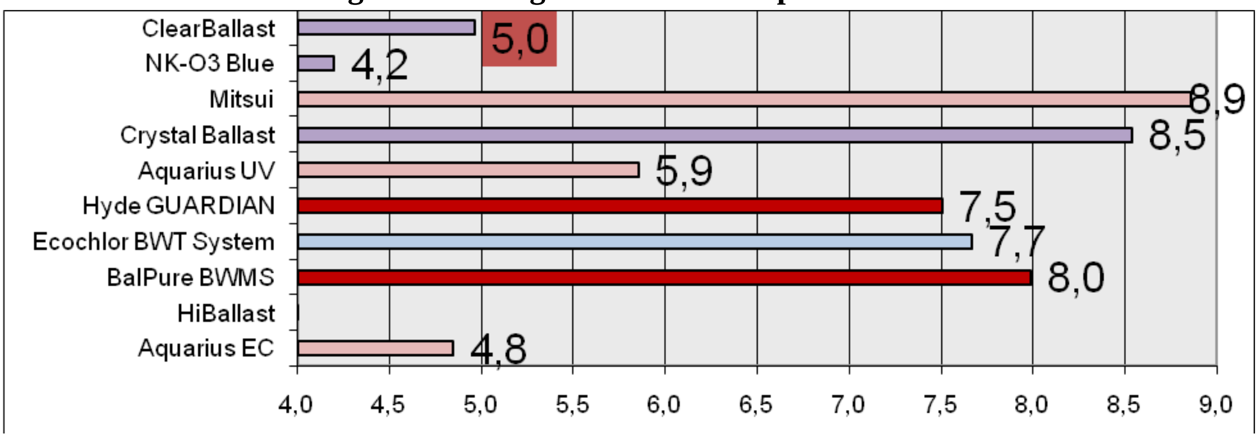


Fig. 7.2 Ranking values after improvements

7.2.2 Systems incompatibilities regarding Ex-Proof Standard[90]

Regarding the systems that are not aplying to Ex-Proof Standard, must be mentioned that are not alowed onboard tankers. Onboard of other type of ships there are not restrictions only if the instalation place is not near flammable products.

In this way, it can be take into consideration for the three examples (41000 TDW and 60000 TDW bulk carriers, 2420 TEU container ship) the increase from 1 to 10 for the raking values, corresponding to Ex-Proof criteria. The bellow diagrams shows the situation before and after the change.

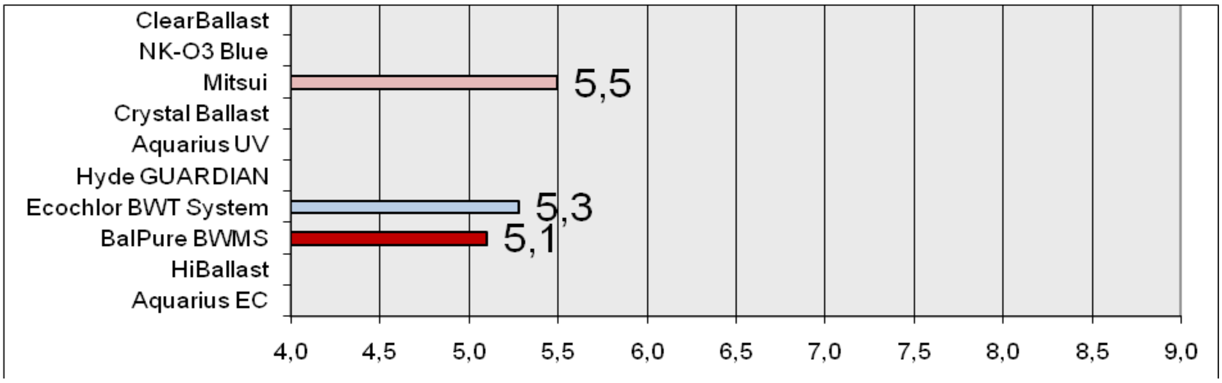


Fig. 7.3 Ranking values before improvements

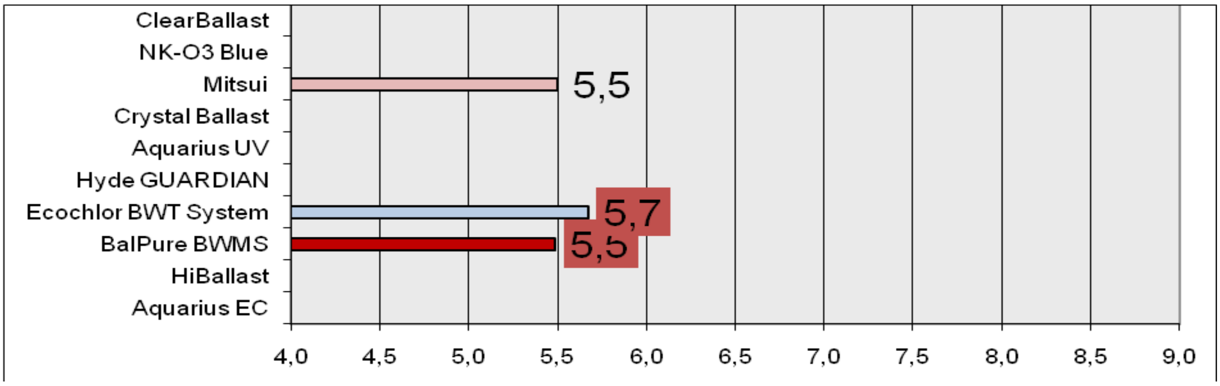


Fig. 7.4 Ranking values after improvements

The example was given for 41000 TDW bulk carrier, beign the most relevant in ranking change. From 5.1, Balpure system rised to 5.5. From 5.3, EcoChlor rised to 5.7, becoming the first one in ranking.

7.2.3 Reducing the incompatibilities number regarding de power demand

Aproximatively 50% of the 100 possible ship-system combinations, can not be considered because of the power demand incompatibility. That is because the available gen-set power is lower than the treatment system power demand.

In the literature there are some possible solutions:

1. Suplementary gen-set installing, called Power-Pack, that is able either to supplement ship`s power system, either to feed independently the treatment system
2. Treatment system feed from emergency diesel-generator

Figure 7.7 corresponds to 40700 TDW tanker. In the initial phase, Aquarius UV system did not figured in the compatible systems list. After reevaluating the situation through RBD methodology, the ranking value for this system is 4.1. Although is the last one in the list, represents however a viable solution for the ones that prefers it against of other systems.

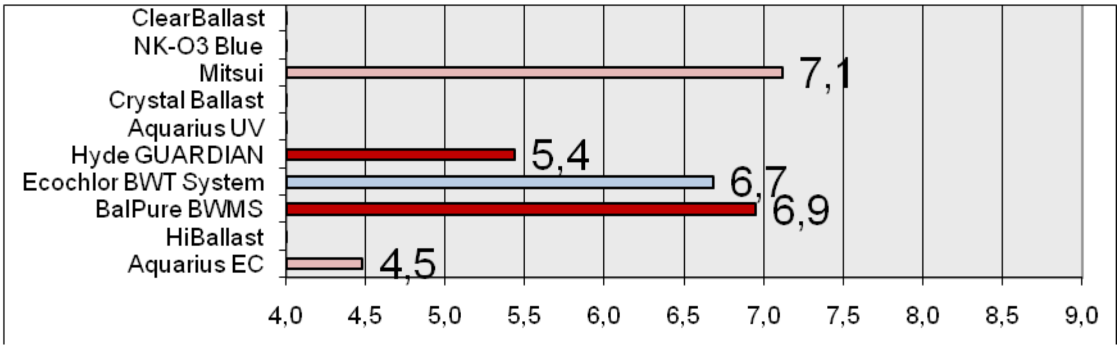


Fig. 7.5 Ranking values before improvements

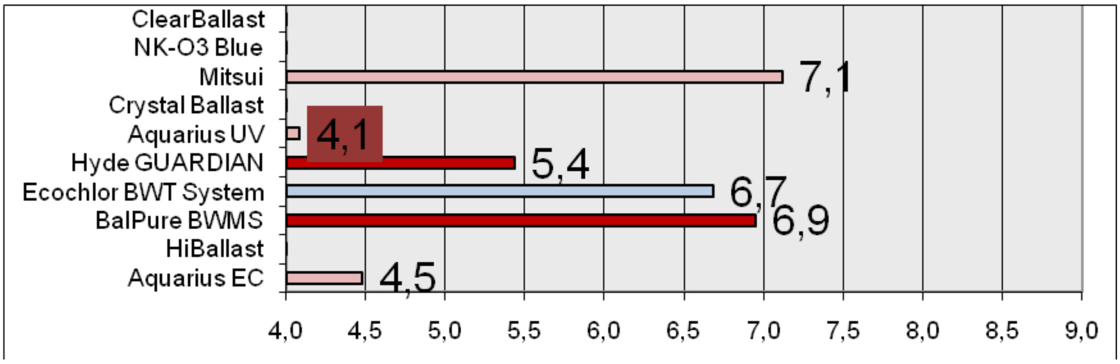


Fig. 7.6 Ranking values after improvements

CAP. VIII REDESIGNING MODELING BY USING THE RISK ANALYSIS PHA, FMEA INSTRUMENTS AND HiP-HOPS SOFTWARE MODEL

8.1 Preliminary hazard analysis (PHA) for selecting and aquisition additional filters

This method is used for identifying that threats that can be subject for an later risk analysis. It was selected against of other methods because it can be used in any moment of existence for an equippment (either in design or operating phase).

Nr.	Cause	Consequence	Combative measures
1.	Filters aquisition cost is to high in relation with the performance	1. The investition will not be payed-off totally 2. Shipping company will be in risk of banckruptcy	1. Optimum price-quality ratio selection 2. Giving up the aquisition

8.2 Failure Modes and Effects analisys (FMEA) risk evaluation

The way in which is calculated the severity, probability and detectability values was evidenced in first chapter. Based on this information was created three FMEA tables, as can be seen below.
There is analysed the remaining risk after applying the system improving solutions.
For facile understanding, in the thesys is presented only three examples:

- selection and aquisition phase for
- onboard installing the additional filters
- treatment system operating, with the emergency generator power feed

Tab. 8.3 FMEA methodology for analysing the treatment system operating, feed by emergency generator [7] [9]

Process -------- Demand	Potential failure	Main effects	S	Potential causes / Failure mechanisms	O	Process observation	D	NPR	Risk class	Recomanded corrective actions	Corrective actions results					
											Applie corrective actions	S	O	D	NPR	Risk class
System operating	Failure occuring due to emergency generator use for feeding the treatment system	Other ship`s systems failure due to electrical distortions Risk of black-out Premature frazzle of the emergency generator due to the overloading	6	Emergency generator overloading	8	Preliminary verification of the system`s characteristics	2	96	M	Technical specification follow	Technical specificatio n follow	6	6	2	72	M
			7	Lack of solutions in case of black out	5	Periodical personell inspection	6	210	R	Treatment system use only in safety conditions	Treatment system use only in safety conditions	7	3	6	126	R
			6	Electrical distortions in ship`s power system	3	Chemical substances circuit feed inspection	8	144	R	Proper maintenance	Proper maintenance	6	2	8	96	M
			3	Expensive maintenance for emergency generator	3	Periodical check of the technical state	4	63	M	Proper maintenance	Proper maintenance	3	2	4	24	S
			1	High air pollution	3	Noxes monitoring system	5	15	S	Emergency generator judicious use	Emergency generator judicious use	1	3	4	12	S

8.3 HiP-HOPS instrument for Risk analysis software modeling

In order to decide if the proposed improving system solutions are viable (can be applied without side effects), I used HiP-HOPS instrument for Risk analysis software modeling. This was created by a group of scientists from Hull Uniersity, coordinated by Prof. Yianis Papadopoulos.
The sollution I chosed to analyse by risk analysis is the BWTS feed from Emergency Generator.

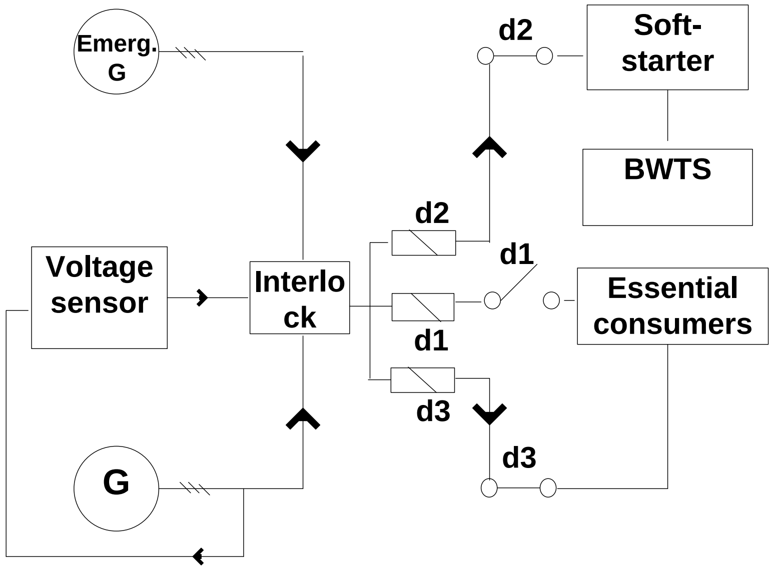


Fig.8.3 BWTS power system feeding

The major risk element from this analysis is the failure of power feeding for the essential consumers, in case of blackout. This can happen if the emergency generator does not starts due to the BWTS interconnection or other various deficiencies (that had been took into consideration).

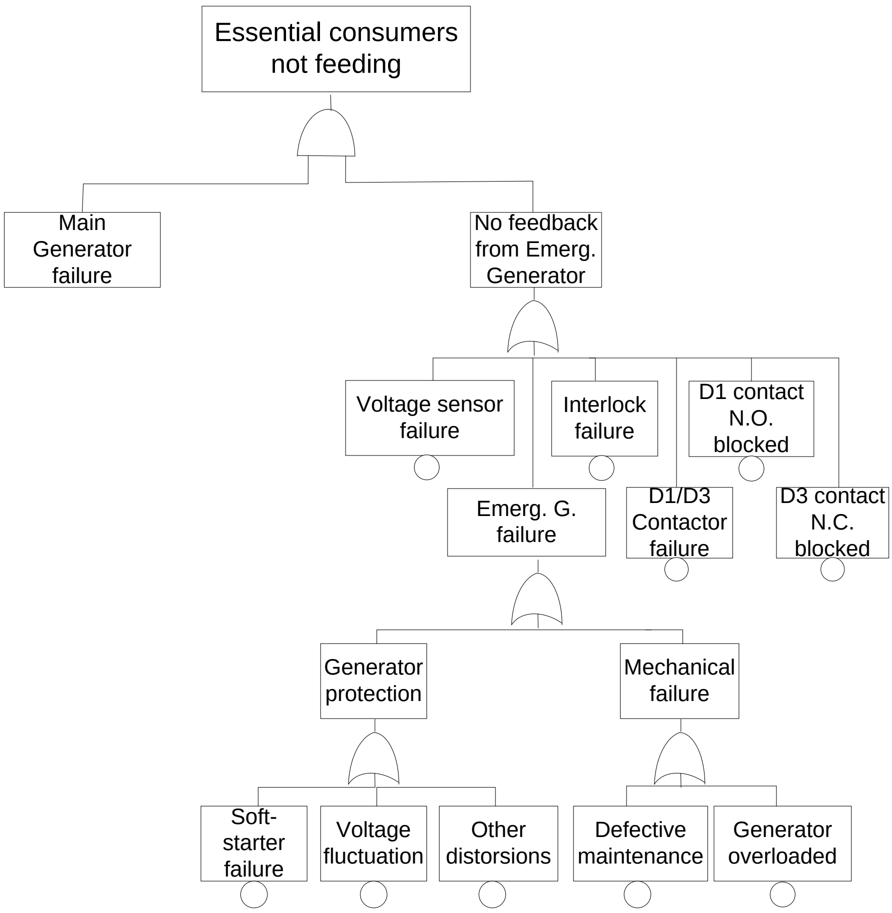


Fig.8.4 Failure tree manual design

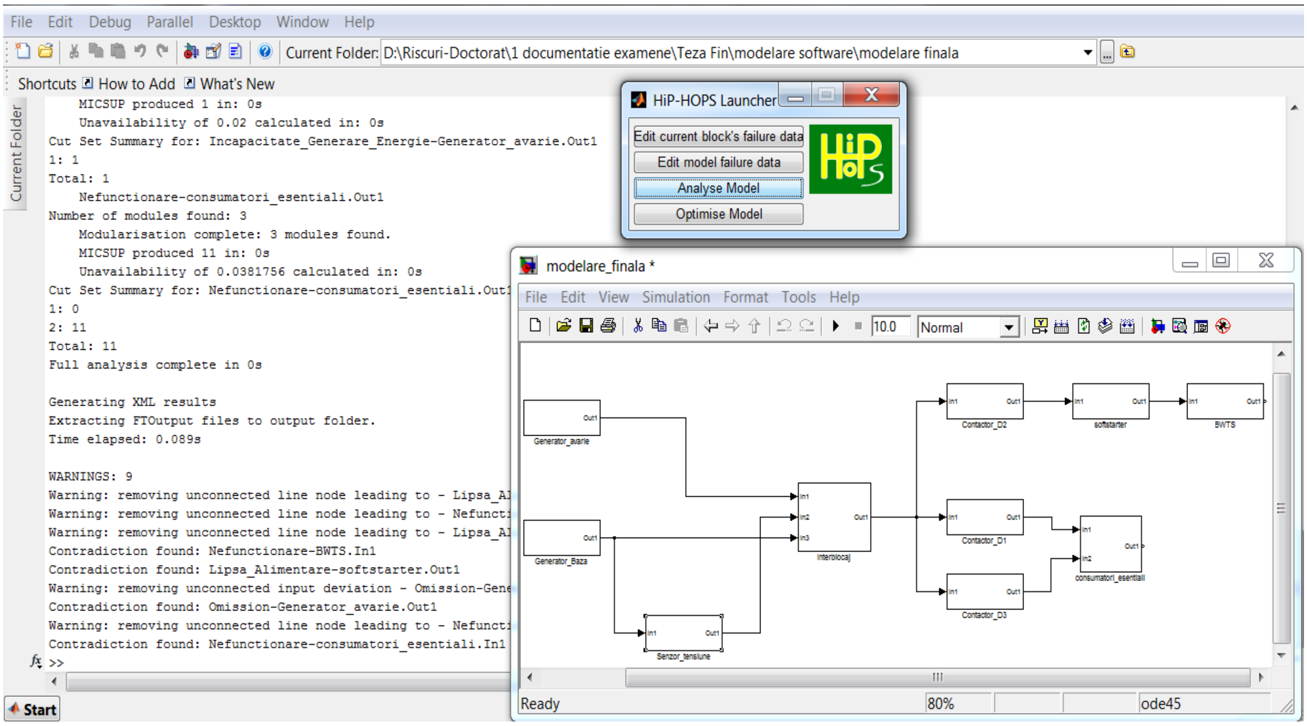


Fig. 8.5 Simulink design for BWTS power system feed

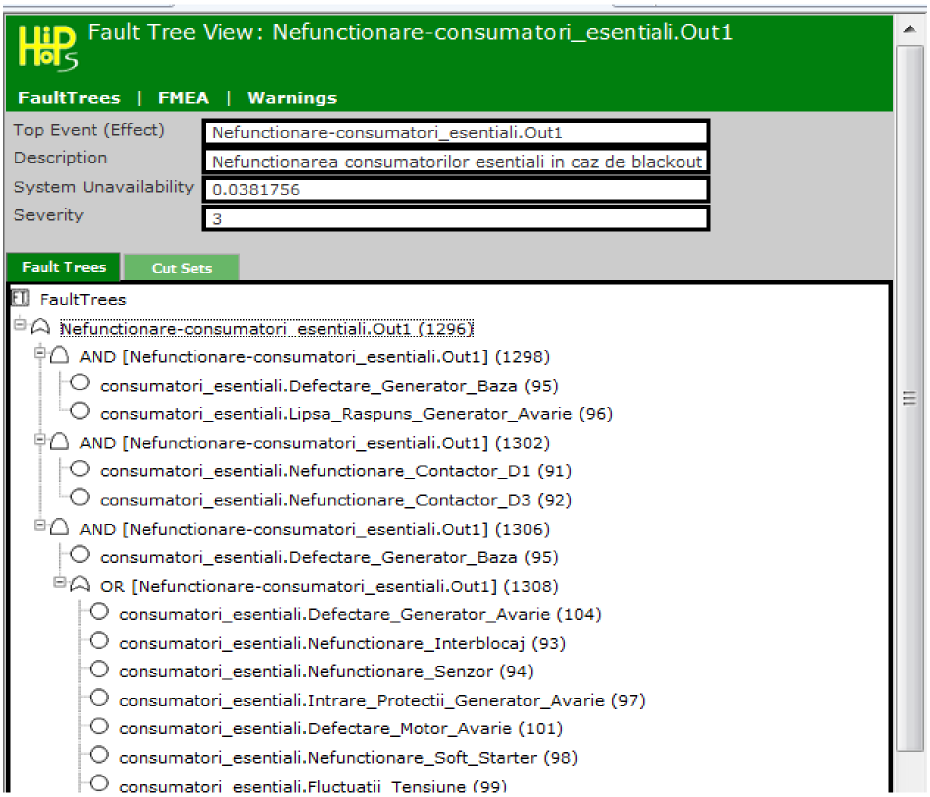


Fig. 8.6 Failure tree corresponding to the BWTS power system feed

In the figure 8.6 it is represented the failure tree, resulted after running the software model. This was created based on the manual designed failure tree, from Fig. 8.4.

In this figure can be identified the resulting value for the main failure probability (0,038). Also, it is represented the severity value (3), on a scale from 1 to 7.

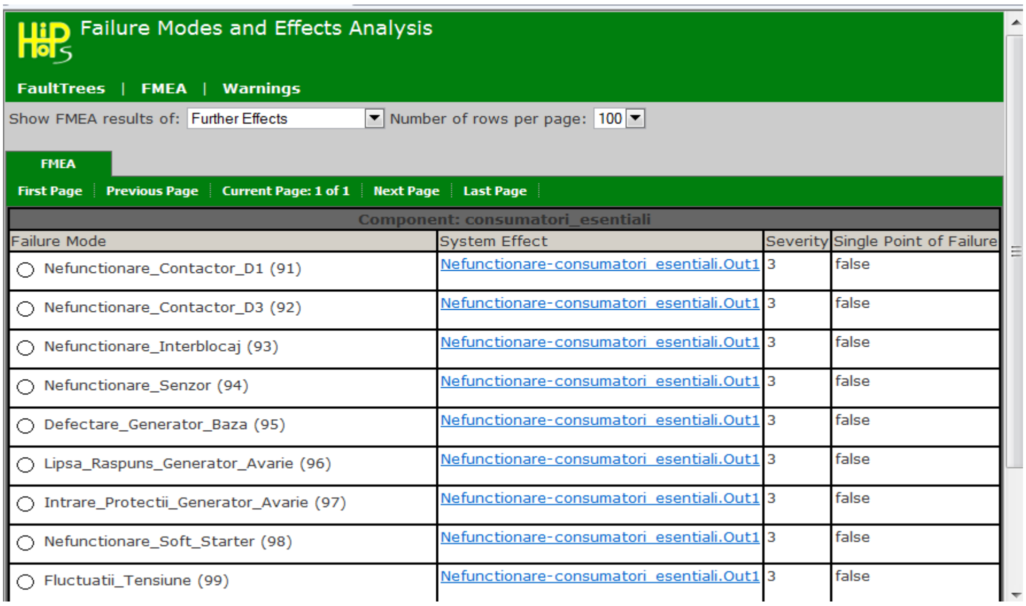


Fig.8.7 Basic elements FMEA structure

In figure 8.7 is represented the FMEA structure, corresponding to the BWTS power system. For each of the basic element from this structure is represented the final effect on the analysed system – Essential consumers failure.

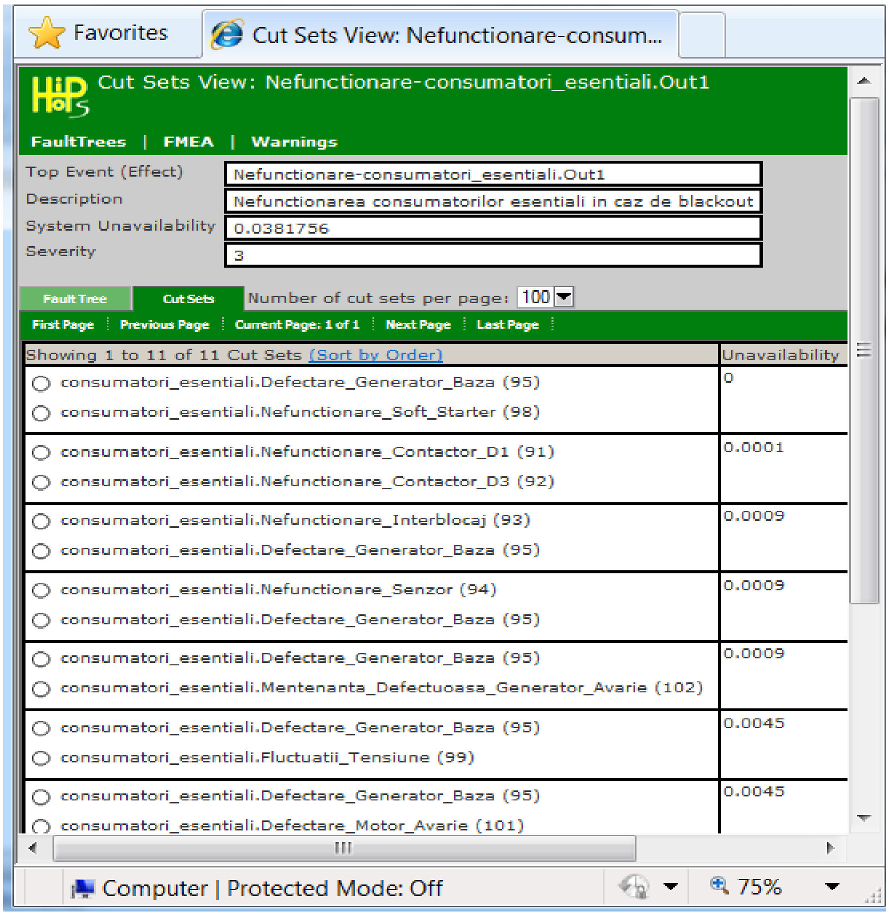


Fig.8.8 Failure tree basic elements and the specific failure probability

The final remark for this software modeling, using HiP-HOPS instrument, is that, due to low value of the risk probability (0,038), correlated with a 3 level severity, indicates a low risk value. That is why, the improving solution of feeding the BWTS by Emergency generator, is a viable one, the potential risk (ship sinking, capsize, colission or run aground), having a low level.

Personal contributions and Recommendation

This thesys is based on the activities developed in colaboration with Constanta Shipyard, Ship Design departament, in the ECOREFITEC Project. The project refered to the BWTS instalation onboard of a 41000 TDW tanker.

The originality elements obtined through this studies is the methodology that helps new solutions developing, regarding water ballast management, for the ships that has not been provided with this kind of system, so to fit to the new standards, together with economical efficiency and safety operation.

There were analysed 10 possible aletrnatives of treatment system, to be installed onboard of other 10 type of ships, resulting 100 possible combinations.

I tried to define a number of alternatives, as big as possible, in order to obtain a global feature, so that the methodology not to be a narrow one.

I used an AHP software model in order to rank all the treatment system.

It was searched and developed possible solutions as alternative answers to the generated incompatibilities, with the aim of supplementing the avialable options for certain ships.

Although there were searched many directions, the most feasible solutions are reffering to:

- Treatment process (filtration) improving
- Treatment duration minimizing, together with the environmental pollution
- Ex-proof standard comply
- Power demand optimum level

After offering this solutions, all the systems were ranked again, in order to highlight the benefits.

Using RBD methodology, it was developed PHA, FMEA and HiP-HOPS model in order to establish if through the improvements does appear major drawbacks, that can compromise the whole activity.

Recommendations

- Use of rigurous and realistic hierarchical instruments, for analysing preliminary any aquisition of systems from the studied category
- The adoption of shipping systems design, based on risk criteria, together with economical, technical, environmental, avoiding the occurence of complex risk scenario
- The development of eco-inovative solutions, as alternatives for the conventional water treatment (Cap. 3.2), due to multiple advantages

Anex IV Technical details of the selected treatment systems

BWMS Name	Required minimum holding time	Quantity of treatment chemicals (g/ ton)	Minimum treatment rate (m3/hour)	Overall treatment rate (m3/hour)	Suitable for freshwater?	Working Temperature	Deballasted oxidants quantity	Micro organisms >50μm [per m3]	Micro organisms 50–10 μm [per ml]	Vibrio Cholerae [per 100 ml]
Aquarius EC	24 h	10 g	100	3500	Yes	15-40°C	10 mg/l TRO	3	3	4
HiBallast	24 h	9 g	75	8000	Yes	15-40°C	9 mg/l TRO	<10	<10	<1
BalPure BWMS	12 h	16 g	500	20000	Yes	16-35°C	16 mg/l TRO	4	3	4
Ecochlor BWT System	48 h	14 g	400	10000	Yes	7 -60°C	14 mg/l TRO	3	3	3
Hyde GUARDIAN	instant		60	6000	Yes	No limitation	No oxidants	0	0,002 – 1,18	0
Aquarius UV	instant		50	1000	Yes	No limitation	No oxidants	2	2	2
Crystal Ballast	instant		100	3000	Yes	No limitation	No oxidants	4	4	4
Mitsui	20 h	3 g	100	2500	No	No limitation	3 mg/l TRO	<10	<10	<1
NK-O3 Blue	20 h	2,6 g	250	8000	Yes	No limitation	10 mg/l TRO	5	5	5
ClearBallast	10 h		200	2400	Yes	No limitation	No oxidants	<10	<10	<1

Anex IV Technical details of the selected treatment systems

BWMS Name	Required minimum holding time	pressure drop	Estimated Footprint for a system of						Max height	EX rating of components	Increasing corrosion factor
BWMS Name			500 m3/h	1000 m3/h	1500 m3/h	2000 m3/h	2500 m3/h	3000 m3/h	m		
Aquarius EC	24 h	1	41	59	74	84	91	95	2	Yes	1.33
HiBallast	24 h	1		25					3	No	1.3
BalPure BWMS	12 h	1	7	7.2	9	12	15	18	3	No	1.44
Ecochlor BWT System	48 h	1	14	20	24	28	31	33	2.5	No	1.4
Hyde GUARDIAN	instant	1	10	10	10	10	15	15	2	No	1
Aquarius UV	instant	1		28.5					3	No	1
Crystal Ballast	instant	1	11	14.3	15.4	18	21	24	2.5	No	1
Mitsui	20 h	1	16	20	23	26	28	30	3	Yes	1.05
NK-O3 Blue	20 h	1	24	32	38	42	46	49	2.5	No	1.34
ClearBallast	10 h	1	28	47	56	63	70	76	2	No	1

Anex VI Treatment system installed area, regarding the chosen ship

Ship Type and Dead Weight [DWT] / BWMS Name	Estimated Footprint for Aquarius EC [m2]	Estimated Footprint for HiBallast [m2]	Estimated Footprint for Balpure [m2]	Estimated Footprint for Ecochlor [m2]	Estimated Footprint for HydeGuardian [m2]	Estimated Footprint for Aquarius UV [m2]	Estimated Footprint for Crystal Ballast [m2]	Estimated Footprint for Mitsui [m2]	Estimated Footprint for NKO3 [m2]	Estimated Footprint for Hitachi [m2]
Tanker 9200	41	20	7	14	10	23	11	16	24	28
Tanker 24 000	74	-	9	24	10	29	-	23	38	56
Tanker 40700	84	-	12	28	10	-	-	26	42	63
Tanker 65000	95	-	18	33	15	-	-	30	-	76
Tanker 95 000	169	-	27	57	-	-	-	53	-	-
Tanker 125 000	168	-	24	56	-	-	-	-	-	-
Tanker 166 000	190	-	36	66	-	-	-	-	-	-
Bulk 41 000	-	-	18	33	-	-	-	30	-	-
Bulk 60 000	-	-	-	56	-	-	36	52	-	-
Container 2420TEU	59	25.6	7.2	20	10	27.5	14.3	20	32	47

Anex VII Hierachical criteria analysis

Aquisition cost parameter from Economical criteria

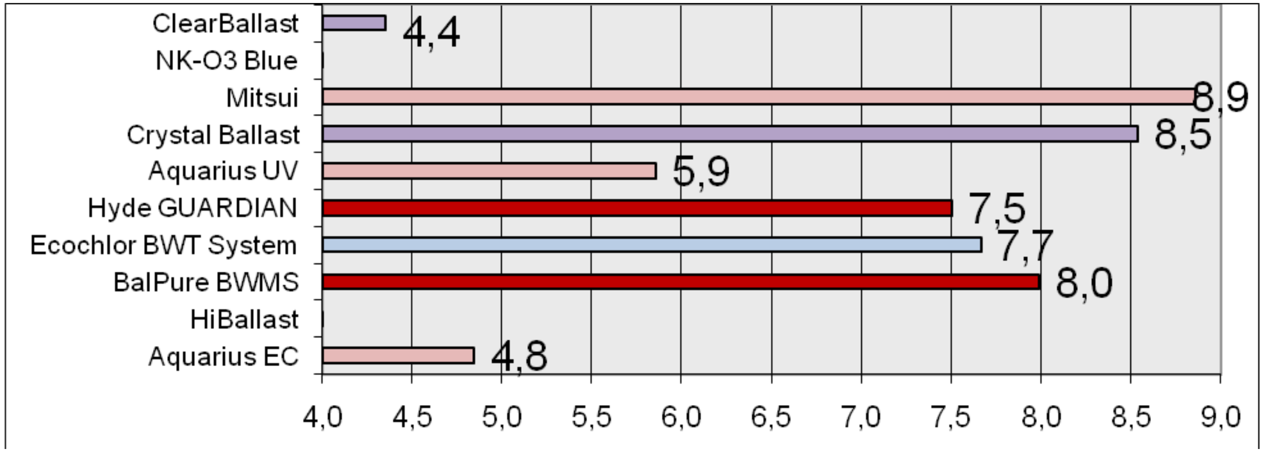
BWMS Name	Tanker 9200 ($x1000)	Rates	Rates	Tanker 24000 ($x1000)	Rates	Rates	Tanker 47000 ($x1000)	Rates	Rates	Tanker 65000 ($x1000)	Rates	Rates	Tanker 95000 ($x1000)	Rates	Rates
Aquarius EC	650	2.03	1	1100	1.69	1	1200	1.85	1	1350	2.08	1	1500	2.31	1
HiBallast	650	2.03	1		0.00			0.00			0.00			0.00	
BalPure BWMS	350	1.09	10	650	1.00	10	816	1.26	7	950	1.46	4	1200	1.85	1
Ecochlor BWT System	350	1.09	10	650	1.00	10	816	1.26	7	950	1.46	4	1200	1.85	1
Hyde GUARDIAN	400	1.25	8	950	1.46	4	1050	1.62	2	1170	1.80	1		0.00	
Aquarius UV	400	1.25	8	950	1.46	4		0.00			0.00			0.00	
Crystal Ballast	350	1.09	10	720	1.11	9		0.00			0.00			0.00	
Mitsui	320	1.00	10	800	1.23	7	950	1.46	4	1100	1.69	1	1200	1.85	1
NK-O3 Blue		0.00			0.00			0.00			0.00			0.00	
ClearBallast		0.00			0.00			0.00			0.00			0.00	

The values from this table are calculated in Excel. As an example, the chosen hierarchical parameter was Aquisition cost. It can be observed that the marks are given in disproportion with the aquisition values. In this way, the system that has the lowest price will get 10. With red were marked all the systems unsuitable for the certain ship.

Similar with this example, there were analysed all the 15 parameters, coresponding with the 4 analysis criteria.

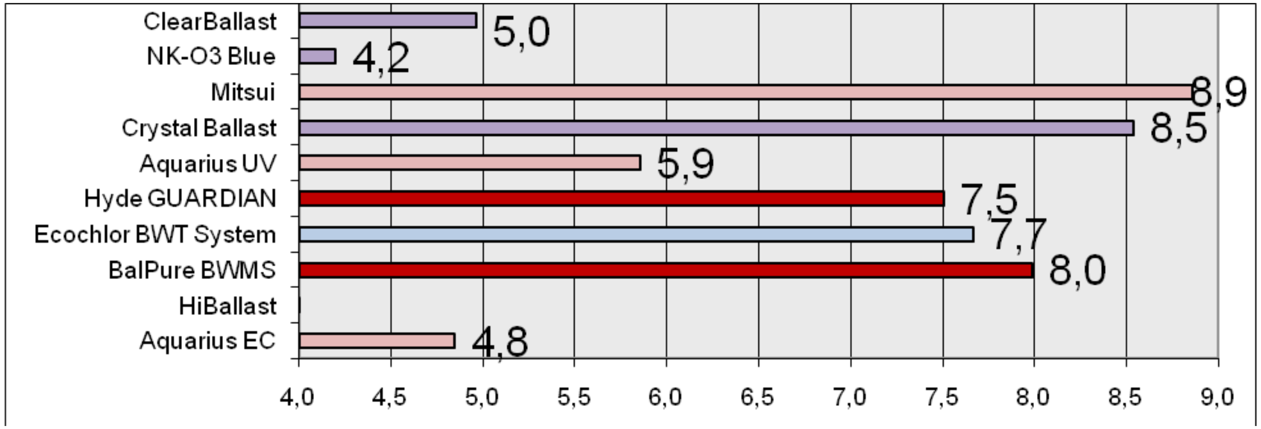
Anex VIII Hierarchical analysis for selecting the best treatment system, suitable for 9200 TDW Tanker

BWMS Name	BWMS Process	Capex (installed cost)	Estimated Opex	Fuel cost)	Corosion Process cost	Water Pollution	Air emissions	Alien Species invasion decrease	Process duration	Footprint	Power consumption	Ex-Proof system	Number of Employees	Registration year	Annual incomes	Number of installed systems
Aquarius EC	Filtration + Electrolysis/Electroc hlorination	1	1	9	5	5	9	10	5	1	7	10	9	6	6	9
HiBallast	Filtration + Electrolysis/Electroc hlorination	1	1	5	6	6	5	5	5	7	1	1	8	7	8	1
BalPure BWMS	Filtration + Electrochlorination	10	2	9	3	3	9	10	8	10	8	1	7	9	5	10
Ecochlor BWT System	Filtration + Electrochlorination	10	2	10	2	2	10	8	3	8	10	1	2	4	4	8
Hyde GUARDIAN	Filter + UV Treatment	8	8	5	10	10	5	10	10	10	6	1	2	7	4	7
Aquarius UV	Filter + UV Treatment	8	8	1	10	10	1	9	10	6	2	1	8	6	6	9
Crystal Ballast	Filter + UV Treatment	10	8	10	10	10	10	7	10	9	3	1	4	7	4	7
Mitsui	Ozonation	10	10	10	9	9	10	3	6	8	10	10	7	10	7	6
NK-O3 Blue	Ozonation	-	-	8	5	5	8	6	6	5	5	1	5	6	3	6
ClearBallast	Filtration + pre- coagulant	-	-	9	10	10	9	3	8	4	7	1	10	9	10	6
Ponderea fiecărui parametru la nivel global		28%	7%	13%	4%	5%	9%	9%	4%	10%	7%	4%	1%	1%	2%	4%



Anex IX Hierarchical analysis after improving the ClearBallast treatment system parameters, regarding the 9200TDW Tanker

BWMS Name	BWMS Process	Capex (installed cost)	Estimated Opex	Fuel cost)	Corosion Process cost	Water Pollution	Air emissions	Alien Species invasion decrease	Process duration	Footprint	Power consumption	Ex-Proof system	Number of Employees	Registration year	Annual incomes	Number of installed systems
Aquarius EC	Filtration + Electrolysis/Electroc hlorination	1	1	9	5	5	9	10	5	1	7	10	9	6	6	9
HiBallast	Filtration + Electrolysis/Electroc hlorination	1	1	5	6	6	5	5	5	7	1	1	8	7	8	1
BalPure BWMS	Filtration + Electrochlorination	10	2	9	3	3	9	10	8	10	8	1	7	9	5	10
Ecochlor BWT System	Filtration + Electrochlorination	10	2	10	2	2	10	8	3	8	10	1	2	4	4	8
Hyde GUARDIAN	Filter + UV Treatment	8	8	5	10	10	5	10	10	10	6	1	2	7	4	7
Aquarius UV	Filter + UV Treatment	8	8	1	10	10	1	9	10	6	2	1	8	6	6	9
Crystal Ballast	Filter + UV Treatment	10	8	10	10	10	10	7	10	9	3	1	4	7	4	7
Mitsui	Ozonation	10	10	10	9	9	10	3	6	8	10	10	7	10	7	6
NK-O3 Blue	Ozonation	1	1	8	5	5	8	6	6	5	5	1	5	6	3	6
ClearBallast	Filtration + pre- coagulant	1	1	9	10	10	9	6	8	4	7	1	10	9	10	6
Ponderea fiecărui parametru la nivel global		28%	7%	13%	4%	5%	9%	9%	4%	10%	7%	4%	1%	1%	2%	4%



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